Preliminary Economic Analysis and Initial Regulatory Flexibility Analysis

Supporting document for the Notice of Proposed Rulemaking for Occupational Exposure to Beryllium

Occupational Safety and Health Administration U.S. Department of Labor

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CHAPTER I: INTRODUCTION

OSHA's Preliminary Economic Analysis and Initial Regulatory Flexibility Analysis (PEA) addresses issues related to the costs, benefits, technological and economic feasibility, and the economic impacts (including impacts on small entities) of the proposed beryllium rule and evaluates regulatory alternatives to the proposed rule. When OSHA identifies a significant risk to workers, section 6(b)(5) of the Occupational Safety and Health Act (OSH Act) directs OSHA to review the best available evidence and select a standard that, to the extent feasible, ensures that employees will not suffer material impairment of health or functional capacity. As OSHA drafts a beryllium standard to fulfill its statutory directive, the Agency must also comply with a number of procedural requirements.

Executive Orders 13563 and 12866 direct agencies to assess all costs and benefits of available regulatory alternatives and, if regulation is necessary, to select regulatory approaches that maximize net benefits (including potential economic, environmental, public health and safety effects, distributive impacts, and equity), unless a statute requires another regulatory approach. Executive Order 13563 emphasizes the importance of quantifying both costs and benefits, of reducing costs, of harmonizing rules and of promoting flexibility.

OSHA has determined that this proposed rule governing occupational exposure to beryllium is an economically significant regulatory action under section 3(f)(1) of Executive Order 12866. Accordingly, the Office of Regulatory Analysis within OSHA has prepared this preliminary economic analysis (PEA) for the proposed rule. In developing this PEA, OSHA has endeavored to meet the requirements of OMB's Circular A-4 (OMB, 2003), a guidance document for regulatory agencies preparing economic analyses under Executive Order 12866.

This rule has been reviewed by the Office of Information and Regulatory Affairs in the Office of Management and Budget, as required by Executive Order 12866.

The purpose of this PEA is to:

- Identify the establishments and industries potentially affected by the proposed rule;
- Estimate current exposures and identify the technologically feasible methods of controlling these exposures;
- Estimate the benefits resulting from employers coming into compliance with the rule in terms of the reduction in fatal cases of lung cancer; fatal cases of chronic beryllium disease (CBD), a non- malignant respiratory disease; and cases of CBD morbidity;
- Evaluate the costs and economic impacts that establishments in the regulated community will incur to achieve compliance with the proposed rule;
- Assess the economic feasibility of the rule for affected industries;
- Evaluate the principal regulatory alternatives to the proposed rule that OSHA has considered; and
- Estimate the impacts of the final rule on small entities as defined by the Small Business Administration (in accordance with the Regulatory Flexibility Act, as amended in 1996).

This PEA includes all of the economic analyses OSHA is required to perform, including the findings of technological and economic feasibility and their supporting materials required by the OSH Act as interpreted by the courts (in Chapters III, IV, V, and VI); those required by EO 12866 and EO13563 (primarily in Chapters III, V, and VII, though these depend on material in other chapters); and those required by the Regulatory Flexibility Act (in Chapters VI, VIII, and IX, though these depend, in part, on materials presented in other chapters).

The rest of this chapter is devoted to a description of the need for a beryllium rule, a discussion of the major provisions of the proposed rule, and a list of the chapters to follow in this PEA. To develop this PEA, OSHA relied considerably on the support of OSHA's contractor, Eastern Research Group (ERG). ERG's individual work products are referenced throughout this PEA.

REASONS WHY ACTION BY THE AGENCY IS BEING CONSIDERED

When establishing the need for an occupational safety and health standard, OSHA must evaluate available data to determine whether or not workers will suffer a material impairment of their health or functional capacity as a result of being exposed to a particular safety or health hazard. Section 6(b)(5) of the Occupational Safety and Health Act (OSH Act) directs OSHA to set the standard ". . . which most adequately assures, to the extent feasible, on the basis of the best available evidence, that no employee will suffer material impairment of health or functional capacity even if such employee has regular exposure to the hazard dealt with by such standard for the period of his working life." 29 U.S.C. 655(b)(5).

The Supreme Court, in reviewing previous OSHA standards, has also directed the Agency to make a determination that ". . . significant risks are present and can be eliminated or lessened by a change in practices" before promulgating any health or safety standard. Indus. Union Dep't, AFL-CIO v. Am. Petroleum Inst., 448 U.S. 607, 642 (1980). While the Supreme Court did not specify what constituted a "significant risk" and considered that determination to be largely a policy decision for OSHA, the Court did offer guidance, stating that a reasonable person might well consider a 1 in 1000 risk of fatality to be significant. Id. at 655.

OSHA makes its material impairment and significant risk determinations by first evaluating available data to identify hazards to which employees are exposed in the workplace that are likely to induce material impairments of their health or functional capacity. The Agency looks at a broad array of scientific data and assesses the overall weight of evidence in making its significant risk determinations. In the next step, the Agency looks at the overall quality of the data to identify studies or other data that are useful in making quantitative estimates of the risk of those impairments of health among exposed employees over their working life (as mandated by the OSH Act). While many studies may add to the overall weight of evidence, often only select studies have suitable information for quantitatively assessing risk.

The epidemiological literature on beryllium provides clear evidence that beryllium is a human lung carcinogen. It includes multiple studies of U.S. beryllium workers (Sanderson et al., 2001; Ward et al., 1992; Wagoner et al., 1980; and Mancuso et al., 1979). Most recently, a NIOSH cohort study found significantly increased lung cancer mortality among employees at seven beryllium processing facilities (Schubauer-Berigan et al., 2011). Evidence supporting beryllium carcinogenicity comes from various animal studies as well as in vitro genotoxicity and other studies (EPA, 1998; ATSDR, 2002; Gordon and Bowser, 2003; NAS, 2008; Nickell-Brady et al., 1994; NTP, 1999 and 2005; IARC, 1993, 2009 and 2012). The International Agency for Research on Cancer (IARC), National Toxicology Program (NTP), and American Conference of Governmental Industrial Hygienists (ACGIH) have all classified beryllium as a known human carcinogen (IARC, 2009).

Exposure to beryllium also leads to a non-malignant respiratory disease, CBD. CBD develops when the body's immune system reacts to the presence of beryllium in the lung, causing a progression of pathological changes including chronic inflammation and tissue scarring. CBD can also impair other organs such as the liver, spleen, and kidneys and cause adverse health effects such as granulomas of the skin and lymph nodes and cor pulmanale (enlargement of the heart) (Conradi et al., 1971; ACCP, 1965; Kriebel et al., 1988a and b).

OSHA's risk assessment for cancer relied in part on the seven-facility study published by Schubauer-Berigan et al. (2011). The cohort was exposed, on average, to lower levels of beryllium than those in most previous studies, had fewer short-term employees, and had sufficient follow-up time to observe lung cancer in the population. OSHA also identified several studies that provided exposure information and screening results for beryllium sensitization (BeS) and/or CBD in cohorts of beryllium-exposed employees. The Agency's preliminary risk assessment for CBD was based on studies conducted at a Tucson, AZ beryllium ceramics plant (Newman et al., 2001; Henneberger et al., 2001; Cummings et al., 2007); a Reading, PA alloy processing plant (Schuler et al., 2005; Thomas et al., 2009); a Cullman, AL beryllium machining plant (Kelleher et al., 2001; Madl et al., 2007); and an Elmore, OH metal, alloy, and oxide production plant

(Kreiss et al., 1997; Bailey et al., 2010; Schuler et al., 2012), all of which demonstrate significant risk from exposure at the current PEL and below. OSHA's quantitative estimates of risk at the current, proposed, and alternate PELs were based on the Cullman, AL machining cohort, because this was the only cohort for which OSHA could examine the effects of changes in airborne exposure independent of extensive respirator and PPE use among exposed employees. Using data from a specific worker cohort to determine the risk to exposed employees has been upheld on judicial review in other standards regulating employee exposure to other toxic substances. It is also an accepted scientific approach used by other regulatory and non-regulatory entities in making decisions regarding public health.

Based on a variety of relative risk models fit to the seven-plant cohort, NIOSH estimated that the excess lifetime lung cancer risk to employees exposed over a working life of 45 years at the current permissible exposure limit (PEL) of 2 $\mu g/m^3$ is between 33 and 200 deaths per 1,000 employees. Reducing the PEL to the proposed PEL of 0.2 $\mu g/m^3$ is expected to achieve a substantial reduction of lung cancer risk, to a range estimated to be between 2.7 and 33 deaths from lung cancer per 1,000 employees. A proportional hazards model fit to the Cullman, AL machinist data estimated a lifetime CBD risk between 96 and 313 per 1000 employees exposed for 45 years at the current PEL. At the proposed PEL, the model estimate is between 8 and 30 per 1000 employees.

Overall, OSHA estimates that the proposed rule would prevent 97 fatalities annually—93 from CBD, and 4 from lung cancer—and an additional 50 cases of non-fatal CBD annually. These estimates are based on exposures over a 45-year working life.

Finally, it should be noted that the U.S. Congress has already recognized the dangers of beryllium exposure. Congress passed the Energy Employees Occupational Illness Compensation Program Act (EEOICPA) in 2000 to address occupational harm to workers from exposure to beryllium. The EEOICPA provides compensation to Department of Energy (DOE) workers and workers employed by DOE contractors and vendors for beryllium-related health effects resulting from exposure on the job. So far, the program, which the Department of Labor administers, has accepted over 2,200 individual cases of beryllium-related health effects and awarded over 1,600 workers more than $21 million in medical costs for cases that only involve beryllium-related health effects (information from U.S. Department of Labor, Office of Workers' Compensation Programs). There are also more compensated cases involving multiple causes, which include beryllium-related health effects. As is the case for most occupational illnesses, especially long-term, or chronic, illnesses, workers with beryllium-related health effects were very unlikely to qualify for workers' compensation benefits before EEOICPA. Workers were neither protected from the risks of occupational beryllium exposure nor compensated for loss of income and health.

Subsequently, DOE established its own beryllium regulation to protect its own workers as well as contract workers. The DOE regulation is similar to OSHA's proposed standard in many respects (see 64 FR 68854, Dec. 8, 1999). Its action level of 0.2 $\mu g/m^3$ is the same as OSHA's proposed PEL. Although DOE's program has reduced the frequency of beryllium-related health effects (the effectiveness of the DOE program is discussed in Chapter VII: Benefits of this PEA), some workers have still become sensitized to beryllium and developed CBD. In recognition that its employees may not be fully protected, DOE has included in its regulations a requirement that covered employers must comply with any more stringent PEL established by OSHA in rulemaking (10 CFR 850.22). Moreover, this DOE regulation does not eliminate the need for beryllium exposure regulation in the workplace; OSHA's proposed beryllium standard would only apply in workplaces not covered by the DOE beryllium rule.

SUMMARY OF THE PROPOSED STANDARD FOR BERYLLIUM

OSHA has developed a comprehensive standard to protect employees from exposure to beryllium in general industry. The proposed standard contains a time-weighted average permissible exposure limit (PEL), short-term exposure limit (STEL), and other requirements, including: employee exposure assessment, beryllium work areas and regulated areas, methods of compliance, respiratory protection, personal protective clothing and equipment, hygiene areas and practices, housekeeping, medical surveillance, medical removal, communication of beryllium hazards to employees, and recordkeeping. The text below summarizes the requirements contained in the proposed standard.

(a) Scope and application

The proposed standard would apply to all workplaces where there is occupational exposure to beryllium within general industry, with two limitations. It would not apply to articles, as defined in the Hazard Communication standard (HCS) (29 CFR 1910.1200(c)), containing beryllium that the employer does not process. And, it would not apply to materials containing less than 0.1% beryllium by weight.

(b) Definitions

The definitions section explains important terms used in the proposed standard, such as “action level”, “beryllium work area”, “exposure”, “regulated area,” and others.

(c) Permissible Exposure Limit (PEL)

OSHA’s proposed time-weighted average (TWA) PEL and STEL are expressed in units of microgram(s) per cubic meter of air ($\mu g/m^3$). The Agency is proposing a TWA PEL of 0.2 $\mu g/m^3$, calculated as an 8-hour time-weighted average, and is considering alternative TWA PELs of 0.5 $\mu g/m^3$ and 0.1 $\mu g/m^3$. The proposed STEL is 2.0 $\mu g/m^3$, measured over a sampling period of 15 minutes and equal to ten times the proposed TWA PEL of 0.2 $\mu g/m^3$. The Agency is considering alternative STELs equal to five times the proposed TWA PEL, or to five or ten times the alternative TWA PELs.

Health risk data and analyses indicate that there is significant risk of CBD and lung cancer associated with exposure to 0.5 $\mu g/m^3$ beryllium over a working lifetime. Although OSHA is still evaluating the scientific evidence underlying these risk analyses, OSHA has made a preliminary decision not to consider an alternative PEL greater than 0.5 $\mu g/m^3$.

In this proposed rule, OSHA is also setting an action level of 0.1 $\mu g/m^3$. In the proposed standard, as in previous OSHA standards, the provisions for initial and periodic exposure monitoring are only triggered once the action level is reached or exceeded. Thus, employers may be able to considerably reduce the burden of complying with the proposed monitoring requirement by reducing employee exposures below the action level.

(d) Exposure Assessment

This paragraph of the proposed standard has provisions for conducting an initial exposure assessment, for performing periodic and additional exposure monitoring, and for observing monitoring. Each employer is required to conduct an assessment of the work site to determine if employees are exposed to levels of beryllium at or above the action level, or above the TWA PEL or STEL. The purpose of this assessment is to determine not only whether or not engineering and work practice controls are required to meet the TWA PEL and STEL, but also whether certain provisions of the proposed standard—such as medical surveillance, periodic monitoring, or respiratory protection—would be needed. Airborne exposures would be measured by personal breathing zone air samples.

In cases when the employer has conducted exposure monitoring in the past, when the current work operations, workplace conditions, and beryllium-containing material used still closely resemble those present when the previous exposure monitoring was conducted, and the employer has satisfied all other requirements within this section, the results of previous monitoring may be used to satisfy the initial monitoring provision. In addition, in cases where the employer has objective data demonstrating that beryllium is not capable of being released in concentrations that meet or exceed the action level or exceed the STEL, the employer may rely upon such data to satisfy the initial exposure assessment requirements of this section.

If the initial monitoring indicates that employee exposures are at or above the action level and at or below the TWA PEL, the employer must conduct periodic exposure monitoring at least annually. The employer is not required to conduct periodic exposure monitoring for employees whose initial monitoring results show exposure levels below the action level or above the TWA PEL.

Additional monitoring is required when there is a change in the production process, equipment, personnel, work practices, or control methods that may result in new or additional exposures to beryllium, or when the employer has any other reason to believe that new or additional exposure is occurring.

The proposed standard requires employers to notify employees of the results of an exposure assessment within 15 days of completing an assessment. This notification may be made individually in writing or by posting the results in a location that is accessible to all employees whose exposure is measured or represented by the exposure assessment. Where exposure levels are above the TWA PEL or STEL, the employer is required to describe in the written notification the corrective action being taken to lower the exposure levels below the TWA PEL and STEL.

In addition, the proposed standard sets forth accuracy criteria for exposure monitoring methods used to conduct monitoring required by the standard. Employers are required to provide affected employees or their designated representatives with an opportunity to observe any monitoring of employees for exposure to beryllium. The employer is also required to provide appropriate personal protective equipment (PPE) at no cost to the observer(s) and to ensure that each observer uses the provided PPE and complies with all applicable OSHA requirements and the employer's workplace safety and health procedures.

(e) Beryllium Work Areas and Regulated Areas

To minimize any unnecessary employee exposures, the proposed standard requires employers to establish and maintain a beryllium work area wherever employees are, or can reasonably be expected to be, exposed to airborne beryllium. The proposed standard also requires employers to establish and maintain a regulated area wherever employees are, or can reasonably be expected to be, exposed to airborne beryllium at levels above the TWA PEL or STEL.

The proposed standard requires employers to identify each beryllium work area through signs or other methods that adequately establish and inform employees of its boundaries. Employers are required to identify regulated areas in accordance with paragraph (m)(2) of the proposed standard. Employers must limit access to regulated areas to persons authorized or required to work in them, designated representatives of employees for the purpose of observing exposure monitoring, and persons authorized by law to be in a regulated area. The employer must provide necessary respiratory protection and other PPE to each employee entering a regulated area and must ensure that the equipment is used in accordance with paragraphs (g) and (h) of the beryllium standard, respectively.

(f) Methods of Compliance

The proposed standard requires employers to establish, implement, and maintain a written exposure control plan for beryllium work areas, including: an inventory of operations and job titles that have beryllium exposure; an inventory of operations and job titles that have exposure at or above the action level, and those that may have exposure above the TWA PEL or STEL; an inventory of required engineering and work practice controls; procedures for minimizing cross-contamination and migration of beryllium out of beryllium work areas; procedures for keeping surfaces in beryllium work areas as free as practicable of beryllium; and procedures for removal, laundering, storage, cleaning, repairing, and disposal of beryllium-contaminated personal protective clothing and equipment, including respirators. Employers must update the exposure control plan when they have reason to believe there are new or additional beryllium exposures, such as a change in production processes, materials, equipment, personnel, work practices, or control methods, and when an employee is confirmed positive for beryllium sensitization, is diagnosed with CBD, or shows signs or symptoms of beryllium exposure. A copy of the exposure control plan must be accessible to all employees who are, or can reasonably be expected to be, exposed to airborne beryllium.

The proposed standard also requires that employers use one or more of the following engineering and work practice controls to minimize employee exposure in beryllium work areas: (1) material and/or process substitution; (2) ventilated partial or full enclosures; (3) local exhaust ventilation; or (4) process controls, such as wet methods and automation. Employers who can establish that such controls are not feasible, or who can demonstrate that employees' exposures are below the action level, are exempt from this requirement. If, after implementing one or more of these controls, exposures exceed the TWA PEL or STEL, the employer must implement additional or enhanced engineering and work practice controls to reduce exposures to or below the TWA PEL and STEL, unless the employer can demonstrate that such controls are not feasible. Wherever feasible engineering and work practice controls are not sufficient to reduce employee exposure to the PEL, the employer must use them to reduce employee exposure to the lowest level feasible and supplement them with respiratory protection. The proposed standard prohibits employers from rotating employees to different jobs to achieve compliance with the PEL or STEL.

(g) Respiratory Protection

The proposed standard requires employers to provide at no cost, and to ensure that employees use, respiratory protection during: (1) periods necessary to install or implement feasible engineering and work practice controls where exposures exceed, or can reasonably be expected to exceed, the TWA PEL or STEL; (2) operations, including maintenance and repair activities and non-routine tasks, where meeting the PEL with engineering and work practice controls is not feasible and exposures exceed, or can reasonably be expected to exceed, the TWA PEL or STEL; (3) work operations for which an employer has implemented all feasible engineering and work practice controls and these controls do not reduce exposures to or below the TWA, PEL or STEL; and (4) emergencies. The use of respiratory protection required by this standard must be in accordance with the Respiratory Protection Standard (29 CFR 1910.134).

(h) Personal Protective Clothing and Equipment

The proposed standard requires employers to provide at no cost, and ensure that employees use, appropriate personal protective clothing and equipment (PPE) in accordance with the written exposure control plan required under paragraph (f) of the standard and OSHA's Personal Protective Equipment standards (29 CFR Part 1910 Subpart I) where any of the following occurs: (1) where employee exposure exceeds, or can reasonably be expected to exceed, the TWA PEL or STEL; (2) where employees' clothing or skin may become visibly contaminated with beryllium, including during maintenance and repair activities or during non-routine tasks; or (3) where employees' skin can reasonably be expected to be exposed to soluble beryllium compounds. Employers must ensure that employees remove all beryllium-contaminated PPE at the end of the work shift or at the completion of tasks involving beryllium, whichever comes first, or when PPE becomes visibly contaminated with beryllium. Employers must ensure that PPE visibly contaminated with beryllium is removed as specified in the exposure control plan required by paragraph (f) of the standard and that employees store and keep required protective clothing separate from street clothing. Employers must ensure that employees do not remove beryllium-contaminated PPE from the workplace, except for employees authorized to do so for laundering, cleaning, maintaining, or disposing of beryllium-contaminated PPE. Employers must ensure that, when PPE is removed for these purposes, it is stored and transported in sealed bags or other closed containers that are impermeable and labeled in accordance with paragraph (m)(3) of this standard and the Hazard Communication standard (29 CFR 1910.1200).

Employers must ensure that all reusable PPE required by this standard is cleaned, laundered, repaired, and replaced as needed to remain effective, and that beryllium is not removed from PPE by blowing, shaking, or other means that disperses beryllium into the air. Employers must inform in writing persons or businesses who launder, clean, or repair PPE required by this standard of the potentially harmful effects of exposure to airborne beryllium and contact with soluble beryllium compounds, and that the PPE must be handled in accordance with this standard.

(i) Hygiene Areas and Practices

The proposed standard requires employers to provide readily accessible washing facilities for employees who work in beryllium work areas to remove beryllium from the hands, face, and neck, and ensure that employees exposed to beryllium use these facilities when necessary. In addition, employers must provide employees with a designated change room and washing facilities in accordance with this standard and the Sanitation standard (29 CFR 1910.141) where employees are required to remove their personal clothing. Employers must provide showers that comply with the requirements of the Sanitation standard where two requirements are met: (1) exposure exceeds, or can reasonably be expected to exceed, the TWA PEL or STEL, and (2) beryllium can reasonably be expected to contaminate employees' hair or body parts other than hands, face, and neck. Where showers are required, employers must ensure that each employee shower at the end of the work shift or work activity if the employee reasonably could have been exposed above the TWA PEL or STEL and if beryllium could reasonably have contaminated the employee's hair or body parts other than hands, face, and neck.

Whenever the employer allows employees to consume food or beverages in a beryllium work area, the employer shall ensure that surfaces in eating and drinking areas are as free as practicable of beryllium; that no employee in an eating and drinking area is exposed to airborne beryllium at or above the action level; and that eating and drinking facilities provided by the employer are in accordance with the Sanitation standard. The employer must ensure that no employees eat, drink, smoke, chew tobacco or gum, or apply cosmetics in regulated areas, and that no employees enter an eating or drinking area with PPE unless surface beryllium has been removed from the PPE.

(j) Housekeeping

The proposed standard requires employers to maintain all surfaces in beryllium work areas as free as practicable of accumulations of beryllium and in accordance with the exposure control plan required under paragraph (f) and the cleaning methods required in paragraph (j) of the standard. Employers must ensure that all spills and emergency releases of beryllium are cleaned up promptly and in accordance with the exposure control plan and required cleaning methods.

The cleaning methods required by paragraph (j) are as follows: (1) surfaces in beryllium work areas must be cleaned by HEPA-filter vacuuming or other methods that minimize the likelihood and level of beryllium exposure; (2) employers must not allow dry sweeping or brushing for cleaning surfaces in beryllium work areas unless HEPA-filtered vacuuming or other exposure-minimizing methods have been tried and were not effective; (3) employers must not allow the use of compressed air for cleaning beryllium-contaminated surfaces unless it is used with a ventilation system designed to capture the airborne particulates that result from using compressed air; (4) where dry sweeping, brushing, or compressed air is used to clean beryllium-contaminated surfaces, employers must provide and ensure employees' use of respiratory protection and PPE in accordance with this standard; and (5) the employer must ensure that cleaning equipment is handled and maintained so as to minimize the likelihood and level of employee exposure and the re-entrainment of airborne beryllium in the workplace.

Employers must ensure that waste, debris, and materials visibly contaminated with beryllium and consigned for disposal are disposed of in sealed, impermeable enclosures, such as bags or containers. These bags or containers must be labeled in accordance with paragraph (m)(3) of this standard. Materials designated for recycling that are visibly contaminated with beryllium must be cleaned to remove visible particulate, or placed in sealed, impermeable enclosures labeled in accordance with paragraph (m)(3).

(k) Medical Surveillance

The proposed standard requires employers to make medical surveillance available, at no cost to the employee and at a reasonable time and place, for those employees who (1) worked in regulated areas for more than 30 days in the previous 12 months; (2) show signs or symptoms of CBD; or (3) were exposed to beryllium during an emergency.[1] Employees meeting one or more of these conditions must be offered a medical examination and any other test deemed appropriate by the physician or licensed health care professional (PLHCP). The medical examination must be offered to an eligible employee within 30 days after determining that the employee has worked in a regulated area for more than 30 days in the previous 12 months; or within 30 days of showing signs or symptoms of CBD or exposure in an emergency. The examinations must be offered annually thereafter, so long as the employee continues to meet the eligibility criteria; and at the termination of employment, unless the employee's last medical examination was provided within the previous 6 months.

The medical examination must include a physical examination with emphasis on the respiratory tract; a physical examination for skin breaks and wounds; pulmonary function tests, including forced vital capacity and forced expiratory volume at one (1)

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[1] Limited medical testing must also be provided to employees exposed to airborne beryllium above .2 $\mu g/m^3$ for more than 30 days in a 12-month period for 5 years or more.

second (FEV1); and a beryllium lymphocyte proliferation test (BeLPT) upon the first examination and within every 2 years from the first examination, ending if and when the employee is found to be sensitized. If a more reliable and accurate test for beryllium sensitization is developed, that test may be used in lieu of the BeLPT. The medical examination must also include an evaluation of the employee's medical and work history, with emphasis on past and present exposure, smoking history, and any history of respiratory system dysfunction.

After an employer learns that an employee is sensitized to beryllium, the employee will consult with the employer's designated physician and, if desired, be provided evaluation for CBD at a CBD diagnostic center at no cost to the employee.

In addition, employees who were exposed to airborne beryllium above 0.2 ug/m^3 for more than 30 days in a 12-month period for 5 years or more must be offered a low dose helical tomography (CT) scan biennially for the duration of their employment. This obligation begins on the start-up date of the standard or on the 15^{th} year after the employee's first exposure above 0.2 ug/m^3 for more than 30 days in a 12-month period, whichever is later.

The employer is required to ensure that the PLHCP has a copy of the standard and all appendices, and must provide the following information, if known: (1) a description of the employee's former and current duties that relate to the employee's occupational exposure; (2) the employee's former and current levels of occupational exposure; (3) a description of any PPE used, including respirators, and when and for how long they were used; and (4) information from records of employment-related medical examinations previously provided to the employee, currently within the control of the employer, after obtaining a medical release from the employee.

The employer is required to obtain a written medical opinion from the licensed physician within 30 days of the medical exam. The written opinion must explain:
(1) whether the employee has any detected medical condition that would place the employee at increased risk of CBD from further exposure to beryllium; (2) any recommended limitations on the employee's exposure, including the use and limitations on use of respirators or other PPE; and (3) a statement that the PLHCP has explained to the employee the results of the medical examination, including any tests conducted, any medical conditions related to exposure that require further evaluation or treatment, and any special provisions for use of protective clothing or equipment. The employer must provide a copy of the licensed physician's written medical opinion to the employee within 2 weeks after receiving it, and must ensure that neither the licensed physician nor any other PLHCP reveals to the employer specific findings or diagnoses unrelated to exposure to airborne beryllium or contact with soluble beryllium compounds.

Upon request by OSHA, employers must convey employees' beryllium sensitization test results to OSHA for evaluation and analysis. Employers must remove employees' names, social security numbers, and other personally identifying information from the test results before conveying them to OSHA.

(l) Medical Removal

If an employee works in a job with exposure at or above the action level and is diagnosed with CBD or confirmed positive for beryllium sensitization, the employee is eligible for medical removal. The employee may choose to be removed from exposure at or above the action level, or to remain in a job with exposure at or above the action level and wear a respirator in accordance with the Respiratory Protection standard (29 CFR 1910.134).

If the employee chooses medical removal, the employer must remove the employee to comparable work in an environment where exposure is below the action level, for which the employee is qualified or can be trained within 1 month. The employee must accept comparable work if it is available. If comparable work is not available, the employer must place the employee on paid leave for 6 months or until comparable work becomes available, whichever comes first. Whether the employee is removed to comparable work or placed on paid leave, the employer must maintain for 6 months the employee's base earnings, seniority, and other rights and benefits that existed at the time of removal. The employer's obligation to provide medical removal protection benefits to a removed employee shall be reduced to the extent that the employee receives compensation for earnings lost during the period of removal from a publicly or employer-funded compensation program, or receives income from another employer made possible by virtue of the employee's removal.

(m) Communication of Hazards

The proposed standard requires chemical manufacturers, importers, distributors, and employers to comply with all requirements of the HCS (29 CFR 1910.1200) for beryllium. This is not a new requirement, as the HCS requires that hazardous chemicals such as beryllium be included in the employer's hazard communication program.

Employers must ensure that each employee has access to labels on containers of beryllium and to safety data sheets, and is trained in accordance with the provisions of the

HCS and paragraph (m) of the proposed standard. In classifying the hazards of beryllium, the employer must address at least the following hazards: cancer; lung effects (CBD and acute beryllium disease); beryllium sensitization; skin sensitization; and skin, eye, and respiratory tract irritation.

The employer must provide and display legible, readily visible warning signs at each approach to a regulated area so that each employee is able to read and understand the signs and take necessary protective steps before entering the area. These warning signs must bear the legend specified in paragraph (m) of the proposed standard. The employer must label each bag and container of clothing, equipment, and materials visibly contaminated with beryllium consistent with the HCS and must include the minimum information specified in paragraph (m).

The employer must provide information and training in accordance with the HCS to each employee who is or can reasonably be expected to be exposed to airborne beryllium, by the time of the employee's initial assignment. The employer must repeat the training required under this section annually for each employee and must ensure that each exposed employee can demonstrate knowledge of at least the following: health hazards associated with beryllium exposure, including signs and symptoms of CBD; the written exposure control plan; the purpose, proper selection, fitting, use, and limitations of PPE, including respirators; emergency procedures; measures employees can take to protect themselves from beryllium exposure, including personal hygiene practices; the medical surveillance and medical removal protection programs; the contents of the beryllium standard; and the employee's right of access to records under the Records Access standard (29 CFR 1910.1020). When a workplace change results in new or increased employee exposure exceeding either the TWA PEL or the STEL, the employer must provide additional training to those employees affected by the change in exposure. The employer must make a copy of this standard and its appendices readily available at no cost to employees and designated employee representatives.

(n) Recordkeeping

The employer is responsible for maintaining a record of employee exposure measurements, objective data, and employee medical surveillance information. Exposure and medical records must be maintained in accordance with 29 CFR 1910.1020.

For records of exposure measurements, the proposed standard requires that the records include the date when each sample was taken; the operation involving exposure to beryllium that was monitored; the sampling and analytical methods used and evidence of their accuracy; the number, duration, and results of the samples; type of PPE, including respirators, used by the employee at the time of monitoring; and name, social security number, and job classification of all employees represented by the monitoring, indicating which employees were actually monitored.

The employer must establish and maintain an accurate record of any historical data used to satisfy the initial monitoring requirements of this standard. The record must demonstrate that the data comply with the requirements of paragraph (d) of the standard and must be maintained as required by the Records Access standard.

Where an employer uses objective data to satisfy the monitoring requirements of the standard, the employer must establish and maintain a record of the objective data relied upon, including at least the following information: the data relied upon; the beryllium-containing material in question; the source of the objective data; a description of the operation exempted from initial monitoring and how the data support the exemption; and other information demonstrating that the data meet the requirements for objective data in paragraph (d) of this standard.

The proposed standard requires employers to establish and maintain records of each employee covered by medical surveillance. The information maintained should include: name, social security number, and job classification of the employee; a copy of all licensed physicians' written opinions; and a copy of the information provided to the PLHCPs as required by the medical surveillance section of the standard.

At the completion of any training required by this standard, the employer must prepare a record of the name, social security number, and job classification of each employee trained, the date the training was completed, and the topic of the training. This record must be maintained for 3 years after the completion of training.

Upon request, the employer shall make all records maintained as a requirement of this standard available for examination and copying to the Assistant Secretary of OSHA, the Director of NIOSH, each employee, and each employee's designated representative(s) in accordance with the Records Access standard (29 CFR 1910.1020).

(o) Dates

Employers are required to comply with effective dates and start-up dates set forth in the proposed rule for certain provisions. The proposed effective date is 60 days after publication of the final standard in the Federal Register. All obligations of the final standard would become enforceable 90 days after the effective date, except for (1) change rooms required by paragraph (i), which must be provided no later than 1 year after the effective date; and (2) engineering controls required by paragraph (f) of this standard, which must be implemented no later than 2 years after the effective date.

THE REST OF THIS PEA

Following this Introduction, the PEA contains the following chapters:

- Chapter II: Assessing the Need for Regulation
- Chapter III: Profile of Affected Industries
- Chapter IV: Technological Feasibility
- Chapter V: Costs of Compliance
- Chapter VI: Economic Feasibility Analysis and Regulatory Flexibility Determination
- Chapter VII: Benefits and Net Benefits
- Chapter VIII: Regulatory Alternatives
- Chapter IX: Initial Regulatory Flexibility Analysis

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CHAPTER II: ASSESSING THE NEED FOR REGULATION

INTRODUCTION

The stated purpose of the OSH Act is to "assure so far as possible every working man and woman in the Nation safe and healthful working conditions and to preserve our human resources" (29 U.S.C. 651(b)). Section 2(b)(3) of the OSH Act specifically authorizes "the Secretary of Labor to set mandatory occupational safety and health standards applicable to businesses affecting interstate commerce" (29 U.S.C. 651(b)(3)). This congressional mandate provides the authority for OSHA's standard for respirable beryllium, which is designed to minimize workers' significant risk of adverse health effects associated with occupational exposure to this hazardous substance.

Section 6(b)(5) of the OSH Act requires the Secretary of Labor, when promulgating health standards, to set the standard at the level "which most adequately assures, to the extent feasible, on the basis of the best available evidence, that no employee will suffer material impairment of health or functional capacity . . . ." (29 U.S.C. 655(b)(5)). In its *Benzene* decision, the Supreme Court more precisely interpreted this language to mean that OSHA's health standards must reduce a "significant risk" of material health impairment, subject to other regulatory constraints such as economic and technological feasibility (*Indus. Union Dep't, AFL-CIO v. Am. Petroleum Inst.*, 448 U.S. 607, 639-40 (1980) (*Benzene*)).

The Agency has preliminarily determined that employees across a range of industries are exposed to levels of airborne beryllium that result in a significant risk that they will develop beryllium sensitization (BeS), chronic beryllium disease (CBD), lung cancer, and premature death. Published studies and exposure data submitted in the record from industrial facilities involved in beryllium work show that occupational exposure to a variety of beryllium compounds at levels below the current PEL poses a significant risk to workers of developing CBD. OSHA's preliminary risk assessment, presented in Section VI of the preamble, indicates that there is significant risk of beryllium sensitization and CBD from a 45-year (working life) exposure to beryllium at the current TWA PEL of 2 $\mu g/m^3$. The risk assessment further indicates that there is significant risk of lung cancer to workers exposed to beryllium at the current TWA PEL of 2 $\mu g/m^3$. This preliminary determination is based on risk models developed by NIOSH and discussed in the preamble at Section VI, Preliminary Beryllium Risk Assessment. OSHA has preliminarily determined that compliance with the proposed PELs will substantially reduce those risks (see Section VI of the preamble, Preliminary Beryllium Risk Assessment). A significant risk of these diseases in the workplace establishes the need for the Agency's remedy: to increase worker protection from exposure to beryllium.

As shown in Chapter VII of this PEA, the Agency estimates that the proposed beryllium standard would prevent 96 deaths and 50 non-fatal cases of CBD annually.

In addition to meeting the statutory obligations of the OSH Act described above, OSHA must promulgate regulations in accordance with White House directives, including Executive Order 12866 (58 FR 51735, September 30, 1993) and Executive Order 13563 (76 FR 3821, January 18, 2011). These executive orders direct regulatory agencies to assess whether, from a legal or an economic view, a Federal regulation is needed. For example, as Executive Order 12866 states:

> <u>Section 1. Statement of Regulatory Philosophy and Principles.</u>
>
> <u>(a)</u> <u>The Regulatory Philosophy.</u> Federal agencies should promulgate only such regulations as are required by law, are necessary to interpret the law, or are

> made necessary by compelling public need, such as material failures of private markets to protect or improve the health and safety of the public, the environment, or the well-being of the American people.

As discussed in this chapter, OSHA believes there is a failure of private markets to protect the health of workers by exposing them to unnecessarily high levels of beryllium. In making this statement, the Agency recognizes that many firms have responded to the risks posed by exposure to beryllium by implementing control programs for their workers. For these firms and these workers, the economic incentives provided by private markets appear to be working effectively. Nevertheless, the effectiveness of private markets in providing the optimal level of worker health and safety is not necessarily universal.

The discussion below considers why private markets, as well as information dissemination programs, workers' compensation systems, and tort liability options, each may fail to protect workers from beryllium exposure, resulting in the need for a more protective OSHA beryllium rule.

PRIVATE MARKETS

In the United States, the preferred mechanism for making economic decisions and taking economic actions is generally considered to be the private market. Under suitable conditions, a market system is economically efficient in the following sense: resources are allocated where they are most highly valued; the appropriate mix of goods and services, embodying the desired bundle of characteristics, is produced; and further improvements in the welfare of any member of society cannot be attained without making at least one other member worse off.

Economic theory, supported by empirical data, states that in the job market employers and workers bargain over the conditions of employment, including not only salary and other worker benefits, but also occupational risks to worker safety and health. Employers compete among themselves to attract workers. In order to induce workers to accept hazardous jobs, employers must offer a higher salary—termed a "wage premium for risk" or "risk premium" for short—to compensate for the additional job risk.[2] Because they must pay higher wages for more hazardous work, employers have an incentive to make the workplace safer by making safety-related investments in equipment and training or by using more costly but safer work practices. According to economic theory, the operation of the private job market will provide the optimal level of occupational risk when each employer's additional cost for job safety just equals the avoided payout in risk premiums to workers.

However, for the job market to function in a way that leads to optimal levels of occupational risk, three conditions must be satisfied. First, workers, as well as employers, must have perfect information—that is, they must be fully informed about their workplace options, including job hazards, or be able to costlessly acquire such information. Second, participants in the job market must directly bear all of the costs and obtain all of the benefits of their actions. In other words, none of the direct impacts of job market transactions can be externalized to outside parties. Third, the relevant job market must be perfectly competitive, which means it must contain such a large number of employers and such a large number of workers that no individual economic agent is able to influence the risk-adjusted wage.

[2] The concept of compensating wage differentials for undesirable job characteristics, including occupational hazards, goes back to Adam Smith's *The Wealth of Nations*, which was originally published in 1776.

In addition, the working of the job market, even if not subject to market imperfections, may sometimes lead to socially sub-optimal outcomes when important social values transcend the market. In such cases, government intervention might be justified to address a compelling public need (OMB, 2003, page 4).   .

The discussion below examines (1) imperfect information, (2) externalities, (3) imperfect competition, and (4) compelling social need in the job market in more detail, with particular emphasis on worker exposure to beryllium, as appropriate.[3]

(1) Imperfect Information

As described below, imperfect information about job hazards is present at several levels that reinforce each other: employers frequently lack knowledge about workplace hazards and how to reduce them; workers are often unaware of the workplace health and safety risks to which they are exposed; and workers typically have difficulty in understanding the risk information they are able to obtain. Imperfect information at these various levels has likely impeded the efficient operation of the job market as far as workplace risk is concerned. The reason is that workers unaware of job hazards do not seek, or receive, full compensation for the risks they bear, and, as a result, employers have less incentive to invest in safer working conditions than they would in the presence of full information.

Lack of Employer Information

In the absence of regulation, employers may lack economic incentives to optimally identify the health risks that their workers face.[4] Furthermore, employers may have some

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[3] The section on workers' compensation insurance later in this chapter identifies and discusses other related market imperfections.

incentive to withhold the information they do possess about job hazards from their workers, whose response would be to demand higher wages to compensate for the risk. Similarly, employers who develop cost-effective methods of reducing workplace risk have little incentive to share information with their competitors about such methods (unless they are patentable).[5] As a result, without regulation, many employers are unlikely to make themselves aware of the magnitude of beryllium-related health risks in the workplace or of the availability of effective ways of ameliorating or eliminating these risks.

Lack of Worker Information

Even without information from their employers, workers might reasonably be cognizant, at least at some simple qualitative level, of many occupational *safety* hazards. Many safety hazards are obvious to the eye, such as holes in floors, ice and snow covered work surfaces, and work near electrical power lines. Likewise, workers can expect that activities involving explosive materials or working at heights are inherently dangerous. Furthermore, workers can develop some, admittedly limited, knowledge of safety hazards in their workplace from their own and their coworkers' on-the-job accident and injury experience.

The same is less likely for occupational *health* hazards. Whereas the relationship between a workplace accident and the resultant injury is both immediate and visible, the connection between exposure to an occupational health hazard and the resultant disease may not be. Most diseases have multiple potential causes and may be the result of synergistic effects,

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[4] Other private parties may lack sufficient incentives to invest resources to collect and analyze occupational risk data due to the public-good nature of the information. See Ashford and Caldart (1996), p. 234.

[5] Relatedly, in the absence of regulation, employers, as well as third parties, may have less-than-optimal incentives to develop new technological solutions to protect workers on the job. For evidence of regulatory stimuli inducing innovations to improve worker health and safety, see, for example, Ashford, Ayers, and Stone (1985), as well as more recent evidence from OSHA's regulatory reviews under section 610 of the Regulatory Flexibility Act (5 U.S.C. 610).

thus creating difficulties in ascertaining whether a worker's disease is job-related rather than an "ordinary disease of life" resulting from genetic, physiological, lifestyle, or non-occupational environmental factors.

In the case of beryllium, causation is less of an issue since BeS and CBD are uniquely associated with occupational beryllium exposure.[6] However, the symptoms of CBD are similar to other types of respiratory disease, and CBD has been misdiagnosed as sarcoidosis in the absence of specialized testing. In addition, lung cancer—although this particular disease represents only a minor share of beryllium-related health conditions—does have multiple potential causes.

In addition to causation issues, occupational health hazards frequently have a long latency period, sometimes 20 years or more between exposure and the manifestation of disease or other adverse effects. Consequently, workers usually cannot logically or intuitively draw a connection between workplace exposure to a health hazard and a chronic disease or adverse health condition, as would be the case for an acute injury resulting from a safety hazard. For example, should workers attribute their signs and symptoms of CBD (e.g., shortness of breath, persistent cough, reduced pulmonary function) to workplace exposure to beryllium, genetic predisposition (e.g., asthma), or non-occupational exposures? Furthermore, by the time that signs and symptoms of occupational health problems arise, it is often too late for workers to make use of that information. Lung cancer does not surface until many years after the exposures that contributed to causing it, and preventive action can no longer be taken. By the time that CBD is advanced enough to cause shortness of breath or a cough, the damage to the lungs cannot be

[6] Other examples of such "signature" diseases include mesothelioma and angiosarcoma, which are caused by exposure to asbestos and vinyl chloride, respectively.

reversed, and can progress in the absence of further exposure (see the preamble for OSHA's beryllium proposal at Section V, Health Effects). However, the BeLPT can be used to detect the first stage towards the development of CBD, potentially allowing workers to avoid further exposure before irreversible damage to the lungs occurs. In this sense, the medical surveillance requirements of the proposed standard make useful and timely information available to workers about their risk of adverse health effects from beryllium exposure.

Even the preceding characterization fails to capture the extent to which imperfect information impairs the idealized job market's decision calculus, as workers supposedly weigh increased workplace safety or health hazards against wage increases. One reason is that the risk information available to the worker is typically crude and imprecise. For example, workers might reasonably be aware, at least over time, that their workplace exposure to beryllium creates some chance of becoming sensitized to beryllium or developing CBD. However, they could hardly be expected to keep abreast of the scientific literature on hazardous exposures in their workplace, such as epidemiological studies showing that there is a CBD prevalence of eight percent among machinists with an average beryllium exposure level between 0.2 and 0.5 $\mu g/m^3$, and that the prevalence of CBD is typically less than one percent among workers whose exposures are kept below 0.1 $\mu g/m^3$ (see the preamble at Section VI, Significance of Risk). Even more to the point, workers would have no way of ascertaining their average beryllium exposure without exposure monitoring, and the current beryllium standard does not require employers to conduct exposure monitoring.

A second, related reason is that workers are unlikely to know the workplace risks associated with their particular employer, or with one employer versus another, even if the types of work assignments are the same or similar. Again, absent exposure monitoring, how do workers know their level of beryllium exposure at a particular workplace? More specifically, on tasks involving beryllium exposure, how do workers know whether their employers or potential employers have implemented adequate engineering controls, or provided respirators (or protective clothing and other personal protective equipment) that have adequate protection factors, have been properly fit-tested, and are properly maintained? In fact, even the assumption that employers currently are using any engineering controls and supplying any personal protective equipment may not be correct in the absence of regulation.

Inability to Process Risk Information

Equally problematic as the ability of workers to obtain workplace risk information is their ability to understand the information they manage to obtain.[7] Both experimental studies and observed market behavior suggest that individuals have considerable difficulty rationally processing information about low-probability, high-consequence events such as occupational injuries, illnesses, and fatalities. For example, most individuals are unable to comprehend or rationally act on risk information when it is presented, as risk analysis often is, in mathematical terms—a 1/1,000 versus a 1/10,000 versus a 1/100,000 annual risk of death from occupational causes.

In order to cope with uncertain situations, individuals have developed various rules of thumb—termed "heuristics"[8] (Tversky and Kahneman, 1974)—to aid in their decision-making. In many circumstances, these heuristics work quickly and effectively, which is their purpose.

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[7] The literature documenting risk perception problems is huge. See, in particular, the classic work of Tversky and Kahneman (1974). For a recent summary of risk perception problems and their causes, see Thaler and Sunstein (2008), pp. 17-37.

[8] Heuristics refer to experience-based techniques (e.g., trial and error) for discovery, learning, and problem-solving or decision-making. Heuristics provide a framework for solving a problem or making a decision in contrast with a fixed set of rules (algorithmic) that cannot vary. Heuristics helps to speed up the process of problem-solving or decision-making when an exhaustive search is impractical.

However, sometimes they introduce unintentional cognitive biases that can lead to illogical, inconsistent, or otherwise poor decision-making.[9] Examples of these apparently almost universal human biases include framing effects;[10] biases due to representativeness, availability, and anchoring heuristics;[11] and the interrelated effects of prior endowment, status quo bias, and loss aversion.[12]

Of course, in the abstract, many of the problems that workers face in obtaining and processing occupational risk can lead workers to overestimate as well as underestimate the risk.

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[9] These decision-making anomalies are the central theme in the growing field of behavioral economics, which has enriched economic modeling with insights from psychology (and which includes the seminal work of Tversky and Kahneman, 1974). For more information on developments in behavioral economics, see, for example, Camerer, Loewenstein, and Rabin (2004).

The emerging field of neuroeconomics has provided scientific evidence to buttress the findings of cognitive biases reported in the behavioral economics literature. Neuroeconomics combines neuroscience, economics, and psychology to study how people make decisions. Brain scans performed in neuroeconomic experiments compare the roles of the different brain areas that contribute to economic decision-making. Neuroeconomic research has shown that human behavior involves a fluid interaction between controlled (reflective) and automatic processes of the brain and between cognitive and affective (emotional) systems. So-called decision-making "anomalies" are therefore the result of simplistic modeling of human decision-making, in which only the reflective processes of the brain and cognitive systems are recognized. For more information on neuroeconomics, see, for example, Camerer, Loewenstein, and Prelec (2005).

[10] Framing effects arise when alternative representations of probabilistically identical decision problems lead to systematically different choices. For example, experiments have shown that subjects' choices in otherwise identical problems depend upon how they are phrased (e.g., as gambling or insurance decisions) or how the statistical outcomes are presented (e.g., in terms of lives saved or lives lost). See, for example, Machina (1987), pp. 141-147.

[11] Representativeness refers to a probabilistic judgment—say, of person A belonging to category B—that is based on the similarity of A to a subject's image or stereotype of B, often without reference to or contrary to statistical principles (such as regression towards the mean) or factors (such as known prior probabilities or sample size). Availability refers to probabilistic judgments based on how readily examples come to mind. Hence, more recent, more vivid, and more highly publicized causes of death tend to generate inflated estimates of likelihood of occurrence. Anchoring refers to an estimation process of adjustment from an initial value (the anchor). Problems arise due to faulty (e.g., sometimes random or externally imposed) anchors and inadequate adjustment. Characterization of these three heuristics, and the biased judgments associated with them, originated with Tversky and Kahneman (1974).

[12] The endowment effect reflects the fact that individuals often demand much more for an object they own than they would be willing to pay to acquire it. Loss aversion is a similar manifestation of asymmetric value in which the disutility of giving up an object is greater than the utility associated with acquiring it. Status quo bias is a preference by individuals for the current state such that they are induced neither to buy nor to sell an object. See, for example, Kahneman, Knetsch, and Thaler (1991).

Just on that basis, these information problems may not necessarily be enough to provide a rationale for regulating a lower standard. However, in the case of beryllium exposure, CBD may be sufficiently unfamiliar and unobvious and the amount of beryllium involved so minute that many workers may be completely unaware of the risk, and therefore will underestimate it. In addition, for markets to optimally address this risk, employees need to be aware of the changes in risk brought about by an employer's actions. Even if employees are aware of a risk, the employer may have limited economic motivation to install controls unless the employees are able to accurately assess the effects of those controls on their occupational risks. Furthermore, there is substantial evidence that most individuals are unrealistically optimistic, even in high-stakes, high-risk situations and even if they are aware of the statistical risks (Thaler and Sunstein, 2009, pp. 31-33). Although the Agency lacks specific evidence in the area of occupational safety and health, this suggests that some workers underestimate their own risk of work-related injury, disease, or fatality and, therefore, fail to demand adequate compensation for bearing those risks. Finally, the difficulty that workers have in distinguishing marginal differences in risk in alternative worksites (even, and particularly, within an industry) create a disincentive for employers to incur the costs of reducing workplace risk.

(2) <u>Externalities</u>

Externalities arise when an economic transaction generates direct positive or negative spillover effects on parties not involved in the transaction. The resulting spillover, which amounts to a divergence between private and social costs, undermines the efficient allocation of resources in the market because the market is imparting inaccurate cost and price signals to economic agents. Applied to the job market, when costs are externalized, they are not reflected in the decisions that employers and workers make—leading to allocative distortions in that market.

Negative externalities exist in the job market because many of the costs of occupational injury and illness are borne by parties other than individual employers or workers. The major source of these externalities, for chronic occupational diseases, has to do with occupational illness costs that workers' compensation does not cover.[13] Workers and their employers often bear only a portion of these residual costs. Outside of workers' compensation, workers incapacitated by an occupational injury or illness and their families often receive health care, rehabilitation, retraining, direct income maintenance, or life insurance benefits, most of which are paid for by society through Social Security and other social insurance and social welfare programs.[14] Furthermore, substantial portions of the medical care system in the United States are

heavily subsidized by the government so that part of the medical cost of treating injured or ill workers is paid for by the rest of society (Nichols and Zeckhauser, 1977, pp. 44-45). To the extent that employers and workers do not bear the full costs of occupational injury and illness, they will ignore these externalized costs in their job-market negotiations. The result may be an inefficiently high level of occupational risk. It should be noted, however, that OSHA expects that the effect of these externalities on the market-determined level of occupational risk would be relatively minor in comparison to the other types of market failure described here.

[13] Workers' compensation is discussed separately later in this chapter. As described there, in many cases (particularly for smaller firms), the premiums that an individual employer pays for workers' compensation are only loosely related, or unrelated, to the occupational risks that that employer's workers bear. However, workers' compensation does not cover chronic occupational diseases in most instances. For that reason, negative externalities tend to be a more significant issue in the case of occupational exposures that result in diseases.

[14] In addition, many occupational injuries and most occupational illnesses, other than musculoskeletal disorders, are not processed through the workers' compensation system at all. In these instances, workers receive care from their own private physician rather than from their employer's physician.

(3) Imperfect Competition

In the idealized job market, the actions of large numbers of buyers and sellers of labor services establish the market-clearing, risk-compensated wage, so that individual employers and workers effectively take that wage as given. In reality, however, the job market is not one market but many markets differentiated by location, occupation, and other factors; entrants in the labor market face search frictions because of limited information on employment options; and, furthermore, in wage negotiations with their own workers, employers are typically in an advantageous position relative to all other potential employers. In these situations, discussed below, employers may have sufficient power to influence or to determine the wage their workers receive. This may undermine the conditions necessary for perfect competition and can result in inadequate compensation for workers exposed to workplace hazards.

Beyond the classic—but relatively rare—example of a town dominated by a single company, there is significant evidence that some employers throughout the economy are not wage-takers but, rather, face upward-sloping labor supply curves and enjoy some market power in setting wages and other conditions of employment.[15] An important source of this phenomenon is the cost of a job search and the employer's relative advantage, from size and economies of scale, in acquiring job market information.[16]

Another potentially noteworthy problem in the job market is that, contrary to the model of perfect competition, workers with jobs cannot costlessly quit and obtain a similar job at the

[15] See, for example, Ashenfelter, Farber, and Ransom (2010) and Boal and Ransom (1997). The term "monopsony" power is usually applied to this situation, but it does not necessarily require a single employer.

[16] Weil (2014) presents theory and evidence both in support of this proposition and to show that, in many situations, larger firms have more monopsony power than smaller firms. Boal and Ransom (1997, p. 97) note that the persistent wage dispersion observed in labor markets is a central feature of equilibrium search models.

same wage with another employer. Workers leaving their current job may be confronted with the expense and time requirements of a job search, the expense associated with relocating to take advantage of better employment opportunities, the loss of firm-specific human capital, the cost and difficulty of upgrading job skills, and the risk of a prolonged period of unemployment. In addition, employers derive market power from the fact that a portion of the compensation their workers receive is not transferable to other jobs. Examples include job-specific training and associated compensation, seniority rights and associated benefits, investments in a pension plan, and most important, until recently,[17] health insurance.[18] Even if competing employers provide health insurance, it may well be subject to exclusions for pre-existing conditions.

Under the conditions described above, employers would not have to take the market-clearing wage as given, but could offer a lower wage than would be observed in a perfectly competitive market,[19] including less than full compensation for workplace health and safety risks. As a result, relative to the idealized competitive job market, employers would have less incentive to invest in workplace safety.

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[17] The Patient Protection and Affordable Care Act (PPACA) (Pub.L. 111-148, 124 Stat. 119), signed into law by President Obama on March 23, 2010, addresses the issue of health care availability in the United States. Key provisions in PPACA remove health-care-related competitive barriers in labor markets, such as exclusions or higher rates for individuals with pre-existing conditions.

[18] It should be noted, however, that the percentage of employers providing health insurance coverage in the United States has been steadily declining over time, both because of rising costs and because of the increased difficulty of obtaining such insurance. In any event, health insurers are only responsible for losses not covered by workers' compensation and not subject to exclusions (e.g., pre-existing conditions) within the life of the policy, which is normally one year. In future years, insurers can raise rates or cancel an employer's health insurance policy if circumstances change.

[19] For a graphical demonstration that an employer with monopsony power will pay less than the competitive market wage, see Borjas (2000), pp. 187-189.

(4) Compelling Social Need

Some individual actions are circumscribed by rights and duties or other social purpose that take precedence over market considerations, and these social purposes provide sufficient justification for regulation (OMB Circular A-4, OMB 2003). Market transactions in such circumstances may be legally forbidden or socially unacceptable on ethical grounds, even if there are willing parties to the transactions. For example, in the United States, one's right to vote cannot be sold to another person, and the prison time a convicted criminal receives cannot be served by another person in exchange for a fee. In the context of the job market, contracts of indentured servitude are not allowed.

The preceding points suggest that, because of important rights and duties or other social purposes, government intervention may sometimes improve the workings of the unfettered job market. In fact, the American people, through their elected representatives, have made a determination to override the operation of the unfettered job market, if necessary, by assuring in the OSH Act "so far as possible every working man and woman in the Nation safe and healthful working conditions . . . ." (29 U.S.C. 651(b)). It is under this congressional mandate that OSHA has developed the proposed beryllium rule.

OSHA welcomes comment and supporting evidence on the extent of these market failures and compelling public need in the job market, as well as their effects on worker health risks from exposure to beryllium.

NON-MARKET AND QUASI-MARKET ALTERNATIVES TO REGULATION

The discussion in this section considers whether non-market and quasi-market alternatives to the proposed rule would be capable of protecting workers from the hazards of beryllium exposure. The alternatives under consideration are information dissemination programs, workers' compensation systems, and tort liability options.

Information Dissemination Programs

An alternative to OSHA's proposed beryllium rule would be the dissemination of information, either voluntarily or through compliance with OSHA's hazard communication standard (HCS) (29 CFR 1910.1200), about the health risks associated with workplace exposure to beryllium. Better informed workers could more accurately assess the occupational risks associated with different jobs, thereby facilitating, through labor market transactions, higher risk premiums for more hazardous work and inducing employers to make the workplace less hazardous. The proposed rule recognizes the link between the dissemination of information and workplace risks by requiring that workers engaged in jobs involving exposure to beryllium be provided with information and training about beryllium-related illnesses and ways to prevent them. There are several reasons, however, why reliance on information dissemination programs alone would not yield the level of worker protection achievable through the proposed beryllium rule.

First, in the context of HCS, which requires employers to transmit information about the inherently hazardous properties of hazardous substances, the standard alone does not require that sufficient information be provided to identify risks in specific workplaces. Beryllium-related risks, for instance, are highly specific to individual tasks and work environments.

Second, in the case of voluntary information dissemination programs, absent a regulation, there may be significant economic incentives, for all the reasons discussed in the private market incentives, for the employer *not* to gather relevant exposure data or distribute occupational risk information so that the workers would not demand higher wages to compensate for their newly identified occupational risks.

Third, even if workers were better informed about workplace risks and hazards, all of the defects in the functioning of the private job market previously discussed—the limited ability of workers to evaluate risk information, externalities, imperfect competition, and factors that transcend the market—would still apply. Because of the existence of these defects, better information alone would not ensure that the job market will yield wage premiums for risk in a manner that is consistent with an efficient allocation of resources.

Thus, while improved access to information about beryllium-related hazards can provide for more rational decision-making in the private job market, OSHA preliminarily concludes that information dissemination programs may not, by themselves, produce an adequate level of worker protection.

Workers' Compensation Systems

Another alternative to OSHA regulation is simply to use State workers' compensation programs to augment the workings of the private job market to limit occupational risks to worker safety and health. After all, one of the objectives of the workers' compensation system is to shift the costs of occupational injury and disease from workers to employers in order to induce employers to improve working conditions. Two other objectives are to provide fair and prompt compensation to workers for medical costs and lost wages resulting from workplace injury and disease and, through the risk-spreading features of the workers' compensation insurance pool, to prevent individual employers from suffering a catastrophic financial loss (Ashford, 2007, p. 1712).

However, there are three reasons, discussed below, why the workers' compensation system has fallen short of the goal of shifting to employers the costs of workplace injury and disease—including, in particular, the costs of worker exposure to beryllium. As a result, OSHA preliminarily concludes that there may be inadequate worker protection in the absence of the proposed beryllium rule.

(1) A Divergence between Workers' Compensation Premiums and Workplace Risk

The first reason workers' compensation does not adequately shift the costs of work-related injuries and illnesses to employers is that the risk-spreading objective of workers' compensation conflicts with, and ultimately helps to undermine, the cost-internalization objective.[20] For the 99 percent of employers who rely on workers' compensation insurance,[21] the

[20] Recall from the earlier discussion of externalities that the failure to internalize costs leads to allocative distortions and inefficiencies in the market.

payment of premiums represents their primary cost for occupational injuries and illnesses, such as beryllium-related illnesses. However, the mechanism for determining an employer's workers' compensation insurance premium typically fails to reflect the actual occupational risk present in that employer's workplace.

Approximately 85 percent of employers have their premiums set based on a "class rating," which is based on ***industry*** illness and injury history. Employers in this class are typically the smallest firms and represent only about 15 percent of workers (Ashford, 2007, p. 1713). Small firms are often ineligible for experience rating because of insufficient claims history or because of a high year-to-year variance in their claim rates. These firms are granted rate reductions only if the experience of the entire class improves. The remaining 14 percent of employers, larger firms representing approximately 70 percent of workers, have their premiums set on the basis of a combination of "class rating" and "experience rating," which adjusts the class rating to reflect a firm's individual claims experience. A firm's experience rating is generally based on the history of workers' compensation payments to workers injured at that firm's workplace, not on the quality of the firm's overall worker protection program and safety and health record. Thus, for example, the existence of circumstances that may lead to catastrophic future losses are not included in an experience rating—only actual past losses are.[22]

Insurance companies do have the right to refuse to provide workers' compensation insurance to an employer—and frequently exercise that right based on their inspections and

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[21] Only the largest firms, constituting approximately 1 percent of employers and representing approximately 15 percent of workers, are self-insured. These individual firms accomplish risk-spreading as a result of the large number of workers they cover. See Ashford (2007), p. 1712.

[22] In order to spread risks in an efficient manner, it is critical that insurers have adequate information to set individual premiums that reflect each individual employer's risks. As the preceding discussion has made clear, by and large, they do not. In that sense, insurers can be added to employers and workers as suffering from imperfect information about job hazards.

evaluations of a firm's health and safety practices. However, almost all States have assigned risk pools that insist that any firm that cannot obtain workers' compensation policies from any insurer must be provided workers' compensation insurance at a State-mandated rate that reflects a combination of class and experience rating.

Workers' compensation insurance does protect individual employers against a catastrophic financial loss due to work-related injury or illness claims. As a result of risk spreading, however, employers' efforts to reduce the incidence of occupational injuries and illnesses are not fully reflected in reduced workers' compensation premiums. Conversely, employers who devote fewer resources to promoting worker safety and health may not incur commensurately higher workers' compensation costs. This creates a type of moral hazard, in that the presence of risk spreading in workers' compensation insurance may induce employers to make fewer investments in equipment and training to reduce the risk of workplace injuries and illnesses.

In short, the premiums most individual employers pay for workers' compensation insurance coverage do not reflect the actual cost burden those employers impose on the worker's compensation system. Consequently, employers considering measures to lower the incidence of workplace injuries and illnesses can expect to receive a less-than-commensurate reduction in workers' compensation premiums.

(2) Failure to Provide Compensation for Most Occupational Diseases

The second, and most important, reason that workers' compensation is not an adequate alternative, as a practical matter, is that State workers' compensation programs tend not to provide benefits for most work-related diseases—including those resulting from beryllium exposure, such as CBD. Several related factors account for this:

- Most occupational diseases have multiple causes and are indistinguishable from ordinary diseases of life. Therefore it is difficult for workers' compensation to trace the cause of these diseases to the workplace;
- Many occupational diseases have long latency periods, which tends to obscure the actual cause of disease or the place of employment where exposure occurred;
- Workers (as well as medical personnel) often do not realize that a disease is work-related and, therefore, fail to file a workers' compensation claim; and
- Most States have filing restrictions. For example, most states have statutes of limitations that are 10 years or less for filing workers' compensation claims. This may preclude claims for illnesses involving long latency periods. Also, many States have a minimum exposure time period before a disease can be attributed to an occupational cause.

With the exception of musculoskeletal disorders, workers' compensation actually covers only 5 percent of occupational diseases and 1.1 percent of occupational fatalities (Ashford, 2007, p. 1714). Beryllium-related occupational diseases face a similar lack of workers' compensation coverage.

(3) Limitations on Payouts

The third reason that employers do not fully pay the costs of work-related injuries and disease under the workers' compensation system is that, even for those claims that are accepted into the system, states have imposed significant limitations on payouts. Depending on the State, these limitations and restrictions include:

- Caps on wage replacement based on the average wage in the State rather than the injured workers' actual wage;
- Restrictions on medical care services that are compensated and the amount of that compensation;
- No compensation for non-pecuniary losses, such as pain and suffering or impairment not directly related to earning power;
- Either no, or limited, cost-of-living increases;
- Restrictions on permanent, partial, and total disability benefits, either by specifying a maximum number of weeks for which benefits can be paid or by imposing an absolute ceiling on dollar payouts;
- A low absolute ceiling on death benefits.

The last two restrictions may be the most important for occupational diseases with long-term health effects and possible fatal outcomes, such as those associated with worker exposure to beryllium.

In summary, for all of the reasons discussed above, the workers' compensation system does not provide adequate incentives to employers to control occupational risks to worker safety and health.

Tort Liability Options

Another alternative to OSHA regulation would be for workers to use the tort system to seek redress for work-related injuries and diseases, including beryllium-related ones. A tort is a civil wrong (other than breach of contract), for which the courts provide a remedy in the form of an action for damages. The application of the tort system to occupational injury and disease would allow workers to sue their employer, or other responsible parties (e.g., “third parties” such as suppliers of hazardous material or equipment used in the workplace) to recover damages. In theory, the tort system could shift the liability for the direct costs of occupational injury and illness from the worker to the employer or to other responsible parties. In turn, the employer or third parties would be induced to improve worker safety and health.

With limited exceptions, however, the tort system has not been a viable alternative to occupational safety and health regulation because State statutes make workers’ compensation the “exclusive remedy” for work-related injuries and illnesses. Workers’ compensation is essentially a type of no-fault insurance. In return for employers’ willingness to provide, through workers’ compensation, timely wage-loss and medical coverage for workers’ job-related injuries and diseases, regardless of fault, workers are barred from suing their employers for damages, except in cases of intentional harm or, in some States, gross negligence (Ashford and Caldart, 1996, p. 233). Practically speaking, in most cases, workers’ compensation is the exclusive legal remedy available to workers.

In principle, workers may attempt to recover damages for work-related injuries and disease from third parties through the tort system. However, the process is lengthy, adversarial, and expensive. In addition, in tort cases involving chronic occupational disease, the likelihood of prevailing in court and ultimately obtaining compensation is small because:

- In a tort action, the burden of proof is on the plaintiff (i.e., the worker) to demonstrate by "a preponderance of the evidence" that the defendant owed a duty to the plaintiff, that the defendant breached that duty, and that the breach caused the worker's injury or disease;
- To establish third-party liability the worker must show that the third party's products or equipment or instructions were defective or negligently designed. Liability is often in dispute and difficult to prove by a preponderance of the evidence;
- In cases of chronic disease, it is typically even more difficult to prove that the third-party was causally responsible. The worker must prove, based on a preponderance of the evidence, that not only was the disease the result of occupational exposure and not an ordinary disease of life or the result of non-occupational exposure, but also the causal exposure was due to the defendant's product at the plaintiff's particular worksite rather than exposure to some other third party's product or exposure at some other worksite. For diseases with long-latency periods and workers with long work histories, it may be almost impossible to establish causation under this test based on a preponderance of the evidence;
- For chronic diseases, the potentially lengthy latency period between worker exposure and manifestation of disease significantly lowers the probability that the responsible third party will still be in business when tort claims are ultimately filed and have sufficient assets to cover the claims, particularly if there are many of them;[23] and

[23] The same qualification about the firm being in business and having sufficient assets to pay claims may also apply to liability insurers, in those cases where the firm has purchased liability insurance. For example, some liability insurers that provided asbestos coverage were unable to settle all claims and had to declare bankruptcy.

- Workers may be deterred from filing tort actions because of the substantial costs involved—including attorney fees, court costs, and the costs of obtaining evidence and securing witnesses—and the lengthy period before a final decision is rendered.

In sum, the use of the tort system as an alternative to regulation is severely limited because of the "exclusive remedy" provisions in workers' compensation statutes; because of the various legal and practical difficulties in seeking recovery from responsible third parties, particularly in cases of occupational disease such as CBD; and because of the substantial costs associated with a tort action. The tort system, therefore, does not adequately serve to protect workers from exposure to hazards in the workplace.

SUMMARY

As shown in the preamble to the proposed beryllium rule, OSHA has determined that some workers in certain industries are exposed to beryllium and face a significant risk of developing lung cancer, BeS, and CBD. The private market—augmented by information dissemination programs, workers' compensation systems, and tort liability options—may be characterized by a level of risk for these workers that is higher than socially optimal; such an outcome could be due to a lack of information about health risks or (potentially) the presence of externalities or imperfect competition, and other factors discussed above. Therefore, the Agency has preliminarily concluded that OSHA's existing beryllium exposure limits and the private market are unlikely to provide the level of protection afforded by an updated occupational beryllium standard that adheres to the statutory requirements of the OSH Act.

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CHAPTER III: PROFILE OF AFFECTED INDUSTRIES

In this chapter, OSHA presents a profile of industries that use beryllium, beryllium oxide, and/or beryllium alloys. For each industry sector identified, the Agency describes the uses of beryllium and estimates the number of establishments and employees that may be affected by this proposed rulemaking. Employee exposure to beryllium can also occur as a result of certain processes such as welding that are found in many industries. This analysis will use the umbrella term “application group” to refer either to an industrial sector or a cross-industry group with a common process. These groups are all mutually exclusive and are analyzed in separate sections below.

Beryllium is rarely used by all establishments in any particular application group because its unique properties and relatively high cost typically result in only very specific and limited usage within a portion of a group. The following sections briefly describe each application group and then explain how OSHA estimated the number of establishments working with beryllium and the number of employees exposed to beryllium. Technological feasibility reports (summarized in Chapter IV of this PEA) for each beryllium-using application group provide a detailed presentation of processes and occupations with beryllium exposure, including available sampling exposure measurements and estimates of how many employees are affected in each specific occupation.

The information in this chapter is based on reports prepared under task order by Eastern Research Group (ERG), an OSHA contractor; information collected during OSHA’s Small Business Advocacy Review Panel (SBAR, 2008); and Agency research and analysis.

OSHA has identified nine application groups that would be potentially affected by the proposed beryllium standard:

1. Beryllium Production
2. Beryllium Oxide Ceramics and Composites
3. Nonferrous Foundries
4. Secondary Smelting, Refining, and Alloying
5. Precision Turned Products
6. Copper Rolling, Drawing, and Extruding
7. Fabrication of Beryllium Alloy Products
8. Welding
9. Dental Laboratories

These application groups are broadly defined, and some include establishments in several North American Industrial Classification System (NAICS) codes. For example, the Copper Rolling and Drawing, and Extruding application group is made up both of NAICS 331421 Copper Rolling, Drawing, and Extruding and NAICS 331422 Copper Wire Drawing. While an application group may contain numerous NAICS six-digit industry codes, in most cases only a fraction of the establishments in any individual six-digit NAICS industry use beryllium and would be affected by the proposed rule. For example, not all companies in the above application group work with copper that contains beryllium.

One application group, welding, reflects industrial activities or processes that take place in various industry sectors. All of the industries in which a given activity or process may result in worker exposure to beryllium are identified in the sections on the application group. The section on each application group describes the production processes where occupational contact with beryllium can occur and contains estimates of the total number of firms, employees, affected establishments, and affected employees.

Throughout this chapter, OSHA will be presenting formulas in the text, usually in parentheses, to help explain the derivation of estimates. Because the values used in the formulas shown in the text are sometimes rounded, while the actual spreadsheet formulas used to create final costs are not, the calculation using the presented formula will sometimes differ slightly from the total presented in the text—which is the actual total as shown in the tables.

At the end of this chapter, OSHA discusses other industry sectors that have reportedly used beryllium in the past or for which there are anecdotal or informal reports of beryllium use. The Agency was unable to verify beryllium use in these sectors that would be affected by the proposed standard (i.e., in general industry, where there is occupational exposure to beryllium or where materials are being processed that contain at least 0.1 percent beryllium by weight), and seeks further information in this rulemaking on these or other industries where there may be significant beryllium use and employee exposure.

AFFECTED APPLICATION GROUPS

1. Beryllium Producers

The Materion Corporation ("Materion," formerly Brush Wellman) plant in Elmore, Ohio, is currently the only facility in the United States that produces beryllium metal. The beryllium manufacturing application group thus consists of a single plant. Materion mines beryllium hydroxide at its Utah mining and extraction operation—which is regulated by the Mine Safety and Health Administration (MSHA) rather than OSHA. The beryllium hydroxide is converted into beryllium metal and beryllium oxide at the Elmore facility. Because Materion integrates a number of different processes into a single plant, the activities at the Elmore plant overlap with some of the other application groups addressed in this industrial profile. For example, copper-beryllium alloy production and rolling and drawing operations are performed at this facility, and a large part of the operation is devoted to manufacturing a range of beryllium alloy products. However, for purposes of this industrial profile, all workers at this facility are classified in this beryllium production application group. More information on specific job groups and their beryllium exposure at this facility is available in Chapter IV: Section 2 of this PEA.

Beryllium production at the Elmore facility is classified in NAICS 331419: Primary Smelting and Refining of Nonferrous Metals. ERG collected information about Materion's Elmore facility during site visits. Materion also provided information to the Agency in several written comments to the docket (OSHA, H005C-2006-0870 Document ID #0080).

Estimates of the Number of Affected Employees

In addition to the workers involved in beryllium, beryllium alloy, and beryllium oxide production, total employment at the Elmore facility includes administrative, research, and maintenance personnel. In response to OSHA's 2002 Beryllium Request for Information, Materion reported beryllium exposure sampling results for 1999 based on an average employment of 616 workers (Materion, 2002). Table III-1 shows the Materion staffing levels by work group at the Elmore plant in 1999. These data from the company are the most recent figures available, and the Agency has based its estimates on these employment figures.

Table III-1				
Beryllium Production				
NAICS code	Industry	Job Category	Employees	Production Employees
331419	Primary Smelting and Refining of Nonferrous Metals	Administrative	103	
331419	Primary Smelting and Refining of Nonferrous Metals	Site Support	127	127
331419	Primary Smelting and Refining of Nonferrous Metals	Production Support	146	146
331419	Primary Smelting and Refining of Nonferrous Metals	Cold Work	118	118
331419	Primary Smelting and Refining of Nonferrous Metals	Hot Work	42	42
331419	Primary Smelting and Refining of Nonferrous Metals	Powdering	4	4
331419	Primary Smelting and Refining of Nonferrous Metals	Chemical	18	18
331419	Primary Smelting and Refining of Nonferrous Metals	Furnace Operations	58	58
	Total		**616**	**513**

Source: Regulations.gov docket: OSHA-H005C-2006-0870-0092

2. Beryllium Oxide Ceramics and Composites

Beryllium oxide (commonly called beryllia) is known for its high heat capacity and is an important component of certain sensitive electronic equipment. Two facilities process beryllium oxide powder into ceramics and composites: Brush Ceramic Products in Tucson, Arizona (a subsidiary of Materion) and American Beryllia Inc. in Haskell, New Jersey. These two beryllium oxide ceramics producers also use fired oxide ceramics to manufacture finished products as well as to ship unfinished beryllium oxide ceramic products to a number of other manufacturers for further processing.

ERG used data from the 2002 Economic Census and from the Occupational Employment Survey (OES) of the Bureau of Labor Statistics (BLS), in combination with information collected through discussions with fabricators and finishers of beryllium oxide products, distributors of beryllium oxide raw materials, professional society board members, ceramic engineers, industrial hygienists, and research scientists, to create the industry profile for this application group (more detail is available in Chapter IV: Section 4 of this PEA).

Estimates of the Number of Affected Establishments

The two beryllium oxide processors have been identified above. Still needed are the downstream users with potentially affected employees. Most downstream users of beryllium that were contacted by ERG noted that they purchase at least some products from Brush Ceramic Products, whether or not they also purchase products from American Beryllia. Accordingly, OSHA assumes that Brush Ceramic Products' customers represent virtually all beryllium oxide customers. Materion (Brush Ceramic Products) reported in 2001 that its beryllium oxide ceramics products were sold to 102 different customers (Kolanz, 2001). By calculating the decrease in the overall number of establishments between the 2002 Economic Census and the

2010 County Business Patterns for each of the NAICS codes listed in Table III-2, and applying the same decreases to the relevant customer industries that received beryllium from Materion, OSHA estimates that 92 establishments are working with beryllium oxide today.[24] Below OSHA analyzes and allocates the 92 establishments among the various industries that have beryllium ceramic applications.

NAICS 327113: Porcelain Electrical Supply Manufacturing

The 2010 County Business Patterns reported a total of 106 establishments in NAICS 327113: Porcelain Electrical Supply Manufacturing. That dataset does not include a further breakdown by industry sub-sectors, so OSHA has relied on earlier economic data to identify the specific sub-sector of ceramics establishments whose employees might be exposed to beryllium during the manufacturing process. The 2002 Economic Census listed 18 firms in subsector 0351 of NAICS product code 327113 that manufacture ceramic materials that contain beryllium oxide, titanate, and other ceramic electrical products and components for electronic applications.[25] OSHA is not aware of other subsectors of NAICS 327113 that involve beryllium. Discussions with persons in the industry suggest that the actual number of firms currently is likely fewer than 18, and possibly as low as half this number (Pekrul, 2004), but absent additional data OSHA is relying on the Census information and assuming that each of these firms uses beryllium in some part of the ceramic manufacture process, and that each of these firms has one establishment, to estimate that 18 establishments performed beryllium oxide operations in this industry in 2002.

[24] More recent information on Materion's customer list is unfortunately not available. This earlier list has an industrial breakdown that is too broad to be used in this industrial profile without further analysis.

[25] The 2002 Economic Census breaks down many 6-digit NAICS industries into more detailed product codes, or lines (also called sub-sectors). Similar data are not available for all industries in the only subsequent Economic Census to date, that of 2007.

OSHA knows that the two primary producers in this subsector in 2002, Brush Ceramics and American Beryllia, remain active. To estimate the decrease from 2002 to 2010 in the remaining 16 firms, OSHA assumes the same percentage decrease in subsector 0351 firms as in the overall number of firms. The overall number of firms in NAICS 327113 decreased between the 2002 Economic Census and the 2010 County Business Patterns from 120 to 106. OSHA therefore estimates that 16 establishments performed beryllium oxide operations in NAICS 327113 in 2010.[26] OSHA seeks comment on the number of domestic producers of beryllium oxide ceramics, including whether there are fewer than the 16 estimated establishments and whether there are additional data that would assist OSHA in identifying the number of affected establishments or firms for this industry.

NAICS 334411: Electron Tube Manufacturing

A second group of downstream manufacturers produce traveling wave tubes included in NAICS 334411: Electron Tube Manufacturing. The 2010 County Business Patterns did not provide disaggregated statistics regarding the number of establishments that manufacture traveling wave tubes, but did report an overall total of 79 firms in this NAICS industry (U.S. Bureau of the Census, 2010). However, ERG's industry contacts indicated that a relatively small number of firms produce traveling wave tubes using beryllium. Based on discussions with an industry expert, OSHA estimates that 25 companies used beryllium in producing electronic wave tubes in 2002, and OSHA assumes that each company operated one establishment. Based on the change in the number of establishments in NAICS 334411 from 2002 to 2010, OSHA estimates that, in 2010, 21 establishments used beryllium to produce electronic wave tubes. OSHA did not identify

[26] Excluding the two primary producers, Brush Ceramics and American Beryllia (mentioned above), the adjustment to the other 16 produces 14 ((106/120) X 16 = 14) downstream manufacturers of beryllium oxide. Including Brush Ceramics and American Beryllia, a total of 16 (14 + 2) manufacturers remain.

any other sources that provided profile information on this group of firms and invites comment on this issue.

From OSHA's estimated total of 92 downstream users, this leaves 55 remaining users to be distributed among relevant industries.[27] Based on Materion's description of customers' use of beryllium oxide, OSHA believes that the remaining 55 customers use beryllium oxide ceramics in the production of four types of electrical and electronic products: (1) wireless base stations (such as cell towers); (2) various electronics devices (including resistor cores, heat sinks for satellites, and automotive ignitions); (3) medical laser devices; and (4) lasers used in entertainment devices.

Product manufacturers for these electronics products are classified in six different NAICS codes:

NAICS 334415: Electronic Resistor Manufacturing;

NAICS 334419: Other Electronic Component Manufacturing;

NAICS 336322: Other Motor Vehicle Electrical and Electronic Equipment Manufacturing;

NAICS 334220: Radio and Television Broadcasting and Wireless Communications Equipment Manufacturing;

NAICS 334510: Electromedical and Electrotherapeutic Apparatus Manufacturing; and

NAICS 334310: Audio and Video Equipment Manufacturing.

OSHA has preliminarily concluded that the remaining 55 customers purchasing beryllium oxide from Materion will fall within these six industries. ERG distributed these companies

[27] OSHA's estimates for establishments already discussed, NAICS 327113: Porcelain Electrical Supply Manufacturing, 16, and NAICS 334411: Electron Tube Manufacturing, 21, account for 37 (16 + 21) of these 92 customers, leaving 55 (92 - 37).

among these six NAICS codes based on Materion customer survey report descriptions and NAICS titles. These estimates are shown in Table III-2.

Estimates of the Number of Affected Employees

The estimated number of affected employees is also presented in Table III-2 and, except for the two beryllium oxide ceramics producers, was derived from the average number of employees in an establishment in a particular NAICS code multiplied by the number of affected establishments estimated to be in this same NAICS code.[28] ERG's industry contacts verified that most beryllium-oxide handling operations at these manufacturing facilities are small and suggested that the fabrication facilities are among the smaller firms in Materion's customer population (and hence American Beryllia's as well). Consequently, the Agency may be over-counting the number of employees by using the average number of employees per establishment to estimate the total. Most establishments contacted by ERG employ between 5 and 20 production workers each. One firm employs 50 to 60 production workers in total, but not all of them work on beryllium oxide projects (see Chapter IV: Section 4 of this PEA). OSHA invites comment on these estimates.

[28] Average employment per firm in a given industry is calculated by dividing the total employment from the 2010 County Business Patterns (CBP) by the total number of establishments reported by CBP.

Table III-2					
Beryllium Oxide					
NAICS code	Industry	Establishments	Employees	Affected Establishments	Affected Employees
327113	Porcelain Electrical Supply Manufacturing	106	4,310	16	689
334220	Cellular telephones manufacturing	810	79,732	10	984
334310	Compact disc players manufacturing	464	8,858	5	95
334411	Electron Tube Manufacturing BeO traveling wave tubes	79	4,884	21	1,298
334415	Electronic resistor manufacturing	61	3,722	12	732
334419	Other electronic component manufacturing	1,133	46,836	9	372
334510	Electromedical equipment manufacturing	629	66,107	9	946
336322	Other motor vehicle electrical and electronic equipment manufacturing	636	38,475	10	605
	Total	**3,918**	**252,924**	**92**	**5,722**

Sources: 2002 Economic Census, 2010 County Business Patterns, OSHA Office of Regulatory Analysis

3. Nonferrous Foundries

Nonferrous foundries produce a variety of cast products using alloyed and unalloyed copper, aluminum, and other metals (see Chapter IV: Section 5 of this PEA). These foundries may produce castings of copper-beryllium alloys or, to a lesser extent, aluminum-beryllium alloys, or both. A limited amount of pure beryllium is cast for specialized aerospace applications; however, beryllium is usually alloyed with another metal. To the extent that pure beryllium casting occurs, it happens as an occasional activity in aluminum foundries.

Foundries that use beryllium alloys are classified as:

NAICS 331525: Copper Foundries (Except Die-casting);

NAICS 331521: Aluminum Die-casting Foundries;

NAICS 331524: Aluminum Foundries (Except Die-casting); and

NAICS 331522: Nonferrous (Except Aluminum) Die-casting Foundries.

ERG used data from the 2002 Economic Census, 2010 OES, OSHA's Integrated Management Information System (IMIS) database, and discussions with industry contacts and trade groups in order to develop a profile of affected industries and estimate the number of employees for this application group (for more detail, see Chapter IV: Section 5 of this PEA). Table III-3 at the end of this section shows U.S. Census Bureau data describing the copper and aluminum foundry industries.

Estimates of the Number of Affected Establishments

NAICS 331525: Copper Foundries (Except Die casting)

U.S. Census Bureau data report the number of copper foundries with shipments of high-copper content alloys, which include copper-beryllium. The data show that, in 2002, 25 firms in NAICS

331525 product code 0416 produced high-copper sand castings, and 25 firms in NAICS 331525 product code 0541 produced investment castings out of high-copper alloys. Fewer foundries produced high-copper mold castings (12 firms), high-copper centrifugal castings (13 firms), and other types of high-copper castings (10 firms). Census data also show four firms in NAICS 331525 product code 06: Copper-base Alloy Bearings and Bushings, Nonmachined, which includes high-copper as well as other types of copper alloys. These product code categories are not exclusive, however, and firms are probably counted in more than one group. Hence, the number of foundries using high-copper alloys is very likely less than the total of 89, summed from these data, due to double-counting. Also, in the 2002 Census, the number of establishments in NAICS 331525 was only one greater than the number of firms; thus, it is reasonable to make the simplifying assumption that each firm mentioned above owns one establishment.
Information from OSHA's IMIS indicated that beryllium was detected in 20 percent of the 110 copper foundries where air samples were taken during the period 1978 through 2008. An extrapolation of this percentage to the total population of copper foundries (208) classified in NAICS 331525 yields an estimate of 42 such foundries (0.2 x 208) that may work with copper-beryllium alloys. Industry contacts suggest that the number of foundries casting beryllium alloys has declined in recent years. Of seven foundries that ERG contacted that indicated they have used copper-beryllium, two have stopped using the material in recent years.

While industry contacts could not provide quantitative estimates, ERG considered whether the number of foundries using beryllium according to the 2002 Economic Census was consistent with industry comments. Representatives of the American Foundry Society and the Non-Ferrous Founders' Society could not provide ERG with an estimate of the number of foundries casting beryllium alloy metals, but both stated that they believe the number is small.

The total population of foundries (according to the 2010 County Business Patterns) was 1,900. In that context, ERG considered that a "small number" likely indicated fewer than 100. Other industry sources, including a copper foundry, an aluminum foundry, a resistance welding electrode manufacturer, and a brass and copper rolling mill, also indicated that few foundries cast beryllium and beryllium alloys, although they could not provide quantitative estimates. Although no industry sources provided quantitative estimates of the number of foundries using beryllium, ERG determined that the profile developed based on U.S. Census data was consistent with industry sources' comments.

Considering the number of foundries suggested by information in the IMIS database (42) and the Census Bureau (89), given the likelihood of double counting by the Census Bureau, and the reported decline in copper-beryllium use in the foundry industry in the last decade, OSHA estimates that 45 establishments in the copper foundry industry sectors cast beryllium-containing alloys.

NAICS 331521 and 331524: Aluminum Foundries (Die Casting and Other)

ERG found no quantitative estimates of the number of foundries in the United States that cast aluminum-beryllium alloys.[29] ERG's research indicated that use of these alloys is much less common than the use of copper-beryllium. Furthermore, a representative of an aluminum foundry that uses aluminum-beryllium master alloys noted that use of beryllium alloys in aluminum foundries is decreasing (Barbetti, 2002).

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[29] Master aluminum-beryllium alloys (produced by beryllium alloyers) are used as stabilizers (deoxidizers), hardeners, and grain refiners in the production of aluminum and aluminum alloys. Small quantities (typically 50 to 100 parts per million) of the master alloy are added to the aluminum melt during the production process to reduce magnesium losses (Diroccho, 2002; KB, 2002; Kosto, 2002; Lefgren, 2002; and Mulcahy, 2002). Beryllium oxidizes more readily than magnesium, thereby limiting oxidation of magnesium in the melt (Lefgren, 2002).

ERG estimated that there are 14 foundry companies that cast aluminum-beryllium alloys. Of these foundries, OSHA estimates that at least 12 use aluminum-beryllium master alloys (Kosto, 2002). The remaining two foundries cast both pure beryllium and beryllium composite or hybrid products. For the purposes of this analysis, OSHA divided these 14 establishments between two application groups, assigning one-half of the total, or seven establishments, to each of the two aluminum foundry industries, NAICS 331521: Aluminum Die-Casting Foundries and NAICS 331524: Aluminum Foundries (Except Die-Casting).

NAICS 331522: Nonferrous Die-casting Foundries (Except Aluminum)

The U.S. Census Bureau (2002) reported that 38 firms in NAICS 331522: Nonferrous Die-casting Foundries produce copper or copper-base alloy die-castings, including bearings and bushings. ERG concluded that all of these establishments would use beryllium-copper alloy to some extent, because beryllium is commonly added to copper used to make bushings. OSHA therefore preliminarily estimates that all of these firms work with copper-beryllium alloys (see Chapter IV: Section 5 of this PEA).

Estimates of the Number of Affected Employees

Estimates of the number of employees in the nonferrous foundries are based on the average employment sizes for each of the respective industries discussed above (U.S. Census Bureau, 2004). OSHA estimates that a total of 97 nonferrous foundry establishments, employing 3,601 workers, use beryllium. Table III-3 summarizes the estimates of the numbers of affected foundries using beryllium alloys and the number of affected employees.

Table III-3					
Foundries					
NAICS code	**Industry**	**Establishments**	**Employees**	**Affected Establishments**	**Affected Employees**
331521	Aluminum die-casting foundries	254	18017	7	497
331522	Nonferrous (except aluminum) die-casting foundries	140	6362	38	1,727
331524	Aluminum foundries (except die-casting)	394	15178	7	270
331525	Copper foundries (except die-casting)	208	5123	45	1,108
	Total	**996**	**44,680**	**97**	**3,601**
Note: Totals may not add due to rounding.					
Sources: U.S. Census Bureau, 2006, 2010; OSHA Office of Regulatory Analysis					

4. Secondary Smelting, Refining, and Alloying

Secondary refining and smelting facilities produce metals from scrap and process waste. Direct handling and processing of beryllium alloy scrap or processing of unalloyed nonferrous metals that contain trace amounts of beryllium can generate beryllium exposures. As described in Chapter IV of this PEA, exposure data, containing industry and job descriptions, were obtained from OSHA's IMIS database, NIOSH Health Hazard Evaluations (HHEs) and an ERG site visit to a precious and base metals recovery facility (ERG, 2003). Based on this information, the Agency has preliminarily judged that the primary potential exposure source for workers in these facilities is processing of beryllium-alloy scrap derived from electronics and computer parts and from metals recycled from defense, aerospace, and other similar applications.

Establishments in secondary smelting, refining, and alloying fall under one of four NAICS industries:

NAICS 331421: Copper Rolling, Drawing, and Extruding;

NAICS 331314: Secondary Smelting and Alloying of Aluminum;

NAICS 331423: Secondary Smelting, Refining, and Alloying of Copper; and

NAICS 331492: Secondary Smelting, Refining, and Alloying of Nonferrous Metals.

Table III-4 at the end of this section presents data from the 2010 County Business Patterns describing affected secondary smelting, refining, and alloying industries. ERG also used data from the 2002 Economic Census, 2010 OES, OSHA's IMIS database, interviews with industry contacts, and the Thomas Register in order to compile the industry profile for this application group. Chapter IV further describes how estimates of the number of affected establishments, a small subset of the entire NAICS population, are derived.

Estimates of the Number of Affected Establishments

Three types of facilities in these industries use copper, aluminum, and other scrap to produce nonferrous metal products: smelters, refiners, and ingot makers.

NAICS 331314, 331421 and 331423: Secondary Smelting, Aluminum and Copper

Based on ERG's industry contacts, a review of the Thomas Register, and Internet searches, ERG identified only six establishments in NAICS 331314: Secondary Smelting and Alloying of Aluminum, that handle and/or produce aluminum-beryllium scrap alloys (Diroccho, 2002; KB, 2002; and Lefgren, 2002; also see Chapter IV: Section 6 of this PEA). One of these is the Materion facility in Elmore, Ohio, which has already been discussed in the earlier section on Beryllium Producers (NAICS 331419) —so Materion's facility is excluded from Table III-4.

One of the remaining five companies produces rolled and extruded copper-beryllium products and is classified in Table III-4 as NAICS 331421: Copper Rolling, Drawing, and Extruding. Three additional companies are classified in NAICS 331423: Secondary Smelting, Refining, and Alloying of Copper.[30] The remaining company—of the six companies that currently produce copper-beryllium or aluminum-beryllium alloys—specializes in aluminum alloys and is classified in NAICS 331314: Secondary Smelting and Alloying of Aluminum.

[30] One of the three processes beryllium scrap and produces copper-beryllium alloys for specialty applications; a second specializes in beryllium alloys and produces nickel-beryllium and aluminum-beryllium in addition to copper-beryllium; and the third produces copper-beryllium alloys in the form of billets and slabs, using both scrap and purchased master ingots (90 percent copper, 10 percent beryllium) as inputs.

<u>NAICS 331492: Secondary Smelting, Refining, and Alloying of Nonferrous Metals (Except Copper and Aluminum)</u>

Establishments in NAICS 331492: Secondary Smelting, Refining, and Alloying of Nonferrous Metals (Except Copper and Aluminum) recover precious metals from copper scrap, which may contain beryllium, extracted from electronics equipment and other wastes.

The 2007 Economic Census reports 29 firms in NAICS 331492 with sales greater than $100,000 that produce "secondary precious metals and precious metal alloys." ERG did not find additional relevant information about firms with lower sales amounts or other information about the number of affected establishments. Based on the possibility that there may be establishments with less than $100,000 in revenues that encounter beryllium and that some establishments with revenues greater than $100,000 may not process beryllium-containing materials, OSHA estimates that 30 establishments nationwide recover precious metals from electronic scrap and therefore could encounter copper-beryllium alloys.

A review of beryllium exposure samples contained in the IMIS database, covering the period 1994 through 2002, shows that all but a few detectible samples in secondary metal recovery facilities came from establishments engaged in secondary copper smelting, copper refining and alloying, or precious metal recovery. While beryllium could be encountered in other types of secondary metal recovery, the Agency has preliminarily concluded that the 30 establishments shown in Table III-4 represent all of the establishments in this industry affected by the proposed beryllium standard. OSHA invites comment and further data on this estimate.

<u>Estimates of the Number of Affected Employees</u>

Census-based industry statistics for NAICS 331423 and 331314 show an average of 32.9 and 39.7 employees per establishment, respectively (U.S. Census Bureau, 2010). Based on these averages, the Agency estimates that the total number of affected employees at the three establishments in NAICS 331423 that are estimated to be affected by this proposed rule is 99 employees (32.9 x 3) and that the total number of affected employees in NAICS 331314 is estimated to be 40 employees (39.7 x 1). Finally, there is only one establishment in NAICS 331421, and that establishment has 103 potentially affected employees. Therefore, the estimated number of affected employees for NAICS 331421 is 103 workers. Table III-4 summarizes employment estimates for these establishments.

Table III-4					
Smelting					
NAICS code	Industry	Establishments	Employees	Affected Establishments	Affected Employees
331314	Secondary smelting & alloying of aluminum	122	4846	1	40
331421	Copper rolling, drawing, and extruding	96	9849	1	103
331423	Secondary smelting, refining, & alloying of copper	24	789	3	99
331492	Secondary Smelting, Refining, and Alloying of Nonferrous Metal (Except Copper and Aluminum)	248	9696	30	1,173
	Total	**490**	**25,180**	**35**	**1,414**

Note: Excludes Materion's Elmore, OH plant, which is included in the Beryllium Production section

Note: Totals may not add due to rounding.

Sources: Office of Regulatory Analysis, OSHA; Economic Census 2010

5. Precision Turned Products

The precision turned product manufacturing application group includes companies that produce metal products by a combination of machining processes such as turning, milling, tapping, drilling, sawing, and grinding. Beryllium-containing materials that might be used for these products include beryllium metal and beryllium alloyed with other metals including copper, nickel, aluminum, magnesium, gold, and zinc. Applications include the manufacture of military aircraft and space shuttle brake systems, structural parts for missiles and satellites, optical systems, and x-ray windows.[31]

Establishments in this application group are found in NAICS 332721: Precision Turned Product Manufacturing. ERG used data from the 2010 County Business Patterns, 2010 OES, and discussions with industry contacts, including representatives of two of the largest machiners of pure beryllium and aluminum-beryllium alloys, in order to estimate the number of affected establishments and employees for this application group.

Estimates of the Number of Affected Establishments

Table III-5 at the end of this section provides profile information for NAICS 332721: Precision Turned Product Manufacturing based on 2010 County Business Patterns data. As shown, the industry includes an estimated 3,124 facilities and 78,749 employees. More than half of the facilities are small, employing fewer than 20 employees. Only 5 percent of the facilities employ 100 or more employees.

The number of establishments that machine pure beryllium or aluminum-beryllium alloys is very small due to the limited demand for beryllium parts and the difficulties of working with

[31] While civilian aerospace workers may be exposed to beryllium during maintenance or overhauling of braking systems, landing gear, or other systems, these activities are outside the scope of precision machining and are addressed in Application Group 10 later in this chapter.

beryllium metals. Representatives of two of the largest machiners of pure beryllium and aluminum-beryllium alloys reported that 15 or fewer companies work with these materials in the United States, and of these companies no more than six work with pure beryllium.

Copper-beryllium alloys, on the other hand, are easily machined and can be worked using conventional metalworking processes. Nevertheless, according to industry sources, several factors limit the number of establishments working with copper-beryllium. First, the market for machined copper-beryllium parts is small. Second, due to a combination of health concerns and the high cost of copper-beryllium, manufacturers have increasingly preferred beryllium-free materials. A number of industry contacts reported to ERG that their machine shops have stopped using copper-beryllium or are using it in small quantities and only occasionally. Sources, including an ERG contact at the National Machining and Tooling Association, reported that the number of machine shops working with copper-beryllium alloys represents a small percentage of the total number of machine shops. Although OSHA included small entity representatives (SERs) from the precision machining industry in the Small Business Advocacy Review (SBAR) Panel process, no comments were provided on the number of affected machine shops. Based on the information discussed above, OSHA estimates that 10 percent, or 312 of the 3,124 establishments in the precision turned products manufacturing industry, work with beryllium or its alloys. Based on discussions with industry contacts, OSHA estimates that about 18 (5.9 percent) of these 312 establishments might work with pure beryllium or high-beryllium alloys (see Chapter IV: Section 7 of this PEA) with the remaining 294 establishments working with low-beryllium alloys. The Agency seeks comment and additional data regarding these estimates.

Estimates of the Number of Affected Employees

OSHA assumes that the size distribution of beryllium-using establishments is the same as the size distribution of all industry establishments. Therefore, based on the 2010 County Business Patterns data identified earlier, OSHA estimates that the 312 establishments working with beryllium or beryllium alloys employ a total of 7,875 workers ((78,749 workers / 3,124 establishments) x 312 affected establishments). The 5.9 percent of these establishments using high-beryllium alloys yields an estimate of 465 (5.9% x 7,875) workers working with high-beryllium alloys, with the remaining 7,410 workers working with low-beryllium alloys. These estimates are summarized in Table III-5.

Table III-5					
Precision Machining					
NAICS code	**Industry**	**Establishments**	**Employees**	**Affected Establishments**	**Affected Employees**
332721	Precision turned product manufacturing	3,124	78,749		
	Facilities using High Be-content alloys			18	465
	Facilities Using Be-Cu alloy or other low Be-content alloys			294	7,410
	Total	**3,124**	**78,749**	**312**	**7,875**

Sources: U.S. Census Bureau, 2010 and OSHA Office of Regulatory Analysis.

6. Copper Rolling, Drawing, and Extruding

Copper rolling, drawing, and extruding mills produce copper and copper-alloy rod, bar, sheet, strip, plate, piping, tube, and wire. The metal-forming processes used to produce copper-beryllium (Cu-Be) products (which generally contain no more than 2 percent beryllium) are common to other metals and, depending on the product, may include rolling, extrusion, and hot or cold drawing. These processes may be accompanied by annealing, pickling or metal cleaning, and slitting or cutting operations. For those establishments making products out of copper alloys, copper-beryllium is only one of several copper alloys that may be used. Brass and bronze, for example, are common copper alloys that do not use beryllium.

There are two NAICS industries in this application group: NAICS 331421: Copper Rolling, Drawing, and Extruding, and NAICS 331422: Copper Wire Drawing. Table III-6 at the end of this section shows data from 2010 County Business Patterns for these two industries. ERG used data from the 2010 OES, County Business Patterns, information from the Copper Development Association, and interviews with contacts in industry and in trade associations in order to create the industrial profile for this application group (for more detail, see Chapter IV: Section 8 of this PEA).

Estimates of the Number of Affected Establishments

A list of copper-beryllium product suppliers maintained by the Copper Development Association contains eight companies with 12 establishments that produce rolled, drawn, and extruded copper-beryllium products (CDA, 2002). ERG identified three additional establishments engaged in re-drawing, re-rolling, or re-extruding copper-beryllium alloy. Based on this information, OSHA estimates that 15 establishments in this industry are currently engaged in the rolling, drawing, and extruding of copper-beryllium products.

Information from Materion's customer database shows that 59 facilities in NAICS 331422: Copper Wire (Except Mechanical) Drawing use Be-Cu metal (see Chapter IV: Section 8 of this PEA).

Estimates of the Number of Affected Employees

The 2010 County Business Patterns reported 96 establishments engaged in copper rolling, drawing, and extruding with a total of 9,849 workers, for an average of 102.6 employees per establishment. Assuming that the 15 affected establishment in NAICS 331421: Copper Rolling, Drawing, and Extruding are typical of other establishments in this industry and have an average of 102.6 employees per establishment, the affected establishments have a total of 1,539 (15 x 102.6) employees.

The 2010 County Business Patterns shows 114 establishments in NAICS 331422: Copper Wire (Except Mechanical) Drawing, employing 9,847 employees, for an average of 86 workers per establishment. With the same assumption for the 59 affected establishments from NAICS 331422: Copper Wire (Except Mechanical) Drawing, there are a total of 5,096 (59 x 86) employees in the affected establishments. Table III-6 summarizes the estimates of the number of affected establishments and employees for this application group. OSHA seeks comment and additional data on these estimates.

Table III-6					
Copper Rolling, Drawing and Extruding					
NAICS code	Industry	Establishments	Employees	Affected Establishments	Affected Employees
331421	Copper rolling, drawing, and extruding	96	9,849	15	1,539
331422	Copper wire (except mechanical) drawing	114	9,847	59	5,096
	Total	**210**	**19,696**	**74**	**6,635**
Sources: U.S. Census Bureau, County Business Patterns, 2010; OSHA Office of Regulatory Analysis					

7. Fabrication of Beryllium Alloy Products

Copper-beryllium alloys (less than or equal to 2 percent beryllium) are used to make a variety of products for electrical applications in this application group, which encompasses four 6-digit NAICS codes:

NAICS 332612: Light Gauge Springs Manufacturing;

NAICS 332116: Metal Stamping;

NAICS 334417: Electronic Connector Manufacturing; and

NAICS 336322: Other Motor Vehicle Electrical and Electronic Equipment Manufacturing.

Establishments producing electronic connectors or other stamped and formed metal products are classified in three NAICS industries. Facilities specializing in the production of electronic connectors and components are classified in NAICS 334417: Electronic Connector Manufacturing or NAICS 332116: Metal Stamping (which produces a wider range of parts). Manufacturers in NAICS 336322: Other Motor Vehicle Electrical and Electronic Equipment Manufacturing might also use copper-beryllium alloys in the assembly or production of electrical or electronic-related automotive parts.

Manufacturers of stamped metal products (NAICS 332116) use a variety of metals, including copper-beryllium alloys, to produce products for a range of applications. Based on information from industry representatives, copper-beryllium is used, at least occasionally, by most stampers that supply the electronics industry (see Chapter IV: Section 9 of this PEA).

Large and medium-size stamping operations are primarily automated. However, smaller shops may still use manually operated presses, and larger shops may maintain manually operated equipment for smaller jobs. According to industry representatives, connector manufacturers may either stamp copper-beryllium components in-house or purchase these components from a stamper, but virtually no grinding or other machining is performed on parts after stamping. Connector assembly is also reported to be largely automated. If employees only assemble but do not manufacture copper-beryllium parts, their exposure is only from handling “articles” and should be negligible. If the employees are not otherwise exposed to beryllium, their employers would not fall within the scope of the proposed standard.

Estimates of the Number of Affected Establishments

NAICS 332612: Light-Gauge Springs Manufacturing

Data from the 2010 County Business Patterns show that there are 323 establishments in NAICS 332612: Light Gauge Spring Manufacturing. Of these establishments, most (93.3 percent) employ fewer than 100 employees. Industry contacts suggested that, because no special equipment is needed to process copper-beryllium (as opposed to other alloys), almost any light gauge spring manufacturer (NAICS 332612) may use copper-beryllium from time to time. All coil spring manufacturers contacted by ERG indicated that they use copper-beryllium. Thus, ERG assumed that all light-gauge spring manufacturers are using beryllium even though they may use it only occasionally and in small amounts (see Chapter IV: Section 9 of this PEA). ERG’s industry contacts and spring manufacturers’ websites indicated that most spring manufacturers use copper-beryllium alloys, but that copper-beryllium springs typically account for only a small percentage of sales. This was reiterated by a representative of the Spring Manufacturers Institute (Wood, 2001).

NAICS 332116: Metal Stamping

According to the 2010 County Business Patterns, the metal stamping industry (NAICS 332116) is comprised of 1,484 establishments, with approximately one-half being small establishments having fewer than 20 employees. Most of these metal stamping establishments do not manufacture products for the electronics industry (the only industry using metal stamping products that contain copper-beryllium alloy), so there would be no beryllium exposure in most of these establishments. Based on data from the 2007 Economic Census Product Summary, it is possible to identify the subset of companies that are likely to be stamping copper-beryllium parts for the electronics industry. The four product codes listed below are the ones that OSHA has preliminarily determined comprise all copper-beryllium electronics applications in this NAICS industry code:

NAICS 332116-1352: Radio and Phonographs;

NAICS 332116-1354: Televisions;

NAICS 332116-1421: Computers; and

NAICS 332116-1441: Office Machines.

The 2007 Economic Census reports a total of 97 companies in these product classes. However, some companies likely produce in more than one of these product classes, and simply adding together the Census-reported manufacturers producing each product almost certainly overestimates the total number of these producers. Instead, based on the number of companies for these four product classes (97) and the average number of establishments per company for the stamping industry as a whole (1.05) (see Chapter IV: Section 9 of this PEA), ERG estimated that a total of 102 (97 x 1.05) establishments are operated by these companies. This estimate was brought forward to an estimate for 2010 by multiplying this number by the ratio of total number of establishments in this NAICS in the 2010 CBP (1,484) to same number in the 2007 Economic Census (1,528), giving an estimate of 99 establishments in 2010 (102 X (1484/1528)).

Based on discussions with industry representatives, OSHA concluded that approximately 75 percent of metal stamping establishments producing parts for the electronics industry work with copper-beryllium alloys. Table III-7 at the end of this section shows the estimated number of 74 establishments (75 percent of 99 establishments) in the metal stamping industry that use copper-beryllium alloys. OSHA has preliminarily determined that these estimates account for all establishments in the metal stamping industry where workers are at risk of beryllium exposures.

NAICS 334417: Electronic Connector Manufacturing

According to the 2010 County Business Patterns, electronic connector industries (NAICS 334417) comprise 231 establishments, with about one-half of these being small establishments having fewer than 20 employees.

None of the industry sources ERG contacted could estimate the share of electronic connector manufacturers that use copper-beryllium, but, because of the cost of this alloy, most sources believe that the number of users in this sector is limited. This assumption is supported by a review of information on connector manufacturers in the Thomas Register and on the Internet (Thomas Register, 2002; Thomas Net, 2006). Based on these sources, OSHA preliminarily estimates that 20 percent of electronic connector manufacturers use copper-beryllium alloys. Applying this percentage to the establishment figures from the 2010 County Business Patterns, the Agency estimates in Table III-7 that 46 establishments in this industry (231 x .20) use beryllium alloys.

NAICS 336322: Other Motor Vehicle Electric and Electronic Equipment Manufacturing

According to the 2010 County Business Patterns, 636 establishments produce automotive electrical and electronic equipment (NAICS 336322). This industry is dominated by small and mid-sized establishments.

Data describing the number of automotive parts manufactured using beryllium alloys are not available. Based on an earlier analysis of data from the 2002 Economic Census and the Materion customer database, ERG estimated that about 25 percent of automotive parts manufacturers perform stamping of beryllium alloys, primarily for electronic applications (see Chapter IV, Section 9). Applying this percentage to the establishment and employment figures from the 2010 County Business Patterns, the Agency estimates that 159 establishments (636 x .25) in this industry use beryllium alloys.

Estimates of the Number of Affected Employees

For all sectors, OSHA has assumed that the number of employees per establishment in affected establishments is the same as that for all establishments in their respective six-digit NAICS. Table III-7 presents the Agency's estimates of the number of employees and affected employees in the stamping, spring, and connector manufacturing application group. OSHA requests comment and additional data regarding these estimates.

Table III-7					
Stamping, Spring, and Connector Manufacturing					
NAICS code	**Industry**	**Establishments**	**Employees**	**Affected**	**Affected**
332116	Metal stamping	1,484	48,855	74	2,436
332612	Light gauge spring manufacturing	323	10,329	323	10,329
334417	Electronic connector manufacturing	231	19,538	46	3,908
336322	Other motor vehicle electrical & electronic equipment	636	38,475	159	9,619
	Total	**2,674**	**117,197**	**602**	**26,292**

Sources: U.S. Census Bureau, 2002 Economic Census; 2010 County Business Patterns; OSHA Office of Regulatory Analysis

8. Welding

For the purposes of assessing beryllium exposure, welding operations can be divided into two broad categories: arc and gas welding, and resistance welding.[32] For both broad categories beryllium exposures are not common, and when observed are low (see Chapter IV: Section 10 of this PEA).

a. Arc and gas welding

Beryllium exposures can occur in arc and gas welding operations when welding on base materials containing beryllium and when using equipment with electrodes that include beryllium (hereafter generally referred to simply as "welding"). Note "gas welding" in this context also uses electrodes; the gas used is to protect the weld from the atmosphere.

The principal area of welding exposures is among workers welding beryllium or beryllium-alloy products. The exposure profile in OSHA's technological feasibility analysis indicates that exposures do occur among these workers (see Chapter IV: Section 10 of this PEA).

ERG used data from a 2001 Materion customer survey to estimate the number of employers engaged in welding beryllium or beryllium-alloy products (ERG, 2005; Kolanz, 2001). In using these data, ERG assumed that Materion customers comprise essentially all domestic users of beryllium-containing materials. While there is one other domestic and one international supplier of beryllium-containing materials, these firms have a much smaller presence in the market, and most of their customers also purchase supplies from Materion.

Materion's customer survey reported that Materion customers employ roughly 2,000 workers who are engaged in welding—1,697 in strip customer facilities and 332 in bulk product

[32] An extended discussion of the difference between arc and gas welding and resistance welding is presented in Chapter IV: Section 10 of this PEA.

customer facilities (Kolanz, 2001). Using ERG's estimate that the average establishment employs 4 welders[33] yields an estimate of 500 establishments that perform these operations.

To distribute these 500 establishments among the appropriate NAICS industries, ERG used beryllium sampling data from OSHA's IMIS database to identify those SIC-classified industries[34] where beryllium alloy welding is likely to be performed, and then mapped these SIC industry codes to NAICS industry codes (OSHA, 2009). This procedure gives an estimate of the relevant number of establishments in these industries, but not every establishment in these industries performs such welding operations.

The 2010 Occupational Employment Survey reported the share of establishments employing arc and gas welders in each industry. ERG multiplied the corresponding share for welding occupations by the number of establishments in each selected industry (as reported by the 2010 County Business Patterns) to calculate the number of establishments in each industry where welding is estimated to be performed. This procedure resulted in an estimate of a total of 17,317 welding establishments across all the relevant industries.

Assuming establishments welding on beryllium alloys are evenly distributed across these industries, ERG multiplied the ratio of 500 beryllium-alloy welding establishments to 17,317 welding establishments overall (500/17,317 = 2.9%), by the number of welding establishments in each industry to generate the industry-specific estimates of the number of beryllium-alloy welding establishments. These totals were then multiplied by 4 (estimated number of welders

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[33] The 2010 OES shows an average of roughly 8 "welders, cutters, solderers, and brazers" per establishment in the 4-digit welding NAICS. Notably, some share of these do not work on alloys, and "cutters, solderers, and brazers" are not welders. In the absence of more detailed information about how many of these workers are performing cutting, soldering, brazing, or welding, ERG assumed that half are welding on alloys and that the workers in each job (welder, cutter, solderer, or brazer) are distributed evenly among facilities. Thus, OSHA estimates an average of 4 welders per establishment.

[34] IMIS still uses the Standard Industrial Classification (SIC) industry classification system, the precursor to the current NAICS system.

per establishment) to estimate the numbers of beryllium alloy welders in each industry. Table III-8 presents the resulting beryllium-alloy welders and welding establishment estimates.

b. Resistance welding

In resistance welding, exposures may occur from beryllium in the base metal or in the electrodes of the welding equipment. However, as discussed in greater detail in Chapter IV: Section 10 of this PEA, ERG's review of IMIS data found only very low exposures for resistance welders, suggesting most exposures well below the proposed PEL of 0.2. Nevertheless, in limited circumstances exposures above the Action Level of 0.1 may occur.

Multiple sources indicate that copper-beryllium resistance welding electrodes might be used in any industry where spot, projection, or seam welding occurs; however, these types of electrodes are used primarily in three industries: (1) the majority are used in NAICS 3363: Motor Vehicle Parts Manufacturing Industry; with additional uses in (2) NAICS 333415: Air-Conditioning and Warm Air Heating Equipment, and Commercial and Industrial Refrigeration Equipment Manufacturing; and (3) NAICS 3352: Household Appliance Manufacturing (Burnett, 2001; Foley; 2001; Green, 2001; Mitchell, 2001; and Pelkey, 2001). One supplier estimates that these three industries account for approximately 90 percent of the market for copper-beryllium electrodes (Burnett, 2001). According to the American Welding Society, roughly half of welding machine operators might operate various types of resistance welding machines (Mitchell, 2001). Based on discussions with industry contacts, ERG analysts consider that beryllium-affected industries are more likely to use resistance welding, versus gas or arc welding, and so estimate that 75 percent of welders are resistance welding machine operators in these industries. Data from the 2010 OES (BLS, 2010) show that between 5 and 7 percent of establishments in these industries, or about 400, employ a total of approximately 6,000 resistance welders. These estimates for resistance welding are summarized in Table III-9.

				Table III-8			
				Arc and Gas Welding			
				Establishments Where Arc or Gas Welding is Performed			
NAICS code	**Industry**	**Total Establishments**	**Total Employees**	**Total Establishments**	**Total Employees**	**Establishments Welding Beryllium**	**Affected Employees**
331111	Iron and steel mills	587	94,089	194	1,062	7	27
331221	Rolled steel shape manufacturing	161	9,971	40	85	1	6
331513	Steel foundries (except investment)	220	13,874	40	85	1	5
332117	Powder metallurgy part manufacturing	133	6,707	27	46	1	4
332212	Hand and edge tool manufacturing	1,066	25,098	85	69	3	12
332312	Fabricated structural metal manufacturing	3,407	89,728	1,635	1,473	56	224
332313	Plate work manufacturing	1,288	28,400	618	466	21	85
332322	Sheet metal work manufacturing	4,173	91,364	2,003	1,500	69	274
332323	Ornamental and architectural metal work m	2,354	30,029	1,130	493	39	155
332439	Other metal container manufacturing	370	12,553	196	228	7	27
332919	Other metal valve and pipe fitting manufacturing	265	14,688	80	151	3	11
332999	All other miscellaneous fabricated metal product manufacturing	3,262	65,821	979	675	33	134
333111	Farm machinery and equipment manufacturing	1,041	53,133	583	1,018	20	80
333414	Heating equipment (except warm air furnaces) manufacturing	460	16,768	175	218	6	24
333911	Pump and pumping equipment manufacturing	571	31,272	194	364	7	27
333922	Conveyor and conveying equipment manufacturing	776	26,970	264	314	9	36
333924	Industrial truck, tractor, trailer, and stacker machinery manufacturing	374	19,974	127	232	4	17
333999	All other miscellaneous general purpose machinery manufacturing	1,524	43,401	518	505	18	71
336211	Motor vehicle body manufacturing	742	38,587	438	779	15	60
336214	Travel trailer and camper manufacturing	683	30,803	403	622	14	55
336399	All other motor vehicle parts manufacturing	1,350	95,426	216	522	7	30
336510	Railroad rolling stock	226	24,491	79	293	3	11
336999	All other transportation equipment manufacturing	374	10,846	105	104	4	14
337215	Showcase, partition, shelving, and locker manufacturing	1,194	33,195	96	91	3	13
811310	Commercial and industrial machinery and equipment repair	21,960	181,220	4,172	1,178	143	571
	Total	**48,561**	**1,088,408**	**14,396**	**12,572**	**492**	**1,970**
Sources: OSHA IMIS, U.S. Census Bureau, 2002; BLS, 2003; OSHA Office of Regulatory Analysis							

Table III-9

Resistance Welding

NAICS code	Industry	Total Establishments	Total Employees	Establishments Where Resistance Welding is Performed: Total Establishments	Total Employees	Establishments Welding Beryllium	Affected Employees
333411	Air purification equipment manufacturing	358	14,521	25	1,016		98
333412	Industrial and commercial fan and blower manufacturing	151	6,908	11	484		47
333414	Heating equipment (except warm air furnaces) manufacturing	460	16,768	32	1,174		113
333415	Air-conditioning, warm air heating, and industrial refrigeration equipment manufacturing	843	79,651	59	5,576		537
335211	Electric housewares and household fan manufacturing	106	5,980	5	299		55
335212	Household vacuum cleaner manufacturing	34	2,577	2	129		24
335221	Household cooking appliance manufacturing	96	9,730	5	487		89
335222	Household refrigerator and home freezer manufacturing	22	9,731	1	487		89
335224	Household laundry equipment manufacturing	11	8,051	1	403		74
335228	Other major household appliance manufacturing	38	9,023	2	451		83
336311	Carburetor, piston, piston ring, and valve manufacturing	109	7,370	5	369		87
336312	Gasoline engine and engine parts manufacturing	742	36,896	37	1,845		437
336321	Vehicular lighting equipment manufacturing	93	9,218	5	461		109
336322	Other motor vehicle electrical and electronic equipment manufacturing	636	38,475	32	1,924		456
336330	Motor vehicle steering and suspension components (except spring) manufacturing	246	26,118	12	1,306		310
336340	Motor vehicle brake system manufacturing	199	20,245	10	1,012		240
336350	Motor vehicle transmission and power train parts manufacturing	476	51,171	24	2,559		607
336360	Motor vehicle seating and interior trim manufacturing	403	39,805	20	1,990		472
336370	Motor vehicle metal stamping	736	66,985	37	3,349		794
336391	Motor vehicle air-conditioning manufacturing	80	11,207	4	560		133
336399	All other motor vehicle parts manufacturing	1,350	95,426	68	4,771		1,131
	Total	**7,189**	**565,856**	**396**	**30,650**		**5,985**

Sources: U.S. Census Bureau, 2010; BLS, 2010; OSHA Office of Regulatory Analysis

9. Dental Laboratories

Dental technicians and other dental workers may be exposed to beryllium, primarily while performing induction casting and finishing the metal framework for dental prosthetic devices—specifically crowns, bridges, and cast partial dentures—made from beryllium-containing metal alloys. Beryllium is added to some dental alloys (typically in quantities of 0.5 to 2.0 percent) to improve strength, corrosion resistance, and elasticity; it is considered to be a less expensive alternative to silver and gold. Crowns and bridges are typically made of metal, ceramic, or a blend of metal and ceramic materials. Metals used to make crowns and bridges are often divided into precious (gold, etc.) and non-precious alloys. Beryllium occurs only in dental prosthetics made with non-precious Nickel-Chromium-Beryllium (Ni-Cr-Be) alloys.

These beryllium exposures occur in dental laboratories located in two types of establishments: onsite laboratories that are part of a dental office, which are included in NAICS 621210: Offices of Dentists, and separate laboratories included in NAICS 339116: Dental Laboratories.

Estimates of the Number of Affected Dental Offices

According to the 2010 County Business Patterns, there are 129,830 establishments in NAICS 621210: Offices of Dentists, which employ a total of 846,092 persons. Beryllium exposure for these offices occurs in captive dental laboratories where technicians might be making dental appliances containing beryllium alloys. OSHA is not aware of any published data regarding the number of dentists' offices that include captive dental laboratories, but a representative of the National Association of Dental

Laboratories estimates that 950 dental practices include such laboratories (see Chapter IV: Section 11 of this PEA).

Estimated Number of Affected Dental Laboratories

According to the 2010 County Business Patterns, there are 6,995 establishments in NAICS 339116: Dental Laboratories. These establishments employ a total of 44,030 persons. Most of the establishments are small: over 94 percent of them have fewer than 20 employees.

While there appears to be some continuing use of beryllium in dental labs for dental implements in the United States, recently there seems to have been a significant shift away from the use of beryllium alloys and towards beryllium-free alternatives. Paul Cascone—Senior Vice President of Technology, Argen, Inc. (San Diego, California), and an expert on the market for suppliers of dental laboratory materials—has reported on the market share of Ni-Cr-Be alloys over a period of ten years. In 2004, he indicated that non-precious metals accounted for 50 percent of the market for dental materials used to make crowns and bridges, of which 90 percent contained beryllium. In 2011 he reported that the non-precious metal share of the market had declined to 40 percent, where again 90 percent contained beryllium. In 2012 and 2013, he noted that due to a continuing increase in the market share of ceramics, non-precious metals' market share had fallen to 30 percent, where the same 90 percent of that non-precious metals continued to be beryllium-containing alloys. In short, the share of dental implements using beryllium declined from 45 percent to roughly 25 percent over the nine-year period from 2004 to 2013. Much of the shift to ceramics was driven by what is perceived as their superior aesthetics and that within the metal-based part of that market, numerous beryllium-free alternatives are increasingly used (ERG, 2013). Based on ERG discussions with Mr. Cascone (Cascone, 2012 and 2013) and with other industry sources, OSHA estimates that 25 percent of the 6,995 dental laboratories (1,749) currently use beryllium alloy to some extent. (Because current data and future trends are uncertain, OSHA will examine the effects of alternative levels of beryllium use in dental labs in its sensitivity analysis presented in Chapter VII of this PEA.)

Due to the declining market-share for non-precious alloys, the increasing popularity of dental prosthetics made with ceramic materials, and the availability of beryllium-free alternatives, the Agency estimates that, after the promulgation of the proposed beryllium standard, 75 percent of the 1,749 (0.75 X 1,749 = 1,312) dental laboratories currently using a beryllium alloy will substitute a non-beryllium alloy due to the increased regulatory costs of working with beryllium, leaving 437 laboratories (1,749 - 1,312) with employees potentially exposed to beryllium in NAICS 339116: Dental Laboratories.

Given the dynamic nature of this market, the Agency invites comment on the extent of beryllium use in the dental laboratories materials market and possible future trends in usage. As well, the Agency solicits comment on possible changes to exposure levels for dental lab employees due to these movements (see also Section IX of the preamble.) The Agency discusses specific details of the dental market in greater detail in Chapter V of this PEA. Table III-8 shows the estimated number of dental labs and labs in dentists' offices. OSHA invites comment on these estimates.

Estimates of the Number of Affected Employees

Occupational employment data indicate that most employees in dental laboratories (NAICS 339116) are dental laboratory technicians (2010 OES). According to the 2010 County Business Patterns, there are 6,995 establishments in NAICS 339116, Dental Laboratories (U.S. Census Bureau, 2010). These establishments employ a total of 44,030 workers. Occasionally, a dentist office (NAICS 621200, Offices of Dentists) may contain a captive dental laboratory that performs the activities of dental laboratories in NAICS 339116. The 2010 County Business Patterns reports 129,830 establishments and 846,092 employees in NAICS 621200. While no data exist on the number of dentist offices that contain captive dental laboratories, a representative of the National Association of Dental Laboratories estimates that 950 dental practices include a captive dental laboratory (Napier, 2004). Assuming that these 950 dental practices employ the average number of workers per establishment in NAICS 621200, there are a total of 6,191 (846,092/129,830 x 950) employees in dental laboratories contained in dentist offices. Based on discussions with industry sources, OSHA estimates that approximately 25 percent of dental laboratories use beryllium alloys (Cascone, 2013; ADA, 2011). Thus, OSHA estimates 1,749 (0.25 x 6,995) affected establishments in NAICS 339116 and 238 (0.25 x 950) affected establishments in NAICS 621200 for a total of 1,986 affected establishments. Assuming that these establishments employ the average number of workers for their respective industries, OSHA estimates 11,008 (44,030/6,995 x 1,749) affected employees in NAICS 339116 and 1,548 (846,092/129,830 x 238) affected employees in NAICS 621200. Thus a total of 1,986 affected dental laboratories employ 12,555 (11,008 + 1,548) workers. Table III-10 contains OSHA's estimate of the number of employees in dental labs, and those employed in dentist offices, who are estimated to currently work with beryllium alloys. OSHA invites comments on these estimates.

Table III-10							
Dental Laboratories							
NAICS code	**Industry**	**Total Establishments**	**Total Employees**	**Laboratories in Offices of Dentists**	**Affected Establishments**	**Affected Employees**
339116	Dental laboratories	6,995	44,030	--	1,749	11,008
621210	Offices of dentists	129,830	846,092	950	238	1,548
	Total	**136,825**	**890,122**	**950**	**1,986**	**12,555**
Sources: U.S. Census Bureau, 2010; BLS, 2008; OSHA Office of Regulatory Analysis						

10. Other Industries

There is anecdotal evidence that beryllium materials may be used in other industries and products, and hence there may be employers and employees affected by the proposed rule in those industries. Beryllium use has been reported in jewelry, golf clubs, and bicycles, but OSHA has not been able to confirm that beryllium is currently used in the production of these items. U.S. laboratory workers may have exposure to beryllium salts where Beryllium Lymphocyte Proliferation Tests (BeLPT) are processed (NJMRC, 2003). Employees in the private aerospace industry may have exposure to beryllium, but OSHA has not been able to confirm a report that non-military personnel perform work on aircraft using beryllium parts. The Agency has preliminarily concluded that it has captured elsewhere in this industry profile[35] the machining and production of beryllium-containing airplane parts in NAICS 332721: Precision Turned Products Manufacturing.

[35] Specifically, in the Precision Turned Products application group, which consists of 332721a (Precision Turned Products Manufacturing - using high content beryllium alloys) and 332721b (Precision Turned Products Manufacturing - using low content beryllium alloys).

The Agency is aware that commercial laundries that wash uniforms of beryllium-exposed workers may have potential exposure. OSHA has preliminarily judged that this does not present a likely health risk so long as such clothing is handled by commercial laundries experienced in working with clothing contaminated with hazardous materials. In practice, these types of commercial laundries are almost exclusively providers of such services. OSHA currently has no evidence of exposures to workers in these types of establishments and no evidence of any improper handling. The proposed rule would require "laundering, cleaning, … at an appropriate location or facility away from the workplace," meaning that the laundering service must already be equipped to handle hazardous materials without exposing their employees (see Section (h)(2)(iv) of the proposed rule).

The Agency seeks comment on these and any other affected industries. The Agency expects that any newly identified industries are likely to have incidental or very low exposures relative to the proposed PEL. Thus, OSHA anticipates that any additional industries would have costs and economic impacts similar to low-exposure industries described above, such as metal stampers, where there are only some costs for ancillary provisions (and no costs for engineering controls).

SUMMARY OF AFFECTED ESTABLISHMENTS AND EMPLOYERS

As shown in Table III-11, OSHA estimates that a total of 35,051 workers in 4,088 establishments will be affected by the proposed beryllium standard. Also shown are the estimated annual revenues for these entities. Table III-12 presents similar information for small entities, as defined by the Small Business Administration (SBA), estimated to be affected by the proposal. Table III-13 presents the same information for the subset of small entities with fewer than 20 employees.

BERYLLIUM EXPOSURE PROFILE OF AT-RISK WORKERS

The technological feasibility analyses presented in Chapter IV of this PEA contain data and discussion of worker exposures to beryllium throughout industry, and the exposure profiles presented here were taken directly from that chapter. Exposure profiles, by job category, were developed from individual exposure measurements that were judged to be substantive and to contain sufficient accompanying description to allow interpretation of the circumstance of each measurement. The resulting exposure profiles show the job categories with current overexposures to beryllium and, thus, the workers for whom beryllium controls would be implemented under the proposed rule.

Table III-14 summarizes, from the exposure profiles, the number of workers at risk from beryllium exposure and the distribution of 8-hour TWA respirable beryllium exposures by affected job category and sector. Exposures are grouped into the following ranges: less than 0.1 $\mu g/m^3$; $\geq$ 0.1 $\mu g/m^3$ and $\leq$ 0.2 $\mu g/m^3$; > 0.2 $\mu g/m^3$ and $\leq$ 0.5 $\mu g/m^3$; > 0.5 $\mu g/m^3$ and $\leq$ 1.0 $\mu g/m^3$; > 1.0 $\mu g/m^3$ and $\leq$ 2.0 $\mu g/m^3$; and greater than 2.0 $\mu g/m^3$. These frequencies represent the percentages of production employees in each job category and sector currently exposed at levels within the indicated range.

Table III-15 presents data by NAICS code on the estimated number of workers currently at risk from beryllium exposure, as well as the estimated number of workers at risk of beryllium exposure above 0 $\mu g/m^3$, at or above 0.1 $\mu g/m^3$, at or above 0.2 $\mu g/m^3$, at or above 0.5 $\mu g/m^3$, at or above 1.0 $\mu g/m^3$, and at or above 2.0 $\mu g/m^3$. As shown, an estimated 12,105 workers currently have beryllium exposures at or above the proposed action level of 0.1 $\mu g/m^3$; and an estimated 8,095 workers currently have beryllium exposures above the proposed PEL of 0.2 $\mu g/m^3$.

Table III-11

CHARACTERISTICS OF INDUSTRIES AFFECTED BY OSHA'S PROPOSED STANDARD FOR BERYLLIUM—ALL ENTITIES

NAICS	Industry	Total Entities [a]	Total Establishments [a]	Total Employees [a]	Affected Entities [b]	Affected Establishments [b]	Affected Employees [b]	Total Revenues ($1,000) [c]	Revenues/Entity ($1,000)	Revenues/Establishment ($1,000)
Beryllium Oxide										
327113	Porcelain Electrical Supply Manufacturing (SIC 3264)	94	106	4,310	14	16	259	$789,731	$8,401	$7,450
334220	Cellular telephones manufacturing	724	810	79,732	9	10	119	$35,475,343	$48,999	$43,797
334310	Compact disc players manufacturing	460	464	8,858	5	5	59	$3,975,351	$8,642	$8,568
334411	Electron Tube Manufacturing BeO traveling wave tube	62	79	4,884	16	21	250	$1,220,476	$19,685	$15,449
334415	Electronic resistor manufacturing	50	61	3,722	10	12	143	$560,967	$11,219	$9,196
334419	Other electronic component manufacturing	1,058	1,133	46,836	8	9	107	$10,013,730	$9,465	$8,838
334510	Electromedical equipment manufacturing	555	629	66,107	8	9	107	$27,480,966	$49,515	$43,690
336322	Other motor vehicle electrical and electronic equipment manufacturing	585	636	38,475	9	10	119	$12,152,053	$20,773	$19,107
Beryllium Production										
331419	Primary Smelting and Refining of Nonferrous Metals	140	161	8,943	1	1	616	$8,524,863	$60,892	$52,949
Dental Laboratories										
339116	Dental laboratories	6,718	6,995	44,030	1,680	1,749	8,148	$4,100,626	$610	$586
621210	Offices of dentists	123,322	129,830	846,092	226	238	1,107	$100,431,324	$814	$774
Fabrication										
332612	Light gauge spring manufacturing	269	323	10,329	269	323	2,071	$2,167,977	$8,059	$6,712
332116	Metal stamping	1,413	1,484	48,855	70	74	496	$9,749,800	$6,900	$6,570
334417	Electronic connector manufacturing	198	231	19,538	40	46	310	$5,029,508	$25,402	$21,773
336322	Other motor vehicle electrical & electronic equipmen	585	636	38,475	146	159	1,066	$12,152,053	$20,773	$19,107
Foundries										
331521	Aluminum die-casting foundries	228	254	18,017	6	7	98	$4,310,021	$18,904	$16,969
331522	Nonferrous (except aluminum) die-casting foundries	137	140	6,362	37	38	534	$1,510,799	$11,028	$10,791
331524	Aluminum foundries (except die-casting)	366	394	15,178	7	7	98	$2,518,097	$6,880	$6,391
331525	Copper foundries (except die-casting)	201	208	5,123	43	45	674	$1,205,574	$5,998	$5,796
Machining										
332721	Precision turned product manufacturing	3,057	3,124	78,749	306	312	3,764	$13,262,706	$4,338	$4,245

Table III-11										
CHARACTERISTICS OF INDUSTRIES AFFECTED BY OSHA'S PROPOSED STANDARD FOR BERYLLIUM—ALL ENTITIES										
NAICS	Industry	Total Entities [a]	Total Establishments [a]	Total Employees [a]	Affected Entities [b]	Affected Establishments [b]	Affected Employees [b]	Total Revenues ($1,000) [c]	Revenues/Entity ($1,000)	Revenues/Establishment ($1,000)
Rolling and Drawing										
331421	Copper rolling, drawing, and extruding	70	96	9,849	11	15	1,539	$12,513,425	$178,763	$130,348
331422	Copper wire (except mechanical) drawing	84	114	9,847	43	59	5,096	$6,471,491	$77,042	$56,767
Smelting										
331314	Secondary smelting & alloying of aluminum	98	122	4,846	1	1	9	$4,837,129	$49,358	$39,649
331421	Copper rolling, drawing, and extruding	70	96	9,849	1	1	9	$12,513,425	$178,763	$130,348
331423	Secondary smelting, refining, & alloying of copper	23	24	789	3	3	27	$723,759	$31,468	$30,157
331492	Secondary Smelting, Refining, and Alloying of Nonferrous Metal (Except Copper and Aluminum)	217	248	9,696	26	30	270	$8,195,807	$37,769	$33,048
Resistance Welding										
333411	Air Purification Equipment Manufacturing	303	358	14,521	21	25	379	$3,060,744	$10,101	$8,550
333412	Industrial and Commercial Fan and Blower Manufacturing	135	151	6,908	9	11	160	$1,681,585	$12,456	$11,136
333414	Heating Equipment (except Warm Air Furnaces) Manufacturing	433	460	16,768	30	32	487	$4,781,561	$11,043	$10,395
333415	Air-Conditioning, Warm Air Heating, and Industrial Refrigeration Equipment Manufacturing	695	843	79,651	49	59	893	$25,454,383	$36,625	$30,195
335211	Electric Housewares and Household Fan Manufacturing	101	106	5,980	5	5	80	$2,209,657	$21,878	$20,846
335212	Household Vacuum Cleaner Manufacturing	29	34	2,577	1	2	26	$891,600	$30,745	$26,224
335221	Household Cooking Appliance Manufacturing	91	96	9,730	5	5	73	$3,757,849	$41,295	$39,144
335222	Household Refrigerator and Home Freezer Manufacturing	16	22	9,731	1	1	17	$4,489,845	$280,615	$204,084
335224	Household Laundry Equipment Manufacturing	9	11	8,051	1	1	8	$3,720,514	$413,390	$338,229
335228	Other Major Household Appliance Manufacturing	34	38	9,023	2	2	29	$3,499,273	$102,920	$92,086
336311	Carburetor, Piston, Piston Ring, and Valve Manufacturing	97	109	7,370	5	5	82	$1,715,429	$17,685	$15,738
336312	Gasoline Engine and Engine Parts Manufacturing	697	742	36,896	35	37	561	$20,000,705	$28,695	$26,955
336321	Vehicular Lighting Equipment Manufacturing	86	93	9,218	4	5	70	$2,322,610	$27,007	$24,974
336322	Other Motor Vehicle Electrical and Electronic Equipment Manufacturing	585	636	38,475	29	32	481	$12,152,053	$20,773	$19,107
336330	Motor Vehicle Steering and Suspension Components (except Spring) Manufacturing	209	246	26,118	10	12	186	$8,856,584	$42,376	$36,002
336340	Motor Vehicle Brake System Manufacturing	159	199	20,245	8	10	150	$8,147,826	$51,244	$40,944
336350	Motor Vehicle Transmission and Power Train Parts Manufacturing	397	476	51,171	20	24	360	$21,862,014	$55,068	$45,929
336360	Motor Vehicle Seating and Interior Trim Manufacturing	305	403	39,805	15	20	305	$15,168,862	$49,734	$37,640
336370	Motor Vehicle Metal Stamping	599	736	66,985	30	37	557	$19,809,238	$33,071	$26,915
336391	Motor Vehicle Air-Conditioning Manufacturing	72	80	11,207	4	4	61	$3,798,464	$52,756	$47,481
336399	All Other Motor Vehicle Parts Manufacturing	1,156	1,350	95,426	58	68	1,021	$32,279,766	$27,924	$23,911

Table III-11											
CHARACTERISTICS OF INDUSTRIES AFFECTED BY OSHA'S PROPOSED STANDARD FOR BERYLLIUM—ALL ENTITIES											
NAICS	**Industry**	**Total Entities [a]**	**Total Establishments [a]**	**Total Employees [a]**	**Affected Entities [b]**	**Affected Establishments [b]**	**Affected Employees [b]**	**Total Revenues ($1,000) [c]**	**Revenues/Entity ($1,000)**	**Revenues/Establishment ($1,000)**
Welding										
331111	Iron and Steel Mills	461	587	94,089	5	7	27	$92,726,004	$201,141	$157,966
331221	Rolled Steel Shape Manufacturing	134	161	9,971	1	1	6	$8,376,271	$62,509	$52,027
331513	Steel Foundries (except Investment)	203	220	13,874	1	1	5	$4,251,852	$20,945	$19,327
332117	Powder Metallurgy Part Manufacturing	121	133	6,707	1	1	4	$1,414,108	$11,687	$10,632
332212	Hand and Edge Tool Manufacturing	999	1,066	25,098	3	3	12	$5,077,868	$5,083	$4,763
332312	Fabricated Structural Metal Manufacturing	3,081	3,407	89,728	51	56	224	$26,119,614	$8,478	$7,666
332313	Plate Work Manufacturing	1,252	1,288	28,400	21	21	85	$6,023,356	$4,811	$4,677
332322	Sheet Metal Work Manufacturing	3,907	4,173	91,364	64	69	274	$17,988,908	$4,604	$4,311
332323	Ornamental and Architectural Metal Work Manufacturing	2,314	2,354	30,029	38	39	155	$5,708,707	$2,467	$2,425
332439	Other Metal Container Manufacturing	321	370	12,553	6	7	27	$3,565,875	$11,109	$9,638
332919	Other Metal Valve and Pipe Fitting Manufacturing	240	265	14,688	2	3	11	$4,584,082	$19,100	$17,298
332999	All Other Miscellaneous Fabricated Metal Product Manufacturing	3,195	3,262	65,821	33	33	134	$13,963,184	$4,370	$4,281
333111	Farm Machinery and Equipment Manufacturing	975	1,041	53,133	19	20	80	$24,067,145	$24,684	$23,119
333414	Heating Equipment (except Warm Air Furnaces) Manufacturing	433	460	16,768	6	6	24	$4,781,561	$11,043	$10,395
333911	Pump and Pumping Equipment Manufacturing	445	571	31,272	5	7	27	$12,395,387	$27,855	$21,708
333922	Conveyor and Conveying Equipment Manufacturing	737	776	26,970	9	9	36	$6,569,120	$8,913	$8,465
333924	Industrial Truck, Tractor, Trailer, and Stacker Machinery Manufacturing	347	374	19,974	4	4	17	$7,444,451	$21,454	$19,905
333999	All Other Miscellaneous General Purpose Machinery Manufacturing	1,463	1,524	43,401	17	18	71	$10,972,258	$7,500	$7,200
336211	Motor Vehicle Body Manufacturing	652	742	38,587	13	15	60	$9,877,558	$15,150	$13,312
336214	Travel Trailer and Camper Manufacturing	602	683	30,803	12	14	55	$7,465,024	$12,400	$10,930
336399	All Other Motor Vehicle Parts Manufacturing	1,156	1,350	95,426	6	7	30	$32,279,766	$27,924	$23,911
336510	Railroad Rolling Stock	157	226	24,491	2	3	11	$11,927,191	$75,969	$52,775
336999	All Other Transportation Equipment Manufacturing	366	374	10,846	4	4	14	$5,250,368	$14,345	$14,038
337215	Showcase, Partition, Shelving, and Locker Manufacturing	1,144	1,194	33,195	3	3	13	$5,815,404	$5,083	$4,871
811310	Commercial and Industrial Machinery and Equipment Repair	20,299	21,960	181,220	132	143	571	$31,650,469	$1,559	$1,441
	Total				**3,795**	**4,088**	**35,051**			

[a] US Census Bureau, Statistics of US Businesses, 2010.

[b] OSHA estimates of employees potentially exposed to beryllium and associated entities and establishments. Affected entities and establishments constrained to be less than or equal to the number of affected employees.

[c] Estimates based on 2007 receipts and payroll data from US Census Bureau, Statistics of US Businesses, 2007, and payroll data from the US Census Bureau, Statistics of US Businesses, 2010. Receipts are not reported for 2010 but were estimated assuming the ratio of receipts to payroll remained unchanged from 2007 to 2010.

Source: US Dept. of Labor, OSHA, Directorate of Evaluation and Analysis, Office of Regulatory Analysis, based on ERG, 2012.

Table III-12										
CHARACTERISTICS OF INDUSTRIES AFFECTED BY OSHA'S PROPOSED STANDARD FOR BERYLLIUM--SMALL ENTITIES										
NAICS	Industry	SBA Small Business Classifi-cation (Employees) [a]	Small Business Entities [b]	Estab-lishments for SBA Entities [b]	SBA Entity Employees [b]	Affected Small Business Entities [c]	Affected Employees for SBA Entities [c]	Total Revenues for SBA Entities ($1,000) [d]	Revenues Per SBA Entity ($1,000)	Revenues per SBA Establish-ment ($1,000)
Beryllium Oxide										
327113	Porcelain Electrical Supply Manufacturing (SIC 3264)	500	85	89	2,244	12	102	$326,127	$3,837	$3,664
334220	Cellular telephones manufacturing	750	724	810	79,732	9	119	$35,475,343	$48,999	$43,797
334310	Compact disc players manufacturing	750	460	464	8,858	5	59	$3,975,351	$8,642	$8,568
334411	Electron Tube Manufacturing BeO traveling wave tubes	750	62	79	4,884	16	250	$1,220,476	$19,685	$15,449
334415	Electronic resistor manufacturing	500	46	51	2,215	9	85	$385,781	$8,387	$7,564
334419	Other electronic component manufacturing	500	990	1,013	26,996	8	62	$4,796,313	$4,845	$4,735
334510	Electromedical equipment manufacturing	500	494	501	14,943	7	24	$3,752,243	$7,596	$7,490
336322	Other motor vehicle electrical and electronic equipment manufacturing	750	585	636	38,475	9	119	$12,152,053	$20,773	$19,107
Beryllium Production										
331419	Primary Smelting and Refining of Nonferrous Metals	750	140	161	8,943	0	0	$8,524,863	$60,892	$52,949
Dental Laboratories										
339116	Dental laboratories	500	6,703	6,741	35,967	1,676	6,656	$3,156,130	$471	$468
621210	Offices of dentists	100	123,077	125,828	798,856	225	1,045	$94,120,777	$765	$748
Fabrication										
332612	Light gauge spring manufacturing	500	262	289	6,367	262	1,276	$1,030,905	$3,935	$3,567
332116	Metal stamping	500	1,367	1,419	40,056	68	407	$7,693,541	$5,628	$5,422
334417	Electronic connector manufacturing	500	176	181	7,608	35	121	$1,556,871	$8,846	$8,601
336322	Other motor vehicle electrical & electronic equipment	750	585	636	38,475	146	1,066	$12,152,053	$20,773	$19,107
Foundries										
331521	Aluminum die-casting foundries	500	209	217	10,558	6	58	$2,070,759	$9,908	$9,543
331522	Nonferrous (except aluminum) die-casting foundries	500	129	131	3,685	35	310	$813,444	$6,306	$6,209
331524	Aluminum foundries (except die-casting)	500	351	367	10,862	6	70	$1,690,008	$4,815	$4,605
331525	Copper foundries (except die-casting)	500	195	200	4,098	42	539	$925,667	$4,747	$4,628
Machining										
332721	Precision turned product manufacturing	500	3,006	3,059	70,334	301	3,362	$11,393,081	$3,790	$3,724

Table III-12										
CHARACTERISTICS OF INDUSTRIES AFFECTED BY OSHA'S PROPOSED STANDARD FOR BERYLLIUM--SMALL ENTITIES										
NAICS	Industry	SBA Small Business Classifi-cation (Employees) [a]	Small Business Entities [b]	Estab-lishments for SBA Entities [b]	SBA Entity Employees [b]	Affected Small Business Entities [c]	Affected Employees for SBA Entities [c]	Total Revenues for SBA Entities ($1,000) [d]	Revenues Per SBA Entity ($1,000)	Revenues per SBA Establish-ment ($1,000)
Rolling and Drawing										
331421	Copper rolling, drawing, and extruding	750	70	96	9,849	11	1,539	$12,513,425	$178,763	$130,348
331422	Copper wire (except mechanical) drawing	1,000	84	114	9,847	43	5,096	$6,471,491	$77,042	$56,767
Smelting										
331314	Secondary smelting & alloying of aluminum	750	98	122	4,846	1	9	$4,837,129	$49,358	$39,649
331421	Copper rolling, drawing, and extruding	750	70	96	9,849	1	9	$12,513,425	$178,763	$130,348
331423	Secondary smelting, refining, & alloying of copper	750	23	24	789	3	27	$723,759	$31,468	$30,157
331492	Secondary Smelting, Refining, and Alloying of Nonferrous Metal (Except Copper and Aluminum)	750	217	248	9,696	26	270	$8,195,807	$37,769	$33,048
Resistance Welding										
333411	Air Purification Equipment Manufacturing	500	283	294	6,357	20	166	$1,327,014	$4,689	$4,514
333412	Industrial and Commercial Fan and Blower Manufacturing	500	118	122	4,221	8	98	$1,001,835	$8,490	$8,212
333414	Heating Equipment (except Warm Air Furnaces) Manufacturing	500	410	417	10,097	29	293	$2,583,472	$6,301	$6,195
333415	Air-Conditioning, Warm Air Heating, and Industrial Refrigeration Equipment Manufacturing	750	695	843	79,651	49	893	$25,454,383	$36,625	$30,195
335211	Electric Housewares and Household Fan Manufacturing	750	101	106	5,980	5	80	$2,209,657	$21,878	$20,846
335212	Household Vacuum Cleaner Manufacturing	750	29	34	2,577	1	26	$891,600	$30,745	$26,224
335221	Household Cooking Appliance Manufacturing	750	91	96	9,730	5	73	$3,757,849	$41,295	$39,144
335222	Household Refrigerator and Home Freezer Manufacturing	1,000	16	22	9,731	1	17	$4,489,845	$280,615	$204,084
335224	Household Laundry Equipment Manufacturing	1,000	9	11	8,051	1	8	$3,720,514	$413,390	$338,229
335228	Other Major Household Appliance Manufacturing	500	24	24	637	1	2	$185,373	$7,724	$7,724
336311	Carburetor, Piston, Piston Ring, and Valve Manufacturing	500	89	91	2,073	4	23	$499,977	$5,618	$5,494
336312	Gasoline Engine and Engine Parts Manufacturing	750	697	742	36,896	35	561	$20,000,705	$28,695	$26,955
336321	Vehicular Lighting Equipment Manufacturing	500	75	75	2,987	4	23	$671,947	$8,959	$8,959
336322	Other Motor Vehicle Electrical and Electronic Equipment Manufacturing	750	585	636	38,475	29	481	$12,152,053	$20,773	$19,107
336330	Motor Vehicle Steering and Suspension Components (except Spring) Manufacturing	750	209	246	26,118	10	186	$8,856,584	$42,376	$36,002
336340	Motor Vehicle Brake System Manufacturing	750	159	199	20,245	8	150	$8,147,826	$51,244	$40,944
336350	Motor Vehicle Transmission and Power Train Parts Manufacturing	750	397	476	51,171	20	360	$21,862,014	$55,068	$45,929
336360	Motor Vehicle Seating and Interior Trim Manufacturing	500	273	283	11,733	14	90	$3,482,677	$12,757	$12,306
336370	Motor Vehicle Metal Stamping	500	540	589	28,949	27	241	$7,262,381	$13,449	$12,330
336391	Motor Vehicle Air-Conditioning Manufacturing	750	72	80	11,207	4	61	$3,798,464	$52,756	$47,481
336399	All Other Motor Vehicle Parts Manufacturing	750	1,156	1,350	95,426	58	1,021	$32,279,766	$27,924	$23,911

Table III-12

CHARACTERISTICS OF INDUSTRIES AFFECTED BY OSHA'S PROPOSED STANDARD FOR BERYLLIUM--SMALL ENTITIES

NAICS	Industry	SBA Small Business Classifi-cation (Employees) [a]	Small Business Entities [b]	Estab-lishments for SBA Entities [b]	SBA Entity Employees [b]	Affected Small Business Entities [c]	Affected Employees for SBA Entities [c]	Total Revenues for SBA Entities ($1,000) [d]	Revenues Per SBA Entity ($1,000)	Revenues per SBA Establish-ment ($1,000)
Welding										
331111	Iron and Steel Mills	1,000	461	587	94,089	5	27	$92,726,004	$201,141	$157,966
331221	Rolled Steel Shape Manufacturing	1,000	134	161	9,971	1	6	$8,376,271	$62,509	$52,027
331513	Steel Foundries (except Investment)	500	188	196	8,933	1	3	$2,739,158	$14,570	$13,975
332117	Powder Metallurgy Part Manufacturing	500	106	109	4,358	1	2	$841,084	$7,935	$7,716
332212	Hand and Edge Tool Manufacturing	500	975	1,022	17,157	3	8	$3,072,300	$3,151	$3,006
332312	Fabricated Structural Metal Manufacturing	500	3,001	3,094	59,199	49	148	$15,405,728	$5,134	$4,979
332313	Plate Work Manufacturing	500	1,220	1,240	24,818	20	74	$4,900,364	$4,017	$3,952
332322	Sheet Metal Work Manufacturing	500	3,835	3,929	73,321	63	220	$12,607,305	$3,287	$3,209
332323	Ornamental and Architectural Metal Work Manufacturing	500	2,287	2,308	23,712	38	122	$4,118,512	$1,801	$1,784
332439	Other Metal Container Manufacturing	500	302	320	7,104	5	15	$1,698,117	$5,623	$5,307
332919	Other Metal Valve and Pipe Fitting Manufacturing	500	207	218	7,315	2	5	$2,028,451	$9,799	$9,305
332999	All Other Miscellaneous Fabricated Metal Product Manufacturing	500	3,111	3,155	52,955	32	108	$10,202,505	$3,279	$3,234
333111	Farm Machinery and Equipment Manufacturing	500	941	969	22,119	18	33	$5,132,720	$5,455	$5,297
333414	Heating Equipment (except Warm Air Furnaces) Manufacturing	500	410	417	10,097	5	14	$2,583,472	$6,301	$6,195
333911	Pump and Pumping Equipment Manufacturing	500	399	417	11,109	5	9	$3,348,262	$8,392	$8,029
333922	Conveyor and Conveying Equipment Manufacturing	500	707	731	20,663	8	28	$4,768,668	$6,745	$6,523
333924	Industrial Truck, Tractor, Trailer, and Stacker Machinery Manufacturing	750	347	374	19,974	4	17	$7,444,451	$21,454	$19,905
333999	All Other Miscellaneous General Purpose Machinery Manufacturing	500	1,385	1,404	25,432	16	42	$5,601,674	$4,045	$3,990
336211	Motor Vehicle Body Manufacturing	1,000	652	742	38,587	13	60	$9,877,558	$15,150	$13,312
336214	Travel Trailer and Camper Manufacturing	500	585	609	13,901	12	25	$2,513,608	$4,297	$4,127
336399	All Other Motor Vehicle Parts Manufacturing	750	1,156	1,350	95,426	6	30	$32,279,766	$27,924	$23,911
336510	Railroad Rolling Stock	1,000	157	226	24,491	2	11	$11,927,191	$75,969	$52,775
336999	All Other Transportation Equipment Manufacturing	500	349	351	4,381	3	6	$941,637	$2,698	$2,683
337215	Showcase, Partition, Shelving, and Locker Manufacturing	500	1,120	1,144	23,705	3	9	$3,688,129	$3,293	$3,224
811310	Commercial and Industrial Machinery and Equipment Repair	100	19,857	20,101	109,197	129	344	$17,088,964	$861	$850
Total	**All Affected Industries**					**3,741**	**28,896**			

[a] Data were not available specifically for small entities with more than 500 employees. For SBA small business classifications specifying 750 or more employees, OSHA used data for all entities in the industry.

[b] US Census Bureau, Statistics of US Businesses, 2010.

[c] OSHA estimates of employees potentially exposed to beryllium and associated entities and establishments. Affected entities and establishments constrained to be less than or equal to the number of affected employees.

[d] Estimates based on 2007 receipts and payroll data from US Census Bureau, Statistics of US Businesses, 2007, and payroll data from the US Census Bureau, Statistics of US Businesses, 2010. Receipts are not reported for 2010, but were estimated assuming the ratio of receipts to payroll remained unchanged from 2007 to 2010.

Source: US Dept. of Labor, OSHA, Directorate of Evaluation and Analysis, Office of Regulatory Analysis, based on ERG, 2012.

Table III-13

CHARACTERISTICS OF INDUSTRIES AFFECTED BY OSHA'S PROPOSED STANDARD FOR BERYLLIUM ENTITIES WITH FEWER THAN 20 EMPLOYEES

NAICS	Industry	Entities with <20 Employees [a]	Estab. For Entities with <20 Employees [a]	Employ-ment for Entities with <20 Employees[a]	Affected Entities with <20 Employees [b]	Affected Employees for Entities with <20 Employees [b]	Total Revenues for Entities with <20 Employees ($1,000) [c]	Revenues Per Entity with <20 Employees ($1,000)	Revenue per Estab. For Entities with <20 Employees ($1,000)
Beryllium Oxide									
327113	Porcelain Electrical Supply Manufacturing (SIC 3264)	53	53	297	7	11	$52,358	$988	$988
334220	Cellular telephones manufacturing	445	446	2,616	4	4	$576,956	$1,297	$1,294
334310	Compact disc players manufacturing	373	373	1,937	4	13	$1,128,513	$3,026	$3,026
334411	Electron Tube Manufacturing BeO traveling wave tubes	38	38	235	10	12	$45,454	$1,196	$1,196
334415	Electronic resistor manufacturing	17	17	141	3	5	$25,647	$1,509	$1,509
334419	Other electronic component manufacturing	624	624	3,801	5	9	$639,599	$1,025	$1,025
334510	Electromedical equipment manufacturing	324	324	1,964	3	3	$420,245	$1,297	$1,297
336322	Other motor vehicle electrical and electronic equipment manufacturing	386	388	2,160	6	7	$349,811	$906	$902
Beryllium Production									
331419	Primary Smelting and Refining of Nonferrous Metals	86	86	438	0	0	$399,861	$4,650	$4,650
Dental Laboratories									
339116	Dental laboratories	6,379	6,383	22,509	1,595	4,166	$1,807,075	$283	$283
621210	Offices of dentists	119,544	120,811	696,415	219	911	$81,995,117	$686	$679
Fabrication									
332612	Light gauge spring manufacturing	164	164	1,083	164	217	$156,603	$955	$955
332116	Metal stamping	807	808	6,032	40	61	$1,033,657	$1,281	$1,279
334417	Electronic connector manufacturing	106	106	719	11	11	$129,405	$1,221	$1,221
336322	Other motor vehicle electrical & electronic equipment	386	388	2,160	60	60	$349,811	$906	$902
Foundries									
331521	Aluminum die-casting foundries	107	107	859	0	0	$153,274	$1,432	$1,432
331522	Nonferrous (except aluminum) die-casting foundries	84	84	549	0	0	$92,703	$1,104	$1,104
331524	Aluminum foundries (except die-casting)	217	219	1,554	0	0	$204,397	$942	$933
331525	Copper foundries (except die-casting)	131	131	1,013	0	0	$139,372	$1,064	$1,064
Machining									
332721	Precision turned product manufacturing	1,970	1,971	16,139	197	771	$2,219,340	$1,127	$1,126

Table III-13									
CHARACTERISTICS OF INDUSTRIES AFFECTED BY OSHA'S PROPOSED STANDARD FOR BERYLLIUM ENTITIES WITH FEWER THAN 20 EMPLOYEES									
NAICS	Industry	Entities with <20 Employees [a]	Estab. For Entities with <20 Employees [a]	Employ-ment for Entities with <20 Employees[a]	Affected Entities with <20 Employees [b]	Affected Employees for Entities with <20 Employees [b]	Total Revenues for Entities with <20 Employees ($1,000) [c]	Revenues Per Entity with <20 Employees ($1,000)	Revenue per Estab. For Entities with <20 Employees ($1,000)
Rolling and Drawin	0	0	0	0	0	0	$0	$0	$0
331421	Copper rolling, drawing, and extruding	26	26	140	4	22	$48,421	$1,862	$1,862
331422	Copper wire (except mechanical) drawing	35	35	252	18	130	$254,426	$7,269	$7,269
0	0	0	0	0	0	0	$0	$0	$0
Smelting	0	0	0	0	0	0	$0	$0	$0
331314	Secondary smelting & alloying of aluminum	45	45	284	0	0	$306,390	$6,809	$6,809
331421	Copper rolling, drawing, and extruding	26	26	140	0	0	$48,421	$1,862	$1,862
331423	Secondary smelting, refining, & alloying of copper	11	11	58	1	2	$85,353	$7,759	$7,759
331492	Secondary Smelting, Refining, and Alloying of Nonferrous Metal (Except Copper and Aluminum)	121	121	673	15	19	$388,603	$3,212	$3,212
0	0	0	0	0	0	0	$0	$0	$0
Resistance Weldin	0	0	0	0	0	0	$0	$0	$0
333411	Air Purification Equipment Manufacturing	189	189	1,249	13	33	$283,628	$1,501	$1,501
333412	Industrial and Commercial Fan and Blower Manufacturing	60	60	428	4	10	$78,644	$1,311	$1,311
333414	Heating Equipment (except Warm Air Furnaces) Manufacturing	283	283	1,553	20	45	$365,551	$1,292	$1,292
333415	Air-Conditioning, Warm Air Heating, and Industrial Refrigeration Equipment Manufacturing	395	396	2,561	28	29	$806,994	$2,043	$2,038
335211	Electric Housewares and Household Fan Manufacturing	70	70	286	4	4	$99,219	$1,417	$1,417
335212	Household Vacuum Cleaner Manufacturing	18	18	104	0	0	$21,745	$1,208	$1,208
335221	Household Cooking Appliance Manufacturing	57	57	273	2	2	$66,863	$1,173	$1,173
335222	Household Refrigerator and Home Freezer Manufacturing	6	6	37	0	0	$8,833	$1,472	$1,472
335224	Household Laundry Equipment Manufacturing	4	4	8	0	0	$1,837	$459	$459
335228	Other Major Household Appliance Manufacturing	15	15	87	0	0	$24,856	$1,657	$1,657
336311	Carburetor, Piston, Piston Ring, and Valve Manufacturing	59	59	354	3	4	$54,436	$923	$923
336312	Gasoline Engine and Engine Parts Manufacturing	545	546	2,288	27	35	$883,783	$1,622	$1,619
336321	Vehicular Lighting Equipment Manufacturing	45	45	264	2	2	$59,894	$1,331	$1,331
336322	Other Motor Vehicle Electrical and Electronic Equipment Manufacturing	386	388	2,160	19	27	$349,811	$906	$902
336330	Motor Vehicle Steering and Suspension Components (except Spring) Manufacturing	116	116	725	5	5	$998,968	$8,612	$8,612
336340	Motor Vehicle Brake System Manufacturing	82	82	430	3	3	$96,867	$1,181	$1,181
336350	Motor Vehicle Transmission and Power Train Parts Manufacturing	240	240	1,300	9	9	$304,951	$1,271	$1,271
336360	Motor Vehicle Seating and Interior Trim Manufacturing	167	167	902	7	7	$310,566	$1,860	$1,860
336370	Motor Vehicle Metal Stamping	225	226	1,726	11	14	$478,984	$2,129	$2,119
336391	Motor Vehicle Air-Conditioning Manufacturing	34	34	241	1	1	$80,741	$2,375	$2,375
336399	All Other Motor Vehicle Parts Manufacturing	653	656	3,701	33	40	$835,261	$1,279	$1,273

Table III-13

CHARACTERISTICS OF INDUSTRIES AFFECTED BY OSHA'S PROPOSED STANDARD FOR BERYLLIUM ENTITIES WITH FEWER THAN 20 EMPLOYEES

NAICS	Industry	Entities with <20 Employees [a]	Estab. For Entities with <20 Employees [a]	Employ-ment for Entities with <20 Employees[a]	Affected Entities with <20 Employees [b]	Affected Employees for Entities with <20 Employees [b]	Total Revenues for Entities with <20 Employees ($1,000) [c]	Revenues Per Entity with <20 Employees ($1,000)	Revenue per Estab. For Entities with <20 Employees ($1,000)
Welding									
331111	Iron and Steel Mills	268	268	1,198	0	0	$1,018,914	$3,802	$3,802
331221	Rolled Steel Shape Manufacturing	50	50	268	0	0	$208,799	$4,176	$4,176
331513	Steel Foundries (except Investment)	94	94	557	0	0	$112,227	$1,194	$1,194
332117	Powder Metallurgy Part Manufacturing	55	55	544	0	0	$100,643	$1,830	$1,830
332212	Hand and Edge Tool Manufacturing	751	754	4,281	2	2	$681,375	$907	$904
332312	Fabricated Structural Metal Manufacturing	2,159	2,162	14,221	35	35	$3,182,459	$1,474	$1,472
332313	Plate Work Manufacturing	845	845	6,124	14	18	$1,007,308	$1,192	$1,192
332322	Sheet Metal Work Manufacturing	2,778	2,780	17,798	46	53	$2,631,155	$947	$946
332323	Ornamental and Architectural Metal Work Manufacturing	1,957	1,958	9,070	32	47	$1,342,443	$686	$686
332439	Other Metal Container Manufacturing	203	203	1,069	2	2	$187,607	$924	$924
332919	Other Metal Valve and Pipe Fitting Manufacturing	115	115	757	1	1	$181,192	$1,576	$1,576
332999	All Other Miscellaneous Fabricated Metal Product Manufacturing	2,353	2,353	13,519	24	28	$2,117,303	$900	$900
333111	Farm Machinery and Equipment Manufacturing	673	675	4,417	7	7	$785,460	$1,167	$1,164
333414	Heating Equipment (except Warm Air Furnaces) Manufacturing	283	283	1,553	2	2	$365,551	$1,292	$1,292
333911	Pump and Pumping Equipment Manufacturing	251	251	1,706	1	1	$497,397	$1,982	$1,982
333922	Conveyor and Conveying Equipment Manufacturing	407	407	2,908	4	4	$541,532	$1,331	$1,331
333924	Industrial Truck, Tractor, Trailer, and Stacker Machinery Manufacturing	195	195	1,183	1	1	$213,335	$1,094	$1,094
333999	All Other Miscellaneous General Purpose Machinery Manufacturing	975	975	5,986	10	10	$1,151,152	$1,181	$1,181
336211	Motor Vehicle Body Manufacturing	400	400	2,657	4	4	$535,923	$1,340	$1,340
336214	Travel Trailer and Camper Manufacturing	410	412	2,619	5	5	$480,503	$1,172	$1,166
336399	All Other Motor Vehicle Parts Manufacturing	653	656	3,701	1	1	$835,261	$1,279	$1,273
336510	Railroad Rolling Stock	83	83	599	0	0	$189,164	$2,279	$2,279
336999	All Other Transportation Equipment Manufacturing	307	307	1,480	2	2	$253,916	$827	$827
337215	Showcase, Partition, Shelving, and Locker Manufacturing	814	815	4,283	2	2	$582,654	$716	$715
811310	Commercial and Industrial Machinery and Equipment Repair	18,714	18,760	72,393	122	228	$10,692,921	$571	$570
Total	**All Affected Industries**				**2,875**	**7,157**			

[a] US Census Bureau, Statistics of US Businesses, 2010.

[b] OSHA estimates of employees potentially exposed to beryllium and associated entities and establishments. Affected entities and establishments constrained to be less than or equal to the number of affected e

[c] Estimates based on 2007 receipts and payroll data from US Census Bureau, Statistics of US Businesses, 2007, and payroll data from the US Census Bureau, Statistics of US Businesses, 2010.
Receipts are not reported for 2010, but were estimated assuming the ratio of receipts to payroll remained unchanged from 2007 to 2010.

Source: US Dept. of Labor, OSHA, Directorate of Evaluation and Analysis, Office of Regulatory Analysis, based on ERG, 2012.

Table III-14

Distribution of Beryllium Exposures by Sector and Job Category or Activity

		Beryllium Exposure Range						
Sector	**Job Category/Activity**	**<0.1 µg/m3**	**0.1 - 0.2 µg/m3**	**0.2 - 0.5 µg/m3**	**0.5 - 1.0 µg/m3**	**1.0 - 2.0 µg/m3**	**>2.0 µg/m3**	**Total**
Sand foundries	Molder	0.0%	0.0%	62.5%	25.0%	0.0%	12.5%	100.0%
	Material Handler	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	100.0%
	Furnace operator	0.0%	18.2%	9.1%	18.2%	18.2%	36.4%	100.0%
	Pouring operator	0.0%	40.0%	0.0%	0.0%	20.0%	40.0%	100.0%
	Shakeout operator	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	100.0%
	Abrasive blaster	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%
	Grinding/finishing operator	6.3%	31.3%	31.3%	6.3%	6.3%	18.8%	100.0%
	Maintenance	20.5%	29.5%	23.1%	14.1%	9.0%	3.8%	100.0%
Non Sand foundries	Molder	0.0%	0.0%	62.5%	25.0%	0.0%	12.5%	100.0%
	Material Handler	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	100.0%
	Furnace operator	0.0%	18.2%	9.1%	18.2%	18.2%	36.4%	100.0%
	Pouring operator	0.0%	40.0%	0.0%	0.0%	20.0%	40.0%	100.0%
	Abrasive blaster	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%
	Grinding/finishing operator	6.3%	31.3%	31.3%	6.3%	6.3%	18.8%	100.0%
	Maintenance	20.5%	29.5%	23.1%	14.1%	9.0%	3.8%	100.0%
Fabrication/Springs	Assembly operator	92.9%	7.1%	0.0%	0.0%	0.0%	0.0%	100.0%
	Deburring Operator	85.7%	0.0%	14.3%	0.0%	0.0%	0.0%	100.0%
	Chemical process operator	88.4%	7.0%	4.7%	0.0%	0.0%	0.0%	100.0%
Fabrication/Stamping	Assembly operator	92.9%	7.1%	0.0%	0.0%	0.0%	0.0%	100.0%
	Deburring Operator	85.7%	0.0%	14.3%	0.0%	0.0%	0.0%	100.0%
	Chemical process operator	88.4%	7.0%	4.7%	0.0%	0.0%	0.0%	100.0%
Smelting - Be Alloys	Mechanical processing operator	25.0%	75.0%	0.0%	0.0%	0.0%	0.0%	100.0%
	Furnace operator	0.0%	0.0%	0.0%	0.0%	25.0%	75.0%	100.0%
Smelting - Precious metals	Mechanical processing operator	25.0%	75.0%	0.0%	0.0%	0.0%	0.0%	100.0%
	Furnace operator	50.0%	0.0%	50.0%	0.0%	0.0%	0.0%	100.0%
Machining (high)	Machinist (high)	13.6%	11.9%	44.1%	15.3%	6.8%	8.5%	100.0%
Machining (low)	Machinist (low)	73.8%	11.3%	7.5%	2.5%	1.3%	3.8%	100.0%
Rolling	Administrative	98.5%	1.5%	0.0%	0.0%	0.0%	0.0%	100.0%
	Other Production support	98.0%	2.0%	0.0%	0.0%	0.0%	0.0%	100.0%
	Wastewater treatment operator	33.3%	33.3%	33.3%	0.0%	0.0%	0.0%	100.0%
	Production	92.8%	4.7%	1.9%	0.6%	0.0%	0.0%	100.0%
Drawing	Administrative	98.5%	1.5%	0.0%	0.0%	0.0%	0.0%	100.0%
	Other Production support	98.0%	2.0%	0.0%	0.0%	0.0%	0.0%	100.0%
	Wastewater treatment operator	33.3%	33.3%	33.3%	0.0%	0.0%	0.0%	100.0%
	Production	70.0%	13.3%	10.5%	1.9%	1.9%	2.4%	100.0%

Table III-14

Distribution of Beryllium Exposures by Sector and Job Category or Activity

		Beryllium Exposure Range						
Sector	**Job Category/Activity**	**<0.1 μg/m3**	**0.1 - 0.2 μg/m3**	**0.2 - 0.5 μg/m3**	**0.5 - 1.0 μg/m3**	**1.0 - 2.0 μg/m3**	**>2.0 μg/m3**	**Total**
Welding (Arc, Gas, & TIG)	Welder	56.8%	13.5%	16.2%	10.8%	0.0%	2.7%	100.0%
Resistance Welding	Welder	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%
Dental laboratories	Dental technicians	30.4%	21.7%	13.0%	17.4%	4.3%	13.0%	100.0%
Be Oxide - Primary	Material preparations operators	13.0%	15.6%	31.2%	19.5%	10.4%	10.4%	100.0%
	Forming operators - pressing	31.0%	25.1%	28.3%	10.6%	3.7%	1.5%	100.0%
	Forming operators - extruding	31.0%	25.1%	28.3%	10.6%	3.7%	1.5%	100.0%
	Kiln operators	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%
Be Oxide - Secondary	Machining operators	40.0%	22.6%	22.3%	10.3%	2.8%	2.1%	100.0%
	Metallization Workers	55.6%	13.9%	27.8%	2.8%	0.0%	0.0%	100.0%
	Production support	74.8%	13.4%	6.7%	2.5%	0.8%	1.7%	100.0%
	Administrative	93.5%	4.3%	1.1%	0.5%	0.5%	0.0%	100.0%
Beryllium Production	Administrative	84.9%	9.2%	4.0%	1.0%	0.6%	0.3%	100.0%
	Wastewater Treatment	58.7%	17.4%	19.6%	4.3%	0.0%	0.0%	100.0%
	Boiler Operators	27.8%	27.8%	44.4%	0.0%	0.0%	0.0%	100.0%
	Decontamination	35.4%	25.0%	14.6%	14.6%	6.3%	4.2%	100.0%
	Other Site Support	86.3%	9.8%	2.7%	0.8%	0.4%	0.0%	100.0%
	Mix/Makeup	27.5%	17.6%	33.3%	9.8%	9.8%	2.0%	100.0%
	Scrap Recycling	12.6%	23.4%	27.0%	12.6%	9.9%	14.4%	100.0%
	Maintenance/Furnace & Tools	10.3%	8.6%	27.6%	20.7%	8.6%	24.1%	100.0%
	Other Production Support	70.2%	13.9%	6.6%	3.6%	3.4%	2.3%	100.0%
	Machining	55.5%	21.2%	15.5%	2.5%	3.2%	2.1%	100.0%
	Other Cold Work	78.6%	12.0%	5.1%	1.7%	2.6%	0.0%	100.0%
	Welding	0.0%	26.7%	40.0%	26.7%	0.0%	6.7%	100.0%
	Other Hot Work	72.7%	18.4%	8.2%	0.7%	0.0%	0.0%	100.0%
	Impact Grinding	19.2%	3.8%	23.1%	23.1%	26.9%	3.8%	100.0%
	Compact loading/Sintering	15.8%	31.6%	26.3%	0.0%	15.8%	10.5%	100.0%
	NNS Operator	0.0%	22.2%	40.7%	29.6%	3.7%	3.7%	100.0%
	Chemical Operations	5.0%	10.0%	50.0%	20.0%	10.0%	5.0%	100.0%
	Alloy Arc Furnace	0.0%	2.6%	15.8%	36.8%	18.4%	26.3%	100.0%
	Alloy Induction Furnace	5.2%	13.4%	32.0%	26.8%	13.4%	9.3%	100.0%
	Vacuum Cast	0.0%	33.3%	22.2%	11.1%	22.2%	11.1%	100.0%
	Atomization	0.0%	0.0%	0.0%	30.8%	0.0%	69.2%	100.0%
	Beryllium Oxide Furnace	20.0%	20.0%	20.0%	6.7%	20.0%	13.3%	100.0%

Source: OSHA Office of Regulatory Analysis-Health

Table III-15									
Numbers of Workers Exposed to Beryllium (by Affected Industry and Exposure Level (µg/m3)									
				Numbers Exposed to Beryllium					
NAICs	**Industry**	**No. of Establishments**	**No. of Employees**	**> 0**	**>=0.1 µg/m3**	**>=0.2 µg/m3**	**>=0.5 µg/m3**	**>=1.0 µg/m3**	**>=2.0 µg/m3**
327113	Porcelain Electrical Supply Manufacturing	106	4,310	259	124	86	25	9	3
331111	Iron and Steel Mills	587	94,089	27	11	8	4	1	1
331221	Rolled Steel Shape Manufacturing	161	9,971	6	2	2	1	0	0
331314	Secondary Smelting and Alloying of Aluminum	122	4,846	9	8	6	6	6	5
331419	Primary Smelting and Refining of Nonferrous Metal (except Copper and Aluminum)	161	8,943	616	250	166	91	53	28
331421	Copper Rolling, Drawing, and Extruding	96	9,849	1,548	97	35	12	6	5
331422	Copper Wire (except Mechanical) Drawing	114	9,847	5,096	995	531	190	132	73
331423	Secondary Smelting, Refining, and Alloying of Copper	24	789	27	25	18	18	18	14
331492	Secondary Smelting, Refining, and Alloying of Nonferrous Metal (except Copper and Aluminum)	248	9,696	270	158	90	0	0	0
331513	Steel Foundries (except Investment)	220	13,874	5	2	2	1	0	0
331521	Aluminum Die-Casting Foundries	254	18,017	98	94	72	40	21	15
331522	Nonferrous (except Aluminum) Die-Casting Foundries	140	6,362	534	512	393	219	115	83
331524	Aluminum Foundries (except Die-Casting)	394	15,178	98	94	72	40	21	15
331525	Copper Foundries (except Die-Casting)	208	5,123	674	647	507	300	177	99
332116	Metal Stamping	1,484	48,855	496	58	45	0	0	0
332117	Powder Metallurgy Part Manufacturing	133	6,707	4	2	1	0	0	0
332212	Hand and Edge Tool Manufacturing	1,066	25,098	12	5	3	2	0	0
332312	Fabricated Structural Metal Manufacturing	3,407	89,728	224	97	67	30	6	6
332313	Plate Work Manufacturing	1,288	28,400	85	37	25	11	2	2
332322	Sheet Metal Work Manufacturing	4,173	91,364	274	119	81	37	7	7
332323	Ornamental and Architectural Metal Work Manufacturing	2,354	30,029	155	67	46	21	4	4
332439	Other Metal Container Manufacturing	370	12,553	27	12	8	4	1	1
332612	Spring (Light Gauge) Manufacturing	323	10,329	2,071	185	74	0	0	0
332721	Precision Turned Product Manufacturing	3,124	78,749	3,764	1,122	697	333	211	152
332919	Other Metal Valve and Pipe Fitting Manufacturing	265	14,688	11	5	3	1	0	0
332999	All Other Miscellaneous Fabricated Metal Product Manufacturing	3,262	65,821	134	58	40	18	4	4
333111	Farm Machinery and Equipment Manufacturing	1,041	53,133	80	34	24	11	2	2
333411	Air Purification Equipment Manufacturing	358	14,521	379	0	0	0	0	0
333412	Industrial and Commercial Fan and Blower Manufacturing	151	6,908	160	0	0	0	0	0
333414	Heating Equipment (except Warm Air Furnaces) Manufacturing	460	16,768	511	10	7	3	1	1
333415	Air-Conditioning, Warm Air Heating, and Industrial Refrigeration Equipment Manufacturing	843	79,651	893	0	0	0	0	0
333911	Pump and Pumping Equipment Manufacturing	571	31,272	27	11	8	4	1	1
333922	Conveyor and Conveying Equipment Manufacturing	776	26,970	36	16	11	5	1	1
333924	Industrial Truck, Tractor, Trailer, and Stacker Machinery Manufacturing	374	19,974	17	8	5	2	0	0
333999	All Other Miscellaneous General Purpose Machinery Manufacturing	1,524	43,401	71	31	21	10	2	2

Table III-15

Numbers of Workers Exposed to Beryllium (by Affected Industry and Exposure Level (μg/m3)

NAICs	Industry	No. of Establishments	No. of Employees	Numbers Exposed to Beryllium > 0	>=0.1 μg/m3	>=0.2 μg/m3	>=0.5 μg/m3	>=1.0 μg/m3	>=2.0 μg/m3
334220	Radio and Television Broadcasting and Wireless Communications Equipment Manufacturing	810	79,732	119	37	22	8	3	1
334310	Audio and Video Equipment Manufacturing	464	8,858	59	19	11	4	1	1
334411	Electron Tube Manufacturing	79	4,884	250	78	45	17	6	3
334415	Electronic Resistor Manufacturing	61	3,722	143	45	26	10	3	1
334417	Electronic Connector Manufacturing	231	19,538	310	36	28	0	0	0
334419	Other Electronic Component Manufacturing	1,133	46,836	107	33	19	7	3	1
334510	Electromedical and Electrotherapeutic Apparatus Manufacturing	629	66,107	107	33	19	7	3	1
335211	Electric Housewares and Household Fan Manufacturing	106	5,980	80	0	0	0	0	0
335212	Household Vacuum Cleaner Manufacturing	34	2,577	26	0	0	0	0	0
335221	Household Cooking Appliance Manufacturing	96	9,730	73	0	0	0	0	0
335222	Household Refrigerator and Home Freezer Manufacturing	22	9,731	17	0	0	0	0	0
335224	Household Laundry Equipment Manufacturing	11	8,051	8	0	0	0	0	0
335228	Other Major Household Appliance Manufacturing	38	9,023	29	0	0	0	0	0
336211	Motor Vehicle Body Manufacturing	742	38,587	60	26	18	8	2	2
336214	Travel Trailer and Camper Manufacturing	683	30,803	55	24	16	7	1	1
336311	Carburetor, Piston, Piston Ring, and Valve Manufacturing	109	7,370	82	0	0	0	0	0
336312	Gasoline Engine and Engine Parts Manufacturing	742	36,896	561	0	0	0	0	0
336321	Vehicular Lighting Equipment Manufacturing	93	9,218	70	0	0	0	0	0
336322	Other Motor Vehicle Electrical and Electronic Equipment Manufacturing	636	38,475	1,666	163	119	8	3	1
336330	Motor Vehicle Steering and Suspension Components (except Spring) Manufacturing	246	26,118	186	0	0	0	0	0
336340	Motor Vehicle Brake System Manufacturing	199	20,245	150	0	0	0	0	0
336350	Motor Vehicle Transmission and Power Train Parts Manufacturing	476	51,171	360	0	0	0	0	0
336360	Motor Vehicle Seating and Interior Trim Manufacturing	403	39,805	305	0	0	0	0	0
336370	Motor Vehicle Metal Stamping	736	66,985	557	0	0	0	0	0
336391	Motor Vehicle Air-Conditioning Manufacturing	80	11,207	61	0	0	0	0	0
336399	All Other Motor Vehicle Parts Manufacturing	1,350	95,426	1,051	13	9	4	1	1
336510	Railroad Rolling Stock Manufacturing	226	24,491	11	5	3	1	0	0
336999	All Other Transportation Equipment Manufacturing	374	10,846	14	6	4	2	0	0
337215	Showcase, Partition, Shelving, and Locker Manufacturing	1,194	33,195	13	6	4	2	0	0
339116	Dental Laboratories	6,995	44,030	8,148	5,668	3,897	2,834	1,417	1,063
621210	Offices of Dentists	129,830	846,092	1,107	770	529	385	192	144
811310	Commercial and Industrial Machinery and Equipment (except Automotive and Electronic) Repair and Maintenance	21,960	181,220	571	247	170	77	15	15
	Totals	**200,970**	**2,892,762**	**35,051**	**12,105**	**8,095**	**4,823**	**2,454**	**1,761**

Source: County Business Patterns, 2010; OSHA Office of Regulatory Analysis-Health

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CHAPTER IV: TECHNOLOGICAL FEASIBILITY ANALYSIS

EXECUTIVE SUMMARY

This section summarizes the technological feasibility analysis presented in Chapter IV of the PEA (OSHA, 2014). The technological feasibility analysis includes information on current exposures, descriptions of engineering controls and other measures to reduce exposures, and a preliminary assessment of the technological feasibility of compliance with the proposed standard, including a reduction in OSHA's permissible exposure limits (PELs) in nine affected application groups. The current PELs for beryllium are 2.0 μg/m^3 as an 8-hour time weighted average (TWA), and 5.0 μg/m^3 as an acceptable ceiling concentration. OSHA is proposing a PEL of 0.2 μg/m^3 as an 8-hour TWA and is additionally considering alternative TWA PELs of 0.1 and 0.5 μg/m^3. OSHA is also proposing a 15-minute short-term exposure limit (STEL) of 2.0 μg/m^3, and is considering alternative STELs of 0.5, 1.0 and 2.5 μg/m^3.

The technological feasibility analysis includes nine application groups that correspond to specific industries or production processes that OSHA has preliminarily determined fall within the scope of the proposed standard. Within each of these application groups, exposure profiles have been developed that characterize the distribution of the available exposure measurements by job title or group of jobs. Descriptions of existing engineering controls for operations that create sources of beryllium exposure, and of additional engineering and work practice controls that can be used to reduce exposure are also provided. For each application group, a preliminary determination is made regarding the feasibility of achieving the proposed permissible exposure limits. For application groups in which the median exposures for some jobs exceed the proposed TWA PEL, a more detailed analysis is presented by job or group of jobs within the application group. The analysis is based on the best information currently available to the Agency, including a comprehensive review of the industrial hygiene literature, National Institute for Occupational Safety and Health (NIOSH) Health Hazard Evaluations and case studies of beryllium exposure, site visits conducted by an OSHA contractor (Eastern Research Group (ERG)), submissions to OSHA's rulemaking docket, and inspection data from OSHA's Integrated Management Information System (IMIS). OSHA also obtained information on production processes, worker exposures, and producer in the United States, Materion Corporation, and from interviews with industry experts.

The nine application groups included in this analysis were identified based on information obtained during preliminary rulemaking activities that included a SBRFA panel, a comprehensive review of the published literature, stakeholder input, and an analysis of IMIS data collected during OSHA workplace inspections where detectable airborne beryllium was found. The nine application groups and their corresponding section numbers in Chapter IV of the PEA are:

Section 3—Beryllium Production,

Section 4—Beryllium Oxide Ceramics and Composites,

Section 5—Nonferrous Foundries,

Section 6—Secondary Smelting, Refining, and Alloying,

Section 7—Precision Turned Products,

Section 8—Copper Rolling, Drawing, and Extruding,

Section 9—Fabrication of Beryllium Alloy Products,

Section 10—Welding, and

Section 11—Dental Laboratories.

OSHA developed exposure profiles by job or group of jobs using exposure data at the application, operation or task level to the extent that such data were available. In those instances where there were insufficient exposure data to create a profile, OSHA used analogous operations to characterize the operations. The exposure profiles represent baseline conditions with existing controls for each operation with potential exposure. For job groups where exposures were above the proposed TWA PEL of 0.2 $\mu g/m^3$, OSHA identified additional controls that could be implemented to reduce employee exposures to beryllium. These included engineering controls, such as process containment, local exhaust ventilation and wet methods for dust suppression, and work practices, such as improved housekeeping and the prohibition of compressed air for cleaning beryllium-contaminated surfaces.

For the purposes of this technological feasibility assessment, these nine application groups can be divided into three general categories based on current exposure levels:

application groups in which current exposures for most jobs are already below the proposed PEL of 0.2 $\mu g/m^3$;

application groups in which exposures for most jobs are below the current PEL, but exceed the proposed PEL of 0.2 $\mu g/m^3$, and therefore additional controls would be required; and

application groups in which exposures in one or more jobs routinely exceed the current PEL, and therefore substantial reductions in exposure would be required to achieve the proposed PEL.

The majority of exposure measurements taken in the application groups in the first category are already at or below the proposed PEL of 0.2 $\mu g/m^3$, and most of the jobs with exposure to beryllium in these four application groups have median exposures below the alternative PEL of 0.1 $\mu g/m^3$ (See Table IV-1 located at the end of this summary). These four application groups include rolling, drawing, and extruding; fabrication of beryllium alloy products; welding; and dental laboratories.

The two application groups in the second category include: precision turned products and secondary smelting. For these two groups, the median exposures in most jobs are below the current PEL, but the median exposure levels for some job groups currently exceed the proposed PEL. Additional exposure controls and work practices could be implemented that the Agency has preliminarily concluded would reduce exposures to or below the proposed PEL for most jobs most of the time. One exception is furnace operations in secondary smelting, in which the median exposure exceeds the current PEL. Furnace operations involve high temperatures that produce significant amounts of fumes and particulate that can be difficult to contain. Therefore, the proposed PEL may not be feasible for most furnace operations involved with secondary smelting, and in some cases, respiratory protection would be required to adequately protect furnace workers when exposures exceed 0.2 μg/m^3 despite the implementation of all feasible controls.

Exposures in the third category of application groups routinely exceed the current PEL for several jobs. The three application groups in this category include: beryllium production, beryllium oxide ceramics production, and aluminum and copper foundries. The individual job groups for which exposures exceed the current PEL are discussed in the application group specific sections later in this summary, and described in greater detail in the PEA. For the jobs that routinely exceed the current PEL, OSHA identified additional exposure controls and work practices that the Agency preliminarily concludes would reduce exposures to or below the proposed PEL most of the time, with three exceptions: furnace operations in primary beryllium production and aluminum and copper foundries, and shakeout operations at aluminum and copper foundries. For these jobs, OSHA recognizes that even after installation of feasible controls, respiratory protection may be needed to adequately protect workers.

In conclusion, the preliminary technological feasibility analysis shows that for the majority of the job groups evaluated, exposures are either already at or below the proposed PEL, or can be adequately controlled with additional engineering and work practice controls. Therefore, OSHA preliminarily concludes that the proposed PEL of 0.2 μg/m^3 is feasible for most operations most of the time. The preliminary feasibility determination for the proposed PEL is also supported by Materion Corporation, the sole primary beryllium production company in the U.S., and by the United Steelworkers, who jointly submitted a draft proposed standard that specified an exposure limit of 0.2 μg/m^3 to OSHA (Materion and Steelworkers, 2012). The technological feasibility analysis conducted for each application group is briefly summarized below, and a more detailed discussion is presented in Sections 3—Beryllium Production through 11—Dental Laboratories of Chapter IV of the PEA (OSHA, 2014).

Based on the currently available evidence, it is more difficult to determine whether an alternative PEL of 0.1 μg/m^3 would also be feasible in most operations. For some application groups, such as fabrication of beryllium alloy products, a PEL of 0.1 μg/m^3 would almost certainly be feasible. In other application groups, such as precision turned products, a PEL of 0.1 μg/m^3 appears feasible, except for establishments working with high beryllium content alloys. For application groups with the highest exposure, the exposure monitoring data necessary to more fully evaluate the effectiveness of exposure controls adopted after 2000 are not currently available to OSHA, which makes it difficult to determine the feasibility of achieving exposure levels at or below 0.1 μg/m^3.

OSHA also evaluated the feasibility of a STEL of 2.0 μg/m^3, and alternative STELs of 0.5 and 1.0 μg/m^3. An analysis of the available short-term exposure measurements presented in Chapter IV, Section 12—Short-Term Exposures of the PEA, indicates that elevated exposures can occur during short-term tasks such as those associated with the operation and maintenance of furnaces at primary beryllium production facilities, at aluminum and copper foundries, and at secondary smelting operations. Peak exposure can also occur during the transfer and handling of beryllium oxide powders. (OSHA, 2009; NEHC, 2003) OSHA believes that in many cases, reducing short-term exposures will be necessary to reduce workers' TWA exposures to or below the proposed PEL. The majority of the available short-term measurements are below 2.0 μg/m^3, therefore OSHA preliminarily concludes that the proposed STEL of 2.0 μg/m^3 can be achieved for most operations most of the time. OSHA recognizes that for a small number of tasks, short-term exposures may exceed the proposed STEL, even after feasible control measures to reduce TWA exposure to below the proposed PEL have been implemented, and therefore assumes that the use of respiratory protection will continue to be required for some short-term tasks. It is more difficult based on the currently available evidence to determine whether the alternative STEL of 1.0 μg/m^3 would also be feasible in most operations based on lack of detail in the activities of the workers presented in the data. OSHA expects additional use of respiratory protection would be required for tasks in which peak exposures can be reduced to less than 2.0 μg/m^3, but not less than 1.0 μg/m^3. Due to limitations in the available sampling data and the higher detection limits for short term measurements, OSHA could not determine the percentage of the STEL measurements that are less than or equal to 0.5 μg/m^3. A detailed discussion of the STELs being considered by OSHA is presented in Section 12—Short-Term Exposures of Chapter IV of the PEA (OSHA, 2014).

OSHA requests available exposure monitoring data and comments regarding the effectiveness of currently implemented control measures and the feasibility of the PELs under consideration, particularly the proposed TWA PEL of 0.2 μg/m^3, the alternative TWA PEL of 0.1 μg/m^3, the proposed STEL of 2.0 μg/m^3, and the alternative STEL of 1.0 μg/m^3 to inform the Agency's final feasibility determinations.

<u>APPLICATION GROUP SUMMARIES</u>

This section summarizes the technological feasibility analysis for each of the nine application groups affected by the proposed standard. Chapter IV of the PEA, Technological Feasibility Analysis, identifies specific jobs or job groups with potential exposure to beryllium, and presents exposure profiles for each of these job groups (OSHA, 2014). Control measures and work practices that OSHA believes can reduce exposures are described along with preliminary conclusions regarding the feasibility of the proposed PEL. Table IV-1, located at the end of this summary, presents summary statistics for the personal breathing zone samples taken to measure full-shift exposures to beryllium in each application group. For the five application groups in which the median exposure level for at least one job group exceeds the proposed PEL, the sampling results are presented by job group. Table IV-1 displays the number of measurements; the range, the mean and the median of the measurement results; and the percentage of measurements less than 0.1 μg/m^3, less than or equal to the proposed PEL of 0.2 μg/m^3, and less than or equal to the current PEL of 2.0 μg/m^3. A more detailed discussion of exposure levels by job or job group for each application group is provided in Chapter IV of the PEA, Sections 3—Beryllium Production through 11—Dental Laboratories, along with a description of the available exposure measurement data, existing controls, and additional controls that would be required to achieve the proposed PEL.

Beryllium Production

Only one primary beryllium production facility is currently in operation in the United States, a plant owned and operated by Materion Corporation,[36] located in Elmore, Ohio. OSHA identified eight job groups at this facility in which workers are exposed to beryllium. These include: chemical operations, powdering operations, production support, cold work, hot work, site support, furnace operations, and administrative work.

The Agency developed an exposure profile for each of these eight job groups to analyze the distribution of exposure levels associated with primary beryllium production. The job exposure profiles are based primarily on full-shift personal breathing zone (PBZ) (lapel-type) sample results from air monitoring conducted by Brush Wellman's primary production facility in 1999 (Brush Wellman Elmore, 2004). Starting in 2000, the company developed the Materion Worker Protection Program (MWPP), a multi-faceted beryllium exposure control program designed to reduce airborne exposures for the vast majority of workers to less than an internally established exposure limit of 0.2 μg/m^3. According to information provided by Materion, a combination of engineering controls, work practices, and housekeeping were used together to reduce average exposure levels to below 0.2 μg/m^3 for the majority of workers (Materion Information Meeting, 2012). Also, two operations with historically high exposures, the wet plant and pebble plants, were decommissioned in 2000, thereby reducing average exposure levels. Therefore, the samples taken prior to 2000 may overestimate current exposures.

Additional exposure samples were taken by NIOSH at the Elmore facility from 2007 through 2008 (NIOSH Elmore database, 2011). This dataset, which was made available to OSHA by Materion, contains fewer samples than the 1999 survey. OSHA did not incorporate these samples into the exposure profile due to the limited documentation associated with the sampling data. The lack of detailed information for individual samples has made it difficult for OSHA to correlate job classifications and identify the working conditions associated with the samples. Also, OSHA does not know if a sampling strategy was used by NIOSH and Materion to identify the most problematic exposure areas, or if some other sampling strategy was employed. In a meeting in May 2012 held between OSHA and Materion Corporation at the Elmore facility, the Agency was able to obtain some general information on the exposure control modifications that Materion Corporation made between 1999 and 2007, but has been unable to determine what specific controls were in place at the time NIOSH conducted sampling (Materion Information Meeting, 2012).

In five of the primary production job groups (i.e., hot work, cold work, production support, site support, and administrative work), the baseline exposure profile indicates that exposures are already lower than the proposed PEL of 0.2 μg/m^3. Median exposure values for these job groups range from nondetectable to 0.08 μg/m^3.

For three of the job groups involved with primary beryllium production, (i.e., chemical operations, powdering, and furnace operations), the median exposure level exceeds the proposed PEL of 0.2 μg/m^3. Median exposure values for these job groups are 0.47, 0.37, and 0.68 μg/m^3 respectively, and only 17% to 29% of the available measurements are less than or equal to 0.2

[36] Materion Corporation was previously named Brush Wellman. In 2011, subsequent to the collection of the information presented in this chapter, the name changed. "Brush Wellman" is used whenever the data being discussed pre-dated the name change.

μg/m^3 (Brush Wellman Elmore, 2004). Therefore, additional control measures for these job groups would be required to achieve compliance with the proposed PEL. OSHA has identified several engineering controls that the Agency preliminarily concludes can reduce exposures in chemical processes and powdering operations to less than or equal to 0.2 μg/m^3. In chemical processes, these include fail-safe drum-handling systems, full enclosure of drum-handling systems, ventilated enclosures around existing drum positions, automated systems to prevent drum overflow, and automated systems for container cleaning and disposal such as those designed for hazardous powders in the pharmaceutical industry. Similar engineering controls would reduce exposures in powdering operations. In addition, installing remote viewing equipment (or other equally effective engineering controls) to eliminate the need for workers to enter the die-loading hood during die filling will reduce exposures associated with this powdering task and reduce powder spills. Based on the availability of control methods to reduce exposures for each of the major sources of exposure in chemical operations, OSHA preliminarily concludes that exposures at or below the proposed 0.2 μg/m^3 PEL can be achieved in most chemical and powdering operations most of the time. OSHA believes furnace operators' exposures can be reduced using appropriate ventilation, including fume capture hoods, and other controls to reduce overall beryllium levels in foundries, but is not certain whether the exposures of furnace operators can be reduced to the proposed PEL with currently available technology. OSHA requests additional information on current exposure levels and the effectiveness of potential control measures for primary beryllium production operations to further refine this analysis.

Beryllium Oxide Ceramics Production

OSHA identified seven job groups involved with beryllium oxide ceramics production. These include: material preparation operator, forming operator, machining operator, kiln operator, production support, metallization, and administrative work. Four of these jobs (material preparation, forming operator, machining operator and kiln operator) work directly with beryllium oxides, and therefore these jobs have a high potential for exposure. The other three job groups (production support work, metallization, and administrative work) have primarily indirect exposure that occurs only when workers in these jobs groups enter production areas and are exposed to the same sources to which the material preparation, forming, machining and kiln operators are directly exposed. However, some production support and metallization activities do require workers to handle beryllium directly, and workers performing these tasks may at times be directly exposed to beryllium.

The Agency developed exposure profiles for these jobs based on air sampling data from four sources: 1) samples taken between 1994 and 2003 at a large beryllium oxide ceramics facility (OSHA-H005C-2006-0870-0094), 2) air sampling data obtained during a site visit to a primary beryllium oxide ceramics producer (ERG Beryllium Site 3, 2003), 3) a published report that provides information on beryllium oxide ceramics product manufacturing for a slightly earlier time period (Kreiss et al., 1996), and 4) exposure data from OSHA's Integrated Management Information System (OSHA, 2009). The exposure profile indicates that the three job groups with mostly indirect exposure (production support work, metallization, and administrative work) already achieve the proposed PEL of 0.2 μg/m^3. Median exposure sample values for these job groups did not exceed 0.06 μg/m^3.

The four job groups with direct exposure had higher exposures. In forming operations and machining operations, the median exposure levels of 0.18 and 0.15 μg/m^3, respectively, are below the proposed PEL, while the median exposure levels for material preparation and kiln operations of 0.41 μg/m^3 and 0.25 μg/m^3, respectively, exceed the proposed PEL.

The profile for the directly exposed jobs may overestimate exposures due to the preponderance of data from the mid-1990s, a time period prior to the implementation of a variety of exposure control measures introduced after 2000. In forming operations, 44% of sample values in the exposure profile exceeded 0.2 μg/m^3. However, the median exposure levels for some tasks, such as small-press and large-press operation, based on sampling conducted in 2003 were below 0.1 μg/m^3. The exposure profile for kiln operation was based on three samples taken from a single facility in 1995, and are all above 0.2 μg/m^3. Since then, exposures at the facility have declined due to changes in operations that reduced the amount of time kiln operators spend in the immediate vicinity of the kilns, as well as the discontinuation of a nearby high-exposure process. More recent information communicated to OSHA suggests that current exposures for kiln operators at the facility are currently below 0.1 μg/m^3. Exposures in machining operations, most of which were already below 0.2 μg/m^3 during the 1990s, may have been further reduced since then through improved work practices and exposure controls (PEA Chapter IV, Section 7—Precision Turned Products). For forming, kiln, and machining operations, OSHA preliminarily concludes that the installation of additional controls such as machine interlocks (for forming) and improved enclosures and ventilation will reduce exposures to or below the proposed PEL most of the time. OSHA requests information on recent exposure levels and controls in beryllium oxide forming and kiln operations to help the Agency evaluate the effectiveness of available exposure controls for this application group.

In the exposure profile for material preparation, 73% of sample values exceeded 0.2 μg/m^3. As with other parts of the exposure profile, exposure values from the mid-1990s may overestimate airborne beryllium levels for current operations. During most material preparation tasks, such as material loading, transfer, and spray drying, OSHA preliminarily concludes that exposures can be reduced to or below 0.2 μg/m^3 with process enclosures, ventilation hoods, and improved housekeeping procedures. However, OSHA acknowledges that peak exposures from some short-term tasks such as servicing of the spray chamber might continue to drive the TWA exposures above 0.2 μg/m^3 on days when these material preparation tasks are performed. Respirators may be needed to protect workers from exposures above the proposed TWA PEL during these tasks.[37] OSHA notes that material preparation for production of beryllium oxide ceramics currently takes place at only two facilities in the United States.

Nonferrous Foundries

OSHA identified eight job groups in aluminum and copper foundries with beryllium exposure: molding, material handling, furnace operation, pouring, shakeout operation, abrasive blasting, grinding/finishing, and maintenance. The Agency developed exposure profiles based on an air monitoring survey conducted by NIOSH in 2007, a Health Hazard Evaluation (HHE) conducted by NIOSH in 1975, a site visit by ERG in 2003, a site visit report from 1999 by the California

[37] One facility visited by ERG has reportedly modified this process to reduce worker exposures, but OSHA has no data to quantify the reduction.

Cast Metals Association (CCMA), and two sets of data from air monitoring surveys obtained from Materion in 2004 and 2010 (NIOSH EPHB 326-11a; NIOSH EPHB 326-16a ; NIOSH HHE 75-087-280; ERG Beryllium Site 7, 2003; CCMA, 2000; MC Pkg I-D, 2010).

The exposure profile indicates that in foundries processing beryllium alloys, six of the eight job groups have median exposures that exceed the proposed PEL of 0.2 $\mu g/m^3$ with baseline working conditions. One exception is grinding/finishing operations, where the median value is 0.12 $\mu g/m^3$ and 73% of exposure samples are below 0.2 $\mu g/m^3$. The other exception is abrasive blasting. The samples for abrasive blasting used in the exposure profile were obtained during blasting operations using enclosed cabinets, and all 5 samples were below 0.2 $\mu g/m^3$. Exposures for other job groups ranged from just below to well above the proposed PEL, including molder (all samples above 0.2 $\mu g/m^3$), material handler (1 sample total , above 0.2 $\mu g/m^3$), furnace operator (81.8% of samples above 0.2 $\mu g/m^3$), pouring operator (60% of samples above 0.2 $\mu g/m^3$), shakeout operator (1 sample total, above 0.2 $\mu g/m^3$), and maintenance worker (50% of samples above 0.2 $\mu g/m^3$).

In some of the foundries at which the air samples included in the exposure profile were collected, there are indications that the ventilation systems were not properly used or maintained, and dry sweeping or brushing and the use of compressed air systems for cleaning may have contributed to high dust levels. OSHA believes that exposures in foundries can be substantially reduced by improving and properly using and maintaining the ventilation systems; switching from dry brushing, sweeping and compressed air to wet methods and use of HEPA-filtered vacuums for cleaning molds and work areas; enclosing processes; automation of high-exposure tasks; and modification of processes (e.g., switching from sand-based to alternative casting methods). OSHA preliminarily concludes that these additional engineering controls and modified work practices can be implemented to achieve the proposed PEL most of the time for molding, material handling, maintenance, abrasive blasting, grinding/finishing, and pouring operations at foundries that produce aluminum and copper beryllium alloys.

The Agency is less confident that exposure can be reliably reduced to the proposed PEL for furnace and shakeout operators. Beryllium concentrations in the proximity of the furnaces are typically higher than in other areas due to the fumes generated and the difficulty of controlling emissions during furnace operations. The exposure profile for furnace operations shows a median beryllium exposure level of 1.14 $\mu g/m^3$. OSHA believes that furnace operators' exposures can be reduced using local exhaust ventilation and other controls to reduce overall beryllium levels in foundries, but it is not clear that they can be reduced to the proposed PEL with currently available technology. In foundries that use sand molds, the shakeout operation typically involves removing the freshly cast parts from the sand mold using a vibrating grate that shakes the sand from castings. The shakeout equipment generates substantial amounts of airborne dust that can be difficult to contain, and therefore shakeout operators are typically exposed to high dust levels. During casting of beryllium alloys, the dust may contain beryllium and beryllium oxide residues dislodged from the casting during the shakeout process. The exposure profile for the shakeout operations contains only one result of 1.3 $\mu g/m^3$. This suggests that a substantial reduction would be necessary to achieve compliance with a proposed PEL of 0.2 $\mu g/m^3$. OSHA requests additional information on recent employee exposure levels and the effectiveness of dust controls for shakeout operations for copper and aluminum alloy foundries.

Secondary Smelting, Refining, and Alloying

OSHA identified two job groups in this application group with exposure to beryllium: mechanical process operators and furnace operations workers. Mechanical operators handle and treat source material, and furnace operators run heating processes for refining, melting, and casting metal alloy. OSHA developed exposure profiles for these jobs based on exposure data from ERG site visits to a precious/base metals recovery facility and a facility that melts and casts beryllium-containing alloys, both conducted in 2003 (ERG Beryllium Site 2, 2003; ERG Beryllium Site 7, 2003). The available exposure data for this application group are limited, and therefore, the exposure profile is supplemented in part by summary data presented in secondary sources of information on beryllium exposures in this application group.

The exposure profile for mechanical processing operators indicates low exposures (3 samples less than 0.2 $\mu g/m^3$), even though these samples were collected at a facility where the ventilation system was allowing visible emissions to escape exhaust hoods. Summary data from studies and reports published in 2005-2009 showed that mechanical processing operator exposures averaged between 0.01 and 0.04 $\mu g/m^3$ at facilities where mixed or electronic waste including beryllium alloy parts were refined. Based on these results, OSHA preliminarily concludes that the proposed PEL is already achieved for most mechanical processing operations most of the time, and exposures could be further reduced through improved ventilation system design and other measures, such as process enclosures.

As with furnace operations examined in other application groups, the exposure profile indicates higher worker exposures for furnace operators in the secondary smelting, refining, and alloying application group (six samples with a median of 2.15 $\mu g/m^3$, and 83.3% above 0.2 $\mu g/m^3$). The two lowest samples in this job's exposure profile (0.03 and 0.5 $\mu g/m^3$) were collected at a facility engaged in recycling and recovery of precious metals where work with beryllium-containing material is incidental. At this facility, the furnace is enclosed and fumes are ducted into a filtration system. The four higher samples, ranging from 1.92 to 14.08 $\mu g/m^3$, were collected at a facility engaged primarily in beryllium alloying operations, where beryllium content is significantly higher than in recycling and precious metal recovery activities, the furnace is not enclosed, and workers are positioned directly in the path of the exhaust ventilation over the furnace. OSHA believes these exposures could be reduced by enclosing the furnace and repositioning the worker, but is not certain whether the reduction achieved would be enough to bring exposures down to the proposed PEL. Based on the limited number of samples in the exposure profile and surrogate data from furnace operations, the proposed PEL may not be feasible for furnace work in beryllium recovery and alloying, and respirators may be necessary to protect employees performing these tasks.

Precision Turned Products

OSHA's preliminary feasibility analysis for precision turned products focuses on machinists who work with beryllium-containing alloys. The Agency also examined the available exposure data for non-machinists and has preliminarily concluded that, in most cases, controlling the sources of exposures for machinists will also reduce exposures for other job groups with indirect exposure when working in the vicinity of machining operations.

OSHA developed exposure profiles based on exposure data from four NIOSH surveys conducted between 1976 and 2008; ERG site visits to precision machining facilities in 2002, 2003, and 2004; case study reports from six facilities machining copper-beryllium alloys; and exposure data collected between 1987 and 2001 by the U.S. Navy Environmental Health Center (NEHC) (NIOSH HHE 76-103-349, 1976; NIOSH HETA 84-510-1691, 1986; NIOSH EPHB 326-14a, 2008; NIOSH EPHB 326-16a, 2008; NEHC, 2000; NEHC, 2003; ERG Beryllium Site 1, 2002; ERG Beryllium Site 4, 2003; ERG Beryllium Site 9, 2004; Brush Wellman Machining, 2004; OSHA-H005C-2006-0870-0097; Materion PSCS 102, 2011; Materion PSCS 103, 2011; and Materion PSCS 104, 2011). Analysis of the exposure data showed a substantial difference between the median exposure level for workers machining pure beryllium and/or high-beryllium alloys compared to workers machining low-beryllium alloys. Most establishments in the precision turned products application group work only with low-beryllium alloys, such as copper-beryllium. A relatively small number of establishments (estimated at 15) specialize in precision machining of pure beryllium and/or high-beryllium alloys.

The exposure profile indicates that machinists working with low-beryllium alloys have mostly low exposure to airborne beryllium. Approximately 85 percent of the 80 exposure results are less than or equal to 0.2 $\mu g/m^3$, and 74 percent are less than or equal to 0.1 $\mu g/m^3$. Some of the results below 0.1 $\mu g/m^3$ were collected at a facility where machining operations were enclosed, and metal cutting fluids were used to control the release of airborne contaminants. Higher results (0.1 $\mu g/m^3$ - 1.07 $\mu g/m^3$) were found at a facility where cutting and grinding operations were conducted in partially enclosed booths equipped with LEV, but some LEV was not functioning properly. A few very high results (0.77 $\mu g/m^3$ - 24 $\mu g/m^3$) were collected at a facility where exposure controls were reportedly inadequate and poor work practices were observed (e.g., improper use of downdraft tables, use of compressed air for cleaning). Based on these results, OSHA preliminarily concludes that exposures below 0.2 $\mu g/m^3$ can be achieved most of the time for most machinists at facilities dealing primarily with low-beryllium alloys. OSHA recognizes that higher exposures may sometimes occur during some tasks where exposures are difficult to control with engineering methods, such as cleaning, and that respiratory protection may be needed at these times.

Machinists working with high-beryllium alloys have higher exposure than those working with low-beryllium alloys. This difference is reflected in the exposure profile for this job, where the median of exposure is 0.31 $\mu g/m^3$ and 75 percent of samples exceed the proposed PEL of 0.2 $\mu g/m^3$. The exposure profile was based on two machining facilities at which LEV was used and machining operations were performed under a liquid coolant flood. Like most facilities where pure beryllium and high-beryllium alloys are machined, these facilities also used some combination of full or partial enclosures, as well as work practices to minimize exposure such as prohibiting the use of compressed air and dry sweeping and implementing dust migration control practices to prevent the spread of beryllium contamination outside production areas. At one facility machining high-beryllium alloys, where all machining operations were fully enclosed and ventilated, exposures were mostly below 0.1 $\mu g/m^3$ (median 0.035 $\mu g/m^3$, range 0.02–0.11 $\mu g/m^3$). Exposures were initially higher at the second facility, where some machining operations were not enclosed, existing LEV system were in need of upgrades, and some exhaust systems were improperly positioned. Samples collected there in 2003 and 2004 were mostly below the proposed PEL in 2003 (median 0.1 $\mu g/m^3$) but higher in 2004 (median 0.25 $\mu g/m^3$), and high exposure means in both years (1.65 and 0.68 $\mu g/m^3$ respectively) show the presence of high exposure spikes in the facility. However, the facility reported that measures to reduce exposure brought almost all machining exposures below 0.2 µg/m^3 in 2006. With the use of fully enclosed machines and LEV and work practices that minimize worker exposures, OSHA preliminarily concludes that the proposed PEL is feasible for the vast majority of machinists working with pure beryllium and high-beryllium alloys. OSHA recognizes that higher exposures may sometimes occur during some tasks where exposures are difficult to control with engineering methods, such as machine cleaning and maintenance, and that respiratory protection may be needed at these times.

Copper Rolling, Drawing, and Extruding

OSHA's exposure profile for copper rolling, drawing, and extruding includes four job groups with beryllium exposure: strip metal production, rod and wire production, production support, and administrative work. Exposure profiles for these jobs are based on personal breathing zone lapel sampling conducted at the Brush Wellman Reading, Pennsylvania, rolling and drawing facility from 1977 to 2000 (Brush Wellman Reading, 2004).

Prior to 2000, the Reading facility had limited engineering controls in place. Equipment in use included LEV in some operations, HEPA vacuums for general housekeeping, and wet methods to control loose dust in some rod and wire production operations. The exposure profile shows very low exposures for all four job groups. All had median exposure values below 0.1 µg/m^3, and in strip metal production, production support, and administrative work, over 90 percent of samples were below 0.1 µg/m^3. In rod and wire production, 70 percent of samples were below 0.1 µg/m^3.

To characterize exposures in extrusion, OSHA examined the results of an industrial hygiene survey of a copper-beryllium extruding process conducted in 2000 at another facility. The survey reported eight PBZ samples, which were not included in the exposure profile because of their short duration (2 hours). Samples for three of the four jobs involved with the extrusion process (press operator, material handler, and billet assembler) were below the limit of detection (LOD) (level not reported). The two samples for the press operator assistant, taken when the assistant was buffing, sanding, and cleaning extrusion tools, were very high (1.6 and 1.9 µg/m^3). Investigators recommended a ventilated workstation to reduce exposure during these activities.

In summary, exposures at or below 0.2 µg/m^3 have already been achieved for most jobs in rolling, drawing, and extruding operations, and OSHA preliminarily concludes that the proposed PEL of 0.2 µg/m^3 is feasible for this application group. For jobs or tasks with higher exposures, such as tool refinishing, use of exposure controls such as local exhaust ventilation can help reduce workers' exposures. The Agency recognizes the limitations of the available data, which were drawn from two facilities and did not include full-shift PBZ samples for extrusion. OSHA requests additional exposure data from other facilities in this application group, especially data from facilities where extrusion is performed.

Fabrication of Beryllium Alloy Products

This application group includes the fabrication of beryllium alloy springs, stampings, and connectors for use in electronics. The exposure profile is based on a study conducted at four precision stamping companies; a NIOSH report on a spring and stamping company; an ERG site visit to a precision stamping, forming, and plating establishment; and exposure monitoring results from a stamping facility presented at the American Industrial Hygiene Conference and Exposition in 2007 (Brush Wellman Stamping, 2004; Corbett, 2007; ERG Beryllium Site 6, 2003; Miller, 2007; NIOSH EPHB 263-12a, 2004). The exposure profiles for this application group include three jobs: chemical processing operators, deburring operators, and assembly operators. Other jobs for which all samples results were below 0.1 $\mu g/m^3$ are not shown in the profile.

For the three jobs in the profile, the majority of exposure samples were below 0.1 $\mu g/m^3$ (deburring operators, 79 percent; chemical processing operators, 81 percent; assembly operators, 93 percent). Based on these results, OSHA preliminarily concludes that the proposed PEL is feasible for this application group. The Agency notes that a few exposures above the proposed PEL were recorded for the chemical processing operator (in plating and bright cleaning) and for deburring (during corn cob deburring in an open tumbling mill). OSHA believes the use of LEV, improved housekeeping, and work practice modifications would reduce the frequency of excursions above the proposed PEL.

Welding

Most of the samples in OSHA's exposure profile for welders in general industry were collected between 1994 and 2001 at two of Brush Wellman's alloy strip distribution centers, and in 1999 at Brush Wellman's Elmore facility (Brush Wellman Stamping, 2004). At these facilities, tungsten inert gas (TIG) welding was conducted on beryllium alloy strip. Seven samples in the exposure profile came from a case study conducted at a precision stamping facility, where airborne beryllium levels were very low (see previous summary, Fabrication of Beryllium Alloy Products). At this facility, resistance welding was performed on copper-beryllium parts, and welding processes were automated and enclosed.

Most of the sample results in the welding exposure profile were below 0.2 $\mu g/m^3$. Of the 44 welding samples in the profile, 75 percent were below 0.2 $\mu g/m^3$ and 64 percent were below 0.1 $\mu g/m^3$, with most values between 0.01 and 0.05 $\mu g/m^3$. All but one of the 16 exposure samples above 0.1 $\mu g/m^3$ were collected in Brush Wellman's Elmore facility in 1999. According to company representatives, these higher exposure levels may have been due to beryllium oxide that can form on the surface of the material as a result of hot rolling. All seven samples from the precision stamping facility were below the limit of detection. Based on these results, OSHA preliminarily concludes that the proposed PEL of 0.2 $\mu g/m^3$ is feasible for most welding operations in general industry.

Dental Laboratories

OSHA's exposure profile for dental technicians includes sampling results from a site visit conducted by ERG in 2003 (ERG Beryllium Site 5, 2003); a study of six dental laboratories published by Rom, *et al.* in (1984); a data set of exposure samples collected between 1987 and 2001, on dental technicians working for the U.S. Navy (NEHC, 2003); and a docket submission from CMP Industries including two samples from a large commercial dental laboratory using nickel-beryllium alloy (OSHA-H005C-2006-0870-0346). Information on exposure controls in these facilities suggests that controls in some cases may have been absent or improperly used.

The exposure profile indicates that 52 percent of samples are less than or equal to 0.2 $\mu g/m^3$. However, the treatment of nondetectable samples in the feasibility analysis may overestimate many of the sample values in the exposure profile. Twelve of the samples in the profile are nondetectable for beryllium. In the exposure profile, these were assigned the highest possible value, the limit of detection (LOD). For eight of the nondetectable samples, the LOD was reported as 0.2 $\mu g/m^3$. For the other four nondetectable samples, the LOD was between 0.23 and 0.71 $\mu g/m^3$. If the true values for these four nondetectable samples are actually less than or equal to the assigned value of 0.2 $\mu g/m^3$, then the true percentage of profile sample values less than or equal to 0.2 $\mu g/m^3$ is between 52 and 70 percent. Of the sample results with detectable beryllium above 0.2 $\mu g/m^3$, some were collected in 1984 at facilities studied by Rom *et al.*, who reported that they occurred during grinding with LEV that was improperly used or, in one case, not used at all. Others were collected at facilities where little contextual information was available to determine what control equipment or work practices might have reduced exposures.

Based on this information, OSHA preliminarily concludes that beryllium exposures for most dental technicians are already below 0.2 $\mu g/m^3$ most of the time. OSHA furthermore believes that exposure levels can be reduced to or below 0.1 $\mu g/m^3$ most of the time via material substitution, engineering controls, and work practices. Beryllium-free alternatives for casting dental appliances are readily available from commercial so

urces, and some alloy suppliers have stopped carrying alloys that contain beryllium. For those dental laboratories that continue to use beryllium alloys, exposure control options include properly designed, installed, and maintained LEV systems (equipped with HEPA filters) and enclosures; work practices that optimize LEV system effectiveness; and housekeeping methods that minimize beryllium contamination in the workplace. In summary, OSHA preliminarily concludes that the proposed PEL is feasible for dental laboratories.

Table IV-1—Beryllium Full-Shift PBZ Samples by Application / Job Group (μg/m³)							
Application / Job Group	**N**	**Range**	**Mean**	**Median**	**%<0.1**	**%≤ 0.2**	**%≤ 2.0**
Beryllium Production Operations (Section 3)							
Furnace Operations	*172*	*0.05 to 254*	*3.80*	*0.68*	*5%*	*17%*	*82%*
Chemical Operations	*20*	*0.05 to 9.6*	*1.02*	*0.47*	*5%*	*15%*	*95%*
Powdering Operations	*72*	*0.06 to 11.5*	*0.82*	*0.37*	*11%*	*29%*	*94%*
Production Support	*861*	*0.02 to 22.7*	*0.51*	*0.08*	*56%*	*71%*	*94%*
Cold Work	*555*	*0.04 to 24.9*	*0.31*	*0.08*	*61%*	*80%*	*98%*
Hot Work	*297*	*0.01 to 2.21*	*0.12*	*0.06*	*69%*	*88%*	*99%*
Site Support	*879*	*0.05 to 4.22*	*0.11*	*0.05*	*81%*	*92%*	*99%*
Administrative	*981*	*0.05 to 4.54*	*0.10*	*0.05*	*85%*	*94%*	*99%*
Beryllium Oxide Ceramics (Section 4)							
Material Preparation Operator	*77*	*0.02 to 10.6*	*1.01*	*0.41*	*13%*	*27%*	*90%*
Forming Operator	*408*	*0.02 to 53.2*	*0.48*	*0.18*	*27%*	*56%*	*99%*
Machining Operator	*355*	*0.01 to 5.0*	*0.32*	*0.15*	*37%*	*63%*	*98%*
Kiln Operator	*3*	*0.22 to 0.36*	*0.28*	*0.25*	*0%*	*0%*	*100%*
Production Support Worker	*119*	*0.02 to 7.7*	*0.21*	*0.05*	*68%*	*88%*	*98%*
Metallization Worker	*36*	*0.02 to 0.62*	*0.15*	*0.06*	*55%*	*69%*	*100%*
Administrative	*185*	*0.02 to 1.2*	*0.06*	*0.05*	*93%*	*98%*	*100%*
Nonferrous Foundries (Section 5)							
Furnace Operator	*11*	*0.2 to 19.76*	*4.41*	*1.14*	*0%*	*18%*	*64%*
Pouring Operator	*5*	*0.2 to 2.2*	*1.21*	*1.40*	*0%*	*40%*	*60%*
Shakeout Operator	*1*	*1.3*	*1.30*	*1.30*	*0%*	*0%*	*100%*
Material Handler	*1*	*0.93*	*0.93*	*0.93*	*0%*	*0%*	*100%*
Molder	*8*	*0.24 to 2.29*	*0.67*	*0.45*	*0%*	*0%*	*88%*
Maintenance	*78*	*0.05 to 22.71*	*0.87*	*0.21*	*15%*	*50%*	*96%*
Abrasive Blasting Operator	*5*	*0.05 to 0.15*	*0.11*	*0.12*	*40%*	*100%*	*100%*
Grinding/finishing Operator	*56*	*0.01 to 4.79*	*0.31*	*0.05*	*59%*	*73%*	*95%*
Secondary Smelting (Section 6)							
Furnace operations worker	*6*	*0.03 to 14.1*	*3.85*	*2.15*	*17%*	*17%*	*50%*
Mechanical processing operator	*3*	*0.03 to 0.2*	*0.14*	*0.20*	*33%*	*100%*	*100%*
Precision Turned Products (Section 7)							
High Be Content Alloys	*80*	*0.02 to 7.2*	*0.72*	*0.31*	*14%*	*25%*	*92%*
Low Be Content Alloys	*59*	*0.005 to 24*	*0.45*	*0.01*	*74%*	*85%*	*96%*
Rolling, Drawing, and Extruding (Section 8)	*650*	*0.006 to 7.8*	*0.11*	*0.024*	*86%*	*93%*	*99%*
Alloy Fabrication (Section 9)	*71*	*0.004 to 0.42*	*0.056*	*0.025*	*83%*	*94%*	*100%*
Welding: Beryllium Alloy (Section 10)	*44*	*0.005 to 2.21*	*0.19*	*0.02*	*64%*	*75%*	*98%*
Dental Laboratories (Section 11)	*23*	*0.02 to 4.4*	*0.74*	*0.2*	*13%*	*52%*	*87%*

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SECTION 1—INTRODUCTION

This report presents OSHA's analysis of the technological feasibility of achieving lower levels of beryllium exposure in general industry through the implementation of engineering, administrative, and work practice controls. This analysis and the resultant conclusions are based on a comprehensive review of the available industrial hygiene literature; exposure data and information from a primary beryllium producer; National Institute for Occupational Safety and Health (NIOSH) industry-specific case studies of the sources of beryllium exposure; findings from Eastern Research Group (ERG) and NIOSH site visits; interviews with industry experts; peer-reviewed journal articles; and data from OSHA's Integrated Management Information System (IMIS).

The following sections discuss the methodology and data sources used in this analysis and evaluate the technological feasibility of the proposed permissible exposure limit (PEL) for each of the affected application groups and corresponding industries:

- Section 2—Methodology
- Section 3—Beryllium Production
- Section 4—Beryllium Oxide Ceramics and Composites
- Section 5—Nonferrous Foundries
- Section 6—Secondary Smelting, Refining, and Alloying, Including Handling of Scrap and Recycled Materials
- Section 7—Precision Turned Products
- Section 8—Copper Rolling, Drawing, and Extruding
- Section 9—Fabrication of Beryllium Alloy Products
- Section 10—Welding
- Section 11—Dental Laboratories

A final section, Section 12—Short-Term Exposures, addresses those situations within the affected industries where short-term (15-minute) tasks can generate peak exposures.

SECTION 2—METHODOLOGY

FORMS OF BERYLLIUM

The element beryllium occurs as a metal (beryllium) and as an oxide of the metal (beryllium oxide). Both forms of beryllium have desirable functional characteristics, such as being heat-conducting, electrical-insulating, nonmagnetic, and extremely strong yet lightweight. Metallic beryllium in small amounts improves the properties of metal alloys; it is combined with copper and aluminum to form specialty alloys of these metals. Beryllium oxide forms readily on the untreated surfaces of pure beryllium metal and beryllium-containing alloys. Beryllium oxide is also manufactured and shaped as a ceramic, or ceramic-metal matrix, to produce other specialty products.

This analysis applies to the element beryllium regardless of whether it is present as pure metal, a component of an alloy, or as beryllium oxide.

SOURCES OF BERYLLIUM IN WORKPLACE AIR SAMPLES

Airborne beryllium occurs where operations generate dusts of beryllium metal or its alloys, either through mechanical action on the beryllium metal or alloy (e.g., grinding, cutting, machining, polishing) or by heating beryllium above its vaporization point (e.g., in a foundry furnace), causing beryllium fumes to be released.

Additionally, airborne beryllium also occurs where beryllium oxide is formed and released:

- While melting and pouring beryllium metal and its alloys, during which beryllium oxides are emitted as fume and also accumulate as part of the dross (impurities) that foundry workers skim off the molten metal (deYoung and Peace, 2009).
- During casting or heat-treating of metals containing beryllium, on which surface oxides form (Kent, 2012).
- Where the oxide is released from surfaces during any manipulation of materials on which the oxide has formed, adhered, collected (e.g., processing beryllium alloy strip, cleaning molds used to cast molten beryllium alloy, servicing industrial ventilation equipment). This can include beryllium particles contained in mist emitted from beryllium alloy surface-treatment tanks in which beryllium has accumulated (Kent, 2012).
- During handling of the manufactured beryllium oxide ceramic powder (beryllia) or finishing ceramic products formed from that oxide (Kolanz, 2001).

Beryllium oxide forms readily when metal is heated. Evidence suggests that in molten alloys, beryllium is concentrated as an oxide in dross, even when the alloys contain low concentrations of beryllium. Investigators analyzed beryllium concentrations in dross produced from aluminum alloys of varying concentrations of beryllium (deYoung and Peace, 2009). Under both experimental (one site) and industrial (two sites) conditions, the investigators found that beryllium was more concentrated in the oxide portion of the dross compared to the parent alloy.[38] These findings demonstrate the importance of dross (and beryllium oxide) as a notable source of worker beryllium exposure in operations where dross occurs (i.e., foundries, smelters).

CONTRACTOR REPORT

For this technological feasibility analysis, OSHA relied primarily on reports developed by its contractor Eastern Research Group, Inc. (ERG). ERG initially acquired beryllium exposure data and related information between 2001 and 2004 using literature search and retrieval processes; records provided by OSHA; findings from site visits conducted by ERG and NIOSH; and communications with representatives of NIOSH, identified industries, and other groups.

ERG analyzed the available data using the methods described below, building on the analysis included in a 2005 ERG report to OSHA. A panel convened under the Small Business Regulatory Enforcement Fairness Act (SBREFA) reviewed the report in 2007, after which it was entered in the associated beryllium rulemaking docket.[39] Since then, OSHA has worked with ERG to update the materials, and ERG presented OSHA with additional interim reports through 2011. In general, OSHA finds the logic and methodology of these studies to be sound, the data complete to the extent available, and the analysis compelling. Unless otherwise noted, OSHA concurs with ERG's findings.

OSHA has based this technological feasibility analysis on the best information available from these reports and internal supplemental information that has been created since 2011. The result is the current draft, available as Chapter IV (Technological Feasibility) of the Preliminary Economic Analysis (PEA). Chapter IV reflects all the current data available to OSHA.

SOURCES OF DATA

This technological feasibility analysis relies on information from a wide variety of sources available to OSHA. This information is found in ERG's report (ERG, 2005) or in subsequent interim reports, as well as from recent supplemental information. The sources of information include:

- Peer-reviewed published literature.
- Beryllium records from OSHA's Integrated Management Information System (IMIS).
- NIOSH reports, including health hazard evaluations (HHE), control technology (CT) assessments, in-depth surveys, recommendations for exposure control, and engineering control feasibility studies.

[38] DeYoung and Peace (2009) measured beryllium concentration factors ranging from 2 to 50 in aluminum-beryllium alloys, but they generally measured at least 5. They calculated the concentration factor as "…the ratio of the beryllium concentration in the oxide portion of the dross to the beryllium concentration in the parent alloy…."

[39] ERG's 2005 report appears in the docket as OSHA-H005C-2006-0870-0340, under the heading *Technological Feasibility Materials.*

- ERG site visits.
- Brush Wellman, Incorporated (known as Materion Corporation since 2010), the sole primary beryllium producer in the United States.
- Unpublished information (e.g., unpublished data and research obtained through personal communications, meetings, presentations, and submissions to OSHA's public docket [OSHA-H005C-2006-0870]).
- Information available from other federal agencies, industry organizations, and other groups.

ERG also obtained OSHA IMIS data from 1978 through mid-2008, which primarily were used to identify industries initially considered for inclusion in this technological feasibility analysis.[40]

As noted above, OSHA has mainly relied on the contractor reports (ERG, 2005); however, OSHA has considered and referenced additional material where available.

Notes on Data Sources and Characteristics

OSHA's Integrated Management Information System

For purposes of this analysis, the documentation for individual results in OSHA's IMIS data (1978 through mid-2008) is incomplete. The IMIS record reports the Standard Industrial Classification (SIC) but not the product produced, action performed, or materials used. Furthermore, IMIS does not include information on the sample duration; thus, it was not possible to confirm whether samples were obtained over 60 minutes or 360 minutes or 480 minutes of the worker's shift (or any other time period). The IMIS record reports the worker's job title (a free text field subject to infinite variability, and therefore difficult to sort into job categories), but it does not report the worker's actual activities during the sampling period or the presence of exposure controls.

As intended, IMIS is useful as a management tool for observing trends and identifying industries in which exposures occur. For the detailed industry-by-industry technological feasibility analyses, however, OSHA used more completely documented data sources. OSHA also based application group exposure profiles on other sources, if available.

[40] The IMIS dataset reviewed for this study covered a 30-year and 4-month period from June 1, 1978 to September 25, 2008 (OSHA, 2009). The data were received in two lots (an initial lot ending May, 2003, and a supplemental lot beginning June 2003). The two lots varied in that the supplemental lot, as received, included only PBZ samples (1,1551 samples, of which 193, or 12.4 percent, were positive for beryllium). The earlier lot included all types of beryllium observations (12,666 individual samples, of which 11,616 were personal breathing zone samples [PBZ]; 334 were area samples; and the remainder were classified as screening, bulk, and wipe samples). Although actual sample durations were not reported, samples were designated in IMIS as applicable to one of the following exposure limits: ceiling (assessed by instantaneous monitoring or as a 15-minute TWA), short-term exposure limit (STEL, also a 15-minute TWA), peak (30-minute TWA), or PEL (8-hour TWA). See the applicable section of this technological feasibility analysis (Section 12—Short Term Exposures) and 29 CFR 1910.1000 for additional information on these exposure limits. Industry analyses considered all PBZ beryllium samples, while the STEL analysis considered only the subset of PBZ samples coded as ceiling, STEL or peak samples.

Limits of Detection for Beryllium Data

Investigators performing data analysis usually follow the common practice of assigning a value to samples with concentrations reported as "nondetectable"(sometimes designated as "ND"). The assigned value is typically related to the reported limit of detection (LOD) and permits the investigator to account for these sample results in quantitative analysis, such as when calculating the mean and median.

The LOD indicates the smallest quantity of beryllium that can be detected. This practical limitation of the laboratory analysis (procedures and analytical equipment) is typically a fixed value for each analytical method. The beryllium LOD can be presented in two formats: as the analytical method LOD, which refers to the smallest mass of beryllium (in micrograms [µg]) that can be detected on the filter, or as the concentration LOD, which refers to a calculated value representing the smallest airborne concentration (in µg/cubic meter [m^3]) of air that can be detected.

Results below the limit of quantitation (LOQ) are those in which beryllium was detected, but not in sufficient quantity to offer an accurate analytical result (this range is sometimes reported nonquantitatively as "trace"). Like the LOD, the LOQ is a function of the laboratory analytical method. OSHA handled results reported as below the LOQ in the same manner as LOD values (e.g., by assigning the reported value of the LOQ to results reported as the LOQ).

The beryllium analytical method LOD is presented as the number of micrograms of beryllium that can be detected on an individual filter used to collect an air sample. For example, since 2002, OSHA's beryllium analytical method (OSHA ID-125G) has a reported LOD value of 0.013 µg. If particulate matter on a filter contains less than 0.013 µg of beryllium, the analytical process will not be able to measure it. The laboratory technician cannot tell whether the filter holds no beryllium at all or some small amount between 0 µg and the LOD of 0.013 µg. The only certainty is that the amount of beryllium on the filter is less than the LOD. Although historically other LODs have been published for other beryllium analytical methods, commonly cited laboratory methods currently offer an LOD of 0.013 µg or lower for beryllium samples (Ashley, 2007).[41] When a laboratory finds that the mass of beryllium on a filter is not detectable, the laboratory report will generally indicate that the mass is "less than 0.013 µg" (<0.013 µg).

When a laboratory reports that the gravimetric result[42] is not detectable because there is not enough beryllium on the sample filter, the analytical LOD is used to represent the beryllium mass in the concentration calculation. The concentration LOD is calculated by dividing the analytical LOD by the volume of air sampled (measured in cubic meters). For example, if the analytical LOD is 0.013 µg and the air volume sampled is 720 liters (0.720 m^3), the concentration LOD would be calculated as 0.013 µg/0.720 m^3, or about 0.018 µg/ m^3.

[41] High beryllium LODs were primarily associated with data from older surveys, where the LODs for beryllium were significantly higher than the reporting limits of current laboratory methods. For example, for a visit to a smelter, NIOSH 78-17-567 (1979) reported an LOD of 1.0 µg per sample using NIOSH's analytical method P&CAM #121. In contrast, for a 2007 NIOSH survey at a copper-beryllium machine shop, the LOD for the PBZ samples was approximately 0.02 µg per sample, 50 times lower than the LOD reported in 1979 (NIOSH EPHB 326-14a, 2008).

[42] A "gravimetric" result is defined as a measurement of weight or mass (e.g., micrograms).

Practical examples of the concentration LOD for beryllium results analyzed using a method with an analytical LOD of 0.013 µg appear in Table IV-2.

Table IV-2—Practical Examples of Concentration LODs for Beryllium Results Obtained Using a Method With an Analytical LOD of 0.013 µg

Sample Duration*	Air Volume Sampled	Calculated Concentration LOD
480 minutes (8 hours)	*960 Liters (0.960 m^3)*	*0.014 µg/m^3*
360 minutes (6 hours)	*720 Liters (0.720 m^3)*	*0.018 µg/m^3*
180 minutes (3 hours)	*360 Liters (0.360 m^3)*	*0.036 µg/m^3*
15 minutes (1/4 hour)	*30 Liters (0.030 m^3)*	*0.43 µg/m^3*

* *Also assumes that the air sample was obtained at 2.0 liters/minute, the recommended rate for OSHA's method ID-125G.*

The resulting concentration LOD indicates the minimum concentration of airborne beryllium that could have been detected. Because beryllium was not detected, the true airborne concentration is less than the concentration LOD. These LODs vary depending on the volume of air sampled. For a given air sampling rate, a shorter sampling period will always result in a smaller volume of air sampled. Thus, all other factors being equal, a sample collected over a short period will result in a higher LOD than a sample collected over a longer period of time. Two results obtained on the same date at the same location, but involving different volumes of sampled air, will have different LODs.

Several different approaches are available for assigning a value to sample results below the LOD (e.g., assigning a value of one-half the LOD concentration, assigning the unmodified LOD concentration value) (Hornung and Reed, 1990; NIOSH ECTB 233-101c, 1999; Succop et al., 2004). For the purposes of this analysis, OSHA elected to use the unmodified concentration LOD value to be as protective as possible.[43] This probably resulted in a slight overestimation of exposure levels; the true concentration is some unknown level between zero and the LOD.

The full-shift sample results that OSHA analyzed for the exposure profiles included nondetectable results (i.e., samples with concentrations reported as nondetectable or, providing sufficient information was available, OSHA estimated the concentration LOD). When discussing individual airborne concentration results for worker breathing zone samples in which beryllium was not detected, OSHA typically includes a note (e.g., "LOD") indicating that the reported value (e.g., 0.018 µg/ m^3) is based on a calculated concentration LOD.

By using full-shift results (defined for purposes of this analysis as having a duration of 360 minutes or greater) for general industry, OSHA minimizes the number of results that are less than the LOD. Specifically, when the sample LOD is 0.013 µg, the concentration LOD is 0.018

[43] For example, consider a nondetectable beryllium sample result obtained over a 360-minute period at an air flow rate of 2.0 liters per minute (lpm) and analyzed using a method with a 0.013 µg LOD. The laboratory will report the result as ND (i.e., below the LOD). OSHA would assign to that sample result the unmodified value of the concentration LOD (in this case 0.018 µg/m^3) (see Table IV-2). In contrast, if the investigator used another common LOD-handling method (assigning a value of one-half of the concentration LOD), that investigator would assign a value of 0.009 µg/m^3 to this particular sample result. Both LOD values are well below 0.2 µg/m^3, so in these examples the value assigned to the 360-minute sample would not affect the distribution of the results in the exposure profile and would be unlikely to affect the median value.

μg/m^3 or less for sample results included in the exposure profiles that were collected using the sampling pump air flow rate of 2.0 lpm. Even when samples are obtained at a lower sampling rate (e.g., 1.0 lpm), the LOD will be somewhat higher (0.036 μg/ m^3) but still below 0.1 μg/ m^3 (and therefore in the lowest range of the exposure profile).

Two data sources, Brush Wellman and the U.S. Navy, adjusted all their nondetectable results using other approaches currently practiced for dealing with such values (Hornung and Reed, 1990). For sample results below the LOD, Brush Wellman uses a sample mass one-half the LOD to calculate the nondetectable sample concentration. The U.S. Navy adjusts results that are below the analytical LOD by dividing by the square root of 2 prior to calculating the 8-hour time-weighted average (TWA) (OSHA-H005C-2006-0870-0145). NIOSH tested a variety of methods for handling the LOD during different studies. For some exposure assessments, NIOSH investigators adjusted results below the LOD in the same manner as the Navy and used the LOD divided by the square root of 2 (LOD/√2) to calculate the LOD concentration (e.g., see NIOSH EPHB 263-13a). In other cases, NIOSH investigators treated nondetectable values using the LOD/2 approximation method, as noted for Brush Wellman (e.g., see NIOSH HETA 83-162-1746). In many cases, the nondetectable sample results, once adjusted, no longer carry the "less than" qualifier in the source document. The Navy and NIOSH data do indicate which sample results are below the analytical LOD; however, this information was not available for the PBZ sampling results for Brush Wellman's operations.

Whenever nondetectable results were adjusted by the data source (e.g., Brush Wellman, NIOSH), ERG analyzed the results as reported by the data sources (e.g., if NIOSH indicated that a concentration was less than the LOD and reported a value of LOD/√2, then ERG used the adjusted value as it was reported by NIOSH).

METHODS TO ASSESS TECHNOLOGICAL FEASIBILITY

Feasibility

OSHA based this analysis on published literature; documents from sources such as NIOSH and other government agencies; trade and industry organizations; IMIS data for beryllium from 1978 through mid-2008; information from industry representatives on typical workplace processes, job categories, available controls, and exposure data; and site visits conducted by ERG.

OSHA evaluated the IMIS data to identify industries in which beryllium had frequently been sampled during OSHA inspections, and in which analytical results frequently showed detectable airborne beryllium in the workplace. Based on these results and information from the available literature, OSHA developed a preliminary list of industries to be included in the technological feasibility analysis. The list was adjusted as information warranted, and a list of affected job categories with notable exposure to beryllium was developed for each industry.

Beryllium exposure data for each job category in each industry were identified in the retrieved literature and other information sources.[44] These results formed the basis for the initial exposure

[44] An underlying assumption is that available data represent exposures of workers across the nation, regardless of whether results come from a few facilities or facilities that were sampled multiple times (e.g., before and after

profiles, which were presented along with process descriptions and methods of exposure control in the contractor report, available in the beryllium docket as OSHA-H005C-2006-0870-0340 under the title *Technological Feasibility Materials*.

For this technological feasibility analysis, OSHA relied on the contractor report (ERG, 2005) and included the same industries and job categories addressed in those documents, with some modifications. OSHA also received more recent materials through June 2012. Where additional information was available, OSHA incorporated it into the current analysis, so that all the current data are reflected in Chapter IV of this PEA. Industries included in this analysis are those identified as having the potential for worker beryllium exposure above 0.1 $\mu g/m^3$.

OSHA recognizes that the available data unequally represent facilities at which more samples were collected, and it seeks additional information to further define the distribution of worker exposure in these industries.

Sector Analysis

The technological feasibility analyses are presented by application groups that correspond to specific industrial sectors or processes as follows:

- Section 3—Beryllium Production
- Section 4—Beryllium Oxide Ceramics and Composites
- Section 5—Nonferrous Foundries
- Section 6—Secondary Smelting, Refining, and Alloying, Including Handling of Scrap and Recycled Materials
- Section 7—Precision Turned Products
- Section 8—Copper Rolling, Drawing, and Extruding
- Section 9—Fabrication of Beryllium Alloy Products
- Section 10—Welding
- Section 11—Dental Laboratories

Additionally, OSHA collected information on three other industries, Primary Aluminum Production, Abrasive Blasting, and Coal-Fired Electric Power Generation. The Agency is considering the inclusion of these industries in the scope of the rule as more information is obtained, and the best available information regarding work practices, exposures and control methods are presented as regulatory alternatives in Appendices A through C of Chapter IV of the PEA.

modifications). Furthermore, results from before facility upgrades represent worker exposure levels under similar conditions at facilities that have not yet been upgraded to that extent.

Within each application group, data are further divided into general job categories representing groups of workers with common trends in materials, work processes, equipment, and available exposure control methods. OSHA notes that these job categories are intended to represent job functions; actual job titles and responsibilities might differ depending on the facility. OSHA recognizes that many other job categories exist in these industries, but those job categories are not associated with substantial direct beryllium exposure and are not included in the analyses.

OSHA seeks additional information that will help identify other job categories that should be addressed in the final rule.

Data Handling

All sample results in the exposure profiles are 8-hour TWA PBZ samples, each collected over a period of at least 360 minutes (defined for this analysis as "full-shift").[45] To determine an 8-hour TWA, the exposure level for the period sampled is assumed to have continued over any unsampled portion of the shift. OSHA has preliminarily determined that this sample criterion is valid because workers in general industry are likely to work at the same general task or same repeating set of tasks over most of their shift; thus, unsampled periods generally are likely to be similar to the sampled periods.

By setting a minimum sampling period criterion of 6 hours, OSHA ensured that every sample included in the analysis encompasses at least three-quarters of a typical 8-hour shift and probably captures most activities at which the worker spends a substantial amount of time (NIOSH-77-173, 1977). If activities differ during the initial and final portions of the shift, the activities are more likely to involve processes required for initial setup and shutdown, which generally contribute less to workers' beryllium exposure. OSHA believes the 6-hour (360-minute) minimum sampling requirement limits the extent of uncertainty about workers' true exposure, as no more than 25 percent of an 8-hour shift would be unsampled.

The minimum sampling period also eliminates the ambiguity associated with the LOD for low-air-volume samples. As noted previously in the discussion of LODs, using a common sampling method for beryllium (i.e., sample LOD of 0.013 μg per sample and air sample collected at the recommended rate of 2.0 lpm), an LOD less than 0.018 $\mu g/m^3$ will always be achieved if the sample was obtained for at least 360 minutes. This permits results that are reported in the original data source as below the LOD to be included without contributing substantial uncertainty regarding their relationship to the proposed PEL.

At beryllium concentrations found in many industrial work sites, the smaller air volume obtained using typical methods during a shorter sample period did not collect sufficient beryllium to result in a reading above the LOD. At the same time, the LODs for these shorter duration samples would be higher than they are for 6-hour samples. Using an extreme example, a result of nondetectable for a 15-minute sample (obtained at 2.0 lpm) would have an LOD of 0.43 $\mu g/m^3$.

[45] An exception is made in the case of the secondary smelting, refining, and alloying application group (which includes handling of scrap and recycled material). Due to an extreme paucity of full-shift exposure data for the furnace operator job category, the exposure profile includes three furnace operator samples of 265 to 314 minutes duration. These sample results are identified in the discussion of that industry.

The assigned LOD-based value for that sample would indicate only that the true value was somewhere between 0 and 0.43 μg/m^3, a range too large to be meaningful to OSHA's analysis concerning a proposed PEL of 0.2 μg/m^3. By relying on 6-hour samples for the exposure profile, OSHA eliminates this ambiguity. OSHA notes that the same 15-minute sample is, however, appropriate for evaluating short-term exposures, and that these provide meaningful information for an analysis of a proposed STEL of 2 μg/m^3.

Particulate Properties and Use in Evaluating Control Options

Ventilation Controls for Airborne Beryllium

Beryllium is a particularly light metal with unique toxicity, strength, and insulating properties. For the purposes of dust management and exposure control, however, airborne beryllium (and its alloys and oxides) behave predictably, like other airborne particles generated and released in a similar manner. Once airborne, the *aerodynamic* particle size (rather than the particle diameter or its substance) is the fundamental factor that most influences the behavior and choice of control options for particles, including beryllium.

The World Health Organization published an overview of aerodynamic particle size as a fundamental concept in controlling airborne particles of all types, ranging from metals (including beryllium) to minerals (e.g., crystalline silica), bulk chemicals, and biological particles (WHO, 1999):

> *…In referring to particle size of airborne dust, the term "particle diameter" alone is an over simplification, since the geometric size of a particle does not fully explain how it behaves in its airborne state. Therefore, the most appropriate measure of particle size, for most occupational hygiene situations, is particle aerodynamic diameter, defined as "the diameter of a hypothetical sphere of density 1 g/cm^3 [gram per centimeter] having the same terminal settling velocity in calm air as the particle in question, regardless of its geometric size, shape and true density." The aerodynamic diameter expressed in this way is appropriate because it relates closely to the ability of the particle to penetrate and deposit at different sites of the respiratory tract, as well as to particle transport in aerosol sampling and filtration devices. There are other definitions of particle size, relating, for example, to the behaviour of particles as they move by diffusion or under the influence of electrical forces. But these are generally of secondary importance as far as airborne dust in the workplace is concerned.*
>
> *In aerosol science, it is generally accepted that particles with aerodynamic diameter >50 µm do not usually remain airborne very long: they have a terminal velocity >7cm/sec* [greater than 7 centimeters per second]. *However, depending on the conditions, particles even >100 µm may become (but hardly remain) airborne. Furthermore, dust particles are frequently found with dimensions considerably <1 µm* [less than 1 micron] *and, for these, settling due to gravity is negligible for all practical purposes. The terminal velocity of a 1-µm particle is about 0.03 mm/sec* [millimeters per second], *so movement with the air is more important than sedimentation through it. Therefore, summarizing in the present context, it is considered that dusts are solid particles, ranging in size from below*

1 µm up to at least 100 µm, which may be or become airborne, depending on their origin, physical characteristics and ambient conditions.

Examples of the types of dust found in the work environment include:

- ***Mineral dusts,** such as those containing free crystalline silica (e.g., as quartz), coal and cement dusts;*
- ***metallic dusts,** such as lead, cadmium, nickel, and beryllium dusts;*
- ***other chemical dusts,** e.g., many bulk chemicals and pesticides;*
- ***organic and vegetable dusts**, such as flour, wood, cotton and tea dusts, pollens;*
- ***biohazards**, such as viable particles, moulds and spores.*

Dusts are generated not only by work processes, but may also occur naturally, e.g., pollens, volcanic ashes, and sandstorms. …The aerodynamic behavior of airborne particles is very important in all areas of measurement and control of dust exposure (WHO, 1999).

In summary, beryllium particles, like other particles, settle out of air at rates related to their aerodynamic diameter. Particles in the range of 100 µm can become airborne when high energy is exerted on them (e.g., when they are "launched" into the air by the energy of a grinding wheel or a broom), but they fall to the ground immediately. Particles between 50 and 100 µm aerodynamic diameter settle more slowly, but still within a few seconds in stationary air. In contrast, smaller particles can stay airborne for hours or days. The behavior of all particles in air is more closely related to the particle aerodynamic diameter than to its other properties. The smaller the particles' aerodynamic diameter, the more easily they are influenced by air motion (i.e., a lower air velocity is required to capture them and carry them away).[46]

Beryllium is a light metal; it has a lower density (mass per volume) than most other metals. A beryllium particle will have a smaller effective aerodynamic diameter compared to otherwise identical particles of a higher density material (e.g., lead, quartz). This means that the lower density beryllium particle will behave consistently with its smaller aerodynamic diameter; in air it will act like a smaller particle than the identical lead or quartz particles.[47] This means that larger beryllium particles may respond more like the smaller respirable dust particles than would identical particles of more dense materials, such as lead. The relationship between density and aerodynamic diameter is demonstrated in Table IV-3.

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[46] For readers who would like to pursue a more in-depth discussion, the WHO (1999) document lists several sources of detailed information on particle aerodynamic diameter, including the relevant physics, in specialized aerosol science literature.

[47] This relationship holds for particles greater than 0.5 µm (USEPA, 2010). The relationship is represented by the equation: $\mathrm{Dpa} = \mathrm{Dps}\sqrt{\mathrm{Pp}}$

Where: Dpa =Aerodynamic particle diameter (µm); Dps= Stokes particle diameter (µm); Pp = Particle density (gm/cm^3).

Table IV-3—Aerodynamic Diameters of Particles With Different Densities

Particle Stokes Diameter *	Relative Density	Density of the Particle**	Aerodynamic Diameter
 *2 µm*	*Low-density particle*	*1 g/cm^3*	*2.0 µm*
 *2 µm*	*Medium-density particle*	*2 g/cm^3*	*2.8 µm*
 *2 µm*	*High-density particle*	*3 g/cm^3*	*3.5 µm*

* *Stokes diameter takes into consideration the drag force of the particle's surface (rough or smooth) and its shape. In this example, the Stokes diameter is the same, 2 µm, for all three particles; only the density changes.*

** *For comparison, the density of beryllium metal is 1.85 g/cm^3 and beryllium oxide is 3.0 g/cm^3 (see Table IV-4).*

Source: USEPA, 2010.

Table IV-4 compares the relative densities of beryllium metal, beryllium oxide, and several other substances. Note that the difference in density between beryllium metal and beryllium oxide is quite modest, and that a mineral (quartz) and another metal (aluminum) fall between the two, suggesting that information on the behavior of beryllium metal and oxide particles could be anticipated by the behavior of quartz and aluminum (in ventilation systems, for example). Similarly, copper and iron are suitable examples for copper-beryllium alloy particle control measures.[48] Even lead is only slightly higher.

Table IV-4—Densities of Materials

Material	Density	Reference
Water	*1.0 g/cm^3*	*NIST[a], no date*
Beryllium metal, pure	**1.8 g/cm^3**	*NIST, no date*
Quartz, pure (crystalline silica)	*2.7 g/cm^3*	*WI Geological Survey, 2010*
Aluminum, pure	*2.7 g/cm^3*	*NIST, no date*
Beryllium oxide	**3.0 g/cm^3**	*Stefaniak et al., 2007; Mishima et al., 2006*
Chromium (IV) compounds[b]	*2.52-6.12 g/cm^3*	*NIEHS[b], 2011*
Iron, pure	*7.9 g/cm^3*	*NIST, no date*
Copper-beryllium alloy *(Example: 1.9% beryllium; 0.4% nickel + cobalt)*	**8.3 g/cm^3**	*Alloy Wire, no date*
Copper, pure	*9.0 g/cm^3*	*NIST, no date*
Lead, pure	*10.1 g/cm^3*	*NIST, no date*

[a] *National Institute of Standards and Technology*

[b] *National Institute of Environmental Health Sciences. The range of densities for chromium (IV) compounds represents those most commonly found in industry (i.e., calcium chromate, chromium trioxide, lead chromate, potassium chromate and dichromate, sodium chromate, strontium chromate, and zinc chromate).*

In reality, many characteristics influence a particle's aerodynamic diameter and its behavior in a given environment (identical particles only exist in theory); however, density remains one of the

[48] The density of an alloy is most influenced by the predominant metals. A copper alloy containing 5 percent beryllium and 95 percent copper has a density similar to that of pure copper (see Table IV-4).

most important factors.[49] Other important factors—particle size and shape—are results of the action that generated the particle.

The resulting particle size and shape are influenced by both the tool and the amount of energy the tool exerts on the material. Low-speed machining actions often produce material turnings (i.e., shavings) that are too large to remain airborne, while high-speed machining releases very fine particles that do remain airborne. Grinding and crushing (e.g., pulverizing) actions produce particles in a range of sizes, depending on the force, speed, and aggressiveness of the tool action.[50] The finest particles emitted from crushing and grinding equipment may stay airborne. In contrast, the larger particles and chips from these processes, which normally would fall to the ground, can be ejected at high velocity; therefore, the equipment requires special ventilation hoods to capture these larger particles as they are ejected, to avoid dispersing them through the work area. Where metals are heated (e.g., welding and furnace operations), the condensed vapors form small particles that are carried by the rising current of hot air.

Various organizations and investigators group similar particles according to their shape and source.[51] For the purpose of designing suitable ventilation controls, ACGIH places great importance on the nature (in this case related to aerodynamic diameter) of the air contaminant and the action that generates it (ACGIH, 2010). Groupings listed by ACGIH are presented here with examples relevant to beryllium industries:

- **Fumes and metal smoke:** Condensed particles from welding and foundry activities.
- **Very fine light dusts:** Fine particles from beryllium metal and oxide production.
- **Average industrial dust:** Grinding dust, dust from pulverizing and abrasive cutting, general foundry dusts.
- **Heavy dusts:** Metal turnings, foundry tumbling barrels and shakeout, sandblast dust, dust of high-density metals (e.g., lead, copper alloys).
- **Heavy or moist dusts:** Metal dusts with small chips, moist cement (ceramic) dust.

Considering particle sizes and the methods that generate the particles provides OSHA great confidence in using studies of control methods involving other materials and other industries to estimate the effectiveness of control methods for beryllium particles. Several studies have

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49 Numerically, the particle density affects the aerodynamic diameter as it is directly proportional to the aerodynamic diameter by its square root, and as it is inversely proportional to the stokes diameter. The relationship between stokes diameter and particle density is explained by the following equation (Hinds, 1999): $d_s = \sqrt{\frac{V_{ts} * 18\eta}{\rho_b * g}}$, where ds is the stokes diameter, Vts is the terminal settling velocity of the particle, η is the coefficient of dynamic viscosity, ρb is the material density, and g is the acceleration due to gravity.

50 In this context an "aggressive" tool action is one that removes a large amount of material rapidly, as a function of the tool shape (a course grinding blade will remove material more quickly than a fine grinding blade).

51 Mishima (2006) in a report analyzing the potential for airborne beryllium release and combustion (of beryllium metal, beryllium oxide, and alloys) during Department of Energy facility accidents, reviewed information on the following particle shapes: powder, chips, turnings, swarfs (i.e., metallic particles and abrasive fragments removed by a cutting or grinding tool), and "large coherent items" (i.e., rods and blocks of a size that would not become airborne).

evaluated the size of beryllium particles generated during workplace activities and found that a notable portion of the sample is in the form of respirable particles (particles of aerodynamic diameter 2 μm to 10 μm, centered at 3.5 μm).[52] Examples include the following studies in a beryllium production facility, a copper-beryllium foundry and machining area, machine shops, and an electronics recycling plant.

Kent et al. (2001) reported on mass mean aerodynamic diameter (MMAD) for particles in 55 air samples collected in five different furnace areas at a beryllium manufacturing facility. Overall, three-quarters of the beryllium mass in the samples was associated with particles of MMAD 18 μm or less. Particles of MMAD 10 μm or less (respirable size) contributed more than half (57 percent) of the total beryllium in these samples.[53]

NIOSH reported similar results in the furnace area and machine shop (near cutting equipment) at a copper-beryllium foundry that manufactures products (0.45 to 2.15 percent beryllium) for the metal die casting industry (NIOSH EPHB 326-11a, 2008).[54] The cutting equipment was used with coolants. In addition to machining, the shop was used for grinding, polishing, and buffing, with most of the equipment fitted with local exhaust ventilation (e.g., canopy hood, side draft, slot). The six samples indicated that 59 to 77 percent of the sample mass concentration was associated with particles less than 18 μm (NIOSH EPHB 326-11a, 2008).[55]

Another study of aerosols generated during beryllium machining under typical working conditions also showed that more than 50 percent of the beryllium machining particles in the workers' breathing zones were less than 10 μm aerodynamic diameter (Martyny et al., 2000).[56]

[52] Interest in particle surface area and particle number has led to a number of studies characterizing very small particles, often including those less than 0.5 μm. These particles contribute little to the mass concentration of airborne beryllium, however, so they are not reviewed as part of this analysis. These very small particles are influenced by any air motion and are easily drawn into industrial ventilation systems. Dust collection efficiency for small particles is the limiting factor in capturing small particles; however, effective filters are readily available. For example, high-efficiency particulate air (HEPA) filters are 99.97 percent efficient for particles 0.3 μm, which have historically been more difficult to capture than larger particles that are readily captured using conventional filters. (ACGIH, 2010).

[53] In this study, the furnaces were engaged in beryllium metal production, beryllium oxide production, and copper-beryllium alloy melting and casting. The three furnace types included reducing furnaces, induction furnaces, and arc furnaces. Kent et al. (2001) used a micro-orifice uniform deposit impactor (MOUDI) within 3 to 5 feet of worker positions to separate particles into specific size ranges as the air was sampled. Total beryllium mass concentration among the 55 samples ranged from 0.0547 $\mu g/m^3$ to 7.65 $\mu g/m^3$. Comparison sampling with an Anderson impactor (a different model of particle-separating equipment, used in this case to evaluate a smaller range of particle sizes) did not correlate well to the MOUDI results (Kent et al., 2001).

[54] NIOSH used a MOUDI for this evaluation of the mass distribution of airborne particles at locations near furnaces and cutting equipment where high particle concentrations were expected. NIOSH reported results for the six samples, which indicate that 59 to 77 percent of the sample mass concentration was associated with particles less than 18 μm (NIOSH EPHB 326-11a, 2008). NIOSH also used another particle-sampling method to evaluate smaller particles, less than 2.5 μm.

[55] At this foundry, 16 of the 24 personal samples for total beryllium exceeded the NIOSH Recommended Exposure Limit (REL) (0.5 $\mu g/m^3$) and seven exceeded the current OSHA PEL (2 $\mu g/m^3$). Overall, the results ranged from 0.06 $\mu g/m^3$ to 5.52 $\mu g/m^3$.

[56] To separate particles into size ranges, Martyny et al. (2000) used Marple personal cascade impactors and obtained paired stationary samples using 8-stage Lovelace Multijet cascade impactors. The larger turnings are too large to become airborne, Martyny et al. show that numerous fine particles are also formed.

NIOSH also evaluated respirable and total beryllium mass concentrations in workers' breathing zones at an electronics recycling operation (receiving, sorting, disassembling, glass breaking, packaging, and shipping), but airborne beryllium was not detected at levels above the LOD of the analytical method (less than 0.03 μg/m^3 for both respirable and total particulate samples) (NIOSH EPHB 326-17a, 2009).[57, 58]

The information presented on the previous pages indicates that ventilation system tests with non-beryllium materials can offer information relevant to beryllium control (aerodynamic diameter is more important than the material itself). Additionally, matching similar actions and intensities (as suggested by ACGIH and WHO) further enhances the relevance of control technologies from one industry or material to another. Furthermore, there is substantial evidence from recent studies that current worker exposures are predominantly to respirable size particles (more than half of the mass concentration is due to particles less than 10 μm in diameter). This finding indicates that control technologies proven for respirable dust are relevant to beryllium exposure reduction and likely will reduce exposure to airborne beryllium particles to a similar extent as other dusts.

Beryllium is not always a dry dust. Beryllium particles can be contaminants of metal working fluids, used as coolant and lubricant during metal machining activities, and aerosols emitted from chemical processing activities that generate bubbles. During metalworking, the machine tool releases beryllium particles, which are captured by the metalworking fluid; the small particles remain suspended in the metalworking fluid solution and are typically recirculated with the fluid applied to the machine tool or blade. Over time, the amount of metal particle contaminants builds up in the fluid. This contaminated fluid can become airborne as a fine mist when aerosols are generated by the action of the machine tool it cools (typically during high speed, high energy activities such as grinding and sawing). NIOSH defines metalworking aerosol as the "mist and all contaminants in the mist generated during grinding and machining operations involving products from metal and metal substitutes" (NIOSH Metalworking Fluid, 2012). Once airborne these combined fluid/beryllium aerosols behave according to the same principles of aerodynamic diameter as other particles.

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[57] At this electronics recycling facility, dust levels were generally modest. Total particulate concentrations (all components of the airborne dust) at this facility ranged from below the LOD to 1,099 μg/m^3 (well below OSHA's PEL of 15,000 μg/m^3). The 10 total respirable particulate samples had concentrations ranging from 33 to 291 μg/m^3 (again well below OSHA's PEL of 5,000 μg/m^3) (NIOSH EPHB 326-17a, 2009).

[58] Beryllium particle size was also of interest several decades ago; however, at that time, the findings suggested that respirable dust was less prevalent, possibly because current control strategies minimize gross release of quantities of the larger particles. As early as 1971 NIOSH conducted extensive sampling for total and respirable beryllium at a poorly controlled smelting facility where beryllium exposure for most workers was greater than 1 μg/m^3 and exceeded 100 μg/m^3 for several workers (highest result was 2,889 μg/m^3) (NIOSH IWS-37-13). NIOSH deemed the powdering operations "out of control" and recommended immediate corrective action (actions not defined). Mishima et al. (2006) describe a beryllium powder obtained from a manufacturer in which 90 percent of the mass comprised particles between 32 μm and 80 μm, well above respirable size. Therefore, it is not surprising that under the conditions that NIOSH found at the smelter in 1971, the mass concentration of total beryllium greatly exceeded the respirable fraction. At this smelter, total particulate concentration was four to 20 times greater than the corresponding respirable fraction for most of the 119 paired PBZ samples. This is a substantially greater proportion of larger particles in the air samples than has been reported in more recent studies of beryllium workplaces.

When employees machine beryllium-containing metals the metalworking fluid can become contaminated with beryllium particles and is therefore a potential source of beryllium exposure, both as airborne aerosol and surface contamination. Once distributed throughout the work area, the particles can dry and be re-suspended if agitated by nearby activity or a broom. In a study on machine enclosures, Hands et al. (1996) explain that “metalworking fluid mist exposures in machining and grinding operations can be controlled by many means, including limiting fluid pressures and volumes, applying fluid only when the tool interfaces with the workpiece, adding mist suppressants to fluids, and ventilating and enclosing operations.”

A similar situation exists with aerosols ejected into the air when bubbles (from the chemical reaction) burst on the surface of chemical treatment tank liquids. If the liquid is contaminated with beryllium particles (e.g., friable beryllium surface oxides that are released into the fluid) these particles can be emitted as part of the aerosol.[59]

Based on these facts, OSHA preliminarily concludes that the results of ventilation controls tested by evaluating capture of any airborne dust particles, of any type, with similar origin, will be equally applicable to control of beryllium particles. For example, investigators have conducted extensive research on dust controls for respirable crystalline silica. OSHA finds that it is reasonable to consider ventilation control studies for silica grinding (or furnace, machining, or other) operations when evaluating potential controls for similar beryllium grinding (or furnace, machining, or other) operations. This finding is supported by the similarity in the densities of beryllium metal, beryllium oxide, and crystalline silica (see Table IV-4), and the routinely high proportion of respirable particles in airborne beryllium dusts.

Wet Methods for Airborne Beryllium

OSHA finds that there is considerable evidence that water spray droplet size is a primary factor in the efficacy of water (or other fluid) sprays used to control dust. The most effective spray uses a droplet size similar to the particle size that the spray is intended to control (Spray Systems, no date). Therefore, OSHA preliminarily concludes that studies of wet dust control methods applied to airborne dust will be similarly applicable to the beryllium portion of dust. This statement applies regardless of whether the fluid is applied as a spray or as a stream that generates a spray or mist through tool action, as is the case for machine tools (e.g., high-speed grinding and cutting equipment used with cutting oil or water coolant in the precision turned products industry).

Use of Short-Term and Area Sampling Results

The exposure profiles in the portions of this technological feasibility analysis that evaluate 8-hour TWA exposures do not include short-term exposure concentrations, for reasons described above (with the exception of the secondary smelting, refining, and alloying application group, as discussed in an earlier footnote). However, short-term samples can provide important information about the effectiveness of controls. Short-term samples also permit multiple trials of controlled and uncontrolled activities. In studies of this nature, investigators measure intensive

[59] Note that in both cases (metalworking fluids and chemical treatment tanks) only very small fluid aerosols (fine mists) remain airborne. Larger droplets fall to the ground. The emission of contaminated fluid aerosols is a different process than use of wet methods (usually clean water mists) to capture air contaminants that are already airborne (discussed below in the paragraph on Wet Methods For Airborne Beryllium).

periods of an activity (such as machining) without pauses or supplemental activities that can complicate comparisons of airborne dust during controlled and uncontrolled conditions. Results of brief samples, even just a few minutes in duration, can provide useful comparative information. Similarly, area samples obtained near the source of emissions provide information useful for evaluating the effectiveness of exposure controls. OSHA considers these experimental results in the discussion of additional controls for specific groups of workers.

Use of Surrogate Data

In some cases, when exposure information from a specific job category is not available, OSHA has based that portion of the exposure profile on the surrogate data from one or more similar job categories in related industries. The "surrogate" data are selected based on strong similarities between raw materials (e.g., sources of beryllium, percentage of beryllium), equipment, worker activities, and exposure duration in the job categories. Although other factors differentiate the industries, the individual job categories were determined to be sufficiently similar. When used, OSHA has clearly identified the surrogate data and the relationship between the industries or job categories.

Materion Worker Protection Model

A combination of control methods usually offers the most effective option for reducing worker beryllium exposure levels. Materion Corporation has identified a combination of measures that the corporation advocates as reducing airborne exposures to 0.2 $\mu g/m^3$ or less for the vast majority of workers in most work areas most of the time. This multi-faceted beryllium exposure control program is known within the beryllium industry as the Materion Worker Protection Model.

The Materion Worker Protection Model includes:

> *improved workplace orderliness and cleanliness, enhanced dermal protection in the form of polymer gloves and long-sleeve uniforms, dust migration control measures (e.g., tacky mats at entrances/exits and company clothing and boots that do not leave the facility), administrative controls (e.g., routine decontamination procedures in work areas), limiting airborne beryllium concentrations through engineering upgrades, such as enclosure and ventilation of high-risk processes to reduce airborne exposures to predominantly less than 0.2 $\mu g/m^3$, and extensive training and involvement of workers"* (Thomas et al., 2009).

The control measures (i.e., engineering controls, work practices, and housekeeping) must be used together to ensure that exposure levels are reliably maintained below 0.2 $\mu g/m^3$ for the vast majority of workers nearly all the time (Materion Information Meeting, 2012).

Deubner and Kent (2007) and Knudson and Kolanz (2009) present the following basic elements of the comprehensive plan:[60]

- Avoid exceeding an 8-hour TWA exposure level of 0.2 µg/m^3.
- Keep work areas visibly clean and take steps to ensure they stay that way.
- Keep beryllium off the skin by using long sleeves and hand/wrist protection.
- Keep beryllium off clothing by keeping work clothes visibly clean.
- Keep beryllium at the source and in the work process by taking steps to avoid spreading it.
- Keep beryllium in the work area by eliminating causes of migration.
- Keep beryllium on the plant site by improving cleanliness standards.

Prepare beryllium workers for safe work with standard operating procedures and appropriate training. Appendix 1 of the Methodology section includes a summary of Materion Corporation's Interactive Guide to Working Safely with Beryllium and Beryllium-Containing Materials (available at http://www.berylliumsafety.com/).

To achieve the first element (avoid exceeding an 8-hour TWA exposure level of 0.2 µg/m^3), Materion Corporation promotes engineering controls that include partial or full enclosures, minimum prescribed exhaust air flow rate across all openings, and efficient air filtration designed to capture even very small particles. Specifically, the enclosure or booth ventilation should provide 250 feet per minute (fpm) across the opening. It should also be fitted with a HEPA air filter, and personnel need to take special precautions when servicing the enclosure or booth or the blower (including while changing the filter). These precautions minimize the release of beryllium into the workplace, where it can affect the exposure of any workers in the space. However, personnel servicing the enclosure or booth or its air handling equipment require respiratory protection during these tasks. Employers still need to identify repair and maintenance activities that can generate airborne particles so that workers can be protected during those specific activities. Materion Corporation also promotes alarms as an important part of the ventilation system, to indicate when filter performance falls outside an effective range.

In cases where an enclosure or booth designed in this way (i.e., with 250 fpm airflow across openings) does not reliably control exposures to levels of 0.2 µg/m^3 or less, Materion Corporation reports achieving lower exposure levels by increasing the ventilation rate to provide 400 fpm across openings. This strategy has proven successful for a wide range of activities, processes, equipment, and hood designs at Materion Corporation's plants and those of their customers (Materion Information Meeting, 2012).

Employers implementing the Materion Worker Protection Model need to ensure that their ventilation system designers pay attention to the type of operations that will be performed in the

[60] Deubner and Kent (2007) also outline the elements of the plan and provide an overview of how Brush Wellman arrived at the decision adopt an internal occupational exposure limit of 0.2 µg/m^3.

area. The designers must match appropriate ventilation systems to the tasks. Materion Corporation reports success using hybrid ventilation systems (pairing two or more dust capture methods) for dusty tasks or high-energy activities, some of which have historically been difficult to control (e.g., grinding on materials that contain beryllium).

Materion Corporation provides a specific example of equipment used successfully to control worker exposure levels for these dusty or high-energy activities. This effective strategy involves using a combination backdraft/downdraft ventilated workstation with partial enclosures (sides and top). For example, Materion Corporation has evaluated grinding booths of this general back-draft-plus-downdraft design, paired with work practices and careful housekeeping methods. This type of ventilation design, used in conjunction with other components of the Materion Worker Protection Model, has reduced exposure levels for workers performing manual grinding (and related tasks using powered or rotary tools, such as polishing and buffing) to concentrations of 0.2 $\mu g/m^3$ or less as an 8-hour TWA, Materion Corporation's internal occupational exposure limit (Materion Information Meeting, 2012).

Once enclosures and ventilation systems are in place, the subsequent steps listed in the Worker Protection Model are necessary to ensure that:

- Equipment operates properly.
- Rigorous housekeeping is conducted on a frequent, routine schedule.
- Workers have knowledge and understanding that allow them to recognize situations that could result in beryllium release and understand the importance of taking appropriate action.

These steps create an environment where it is easy for workers to notice something amiss and respond effectively.

DISCLAIMER

References to specific commercial products or manufacturers in this technological feasibility analysis are included for informational purposes only and do not constitute endorsements by OSHA of such products or manufacturers.

TECHNOLOGICAL FEASIBILITY ANALYSIS

The remainder of this analysis addresses the technological feasibility of controlling exposures to or below the proposed PEL in general industry.

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SECTION 2—METHODOLOGY, APPENDIX 1—MATERION BERYLLIUM WORKER PROTECTION MODEL

Materion Corporation, the primary beryllium producer in United States, has developed a beryllium worker protection model to prevent chronic beryllium disease (CBD) and other adverse effects associated with the inhalation of beryllium-containing particles (Deubner and Kent, 2007; Knudson and Kolanz, 2009). This producer's experience has shown that worker protection is best provided by a comprehensive exposure control program applied to specific tasks and operations. The worker protection model incorporates eight program elements:

- Keep beryllium-containing particles out of the lungs by adhering to the beryllium producer's recommended 8-hour TWA exposure guideline of 0.2 $\mu g/m^3$ with a very high degree of statistical confidence.

- Keep beryllium work areas visibly clean, well lit, orderly, and free of clutter. Systematic cleaning and maintenance of orderliness will make it easier to determine when work surfaces are not visibly clean and to control worker exposure to hazardous materials.

- Keep beryllium off the skin (whenever beryllium particulate or salt contact is possible) to prevent beryllium-containing particles from entering the skin through cuts, abrasions and rashes. Prevent skin contact with beryllium particulate or salt-contaminated surfaces or with beryllium-containing liquids or dusts (splashing or falling) through the use of appropriate PPE (such as impervious gloves, wrist covers, long-sleeved shirts and pants; and additional protective clothing as necessary when liquids can contact clothes and penetrate through to the skin). Hand and arm contact with the face can be a source of inhalation exposures.

- Keep beryllium off clothing and shoes to prevent the transfer of beryllium between work areas. Prevent clothing contamination by keeping work clothes visibly clean. If work clothes can become visibly dirty, use overgarments to protect work clothes. Beryllium-contaminated clothing can be a source of worker exposure (through redispersion of beryllium-containing particles into the air and from hand to face contact) and a major route for carrying beryllium out of the work area.

- Keep beryllium at the source and in the work process. Prevent the generation or release of airborne particles by not producing beryllium-containing particles in the process or by capturing particles (e.g., through the use of ventilation and enclosures) before they can become airborne.

- Keep beryllium in the work area. Prevent beryllium-containing particles and solutions from migrating to work areas where beryllium work is not performed (e.g., break, office, meeting room, and cafeteria areas) through the use of engineering controls, work practices, administrative actions, and PPE. "Beryllium migration from work areas occurs when beryllium is carried in air and on tools, vehicles, scrap, product, and people" (Deubner and Kent, 2007).

- Keep beryllium on the plant site. Prevent beryllium contaminated people and/or objects from leaving the plant and potentially exposing others in the community. For example, by improving and maintaining cleanliness standards for all products and shipped materials including pallets and trailer vans.
- Keep beryllium workers prepared to work safely. Ensure that appropriate safety training (e.g., awareness level or full competency) is provided by operational management (supervisors) prior to potential exposure to beryllium. Include safety standard operating procedures to ensure tasks are performed safely from both general safety and beryllium safety perspectives. Where full competency is required, include observation of competency.

The program elements are described in greater detail in Materion Corporation's online Interactive Guide to Working Safely with Beryllium and Beryllium-Containing Materials (see http://www.berylliumsafety.com/). Applying the worker protection model can reportedly be as simple as implementing the types of controls typically found in most industrial operations in conjunction with full consideration of all elements of the model.

SECTION 3—BERYLLIUM PRODUCTION

One primary beryllium production facility is currently in operation in the United States, a plant owned and operated by Materion Corporation,[61] located in Elmore, Ohio. The facility is classified in NAICS 331419, Primary Smelting and Refining of Nonferrous Metal. The Elmore plant is a large integrated facility that, in addition to beryllium metal, also produces beryllium alloys and beryllium oxide ceramics that are further processed on site or shipped to other facilities for processing into a variety of products.[62] Thus, some of the production processes at the Elmore plant, such as rolling, drawing, welding, and machining operations, overlap with industry sectors addressed in other sections of Chapter IV (Technological Feasibility) of the Preliminary Economic Analysis (PEA).

NUMBER OF EMPLOYEES

In response to a Request for Information in 2002, Brush Wellman provided a list of job titles for the Elmore facility, based on an average employment of 616 workers (OSHA-H005C-2006-0870-0092). This total includes workers producing beryllium metal, alloys, and beryllium oxide product, as well as administrative, research, and maintenance personnel. Table IV-5 shows the staffing levels at the Elmore plant by job category and work group.

Table IV-5—Employment by Department (1999)—Brush Wellman, Inc., Elmore, Ohio

Job Category	Work Group	Total No. of Workers	
Chemical Operations		*18*	
	Beryllium Sulfate Salt (GC salt and wet screen operators)		*18*
Furnace Operations		*58*	
	Alloy Induction		*30*
	Alloy Arc		*13*
	High Beryllium Vacuum Cast		*3*
	High Beryllium Atomization		*3*
	Beryllium Oxide		*9*
Production Support		*146*	
	Mix Makeup (furnace charge)		*5*
	Scrap Recycling:		
	Inventory Control Center		*2*

[61] Materion Corporation used to be called Brush Wellman. In 2011, however, subsequent to the collection of the information presented in this chapter, the name changed. “Brush Wellman” is used whenever the data being discussed pre-dated the name change.

[62] In all, Materion Corporation operates four manufacturing facilities that handle beryllium, including the Elmore plant; an alloy rolling and drawing mill in Reading, Pennsylvania (discussed in Section 8—Copper Rolling, Drawing, and Extruding); a ceramics facility in Tucson, Arizona (discussed in Section 4—Beryllium Oxide); and a facility producing specialized beryllium products (e.g., X-ray equipment components made from beryllium oxide) in Fremont, California.

Table IV-5—Employment by Department (1999)—Brush Wellman, Inc., Elmore, Ohio

Job Category	Work Group	Total No. of Workers	
	Scrap Reclamation		*4*
	Leaching		*3*
	Resource Recovery		*13*
	Maintenance:		
	Production Equipment		*47*
	Furnaces and Tools		*23*
	Molds and Dies		*7*
	Research and Development		*12*
	QA/QC/Inspection		*30*
Hot Work		*42*	
	Hot Rolling/Extrusion		*16*
	Annealing		*14*
	Welding		*1*
	Pickling		*6*
	Degreasing		*5*
Cold Work		*118*	
	Rolling		*8*
	Straightening		*9*
	Drawing		*6*
	Machining:		
	Billet Preparation		*19*
	Alloys		*33*
	High Beryllium		*43*
Powdering		*4*	
	Operator/Impact Grinding		*1*
	Compact Loading/Sintering		*1*
	Near Net Shape (operator and welder)		*2*
Site Support		*127*	
	Laundry		*11*
	Janitorial		*6*
	Landfill		*2*
	Facility Maintenance		*24*
	Analytical Laboratories		*18*
	Ship/Receive/Material Handling		*19*
	Wastewater Treatment		*7*
	Store (supply) Rooms		*4*
	Security		*7*
	Boiler Operators		*4*

Table IV-5—Employment by Department (1999)—Brush Wellman, Inc., Elmore, Ohio			
Job Category	**Work Group**	**Total No. of Workers**	
	Facility Engineering		*9*
	Cafeteria		*9*
	Decontamination		*7*
Administrative		*103*	
	Operations/Management		*44*
	Human Resources		*3*
	Information Systems		*4*
	Credit Union		*5*
	Environmental Health and Safety		*9*
	Medical		*4*
	Training		*2*
	Production Planning		*19*
	Engineering		*13*
Total		*616*	
Source: OSHA-H005C-2006-0870-0092			

OVERVIEW OF PROCESS

This section covers the production of beryllium metal, beryllium alloys, and beryllium oxide powder. The processing and machining of beryllium oxide ceramic and composite is covered in the subsection titled Beryllium Oxide Ceramics and Composites, and the processing and machining of beryllium and beryllium alloys is covered in the sections on Precision Turned Products and Copper Rolling, Drawing, and Extruding, in Chapter IV of the PEA.

A survey conducted by the National Institute for Occupational Safety and Health (NIOSH) indicate that exposure to beryllium occurs in the following departments on a routine (i.e., daily) basis: Alloy (Alloy R&D), Pebble/Oxide Plant, Powdered Metal Products, and Resource Recovery. Maintenance workers can also be exposed when working in these parts of the plant) (McCawley, 2000). The chemical form of the beryllium varies among those departments. In the Alloy department, the beryllium typically is contained in copper-beryllium (CuBe), nickel-beryllium (NiBe), and aluminum-beryllium (AlBe) alloys. Beryllium oxide (BeO) may be produced intentionally as metallic powder, and can form as a byproduct during processing, such as in alloy "hot work" applications (e.g., melting and casting, hot rolling, annealing and extrusion). In the Pebble/Oxide Plant, the beryllium is most commonly present as beryllium oxide, ammonium beryllium fluoride, beryllium fluoride, and beryllium pebbles (98 percent pure beryllium metal). In the Powdered Metal Products department, the beryllium is in its elemental form, and for activities associated with the Resource Recovery Department, the beryllium can be in any of the forms mentioned above.[63]

Beryllium Metal Production

The production of beryllium metal is a multistep process that begins with wet chemical processing of beryllium hydroxide $Be(OH)_2$ obtained from mining and extraction operations in Utah. The $Be(OH)_2$ is dissolved in ammonium biflouride to form an ammonium beryllium fluoride (ABF) solution. The solution is purified through a series of precipitation and filtration steps to form ABF salts, which are then decomposed to beryllium fluoride (BeF_2) in the fluoride furnace. The beryllium fluoride is reduced in a reduction furnace at approximately 900°C in the presence of magnesium to produce beryllium pebbles. The beryllium pebbles are then separated from the magnesium fluoride in a hammer mill. The result is 98-percent pure beryllium pebbles (National Materials Advisory Board, 1989).

Beryllium pebbles and other high-grade beryllium scrap (e.g., machining chips) are charged into a vacuum-melting furnace. The vacuum-melted beryllium metal is poured into a graphite mold to produce a 400-lb vacuum-cast billet.[64] Vacuum-cast beryllium billets are machined into chips on lathes with multiple machining cutters. The chips are then processed into beryllium metal powder in one of four powder-producing operations: attrition mill, impact grinding mill, ball mill, or atomization.

Beryllium metal powder is consolidated with hot vacuum pressing or near-net-shape (NNS) technologies. In hot vacuum pressing, beryllium powder is loaded into a graphite die; the powder inside the die is subjected to temperatures up to 1,125°C and pressures up to 1,200 psi to produce vacuum hot-pressed billets of varying dimensions. The vacuum hot-pressed billets are machined using typical metal fabrication techniques (e.g., lathe turning, milling, band sawing, surface grinding) in the machine shop.

NNS powder consolidation techniques include hot isostatic pressing and cold isostatic pressing. In hot isostatic pressing, NNS beryllium parts are produced by loading beryllium powder into a welded mild steel container, shaped and sized to account for the shrinkage that occurs after hot isostatic pressing. The container is sealed and vacuum-outgassed to remove residual gas inside the container. The container is loaded into an isostatic press, where it is subjected to high temperatures and pressure to compress the powder into a product of a particular size and shape, which is determined by the container volume. The mild steel container is then removed by chemically dissolving the steel in a nitric acid bath. Cold isostatic pressing is similar to hot isostatic pressing in that beryllium powder is loaded into a die (usually made of rubber), which is

[63] OSHA notes that the departments listed here to not directly correspond with the job categories in Table IV-5. For analytical reasons, OSHA analyzed exposures by job category rather than by department.

[64] A billet refers to the object cast from the melted beryllium. It is traditionally cast into a generic shape convenient for further processing.

then sealed, outgassed, and cold-pressed.[65] The rubber mold is then mechanically removed. The NNS parts are generally sent out for final machining at a precision machine shop.

Beryllium Alloy Production

The Elmore facility produces beryllium alloys in a variety of shapes, including bars, rods, tubes, wires, strips, and plates.

To produce beryllium alloys, beryllium hydroxide is calcined into beryllium oxide powder and mixed with carbon/binders to form pellets that are transferred to a charge bin. This is done through a computer-controlled closed system. The charge bin holds approximately 1 ton of beryllium oxide pellets, copper, and petroleum coke. These materials are used to charge the Whiting Arc Furnace. The output from the Whiting Arc Furnace is a 30-lb copper-beryllium "master alloy" that has a beryllium content of 3.8 percent by weight. This product is then used along with other forms of alloy (e.g., scrap) in casting the larger product billets, which are lower in beryllium content. Dross from this and other operations can be recycled into the furnace to be reclaimed.[66]

Melting and casting of master alloys is performed in the cast shop. The cast shop produces billets of copper-beryllium, nickel-beryllium, and aluminum-beryllium up to 40 feet long. Both old and new cast shops are in operation at the Elmore facility, located separately from each other.[67] The large billets (up to several feet in diameter and 10 to 40 feet long) are cast using a direct chill process. A 1- to 2-feet-deep, open-ended, water-cooled mold is used in the process. Hydraulically controlled, tilting melting furnaces are used to pour the molten metal into a tundish[68] that transfers the molten metal to the water-cooled mold in a vertical water-filled pit. As the metal is poured through the mold, it rapidly solidifies and retains the shape of the mold, forming a billet. Further cooling and solidification of the billet occurs in the pit. Either rectangular or cylindrical billets can be produced, depending on the processing needs. Round billets are processed in an extrusion press to make various objects, such as rods, bars, tubes, and wire products. Rectangular billets are also processed to make strip and plate products and to be sold directly to customers.

The casting operation also includes scrap furnace operations, in which scrap (produced by the operations at Elmore, the distribution centers, and customers) is returned, melted, and reused. Scrap contaminated with rolling or cutting oils is melted in the scrap-melting furnace in the old

[65] Cold isostatic pressing does not require the application of heat external to the heat generated by the pressure of the press.

[66] Dross refers to metal oxides in or on the surface of molten metal. Slag is a nonmetallic covering that forms on the molten metal from impurities contained in the original charge, some ash from the fuel, and silica and clay eroded from the refractory lining. Slag is skimmed off prior to tapping (pouring) the molten metal (NIOSH 85-116F). The two terms are frequently used interchangeably in the literature.

[67] The new cast shop has an improved ventilation design as well as limited access to ensure better control of beryllium dust migration. The new cast shop produces the alloy that will be used for final products by charging the furnace with master alloy, copper rod, and clean scrap. The old cast shop produces ingots from contaminated scrap. These ingots are then used in the new cast shop.

[68] A tundish is a container that is used to transfer molten metal into molds.

cast shop and cast into ingots.[69] Clean scrap can be introduced directly into the furnaces in which beryllium products are made.

Billet Preparation

Billets are reheated after casting through a process similar to tempering. The reheating homogenizes the various materials within the billet. This homogenization can also be done to the material at other stages in the manufacturing process. For example, Materion regularly heats its products after rolling or cutting. Once the billets have been cast and reheated, they can be cut into multiple lengths, sectioned on a saw, turned on a lathe, or conditioned on the scalping mill. For those billets that will become tubing, a deep hole-drilling machine is used to bore holes before the billet is sent to extrusion.

Production of Final Shapes

This section details the hot and cold work operations used to produce rods, bars, tubes, and sheets of alloy strip.

Both hot-worked and cold-worked items are manufactured from the billets. The hot-worked items are either forged or extruded to dimensionally form the product and refine the cast grain structure. Solution annealing, flattening or straightening, age-hardening, cutting to size, surface cleaning, and inspection operations are used. Shapes commonly manufactured include rods, bars, tubes, rings, and some special cross-sectional shapes, all in a wide range of sizes. Note that the exposure profile contains a major job category titled "Hot Work," and it includes activities such as extrusion and hot rolling, annealing, pickling, degreasing, and welding.

The cold-worked products are manufactured when the application requires closer dimensional tolerance, more refined metallurgical properties, more stringent physical or mechanical property ranges, or better surface finish than the less costly hot-worked products. The additional processing can be as simple as adding a pointing and drawing operation but could also include additional annealing and cleaning steps or other metallurgical, dimensional, and quality assurance tests. Note that the exposure profile contains a major job category titled "Cold Work," and it includes activities such as rolling, straightening, drawing, and machining.

Both cold and hot work operations are described below in relation to the final product being manufactured.

Rod, Bar, and Tube Products

Extrusion (Hot Work)

The extrusion press refines the cast structure by pushing a round cast billet through a die, producing a semi-finished hot-worked product. Rods, bars, and tubes of many dimensions can be produced this way. An abrasive cut-off saw is used to cut the product at the exit end of the extrusion press die. Additionally, a hot coiler is attached to the system to produce wire up to 1.25 inches in diameter. Water spray nozzles along the length of the runout and walking beam tables

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[69] Similar to a billet, an ingot is a casting shaped into a generic shape for further processing. Contaminated scrap is melted separately and made into ingots in order the remove impurities created by the contaminants. These ingots are then fed into the melting and casting operations that produce the billets that will be used for the final products.

are used to provide uniform cooling and keep the materials straight. Some products are cut to length on an abrasive cut-off saw at the end of the runout table. The extrusion process is located adjacent to the billet preparation area and not in the rod, bar, and tube mill.

Annealing (Hot Work)
The Sauder furnace complex at the Elmore facility ages and anneals the rod, bar, and tube products. Annealing is a process in which the alloy is heated and then cooled very slowly and uniformly. The time and temperature of the process are set according to the properties desired. Annealing increases ductility and minimizes the possibility of a failure in service by reducing internal strain.

Swager (Cold Work)
Before cold drawing, rods or tubes must be made smaller on one end to be able to feed material through the drawing die to the jaw grips. Additionally, the smaller end must be strengthened to prevent breaking during drawing. A swager is used to cold point all rod and tube products prior to drawing. At the swager, material is fed into four tapered dies that hammer the work piece over a 3-inch length. An 8-inch point length is required before drawing.

Bulk Pickling (Hot Work)
The bulk pickler is used to clean rod, bar, tube, and wire products that either have been cut to length or are in coil form. The operation consists of three steps:

- A sodium hydroxide (NaOH) bath for 30 minutes.
- A nitric acid bath for 5 minutes or less.
- Dipping in stain/oxidation inhibitor (benzotriazole or BTA).

The acid content, bath temperature, copper content, and urea content are computer-controlled to maintain optimal surface cleanliness and minimize fuming.

Drawing (Cold Work)
After annealing, bulk pickling, and pointing, rods and tubes are drawn (pulled) through a die to produce a wide variety of shapes and sizes. The Lombard drawbench utilizes a hydraulic ram to provide the force necessary to achieve the required product reduction. Products finished by this process have very smooth surfaces and are straight within the required tolerance. The product can be further heat treated or subjected to rotary straightening for improved straightness and finish.

Degreasing (Hot Work) and Cutting (Cold Work)
After the drawing process, the Phillips degreaser uses perchloroethylene in liquid and vapor form to remove the drawing lubricant on the products prior to straightening and age hardening. The Marvel band saw is used to cut rods and tubes to specific lengths. The saw gives a square cut for tight tolerances.

Straightening (Cold Work)
The straightening process requires that a material be flexed slightly beyond its elastic limit in both tension and compression. In rotary straightening, two specially contoured rolls inclined at

opposing angles cause the round product to rotate while pressure is applied. In bump straightening, sheet metal is guided on a surface by rollers where pressure is applied to straighten the material.

Wire Rolling (Cold Work)
Wire rolling reduces the cross-sectional area of the feed material to produce wires of specific diameters. Two tandem wire mills are used for the initial cold working process. The strands of grooved rolls are alternately opposed to improve the uniformity of the work. The shaped grooves are progressively reduced in size to provide the desired reduction as the wire passes through the mill. Coiled wire from the tandem mills is supplied at various gauges of 0.125 inches and greater.

Strip Operations
Sheets of alloy strip are produced from castings from the induction furnace and are rolled from billets into single coils on the hot mill. Two hot mills are in operation at the Elmore plant—an old, smaller hot mill and the new, larger hot mill. Smaller coils from the old hot mill are welded together to produce full-length coils weighing approximately 8,000 pounds. The new hot mill produces larger coils, and the intermediate coil-welding step is not required. The coils are then milled, dimensioned, and cut to specification and length. With the exception of hot rolling and slab milling (both described below), these operations are mirrored in the Reading plant. The Reading plant produces multiple dimensions of strip to customer specification, while the Elmore plant primarily produces a limited variety of dimensions and lengths, much of which is shipped to the Reading plant.

Roller Hearth Furnace (Includes Hot Rolling) (Hot Work)
Large coils of alloy are continuously solution-annealed in the roller-hearth furnace to soften them for further cold rolling. The roller-hearth furnace has heating zones in which the strip is heated to recrystallize the microstructure and redissolve the copper-beryllium compounds present after the rolling process. After cold rolling, the strip is annealed again in the furnace.

Slab Milling Machine (Cold Work)
The function of the slab-milling machine is to remove scale, defects, and undesirable metal phases from the surface of the strip of various alloys before further processing. To do this, the strip is fed through the slab-milling machine, where the cutter mills one surface at a time. The depth of the cut is determined by an adjustable pinch roll controlled by the operator.

Light-Gauge Slitter (Cold Work) and Weld Line (Hot Work)
After the material has been processed through the roller-hearth furnace, slab-milled, and cold-rolled on the four-high mill, coils are sent to the light-gauge slitter/weld line for slitting of edges to eliminate edge cracks and provide a uniform width. It is also capable of multiple slit strip widths to increase versatility for meeting customer requirements. A tungsten inert gas (TIG) butt welder is used to connect smaller coils into larger coils to meet customer coil length requirements.

Strand and Light-Gauge Strip Pickle Lines (Hot Work)
The role of the strand pickle line is to chemically remove stains and oxidation formed on the strip during annealing. Sodium hydroxide is used to remove the oils and condition the oxidized

surface for pickling. Nitric acid is then used to remove oxide scale and produce a bright surface. There is also a light-gauge strip pickle line that functions in a similar manner.

Sendzimir Mill (Z-Mill) (Cold Work)
The Z-Mill is a 20-roll cluster, reversing, cold-rolling mill. It is designed for precision rolling to thin gauges, with the strip held taut by the winders.

Light-Gauge Strip Annealing (Hot Work)
The light-gauge strip annealing line performs the same task as other annealers noted above. A protective nitrogen atmosphere is used in the heating zone to reduce oxidation. Quenching is also done with a recirculating protective atmosphere.

Plate Leveling (Cold Work)
The roller levelers are used to flatten alloy plate products. The actual flattening or leveling process is performed by bending the material past its elastic limit while it passes over the roller. The amount of bending can be controlled by adjusting the bottom rolls up or down. During the operation, unleveled plate is fed into the pinch rolls and formed into a uniformly bent shape. While still in the machine, the roll is reversed and final leveling is accomplished. The process can be repeated if necessary.

Plate Sawing (Cold Work)
Plates at intermediate, ready-to-finish, or finished gauges are sawed to size or for metallurgical samples. Side trimming can be performed on pieces up to 12 feet long.

Beryllium Oxide Production

Beryllium oxide is made from the beryllium hydroxide produced at the Delta, Utah, mining facility. Ceramic grade and high-purity beryllium oxide powders are formulated using the following processes:

- **Primary extraction.** In the primary production process, beryllium hydroxide is dissolved in sulfuric acid. This solution is then filtered to remove insoluble oxide and sulfate impurities. The resulting clear filtrate is allowed to evaporate and become concentrated, producing high-purity beryllium sulfate upon cooling.

- **Calcination.** The beryllium sulfate salt is then calcined in a hearth furnace at carefully controlled temperatures between 1,150°C and 1,450°C. The temperatures are selected to induce specific properties of the beryllium oxide powders, as required by individual beryllium oxide ceramic fabricators. Commercial beryllium oxide powder, calcined at 1,150°C, consists of crystallites ranging from about 0.1 micrometer (μm) to 0.2 μm in size. Powder particles are made up of larger clusters or aggregates of the smaller crystallites.

- **Chelating.** Ceramic-grade beryllium oxide is manufactured by adding organic chelating agents to the filtered beryllium sulfate solution and then precipitating out beryllium hydroxide using ammonium hydroxide powder.

- **Gas atomization.** This process converts beryllium oxide powder crystals into smaller, isotropic, spherical beryllium powders used for metal matrix composites.

- **Packaging.** Powdered beryllium oxide is packaged in drums for shipment directly to customers, as well as to Materion Corporation's Tucson plant.

Support Operations

The Elmore plant has its own analytical laboratories for both metallurgical and environmental analyses. Laboratory technicians visit the operations described above. There are also maintenance and janitorial staffs as well as a small laundry staff to care for the company-provided clothes (kept on site) that workers must change into and out of each day. Medical staff is on site and may be out on the plant floor at times.

Engineering and administrative staffs are located in two buildings—the east and west administrative buildings. In the past, both buildings were open to foot traffic from the plant. Currently, only the west administrative building remains open to foot traffic from the plant, and workers in that building must abide by the same clothing protection rules as the plant workers.

BERYLLIUM EXPOSURE PROFILE AND TECHNOLOGICAL FEASIBILITY ANALYSIS

Exposure Profiles

The exposure profiles for the major categories at the Elmore primary production facility represent baseline exposure levels for this industry, developed based on air monitoring results at the facility, which is the only U.S. establishment that produces beryllium metal. Individual full-shift personal breathing zone (PBZ) (lapel-type) sample results were obtained from Brush Wellman (Brush Wellman Elmore, 2004). These data represent baseline exposure monitoring conducted by Brush Wellman in 1999 and are summarized in the OSHA beryllium docket (OSHA-H005C-2006-0870-0092). Samples were analyzed by NIOSH Methods 7102 (Beryllium and compounds, as Be) or 7300 (Elements by ICP), and the analytical limit of detection (LOD) was reported to be 0.1 micrograms (µg) per filter.[70] For sample results less than the LOD, a sample weight of 0.05 µg (one-half the LOD) was used by Brush Wellman to calculate the volume-adjusted nondetectable sample concentrations (Kent, 2005). For this general technological feasibility analysis, OSHA has defined a full-shift sample as one having a duration of at least 360 minutes. All of the samples used in the exposure profile from the 1999 survey have durations of at least 400 minutes, and as such, are considered full-shift samples.

Job titles listed in the Brush Wellman exposure database were reviewed with industry experts to obtain information regarding work tasks, sources of beryllium exposure, existing exposure controls, and potential additional exposure controls. Each job title was broadly categorized into

[70] For further information on LODs, refer to Section 2—Methodology in Chapter IV (Technological Feasibility) of the PEA.

one of eight job categories based on the type of work employees perform. Each job category contains work groups that more specifically identify employee job functions. The eight job categories and work groups utilized in the exposure profile are presented in Table IV-5.

The exposure profiles for job categories involved in primary beryllium production are presented Tables IV-6 and IV-7. Table IV-6 summarizes the 1999 full-shift PBZ (lapel-type) total beryllium sample results for workers at Brush Wellman's Elmore, Ohio, beryllium production facility. The frequency distribution of the air sampling results are presented in Table IV-7 in relation to the permissible exposure limit (PEL) options of 0.1 μg/m^3, 0.2 μg/m^3, 0.5 μg/m^3, and 1.0 μg/m^3.

For individual work groups with median exposures greater than or equal to 0.1 μg/m^3, this technological feasibility analysis provides a brief process overview along with the available information regarding potential sources of exposure and existing and possible additional controls. When the majority of samples indicate that workers in a group already have exposures below 0.1 μg/m^3, the technological feasibility discussion for that group includes the available information regarding existing baseline exposure controls (based on telephone interviews with industry consultants and representatives, as cited the discussion). The discussion is supplemented with information obtained from published documents and observations made during a tour of the Brush Wellman Elmore facility by OSHA and Eastern Research Group staff on August 30–31, 2004.

Table IV-6—Personal Exposure Profile in the Beryllium Production Industry (1999) (NAICCS 331419)[a,b,c]

Job Category and Work Group	No. of Full-Shift PBZ Samples[d]	Range (μg/m^3)	Mean (μg/m^3)	Median (μg/m^3)
CHEMICAL OPERATIONS	*20*	*0.05 to 9.64*	*1.02*	*0.47*
Be Sulfate (GC salt & wet screening operators)[e]	*20*	*0.05 to 9.64*	*1.02*	*0.47*
FURNACE OPERATIONS	*172*	*0.05 to 254.23*	*3.80*	*0.68*
Alloy Induction	*97*	*0.06 to 48.07*	*1.46*	*0.50*
Alloy Arc	*38*	*0.15 to 9.37*	*1.95*	*0.95*
High Beryllium Vacuum Casting	*9*	*0.13 to 4.03*	*1.05*	*0.31*
High Beryllium Atomization	*13*	*0.54 to 254.23*	*31.67*	*5.56*
Beryllium Oxide	*15*	*0.05 to 5.13*	*1.07*	*0.27*
POWDERING	*72*	*0.06 to 11.52*	*0.82*	*0.37*
Operator/Impact Grinding	*26*	*0.08 to 3.33*	*0.79*	*0.59*
Compact Loading/Sintering	*19*	*0.06 to 11.52*	*1.11*	*0.22*
Near Net Shape (operator and welder)	*27*	*0.14 to 5.89*	*0.65*	*0.41*
HOT WORK	*297*	*0.01 to 2.21*	*0.12*	*0.06*
Hot Rolling/Extrusion	*150*	*0.01 to 0.56*	*0.09*	*0.06*
Annealing	*64*	*0.05 to 0.52*	*0.13*	*0.08*
Welding	*15*	*0.15 to 2.21*	*0.52*	*0.33*
Pickling (elevated bath temperatures)	*47*	*0.05 to 0.31*	*0.08*	*0.05*
Degreasing (elevated solvent temperature)	*21*	*0.05 to 0.21*	*0.07*	*0.05*
COLD WORK	*555*	*0.04 to 24.89*	*0.31*	*0.08*
Rolling	*30*	*0.05 to 1.08*	*0.13*	*0.05*
Straightening	*56*	*0.05 to 1.83*	*0.17*	*0.06*

Table IV-6—Personal Exposure Profile in the Beryllium Production Industry (1999) (NAICCS 331419)[a,b,c]				
Job Category and Work Group	**No. of Full-Shift PBZ Samples[d]**	**Range (µg/m³)**	**Mean (µg/m³)**	**Median (µg/m³)**
Drawing	*31*	*0.05 to 0.20*	*0.07*	*0.05*
Machining	*438*	*0.04 to 24.89*	*0.36*	*0.09*
Billet Preparation	*90*	*0.05 to 18.97*	*0.46*	*0.13*
Alloys	*216*	*0.04 to 16.00*	*0.19*	*0.06*
High Beryllium	*132*	*0.05 to 24.89*	*0.56*	*0.17*
PRODUCTION SUPPORT	*861*	*0.02 to 22.71*	*0.51*	*0.08*
Mix Makeup (furnace charge material)	*51*	*0.05 to 4.20*	*0.46*	*0.24*
Scrap Recycling	*111*	*0.05 to 16.38*	*1.08*	*0.31*
Inventory Control Center	*16*	*0.08 to 2.66*	*0.36*	*0.17*
Scrap Reclamation	*26*	*0.05 to 8.89*	*1.22*	*0.43*
Leaching	*6*	*0.05 to 16.38*	*3.39*	*0.44*
Resource Recovery	*63*	*0.05 to 6.75*	*0.98*	*0.30*
Maintenance	*345*	*0.02 to 22.71*	*0.73*	*0.12*
Production Equipment	*232*	*0.05 to 22.71*	*0.61*	*0.11*
Furnaces and Tools	*58*	*0.05 to 14.62*	*1.73*	*0.53*
Molds and Dies	*55*	*0.02 to 2.98*	*0.19*	*0.05*
Research and Development	*119*	*0.05 to 2.01*	*0.11*	*0.05*
QA/QC/Inspection	*235*	*0.05 to 13.72*	*0.14*	*0.05*
SITE SUPPORT	*879*	*0.05 to 4.22*	*0.11*	*0.05*
Laundry (work clothing and respirators)	*48*	*0.05 to 0.49*	*0.07*	*0.05*
Janitorial	*65*	*0.05 to 0.65*	*0.09*	*0.07*
Landfill	*30*	*0.05 to 0.11*	*0.05*	*0.05*
Facility Maintenance	*130*	*0.05 to 1.23*	*0.11*	*0.07*
Analytical Laboratories	*167*	*0.05 to 1.52*	*0.08*	*0.05*
Shipping/Receiving/Material Handling	*132*	*0.05 to 0.19*	*0.06*	*0.05*
Wastewater Treatment	*46*	*0.05 to 0.99*	*0.17*	*0.09*
Store (supply) Rooms	*32*	*0.05 to 0.15*	*0.06*	*0.05*
Security	*31*	*0.05 to 0.22*	*0.07*	*0.05*
Boiler Operators	*18*	*0.05 to 0.48*	*0.23*	*0.16*
Facility Engineering	*116*	*0.05 to 1.13*	*0.08*	*0.05*
Cafeteria	*16*	*0.05 to 0.17*	*0.07*	*0.06*
Decontamination	*48*	*0.05 to 4.22*	*0.47*	*0.18*
ADMINISTRATIVE	*981*	*0.05 to 4.54*	*0.10*	*0.05*
Operations/Management	*440*	*0.05 to 2.68*	*0.09*	*0.05*
Human Resources	*48*	*0.05 to 0.05*	*0.05*	*0.05*
Information Systems	*45*	*0.05 to 0.10*	*0.05*	*0.05*
Credit Union	*15*	*0.05 to 0.10*	*0.05*	*0.05*
Environmental Health and Safety	*132*	*0.05 to 1.88*	*0.07*	*0.05*
Medical	*52*	*0.05 to 0.17*	*0.06*	*0.05*
Training	*15*	*0.05 to 0.34*	*0.07*	*0.05*
Production Planning	*134*	*0.05 to 4.54*	*0.16*	*0.05*
Engineering	*100*	*0.05 to 1.98*	*0.13*	*0.07*

[a] *The beryllium production exposure profile is a summary of the 1999 full-shift PBZ (lapel-type) total beryllium*

Table IV-6—Personal Exposure Profile in the Beryllium Production Industry (1999) (NAICCS 331419)[a,b,c]

Job Category and Work Group	No. of Full-Shift PBZ Samples[d]	Range (µg/m^3)	Mean (µg/m^3)	Median (µg/m^3)

exposure results for workers at the Brush Wellman, Inc., Elmore, Ohio, plant.

[b] *Full-shift sample results are based on the actual sample duration. Full-shift samples have a sample duration of 360 minutes or longer (in dataset, all samples are at least 400 minutes duration).*

[c] *Samples were analyzed by NIOSH Methods 7102 (Beryllium and compounds, as Be) or 7300 (Elements by ICP), and the analytical LOD was reported to be 0.1 µg per filter. In the dataset received by OSHA, a value had been assigned to each sample result that was below the LOD; a sample weight of 0.05 µg (one-half the analytical LOD) was used to calculate the volume-adjusted nondetectable sample concentrations (i.e., every sample was assigned a value). Samples with results below the LOD were not identified.*

[d] *PBZ means personal breathing zone (lapel-type) samples.*

[e] *Be Sulfate means beryllium sulfate salt production.*

Source: Brush Wellman, 2004

Table IV-7—Distribution of Full-Shift PBZ Exposure Results for Total Beryllium in the Beryllium Production Industry by Job Category (1999) (NAICCS 331419)[a,b,c]

Job Category	Number of Full-Shift PBZ Sample Results in Range (µg/m^3)						Total No. of Samples
	< 0.1	≥ 0.1 to ≤ 0.2	> 0.2 to ≤ 0.5	> 0.5 to ≤ 1.0	> 1.0 to ≤ 2.0	> 2.0	
CHEMICAL OPERATIONS	*1 (5%)*	*2 (10%)*	*10 (50%)*	*4 (20%)*	*2 (10%)*	*1 (5%)*	*20 (100%)*
FURNACE OPERATIONS	*8 (5%)*	*20 (12%)*	*42 (24%)*	*46 (27%)*	*25 (14%)*	*31 (18%)*	*172 (100%)*
POWDERING	*8 (11%)*	*13 (18%)*	*22 (31%)*	*14 (19%)*	*11 (15%)*	*4 (6%)*	*72 (100%)*
HOT WORK	*205 (69%)*	*56 (19%)*	*29 (10%)*	*6 (2%)*	*0 (0%)*	*1 (0%)*	*297 (100%)*
COLD WORK	*335 (61%)*	*107 (19%)*	*74 (13%)*	*13 (2%)*	*17 (3%)*	*9 (2%)*	*555 (100%)*
PRODUCTION SUPPORT	*484 (56%)*	*129 (15%)*	*105 (12%)*	*54 (6%)*	*43 (5%)*	*46 (6%)*	*861 (100%)*
SITE SUPPORT	*711 (81%)*	*100 (11%)*	*45 (5%)*	*15 (2%)*	*6 (1%)*	*2 (0%)*	*879 (100%)*
ADMINISTRATIVE	*833 (85%)*	*90 (9%)*	*39 (4%)*	*10 (1%)*	*6 (0.5%)*	*3 (0.5%)*	*981 (100%)*

[a] *The beryllium production exposure profile is a summary of the 1999 full-shift PBZ (lapel-type) total beryllium exposure results for workers at the Brush Wellman, Inc., Elmore, Ohio, plant.*

[b] *Full-shift sample results are based on the actual sample duration. Full-shift samples have a duration of 360 minutes or longer (in dataset, all samples are at least 400 minutes duration).*

[c] *Samples were analyzed by NIOSH Methods 7102 (Beryllium and compounds, as Be) or 7300 (Elements by ICP), and the analytical LOD was reported to be 0.1 µg per filter. In the dataset received by OSHA, a value had been assigned to each sample result that was below the LOD; a sample weight of 0.05 µg (one-half the analytical LOD) was used to calculate the volume-adjusted nondetectable sample concentrations (i.e., every sample was assigned a value). Samples with results below the LOD were not identified.*

Source: Brush Wellman Elmore, 2004

OSHA also obtained more recent exposure samples taken by NIOSH at the Elmore facility from 2007 through 2008 (NIOSH Elmore database, 2011). This dataset, which was made available to

OSHA by Materion Corporation, contains fewer samples than the 1999 survey.[71] OSHA did not incorporate these samples into the exposure profile due to the limited documentation associated with the data. The lack of detailed information has made it difficult for OSHA to correlate job classifications and identify the exact working conditions associated with the samples. Also, OSHA does not know if this was a targeted sampling effort by NIOSH and Materion to identify the most problematic exposure areas, or if any other sampling strategy was employed. A more recent effort allowed OSHA to better understand the general tasks performed by workers reported by NIOSH at the time of sampling. Also, in a meeting held between OSHA and Materion Corporation in May 2012 at the Elmore facility, the Agency was able to obtain information on the exposure control modifications that Materion Corporation made between 1999 and 2007. OSHA still, however, cannot confirm what the baseline working conditions were at the time of sampling (NIOSH took the samples in 2007 and 2008) (Materion Information Meeting, 2012). Further, the dataset, as provided, did not include information documenting how the data might have been handled before they were made available for this analysis. For a more detailed breakdown of the supporting data by work groups, refer to Beryllium Production Appendix 1.

Overall, OSHA is cautious about drawing any conclusions from the supporting data, as it is not clear what the workers were doing and what controls were in place at the time of sampling. However, the dataset shows that the maximum values are considerably lower than those presented in the exposure profile in Table IV-6 (i.e., the highest exposure levels dropped dramatically between 1999 and 2008). This may be due to the exposure control improvements made by Materion at the Elmore facility between 1999 and 2007 (Materion Information Meeting, 2012). These controls may have helped reduce the variability of exposures. Additionally, three of the six mean values for the major job categories in the 2007–2008 dataset are lower than those in the profile, and two of the six median values are lower than those reported in the profile.

Table IV-8—Supporting Personal Exposure Profile in the Beryllium Production Industry (2007–2008) (NAICCS 331419)[a,b,c,d,e,f]

Job Category and Work Group	No. of Full-Shift PBZ Samples[f]	Range (µg/m^3)	Mean (µg/m^3)	Median (µg/m^3)
CHEMICAL OPERATIONS	*3*	*0.16 to 0.44*	*0.27*	*0.24*
FURNACE OPERATIONS	*24*	*0.01 to 9.24*	*1.19*	*0.62*
PRODUCTION SUPPORT	*42*	*0.01 to 9.24*	*1.42*	*0.40*
COLD WORK	*70*	*0 to 2.91*	*0.30*	*0.09*
HOT WORK	*33*	*0.01 to 1.30*	*0.13*	*0.06*
POWDERING	*22*	*0.11 to 11.57*	*2.60*	*1.50*
SITE SUPPORT	*NO DATA*			
ADMINISTRATIVE	*NO DATA*			

[a] *This supporting profile is a summary of the NIOSH 2007 full-shift PBZ (lapel-type) total beryllium exposure results for workers at the Brush Wellman, Inc., Elmore, Ohio, plant.*

[b] *Full-shift sample results are based on the actual sample duration. These sample durations are of 360 minutes or longer. Exceptions were made for several job categories due to the limited number of samples, and samples greater than 300 minutes were included for Production Support (i.e., ICC, Furnace and Tools, and Mold and Dies workgroups).*

[c] *Samples were analyzed by NIOSH Methods 7102 (Beryllium and compounds, as Be) or 7300 (Elements by ICP),*

[71] These samples are summarized later, in Table IV-8, where they are presented in support of the exposure profile.

Job Category and Work Group	No. of Full-Shift PBZ Samples[f]	Range (μg/m³)	Mean (μg/m³)	Median (μg/m³)

Table IV-8—Supporting Personal Exposure Profile in the Beryllium Production Industry (2007–2008) (NAICCS 331419)[a,b,c,d,e,f]

and the analytical LOD was reported to be 0.1 μg per filter. For sample results below the LOD, a sample weight of 0.05 μg (one-half the analytical LOD) was used to calculate the volume-adjusted nondetectable sample concentrations.

[d] *No sampling data was available for the following job categories and work groups: Administrative, Site Support, Production Support (Research and Development), Cold Work (Straightening, and Drawing), Hot Work (Welding), Furnace Operations (High Beryllium Atomization).*

[e] *Three outliers were excluded: a 321 μg/m³ sample for Production Support (Leaching), a 33 μg/m³ sample for Powdering (Impact Grinding), and a 29 μg/m³ sample for Powdering (Compact Loading).*

[f] *PBZ means personal breathing zone (lapel-type) samples.*

Source: NIOSH Elmore database, 2011.

Technological Feasibility Analysis

This section presents the sampling data and information on exposure control methods that OSHA is relying on to evaluate the feasibility of a proposed PEL of 0.2 μg/m³ in the beryllium production industry. One indication of the feasibility of the proposed rule is the support that it has received from Materion Corporation, which worked closely with the United Steel Workers to produce a draft standard that was subsequently presented to the Agency for consideration (Materion and Steelworkers, 2012). Materion Corporation's adoption of a voluntary exposure limit of 0.2 μg/m³ demonstrates its belief that achieving compliance with the proposed PEL is feasible. Materion Corporation provided a letter to OSHA stating the following:

> *Based on many years' experience in controlling beryllium exposures, its vigorous product stewardship program in affected operations, and the judgment of its professional industrial hygiene staff, Materion Brush believes that the 0.2 μg/m³ PEL for beryllium, based on median exposures, can be achieved in most operations most of the time. Materion Brush does recognize that it is not feasible to reduce exposures to below the PEL in some operations, and in particular, certain beryllium production operations, solely through the use of engineering and work practice controls.* (Materion Corporation, 2012)

OSHA recognizes that the professional staff at Materion Corporation has substantial experience with controlling beryllium exposure. Its staff has a unique perspective and understands how control measures perform in actual workplace conditions. Thus, OSHA recognizes that Materion Corporation's perspective is useful in the technological feasibility analysis that the Agency must conduct to support the proposed rule. However, in the technological feasibility analysis of the proposed rule for beryllium production, OSHA has collected and analyzed all available data to determine the lowest feasible exposure level that can be achieved in most operations most of the time.

Chemical Operations

The first step in beryllium oxide production involves a chemical operation that occurs in the wet plant, where high-purity beryllium sulfate salts are produced by dissolving beryllium hydroxide in sulfuric acid, filtering the solution to remove insoluble materials/impurities, and concentrating the resulting filtrate through evaporation/cooling.

The exposure profile for chemical operation workers (see Tables IV-6 and IV-7) is characterized by a median of 0.47 $\mu g/m^3$, a mean of 1.02 $\mu g/m^3$, and a range from 0.05 $\mu g/m^3$ to 9.64 $\mu g/m^3$. According to Table IV-7, 85 percent of the full-shift PBZ total beryllium sample results for workers classified in the chemical operations job category were greater than 0.2 $\mu g/m^3$.

The wet plant manufacturing process is almost entirely enclosed and isolated from workers (i.e., chemical additions and mixing are automated and enclosed), except at the process entry and exit points. At the process entry point, operators load drums of beryllium hydroxide into a barrel tilter inside an enclosed and ventilated feed station. After the beryllium hydroxide is loaded into the process, the operator cleans/rinses the empty drums with water inside the enclosure before removal. At the process exit point, the material is separated and sized by an automated wet-screening step and then dropped into drums at a filling station equipped with local exhaust ventilation (LEV) (collar-type local exhaust hood on drums during filling). After the drums are filled, the operator installs and seals the drum lids and removes and transfers the drums to the beryllium oxide furnaces using a lift truck equipped with a barrel grabber.

During chemical operations, operator exposure is attributable to: 1) filling/overfilling drums at the process exit and 2) handling, loading, dumping, and washing drums at the material feed station (process entry). Of the two, worker exposures are primarily associated with drum-filling at the process exit (Kent, 2005).

Exposures during drum-filling/overfilling can be reduced by installing a fail-safe drum-handling system to prevent fugitive emissions at connection points during material transfer operations, or by fully enclosing the engineered drum-handling systems. Potential problems with the existing drum-handling system also include material being retained inside valves and tubing, perhaps due to surface roughness, and the inability to see or otherwise determine if all the material has transferred. Ventilated enclosures around existing drum positions would reduce exposures during powder transfer activities. Exposures that result from drum overfilling can be reduced by automatic systems for detecting when a drum is full and automatically stopping the flow of product into the drum overflows (e.g., interlocked product containers with a weigh scale or timer function to prevent drum overflows).

Automated systems for cleaning and disposing of containers have been developed for other industries. For example, dust-free tipping booths have been designed for the pharmaceutical industry for handling highly hazardous powders and granules and reportedly can achieve dust control levels of 0.1 $\mu g/m^3$ or less. Exposures are reduced with automatic container lifting/tipping, high-visibility viewpoints, and glove port access. A modular design allows application customization for handling a wide variety of containers. Empty container disposal and cleaning systems can also be incorporated into the tipping and discharge systems (Hosokawa Micron Group, 2005). While OSHA has no data to show that such equipment can be adapted to the heavy industrial environment at the Elmore plant, the design concepts and approaches may be useful for addressing beryllium salt exposure.

Working in the same building with other high exposure operations (such as the wet plant, pebble plant, oxide furnaces, and resource recovery) also contributes to worker exposures (i.e., co-location exposures). Subsequent to the 1999 baseline exposure monitoring, the pebble plant and oxide furnaces were physically isolated from the rest of the building. Additionally, in 2000, the wet plant and pebble plants were decommissioned. The exposure reduction due to these changes is not known; however, an industry expert estimates that exposures might have been reduced by as much as 50 percent (Kent, 2005). Assuming a 50-percent reduction associated with isolating adjacent processes, a new exposure profile could be calculated with a median exposure of 0.23 $\mu g/m^3$ and 40 percent of exposures at or less than the proposed 0.2 $\mu g/m^3$ PEL. See Beryllium Production Appendix 2 for details.

Feasibility Conclusion for Chemical Operations

Besides removing the chemical operations from their physical proximity to other higher exposure operations, OSHA has limited information on the potential reduction in exposures that might occur as a result of the control methods discussed in this section. Based on the availability of control methods to reduce exposures for each of the major sources of exposure in chemical operations, OSHA preliminarily concludes that exposures at or below the proposed 0.2 $\mu g/m^3$ PEL can be achieved in most chemical operations most of the time. However, the Agency does not have sufficient information to conduct a more quantitative assessment for this operation. As a result, significant uncertainty exists in its preliminary conclusion. OSHA seeks additional information and exposure data through the rulemaking process to further refine this analysis. Further, the Agency has insufficient information to preliminarily conclude that reducing exposures to or below a 0.1 $\mu g/m^3$ alternative PEL is feasible.

Furnace Operations

As shown in Table IV-6, the exposure profile for the furnace operation job category is characterized by a median of 0.68 $\mu g/m^3$, a mean of 3.80 $\mu g/m^3$, and a range from 0.05 $\mu g/m^3$ to 254.23 $\mu g/m^3$. Only 17 percent of the of 172 full-shift PBZ total beryllium sample results reported for workers categorized in furnace operations work groups were at or below 0.2 $\mu g/m^3$. For this analysis, furnace operation workers include those involved with pure beryllium, both high- and low-beryllium-content alloys, and beryllium oxide furnace operations. Furnace operations involving the manufacture of beryllium pebbles from beryllium fluoride (fluoride and reduction furnaces) were in operation during the 1999 baseline exposure monitoring but have since been decommissioned and will not be discussed further.

The median exposures for all of the work groups included in the furnace operation job category exceed 0.2 $\mu g/m^3$. The median levels include:

- 0.27 $\mu g/m^3$ for the beryllium oxide furnaces
- 0.31 $\mu g/m^3$ for high-beryllium vacuum casting
- 0.50 $\mu g/m^3$ for the alloy induction furnaces

- 0.95 μg/m^3 for the alloy arc furnace
- 5.56 μg/m^3 for high-beryllium atomization

Beryllium Production Appendix 2 also shows that all of the furnace operations sub-groups have exposures that exceed the current PEL of 2 μg/m^3. The highest exposures are reported for the alloy induction (48.07 μg/m^3) and high-beryllium atomization (254.23 μg/m^3) furnace operations. Table IV-7 indicates that 5 percent of the full-shift PBZ total beryllium sample results reported for furnace operations are less than 0.1 μg/m^3 and that 83 percent of the sample results are greater than 0.2 μg/m^3.

The size and operation of the furnaces at the Elmore plant vary substantially, and not all of the furnaces have the same sources of exposure. However, six major sources of exposure, if controlled, will reduce exposures in the various furnace operations:

- Sampling furnace charge materials
- Furnace charging
- Dross removal
- Fugitive emissions
- Drum filling
- Inconsistent work practices

The Agency has no data on the relative contribution of these sources to the overall exposure level in furnace operations. Controls for these major sources of exposure, where applicable, are discussed below for each of the types of furnaces at the Elmore facility.

The **alloy arc furnace** operations produce an ingot of 4 percent copper-beryllium master alloy that is subsequently remelted and diluted with other metals to form alloys with a reduced percentage of beryllium. These alloys are cast, hot rolled, and otherwise fabricated (NIOSH IWS-37-11). The process begins when beryllium hydroxide is rotary calcined to create beryllium oxide. Pelletizer feed materials consisting of beryllium oxide, carbon, and ventilation fines (dust collected from ventilation systems) are mixed and pelletized to create beryllium pellets. Copper and beryllium pellets (following sampling) are then charged remotely into the arc furnace. After charging, the furnace is tapped into a transfer ladle and dross is removed using a specialized tool. The metal is allowed to cool and then is degassed with nitrogen lances and poured into an ingot conveyor machine that generates 50-pound ingots. The pelletizing and furnace operations are fully enclosed and ventilated by a 40,000 cfm dust collection system (Kent et al., 2001).

The pelletizer's work tasks include monitoring feed material bin levels, unplugging storage bins, and ensuring proper operation of the calcining and pelletizing systems. Furnace operators weigh the raw copper, transfer 55-gallon drums of beryllium hydroxide into the calciner feed station, wash empty drums in the calciner feed station, charge and tap the furnace, remove and recycle dross, add furnace electrodes, and cast ingots (Corbett, 2006; Kent et al., 2001).

The arc furnace is charged through a computer-controlled closed system and is completely covered with a ventilated enclosure (furnace/room hood). An enclosed and ventilated operator control booth is available, and upon leaving the furnace area, workers must step onto a tack mat and pass through an air-wash chamber. Reportedly, the work tasks associated with the highest potential exposure include preparing the pelletizer feed material and sampling pellets for quality control (Kent et al., 2001). Operator interaction with the furnace is also a possible source of exposure. For example, furnace operators manipulate long tools (approximately 10 to 12 feet long) so that they slide in and partially out of the furnace. Operator movement and positioning with respect to access openings in the furnace hood and contaminated tools might be a factor associated with potential exposure. Additionally, the pelletizing and arc furnace operations are integrated with each other. Beryllium contamination and migration associated with the pelletizing operation might be factors in the exposure of the arc furnace operator and vice versa. Other sources of exposure include electrode replacement (not conducted on a regular basis) and process-related leaks associated with the calciner (e.g., gasket/seal failures). Process equipment leaks and fugitive emissions might account for up to 40 percent of worker exposure (Kent, 2005). Enhancing the preventive maintenance program for the calciner and other process equipment will prevent process-related leaks and resultant exposures. Reducing the number or magnitude of process-related leaks will reduce fugitive emissions and contribute to lower worker exposures.

Exposures may also be reduced by improving engineering controls for pellet and oxide sampling. For example, creating a small opening (or some other type of engineering intervention) for workers to sample pellets, as opposed to opening the pelletizer access door, would reduce contact with large amounts of beryllium-containing material. NIOSH reported on a beryllium alloy plant that uses five automatic Isolok® solid-material samplers in their calcining and reduction operation to sample fresh beryllium oxide from the calciner and storage bins, flue dust, blended material, and finished product (4 percent beryllium-copper alloy) (NIOSH ECTB 113-14a; NIOSH ECTB 113-14b).[72] The pneumatic samplers operate on a positive displacement, closed collection principle. A fixed amount of solid sample is withdrawn with each stroke of the single moving plunger. The extracted sample falls into a closed sample container (plastic collection bottle) that is manually removed on a periodic basis and carried to the laboratory for analysis. A new collection container is manually attached to the sampler for the next sampling cycle. In addition to the automatic samplers, the plant also utilizes a negative pressure isolation/enclosure chamber for the beryllium oxide storage bin and the calciner operation. To evaluate the solid material sampling operations, NIOSH investigators collected area air samples over five shifts at 13 locations in the calcining and reduction area. The average beryllium concentrations ranged from 0.1 $\mu g/m^3$ to 1.06 $\mu g/m^3$. NIOSH investigators concluded that the design of the automatic solid material samplers significantly contributed to lower worker exposures (NIOSH ECTB 113-14a; ECTB 113-14b).

Further reductions in exposure can be achieved by incorporating Isolok™ solid material samplers with pharmaceutical-quality glove boxes to control exposures associated with removing and

[72] The beryllium alloy plant evaluated by NIOSH was the former Cabot Berylco plant in Reading, Pennsylvania. In 1986, Cabot Corporation sold its beryllium alloy business to NGK Insulators Ltd. of Japan. NGK Metals Corporation was established in October of that year. In 2000, NGK Metals Corporation moved its beryllium alloy production operations in Reading to Sweetwater, Tennessee.

capping sample collection containers (Sentry Equipment Corporation, 2005). The suitability of Isolok solid material samplers in conjunction with pharmaceutical-quality glove boxes for beryllium pellets is not known and is likely contingent on the size and flow characteristics of the pellets. The equipment manufacturer indicates that its solid material point samplers (Isolok series and other models) may be used with free-flowing and non-free-flowing bulk solids with particle sizes up to ¾-inch (depending on model); samplers for larger product sizes are available upon request (Sentry Equipment Corporation, 2006). This equipment could potentially be used at the Materion pellet and oxide sampling operations. The samples at the Elmore plant can be both free- and non-free flowing, and the oxide powder and beryllium metal pellets particles are both expected to be less than ¾ of an inch in size.

Improving work practices can minimize potential exposures associated with some of the arc furnace operation, such as rubbing/skimming, tapping, casting, and drum loading. Work practice improvements might include additional employee training, better supervision of existing procedures, and/or the development of new or revised procedures to better control workplace exposures. For example, arc furnace operators could lower their beryllium exposures by waiting until their tools have cooled (and are not fuming) before withdrawing them from the furnace. During casting, workers need to skim dross from the ingot mold and carefully place it in the appropriate collection containers. If workers handle the dross in a careless and sloppy manner, they increase the level of contamination in the work area and their exposure to beryllium. While OSHA has no data to estimate exposure reductions that may be realized by improving these work practices, it seems clear that substantial opportunities exist for reducing exposures through improved work procedures.

The **induction furnace** melting and casting operations produce beryllium alloys containing a lower percentage of beryllium (0.1 to 2 percent). Furnace charges are prepared in mix stations, placed in tubs, and charged in the furnaces through pneumatically controlled carts. After the charge has melted, the furnace walls are rubbed to remove buildup, dross is skimmed off the surface, and the molten metal is degassed and cast into water-cooled molds (Kent et al., 2001).

Two workers operate each furnace: a deck worker and a floor worker. Tasks with potential exposure that are conducted by the deck worker include charging, rubbing, skimming, degassing, and changing full dross barrels. Tasks with potential exposure that are performed by the floor worker include setting up the mold; heating, placing, and cleaning the tundish; and pouring the furnace. The tasks associated with the most significant exposures are reported to be rubbing and skimming, changing full dross barrels, and cleaning the tundish (Kent et al., 2001; Kent, 2005). Dross-related tasks present the greatest exposure potential—accounting for as much as 70 percent of worker exposures—because the dross may contain up to 16 percent beryllium (Kent, 2005). Dross formation can be minimized, but not eliminated, by melting under inert gas (e.g., inert gas blanketing with liquid argon) or by melting in air with a graphite cover or blanket. The percent reduction in dross formation achieved with these techniques is not available. However, inert gas or molten metal blanketing technologies developed by one company reportedly reduce dross/slag formation by up to 50 percent (Air Products, 2005).

At the time the 1999 baseline exposure data were collected, some engineering controls were operational, such as custom-designed LEV hoods and/or enclosures at furnace openings, LEV for tool holders and integrated dross chute/collection systems, and LEV for tundish cleaning activities. Several controls have been added since the 1999 baseline exposure data were collected, including operator control booths equipped with air conditioning and HEPA filters installed near the furnaces (for furnace and casting operators). In addition, workers exiting the melting and casting area in the New Cast Shop must clean their work shoes with a foot cleaner and pass through a HEPA-filtered air shower, both of which serve to limit the spread of beryllium contamination from the furnace operation to other areas of the plant.

Another improvement that will reduce exposures is enhancing and/or installing LEV where appropriate. Potential examples in the Old Cast Shop include the following: 1) modifying the dross chute LEV to accommodate the extremes during filling of the dross barrel; 2) ensuring adequate LEV throughout drossing (reportedly there is a short period of time with inadequate LEV when the filled dross tray is tipped into the dross barrel); and 3) using LEV while mechanically removing (i.e., prying/chipping) solidified dross and metal from the tundish. Improved LEV and work practices together might be expected to reduce exposures by one-half or one-third of previous exposures (Kent, 2005).

Exposures can be further reduced by automating (partially or fully) the drossing operation to eliminate manual skimming, rubbing, and changing of the dross barrel. The feasibility of mechanically removing dross and deposits on furnace walls needs to be investigated. Several induction furnace manufacturers suggest that it is possible to automate dross removal and retrofit existing furnaces (Pillar, 2005; Inductotherm, 2005; ABB, 2005). One furnace manufacturer is creating partially automated dross removal for iron and aluminum furnaces for some of its customers (ABB, 2005). Because beryllium furnaces operate at a higher temperature, this technology is not directly applicable, but it suggests that such technology is promising if it can be adapted to higher operating temperatures.

Removing slag deposits on furnace walls requires applying the correct amount of hand pressure during rubbing and scraping of the furnace lining after casting. If done incorrectly, the refractory lining could be damaged (cracked), possibly resulting in superheated molten metal and/or a furnace explosion during subsequent melting cycles. Furnace manufacturers suggest that employers might be reluctant to allow modifications to furnace designs because of concerns that dross removal features might impact the safety of furnaces. Although automated dross removal (i.e., skimming dross off the surface of molten metal) appears possible, manual rubbing of furnace walls is likely more efficient than mechanical removal and may be preferred due to safety concerns (Pillar, 2005; Inductotherm, 2005; ABB, 2005; AFS, 2005).

Work practices can be enhanced through operator training, work practice modifications, and better supervision. For example:

1. During drossing in the Old Cast Shop, operators should avoid overfilling the dross tray. When the overfilled tray is tipped into the dross barrel, the dross chute LEV can be overwhelmed by excessive fumes, causing increased worker exposure.

2. When removing rub bars from the furnace, operators need to lay the tools on the furnace deck to allow the fuming parts to cool near the furnace LEV before placing the tools in the ventilated holder.

3. After casting, furnace operators need to clean the tundish and furnace pour spout and carefully place "cleanings" in the appropriate collection containers. If operators handle the cleanings in a careless and sloppy manner, they increase the level of contamination in the work area and their exposure to beryllium.

Although beryllium exposure reductions specifically associated with enhanced housekeeping practices in foundries are not available, information on other common foundry dusts demonstrates the point. An OSHA inspection report describes crystalline silica and respirable dust reductions in a ferrous sand casting foundry after the facility vacuumed and washed walls and dust accumulation points in the casting cleaning department (OSHA SEP Inspection Report 303207518). Initially, general area samples indicated that the background respirable silica level in the casting cleaning department was 63 $\mu g/m^3$. After the foundry-wide cleaning, no respirable silica was detected in the casting cleaning department air (estimated as less than 12 $\mu g/m^3$ or an exposure reduction of at least 81 percent). Additionally, total respirable (which contains respirable silica and other particles) dust levels were 60 percent to 80 percent lower than the original level of 1.4 mg/m^3. While it is not known whether a similar exposure reduction could be achieved in the Elmore plant, this example demonstrates the extent to which worker exposures can be influenced by diligent housekeeping efforts.

High-Beryllium Vacuum Casting is a furnace operation designed to produce feedstock (vacuum-cast billets) for powder-making operations (National Materials Advisory Board, 1989). Beryllium feed material (e.g., reclaimed chips and scrap) is vacuum-melted inside a tilt-pour induction furnace and poured into graphite molds to produce round billets that are approximately 3 to 4 feet long. The billets are manually cleaned (pressure washed) and prepared inside an exhaust hood and then transferred to the powder-making operation. Likely sources of exposure include charge makeup (i.e., the job task in which the furnace charge is prepared inside a hood that the operator enters), and cleaning/preparing billets for powder making.

Workers currently enter the charge makeup hood to charge the furnace and, as a result, are exposed to furnace emissions that exist within the hood. Isolating or automating the furnace charge operation such that the operator no longer needs to enter and work inside the hood will reduce worker exposure as well as furnace emissions that also contribute to exposure. More effective LEV that is enhanced through additional exhaust flow and/or better hood design will also contribute to reduced exposures.

Additional opportunities for reducing exposures can be identified by performing a task analysis to determine which tasks associated with billet preparation contribute most to worker exposure and then implementing work practice improvements and LEV changes/modifications to further reduce worker exposures. For example, the effectiveness of the billet preparation hood could be enhanced through additional exhaust flow and/or better hood design. An LEV system meeting design criteria developed by the ACGIH would be expected to achieve a significant reduction in exposure (assuming that the existing billet preparation hood is not effective enough in controlling operator exposure).

High-Beryllium Atomization is a furnace operation where the final product is aluminum-beryllium or beryllium powder. Appropriate feed material (e.g., aluminum, beryllium scrap, virgin materials) is melted, refined, and degassed in a small vacuum induction melting furnace (approximately 8 to 10 inches in diameter and 18 to 24 inches long) (Corbett, 2004). The refined furnace melt is poured through a preheated tundish system into a gas nozzle, where the melt stream is disintegrated by the kinetic energy of a high-pressure gas stream of argon. The metal powder that is produced solidifies in flight in the atomization tower located directly beneath the atomization nozzle. The powder-gas mixture is transported through a conveying tube to a cyclone where the course and fine powder fractions are separated from the atomization gas. The metal powder is collected in sealed intermediate product containers located directly below the cyclones. The powder is screened, blended, and collected in final product containers (Kent, 2005).

Atomization work tasks include manually charging the furnace, cleaning the furnace and tundish after each pour, and cleaning the atomization cyclone at periodic intervals. Atomized powder is screened and collected in product containers that are connected to the process through engineered drum-break valves with LEV (Kent, 2005).

Potential worker exposure is associated with powder leakage when removing filled collection containers at the base of the atomizer. A number of other factors also might affect exposure. The atomizer operator prepares the furnace charge in a separate LEV hood and manually transports it to the furnace chamber. Operators charge the furnace by physically picking up the charge material and manually placing it in the furnace chamber. This operation was done without LEV during the 1999 baseline exposure monitoring. The operator performs rubbing and skimming and also cleans the atomizer cyclone and the ceramic tundish inside the furnace. The tundish is manually cleaned (by chipping with a bar) between pours. It is cleaned in place inside the furnace chamber, which is under negative pressure. The chipped material is removed from the furnace chamber and placed in a ventilated chute, where it drops into a collection drum. Information regarding the potential exposure associated with this task is not available. Reportedly, the LEV associated with the furnace chamber was insufficient for controlling beryllium particulate generated during tasks requiring chamber access (Kent, 2005).

The atomizer cyclone is cleaned infrequently (about once a year) and is also under negative pressure. It is large enough that the operator can physically get his head/torso inside, and it is cleaned by vacuuming and scraping down the sides. Potential exposure is associated with this cleaning task because the operator can place his head inside the cyclone; however, no information is available regarding the exposure associated with this task.

After the 1999 baseline exposure monitoring, several engineering changes were made to the atomization operation. These changes include the following: 1) replacing the baghouse collector with a new, larger capacity HEPA-filtered collector; 2) replacing the ventilation ductwork with correctly sized ductwork for maximum effectiveness; 3) installing a HEPA-filtered makeup air system (laminar flow design); 4) modifying the powder collection system to reduce the total number of times drums are opened or handled per shift (by using larger collection containers); 5) enclosing the furnace/tundish access area with a box-like Plexiglas enclosure (with access door) to better contain beryllium contamination and migration; and 6) installing LEV over/around the furnace charging area.

After the installation of the additional engineering controls, peak exposures were reduced more than 90 percent, from 253 $\mu g/m^3$ to 24 $\mu g/m^3$, and mean exposure was reduced more than 67%, from 31.76 μg/m^3 to 9.82 μg/m^3 (based on 13 samples) (Kent, 2005). Information on how much the median exposure was reduced is not available. However, based on Kent's (2005) estimate that engineering controls reduce exposures by an average of 20 to 50 percent, OSHA estimates that these engineering improvements reduced the median exposure level by 35 percent (average of 20 to 50 percent), from 5.56 μg/m^3 to approximately 3.61 μg/m^3.

Performing a task analysis for the atomization process would identify work methods (e.g., charge makeup, rubbing/skimming, and make/break connections) that contribute most to worker exposure, and work practice improvements. For example, there is a proper sequence of steps (such as avoiding spills by ensuring that the transfer equipment is empty before breaking connections) that must be followed during make-break connections. Workers might not realize that following a certain sequence of steps impacts their beryllium exposure. Work practice improvements might include additional employee training, better supervision of existing procedures, and/or the development of new or revised procedures to better control workplace exposures.

Once engineering and work practice improvements have been implemented, worker exposure associated with opening powder drums and removing filled collection containers at the base of the atomizer should be re-evaluated. Additional controls include installing a fail-safe drum-break system to prevent fugitive emissions from the collection container connection point at the base of the atomizer or fully enclosing the powder drum break (e.g., with a high-containment isolation booth). Potential problems with the existing drum-break system also may include material retained inside valves and tubing—perhaps due to surface roughness—and the inability to see or otherwise determine if all the material transfer has occurred.

The **beryllium oxide furnaces** produce beryllium oxide powders when wet-screened beryllium sulfate salt is calcined in hearth furnaces. The furnaces have top-ventilated, full enclosures at the loading/unloading point that consist of removable metal wall panels. To load the furnaces, operators remove one of the front wall panels from the enclosure, empty drums of wet beryllium sulfate salt into large rectangular refractory containers with a lift truck equipped with a barrel grabber, and then load the refractory containers into the furnace chamber. The refractory containers are thick walled (approximately 1 foot thick), about 10 feet wide and 20 feet long, and are positioned on a roller track that leads into the furnace chamber. The furnace chamber is under negative pressure and is accessed through a set of doors. Although the furnace has LEV, bake-out emissions are released into the workplace and significantly affect worker exposure. After the furnace is loaded and closed, operators reinstall the removable wall panel on the enclosure. The beryllium sulfate salt gets fired in the furnace for several days and is transformed into a fluidized bed of beryllium oxide powder. After a cooling period (approximately one day), the operators again remove a front wall panel from the enclosure and manually vacuum-convey and screen (size) the beryllium oxide powder to collection containers. The beryllium oxide powder inside the vacuum-conveyance system is enclosed and isolated from the operator, and the product collection containers are located in a ventilated hood. Operators use a vacuum wand that is about 10 feet long to vacuum-convey the beryllium oxide powder.

Key sources of potential operator exposure include the following activities: charging the furnace with beryllium sulfate salt, empty drum handling and cleaning, manually vacuum-conveying the beryllium oxide powder to collection containers, filling/overfilling the collection containers, and changing out product drums.

Rough estimates of exposures by activity are provided by Kent (2005). Exposures associated with furnace charging and bake-out emissions are estimated to account for 50 percent of worker exposure (fifteen percent might be attributed to furnace charging and empty drum handling and cleaning, and 35 percent could result from bake-out emissions). Kent estimates that the other 50 percent of worker exposure is due to filling and changing out product collection containers.

As shown in Table IV-6, the median (and baseline) exposure level for beryllium oxide furnace operators is 0.27 $\mu g/m^3$. Additional controls are required to further reduce worker exposures. Based on the available information, these additional controls include:

- Performing a task analysis to identify work methods that contribute most to worker exposure, and implementing work practice improvements to further reduce exposure. For example, during furnace charging and vacuum filling, workers should never have more than one panel removed from the furnace enclosure. Removing more than one panel can adversely affect the exhaust flow within the enclosure. Additionally, during container filling, the vacuum wand gets contaminated and contributes to worker exposure if it is pulled too far out. To reduce the potential for exposure, workers need to leave the wand inside the ventilated enclosure. Such work practice improvements might also include additional employee training, better supervision of existing procedures, and/or the development of new or revised procedures to better control workplace exposures.

- Increasing the effectiveness of the exhaust ventilation in the paneled furnace enclosure by replacing/fixing damaged wall panels and/or increasing the exhaust flow. The exposure reduction that might be achieved with this improvement is estimated to be about 10 percent (Kent, 2005).

- Enhancing engineering controls associated with filling and changing out product collection containers (estimated to account for 50 percent of worker exposure). For example, high-hazard, laminar-flow powder booths (containment isolators) with integrated weighing systems can reduce operator exposure associated with drum filling operations.

- Enhancing/installing engineering controls for furnace charging and empty drum handling and cleaning (estimated to account for 15 percent of worker exposure). For example, dust-free tipping booths have been designed for the pharmaceutical industry for handling highly hazardous powders and granules and reportedly can achieve dust control levels of 0.1 $\mu g/m^3$ or less. Exposures are reduced with automatic container lifting/tipping, high-visibility viewpoints, and glove port access. A modular design allows application customization for the handling of a wide variety of containers. Empty container disposal and cleaning systems can also be incorporated into the tipping and discharge systems (Hosokawa Micron Group, 2005). While OSHA has no data to show whether such equipment can be adapted to the heavy industrial environment at the Elmore plant, the design concepts and approaches may be useful.

- Eliminating bake-out emissions from the 1950s-era furnace (perhaps by sealing/ventilating furnace openings and/or redesigning the furnace doors). The estimated exposure reduction that might be achieved with this engineering control is 35 percent. However, OSHA lacks adequate information regarding the source(s) of the emissions and whether engineering improvements are feasible.

Feasibility Conclusion for Furnace Operators

Overall, furnace operations have the highest exposure levels in the Elmore plant and therefore present a significant challenge in controlling exposures to or below the proposed 0.2 $\mu g/m^3$ PEL. A variety of sources of beryllium exposure are associated with the furnace operations. Each source contributes to workers' exposures, but data are not available to estimate the relative contribution of each source to workers' overall exposure. The Elmore plant has implemented many control measures since the 1999 survey and, as a result, has achieved significant exposure reductions. OSHA has identified additional control measures for reducing exposures for each major source of exposure. Employers have additional control options that have been shown to be effective in other industries. Whether controls developed for other industries are directly applicable to the beryllium production environment is uncertain, but the design concepts and general approaches may be effective in further reducing workers' exposures to or below the proposed 0.2 $\mu g/m^3$ PEL. However, OSHA acknowledges that furnace operations pose perhaps the greatest challenge to controlling beryllium exposures in beryllium production operations. The furnaces in Materion's Elmore facility are unusual compared to furnaces in aluminum and copper foundries, in that they contain either pure beryllium or high-beryllium content alloys in addition to low-beryllium alloys.[73] OSHA preliminarily concludes that exposures at or below the proposed 0.2 $\mu g/m^3$ PEL can be achieved in some furnace operations most of the time. However, the Agency is not certain whether exposures can be reduced to the proposed PEL in most operations most of the time. Additionally, the Agency believes that reducing exposures to a 0.1 $\mu g/m^3$ alternative PEL would also be challenging. Therefore, OSHA requests additional information, including exposure data and effectiveness of controls, which demonstrate the ability of control strategies to maintain exposures to the proposed PEL or an alternative PEL of 0.1 $\mu g/m^3$.

OSHA acknowledges that respiratory protection may be needed in some high-exposure furnace operations. The Agency does not have sufficient information to conduct a quantitative assessment for this operation. As a result, there is significant uncertainty in its preliminary conclusion. OSHA seeks additional information and exposure data through the rulemaking process to further refine this analysis.

Powdering Operations

The Elmore plant produces beryllium powder, which is then used in other processes. Three major powdering operations are:

- **Impact grinding.** Vacuum-cast billets are prepared for machining, loaded into lathes, and milled into chips. The beryllium chips are vacuum-conveyed into collection containers and subsequently loaded into an impact-grinding (powder-generating)

[73] Section 5—Nonferrous Foundries also describes the difficulties in reducing exposures to the proposed 0.2 $\mu g/m^3$ PEL or below in furnace operations involving low beryllium alloys.

operation. During impact grinding, beryllium chips are injected into a high-speed air stream and impacted against a beryllium target to generate beryllium powder. The beryllium powder is sized using screens, collected in containers, and transferred to powder blenders for mixing. The powder containers are manually loaded and unloaded into/from the blenders. The blended powder containers are then transferred to the compact loading operation for subsequent processing. The primary source of exposure is associated with fugitive emissions when connecting and disconnecting chip-containing drums from chipping operations, and when connecting and disconnecting powder-containing drums from blenders.

- **Compact loading/sintering.** During compact loading, workers load and cap vertically oriented cylindrical graphite dies with beryllium powder. The dies are placed in a tall, fully enclosed loading hood (approximately 15 to 20 feet tall) equipped with back and side-draft exhaust ventilation and are top-loaded with beryllium powder received from the impact grinding operation. A worker is located inside the hood to physically observe the loading process (with a flashlight) in an effort to prevent overloading of the die and a subsequent powder spill. During loading, the beryllium powder is packed by vibrating the drum (shaken and compacted as much as possible). The loaded die is capped with a graphite plug, removed from the loading hood, and transferred to a belowground sintering furnace. During the sintering process, the powder is consolidated into a billet in an inert environment using heat and pressure. The finished billet is removed from the die (pushed out with a hydraulic ram) in a die-stripping hood that is equipped with back-draft exhaust ventilation. Worker exposure is primarily associated with two activities—installing and removing containers of powder from the compact loading hood and die loading.

- **Near Net Shape.** NNS refers to a process in which beryllium powder is consolidated into a part of a shape that is determined by the container volume. The powder is created after beryllium chips are minimized through impact grinding. This beryllium powder is loaded into dies and consolidated into preformed shapes with one or more techniques involving heat and/or pressure (cold and hot isostatic pressing). After consolidation, the dies are unloaded using different techniques depending on the type of die (i.e., rubber, steel, or copper). Rubber dies are used for cold isostatic pressing, and steel and copper dies are used for hot isostatic pressing. Dies are unloaded differently depending on the type of die. Rubber dies are cut open inside an exhaust hood. Steel and copper dies are loaded into a nitric acid bath and dissolved. The acid tank is located in a separate room and is equipped with an exhausted partial enclosure that is open at the top/face for loading purposes. Worker exposure is primarily associated with the loading of powder into dies, and removal of the consolidated shape from the die.

Tables IV-6 and IV-7 shows that exposures in these operations are high. Exposures in powdering operations are characterized by a median of 0.37 $\mu g/m^3$ and a mean of 0.82 $\mu g/m^3$, and 71 percent of the 72 samples taken on workers in powdering operations exceed the proposed 0.2 $\mu g/m^3$ PEL. Material transfer points, where powder is transferred from the process to containers or from containers to other areas of the process, are likely the major sources of exposure in these operations. In addition, the compact loading/sintering operation has another source of exposure—when the worker enters the loading hood to visually (with a flashlight) observe the level of powder as the cylindrical graphite die is filled.

Installing a fail-safe system for handling open drums or fully enclosing the engineered drum-handling system could prevent fugitive emissions at connection points and reduce exposures during material transfer operations. These fugitive emissions in powdering operations may occur when transfer equipment (e.g., drums and tubing) are disconnected, and material retained inside valves and tubing is released in to the air. Additionally, with existing material transfer equipment, a worker may not have the ability to see or otherwise determine if all of the material transfer has occurred and may disconnect the transfer equipment prematurely, releasing emissions in to the air.

One example of a fail-safe system is provided by the pharmaceutical industry. Pharmaceutical quality packing head systems are used for filling/weighing operations involving high-hazard powders. Packing head systems provide a sealed connection between the filling device and the container for dust-free transfer of product (Hosokawa Micron Group, 2005). Reportedly, pharmaceutical quality high containment powder and granule handling systems can achieve dust control exposure levels of 0.1 μg/m^3 or less (Hosokawa Micron Group, 2005). OSHA does not know whether these controls are suitable for metallic beryllium machining chips (i.e., materials other than powder and granular solids).

Ventilated enclosures around existing drum stations would also reduce exposures during powder transfer activities. The Elmore facility installed ventilated enclosures for scrap handling operations that may also be installed during transferring of powder and chips. Hosokawa Micron Group (2005) also reports that packing heads used in conjunction with ventilated containment booths further ensure operator safety during container filling. Alternatively, containment booths can be used as secondary containment between two vessels during transferring operations. Typical applications for powder containment booths include large scale dispensing, weighing, and product sampling.

In the compact loading/sintering operations, installing remote viewing equipment (or other equally effective engineering controls) to eliminate the need for workers to enter the die-loading hood during die filling will reduce exposures associated with this work task as well as potential powder spills. The installation of remote viewing equipment for compact loading/sintering operations could be in the form of cameras inside the hood that would transmit the loading process to a control booth equipped with monitors to observe the loading operations, and controls to stop or start the loading process. OSHA notes that while the Materion Elmore plant may not have these controls in place, OSHA believes that control booths are common enough in industry that retrofitting this and similar powdering operations with control booths would be feasible.

Feasibility Conclusion for Powdering Operations

Based on the availability of control methods to reduce exposures for each of the major sources of exposure in powdering operations, OSHA preliminarily concludes that exposures at or below the proposed 0.2 μg/m^3 PEL can be achieved in most powdering operations most of the time. However, the Agency believes that achieving an alternative PEL of 0.1 μg/m^3 most of the time would be challenging for this job category most of the time with the use of engineering controls and work practices. Note that even though Hosokawa Micron Group (2005) may suggest that 0.1 $\mu g/m^3$ may be possible during transferring of powder, OSHA is not certain whether all sources of exposure in powdering operations can be consistently controlled to 0.1 $\mu g/m^3$.

The Agency also lacks sufficient information to conduct a quantitative assessment for this operation. As a result, there is significant uncertainty in its preliminary conclusion. OSHA seeks additional information and exposure data through the rulemaking process to further refine this analysis.

Hot Work

Hot work is metal shaping and forming using equipment that heats the metal during processing. Hot work includes hot rolling/extrusion, annealing, pickling, degreasing, and welding. Exposures are generally relatively low in these activities. According to Table IV-6, workers in hot work operations experience mean and median exposures of 0.12 and 0.06 $\mu g/m^3$, respectively, with a maximum exposure level of 2.21 $\mu g/m^3$. Table IV-7 shows that 88 percent of hot work exposures are less than or equal to the proposed 0.2 $\mu g/m^3$ PEL, and 69 percent are less than the alternative PEL of 0.1 $\mu g/m^3$. Welding is the highest exposure activity in the hot work category. Welding on beryllium-containing material is discussed in detail in the section on Welding and will not be discussed here because no substantial difference exists between the welding operations conducted at the Elmore plant and those at other establishments potentially affected by the proposed rule. Removing the welding data from the hot work exposures profile, OSHA calculates that 91 percent of exposures related to hot rolling/extrusion, annealing, pickling, and degreasing are less than or equal to the proposed 0.2 $\mu g/m^3$ PEL.

Exposure controls for workers performing hot work vary depending on the work group and are briefly summarized in Table IV-9.

Table IV-9—Baseline Controls for Hot Work

Work Group	Baseline Exposure Controls
Hot Rolling	• *Use of canopy hoods over the entry and exit mill stands.* • *Daily housekeeping to prevent accumulation of loose surface oxides along the run-out tables.* • *Work uniforms.*
Extrusion	• *Use of close-capture exhaust hoods on cut-off saws.* • *Use of partially enclosed exhaust hood for die-grinding work.* • *Work uniforms.*
Annealing	• *Use of inert nitrogen atmospheres to reduce formation of loose surface oxides.* • *Work uniforms.*
Pickling (elevated bath temperatures)	• *Use of pickling and rinse baths that are fully enclosed and exhausted.* • *Work uniforms.*
Degreasing (elevated solvent temperatures)	• *Nothing additional—product is clean and free of loose surface oxides.* • *Work uniforms.*

Feasibility Conclusion for Hot Work Operations

For those situations in which hot work results in exposures above the proposed 0.2 $\mu g/m^3$ PEL, additional controls are available, as described in the sections on Precision Turned Products; Copper Rolling, Drawing, & Extruding; and Welding, of Chapter IV of the PEA. OSHA preliminarily concludes that exposures at or below the proposed 0.2 $\mu g/m^3$ PEL and below a 0.1$\mu g/m^3$ alternative PEL can be achieved in most hot work operations most of the time.

Cold Work

Cold work is the process of shaping and forming beryllium and beryllium alloys without applying heat. Cold work includes rolling, straightening, drawing, and machining the variety of beryllium-containing metal products manufactured at the Elmore facility. In general, these processes have a relatively low potential for beryllium exposure, as they produce very little dust, fume, or other small beryllium-containing particles. As shown in Table IV-7, 80 percent of exposures related to cold work are less than or equal to the proposed 0.2 $\mu g/m^3$ PEL, and 61% are below the alternative PEL of 0.1 $\mu g/m^3$; however, these sample results range from 0.04 $\mu g/m^3$ to 24.89 $\mu g/m^3$, indicating that extreme exposures occasionally do occur (see Table IV-6). Mean and median exposures for cold work, according to Table IV-6, are 0.31 $\mu g/m^3$ and 0.08 $\mu g/m^3$, respectively.

Cold work operations already have significant and effective control methods in place. Exposure controls for workers engaged in rolling, straightening, drawing, and machining are summarized in Table IV-10.

Table IV-10—Baseline Controls for Cold Work Groups

Work Group	Baseline Exposure Controls
Rolling	• *Use of canopy hoods over mills, coilers, and up-coilers to control oil mist.* • *Filter rolling oil to minimize the accumulation of beryllium in the oil.* • *Work uniforms.*
Straightening	• *Remove loose surface oxides (by cleaning) from material surfaces prior to straightening.* • *Wet material surfaces to contain loose surface oxides and minimize airborne dispersion.* • *Use LEV along roller stands.* • *Work uniforms.*
Drawing	• *Remove loose surface oxides (by cleaning) from material surfaces prior to drawing.* • *Work uniforms.*
Machining (alloys)	• *Remove loose surface oxides (by cleaning) from material surfaces prior to machining.* • *Machine under flood coolant.* • *Filter machining coolant (if necessary) to minimize the accumulation of beryllium.* • *Work uniforms.*

The mean and median exposures for rolling, straightening, and drawing are 0.13 $\mu g/m^3$ and 0.05 $\mu g/m^3$, 0.17 $\mu g/m^3$ and 0.06 $\mu g/m^3$, and 0.07 $\mu g/m^3$ and 0.05 $\mu g/m^3$, respectively. For the few exposures in rolling, straightening, and drawing that exceed the proposed 0.2 $\mu g/m^3$ PEL, additional controls may be needed. These controls are described in detail in Section 8—Copper Rolling, Drawing and Extruding.

Overall, machining activities have a significantly wider range of exposures, as can be observed by the highest values for the three machining subgroups (18.97 $\mu g/m^3$ for billet preparation, 16 $\mu g/m^3$ for alloys, and 24.89 $\mu g/m^3$ for high beryllium) when compared to the highest values for rolling, straightening, and drawing (1.08 $\mu g/m^3$, 1.83 $\mu g/m^3$, and 0.20 $\mu g/m^3$, respectively). Therefore, additional controls may be needed for these machining activities to ensure that workers are not exposed to these elevated levels of airborne beryllium. Only those aspects of machining operations that are specific to the Elmore plant (such as machining large billets and machining in close proximity to high-exposure potential beryllium manufacturing operations) are discussed here. Section 7—Precision Turned Products provides a detailed description of machining operations in general, along with the available control methods for reducing worker exposures. Note that the controls discussed below apply to machining with low- and high-beryllium-containing billets.

At the Elmore plant, machining may be done manually or with the use of precision computer-controlled equipment. Activities associated with machining might include milling, turning, cutting, grinding, drilling, deburring, sawing, swaging, slitting, sanding, tool grinding, and other forms of tool maintenance. Machining might be conducted with no engineering controls, wet (with flood coolant) or dry, with or without LEV, and with or without equipment enclosures. The controls utilized depend on the beryllium content of the parts or shapes being machined and the type of machining being performed (i.e., beryllium particle size and generation rate). For example, high-beryllium-content parts are machined wet or dry, with LEV hoods and enclosures. Dry machining utilizes low-volume/high-velocity (LVHV) source capture with specially designed hoods providing close capture. If machining is performed wet, the machining equipment can be enclosed in a high-volume/low-velocity (HVLV) hood to contain the coolant. Beryllium alloys are typically machined wet but without LEV or machine enclosures. Worker exposures are associated with numerous factors, including working in close proximity to high-exposure activities (e.g., melting and casting); work practice issues, such as improper positioning of LVHV source capture exhaust ducts and opening machine enclosures during the machining cycle and/or too soon after the completion of the machining cycle; inadequate management/containment of beryllium-contaminated coolant; and inadequate or absent LEV and/or machine enclosures.

Machining exposures are influenced by the concentration of beryllium present in the material. Beryllium Production Appendix 2 shows that exposures for beryllium alloys (those containing 2 percent or less Be) generally meet the proposed PEL (88 percent) and alternative PEL of 0.1 $\mu g/m^3$ (70 percent). The exposures associated with machining materials with high beryllium concentration (those greater than 30 percent) are a bit higher overall, with 59 percent of exposures meeting the proposed PEL and only 41 percent below the alternative PEL of 0.1 $\mu g/m^3$. Additional controls for machining any type of beryllium-containing metal at the Elmore plant would include:

- Isolating the machining process (particularly machining billets).
- Enclosing machining equipment.
- Adding or enhancing ventilation systems.

Workers machining alloy billets work in close proximity to the melting and casting operations, and their exposures might be predominately associated with this co-location issue (Corbett, 2004; Kent, 2005). As exposures in the melting and casting operations are reduced, exposures in the billet machining operations would be reduced accordingly. In addition, reducing co-location exposures by isolating billet machining operations from nearby high-exposure activities associated with melting and casting could potentially further reduce exposures significantly. It might be possible to build a floor-to-ceiling wall to isolate billet preparation or to move the billet preparation activity a greater distance from the melting and casting operations. However, the use and placement of overhead cranes may present obstacles to isolating the billet preparation from melting and casting operations because such an approach may require significant process redesign. The exposure reduction that might be achieved by isolating billet preparation from melting and casting is not known. Discussions with industry experts suggest that exposures below 0.1 $\mu g/m^3$ might be achievable by isolating the operation (Corbett, 2004).

Enclosing the machining operation is another method of reducing exposure. In an investigation of exposure to cobalt during wet grinding of hard metal blades, Linnainmaa (1995) observed that full-shift PBZ exposures were reduced 50 to 91 percent when two semiautomatic grinding machines with splash guards (minimally enclosed) were fully enclosed. Exposures before enclosing the machines ranged from 6 $\mu g/m^3$ to 33 $\mu g/m^3$; after fully enclosing the grinding machines, exposures were 3 $\mu g/m^3$. Post-control exposures are based on three samples and were not reported as a range, but simply as 3 $\mu g/m^3$. While these data do not necessarily establish that exposures less than or equal to the proposed 0.2 $\mu g/m^3$ PEL can be achieved using process enclosure, they do suggest that significant exposure reduction can be realized.

Adding LEV or enhancing existing LEV will also reduce exposures during machining of beryllium-containing material. Section 7—Precision Turned Products describes fully enclosed, sealed, and ventilated machining operations on high-beryllium-content products (including pure beryllium) (ERG Beryllium Site 1, 2002). The section provides detailed descriptions of controls for machining operations that are applicable to the machining operations at the Elmore plant and would provide similarly reduced exposures.

Feasibility Conclusion for Cold Work Operations

As discussed above, 80 percent of exposures in the cold-work operations (rolling, straightening, drawing, and machining) are less than or equal to the proposed 0.2 $\mu g/m^3$ PEL, and 61 percent are less than the alternative PEL of 0.1 $\mu g/m^3$. In those few instances where exposures need to be further reduced, available control methods include work area isolation, process enclosure, and enhanced ventilation, as described above, and the additional controls described in Section 7—Precision Turned Products and Section 8—Copper Rolling, Drawing and Extruding of this technological feasibility analysis. Based on current exposures and the availability of additional controls, OSHA preliminarily concludes that exposures at or below the proposed 0.2 $\mu g/m^3$ PEL and a 0.1 $\mu g/m^3$ alternative PEL can be achieved most of the time in most cold-work operations.

Production Support

As shown in Table IV-6, the exposure profile for the production support job category is characterized by a median of 0.08 $\mu g/m^3$, a mean of 0.51 $\mu g/m^3$, and a range from 0.02 $\mu g/m^3$ to 22.71 $\mu g/m^3$. Overall, 71% of the 861 full-shift PBZ total beryllium sample results reported for workers categorized in production support work groups were less than or equal to 0.2 μg/m^3, and 56% were less than 0.1μg/m^3. For this analysis, production support workers include those involved with:

- Furnace charge material preparation ("mix makeup").
- Onsite scrap recycling (beryllium and copper).
- Maintenance (production equipment, furnaces and furnace tools, molds and dies).
- Research and development (R&D).
- Quality Assurance/Quality Control (QA/QC) inspection.

Mix Makeup workers prepare and charge (load) furnaces with alloy melting mixes. This activity involves using material-handling equipment, such as industrial lift trucks, and transferring bulk material between charge tubs and furnaces. Furnace charges are prepared in ventilated mix stations and loaded into tubs, where they are charged in the furnaces through a pneumatically operated cart (Kent et al., 2001). Mix makeup workers work in a wide-open area in close proximity to the alloy melting and casting operations. A partial enclosure equipped with a slot hood is used to control exposures at the mix station in the Old Cast Shop (floor weigh-scale location). In the New Cast Shop, mix makeup is incorporated into the furnace operator's job, and a sub-grade ventilated pit is used as a mixing station. Other exposure controls for this activity include the use of HEPA filter vacuum systems (centralized and portable) and wet methods for workplace cleaning. Worker exposure is primarily associated with adjacent contaminant-producing operations (i.e., melting and casting) and the handling of dusty scrap in the Old Cast Shop. (The New Cast Shop uses master alloy, pure copper rod, and clean scrap for furnace charges.) How much of the exposure comes from the nearby melting and casting operations and how much is generated by the handling of dusty scrap is not known. The industrial hygienist for the Elmore facility estimated that nearby melting and casting operations might account for up to 70 percent of mix makeup worker exposures (Kent, 2005).

As shown in Table IV-6, the median exposure for mix makeup workers is 0.24 μg/m^3, the mean is 0.46 μg/m^3, and the maximum exposure level is 4.2 μg/m^3. Additional controls are required to reduce exposures to the proposed PEL of 0.2 μg/m^3 for workers who perform mix makeup operations.

Using industrial lift trucks equipped with properly enclosed, sealed, and ventilated operator cabs (i.e., no leaks, positive pressure, and effective air filtration) will reduce exposures. Direct reading instruments show that fine particle (i.e., less than 0.3 μm) concentrations inside the operator cab can be reduced by an average of 96 percent when cabs are clean; are sealed with effective door gaskets with no cracks or holes; and have a properly designed, installed, and maintained filtration and pressurization system (Cecala et al., 2005).[74] Based on two full-shift area samples and direct-reading measurements with light-scattering aerosol monitors, NIOSH investigators reported

[74] This study shows that the cabs can control 96 percent of airborne beryllium particles that are equal to or greater than 3 μm in size.

respirable dust exposures were reduced by 97 to 98 percent inside a modified ballast regulator cab (NIOSH HETA 92-0311).

According to company estimates, nearby melting and casting operations contribute approximately 70 percent of the daily cumulative exposure experienced by mix makeup workers (Kent, 2005). The melting and casting operations' contribution to the mix makeup workers' exposure will be reduced when effective controls are added to those operations. OSHA believes that the scrap handling tasks that may contribute to mix make-up workers are fugitive emissions from scrap handling and dust suspended by forklift traffic. Installing ventilated enclosures at scrap handling stations and enhancing the housekeeping program may also contribute to lower exposures to mix make-up workers. Additionally, using an enclosed ventilated forklift truck will reduce exposures further, perhaps as much as 98 percent during the time these workers remain within the ventilated enclosure (NIOSH HETA 92-0311). The amount of time workers spend using forklifts is not known. Assuming that workers in this area spend half their time using forklifts, and that these exposure-reduction estimates are realized, the resulting maximum exposure level would be approximately 0.64 $\mu g/m^3$, and the average exposure level would be reduced to approximately 0.07 $\mu g/m^3$.[75]

Feasibility Conclusion for Mix Makeup Operations—Production Support
Based on this analysis, OSHA preliminarily concludes that exposures at or below the proposed 0.2 $\mu g/m^3$ PEL can be achieved for mix make-up workers most of the time. Also based on this information, the Agency preliminarily concludes that exposure levels less than an alternative PEL of 0.1 $\mu g/m^3$ can be achieved most of the time.

Scrap recycling is another potential source of beryllium exposure for production support workers. Table IV-6 indicates that workers in scrap recycling have a median beryllium exposure of 0.31 $\mu g/m^3$ and a mean exposure of 1.08 $\mu g/m^3$. The scrap recycling work group is responsible for monitoring scrap metal and extracting beryllium that will be processed in the furnaces. This work group has four subgroups: inventory control center, scrap reclamation, leaching, and resource recovery. Beryllium Production Appendix 2 shows that 36 percent of exposures are already at or below the proposed 0.2 $\mu g/m^3$ PEL. Worker exposures in scrap recycling occur from four sources: 1) the scrap materials often have dust attached that can become airborne during manual handling; 2) beryllium-containing dust can become airborne when drums containing dusty scrap are opened and unloaded; 3) dust can be generated by forklift traffic disturbing surface dust in the scrap recycling area; and 4) dust can be generated during scrap sampling. Information on the relative contribution of each of these sources to workers' exposures is not available. Similarly, the data to determine how much time workers spend on the

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[75] OSHA estimated this maximum exposure level by reducing the highest exposure level for workers in this subcategory (4.2 $\mu g/m^3$ from Table IV-6) by the 70 percent that is due to the nearby melting and casting operations: 4.2 x 0.3 =1.26 $\mu g/m^3$. OSHA then applied an exposure reduction of 98 percent for the example time of 4 hours (of an 8-hour shift): 1.26 $\mu g/m^3$ x 0.02 = 0.025 $\mu g/m^3$. This is the maximum concentration the worker experiences during the cumulative total of 4 hours spent inside the forklift enclosure during the shift. The worker experiences the exposure level of 1.26 $\mu g/m^3$ during the remaining 4 hours of the shift (time spent outside the enclosure). OSHA next calculated a time-weighted average using the standard equation published in 29 CFR 1910.1000(d)(1)(i): [(0.025 $\mu g/m^3$)(4 hours) + (1.26 $\mu g/m^3$)(4 hours)]/8 hours = 0.64 $\mu g/m^3$. Alternatively, starting with the mean (0.46 $\mu g/m^3$) instead of the maximum exposure level for this worker subcategory, the same method can be used to estimate the mean exposure level (0.07 $\mu g/m^3$) with these same controls put in place.

variety of activities in scrap recycling do not exist. As a result, it is not possible to precisely predict the reduction in exposure that might occur as these sources are controlled. Nonetheless, effective control methods are available for reducing exposures from each of these sources.

Manual handling of scrap materials occurs in ventilated partial enclosures. Since the time that samples in the exposure profile were taken, the facility has enhanced the ventilation throughout the operation by doubling the exhaust flow. Information regarding the exposure reduction that was achieved with this engineering modification is not available. However, Kent (2005) suggests that ventilation enhancements alone might achieve an exposure reduction of 20 to 50 percent. Enhanced engineering and work practice controls together typically might be expected to reduce exposures by half or one-third of previous exposures (Kent, 2005).

Since 1999, the facility has also designed and installed ventilated enclosures for handling open drums. This equipment captures residual material released during drum connection and disconnection to/from the process. This system reduces the amount of contamination that results when drums are opened and emptied. Installing these ventilated enclosures at all drum-handling stations would contribute to a reduction in workers' exposures. These fugitive emissions in scrap handling operations may occur when transfer equipment (e.g., drums and tubing) are disconnected, and material retained inside valves and tubing is released in to the air. Additionally, with existing material transfer equipment, a worker may not have the ability to see or otherwise determine if all of the material transfer has occurred and may disconnect the transfer equipment prematurely, releasing emissions in to the air.

Exposures associated with forklift operations can be addressed in two ways. First, enhancing the housekeeping program to reduce the level of contamination and migration within the workplace will reduce surface dust that may be disturbed by forklift traffic. Since the time of the 1999 baseline exposure monitoring, housekeeping has been improved in the scrap recycling area. Wet floor sweepers are used to clean the floors on a daily basis to reduce the level of dust generated by material-handling activities (i.e., fork truck traffic), and containers of dusty scrap are kept covered. As previously discussed, significant improvements in the level of housekeeping through more effective and/or more frequent cleaning might further reduce exposures by 60 to 80 percent (OSHA SEP Inspection Report 303207518).[76] Second, forklift cabs can be enclosed and ventilated to reduce exposures during forklift operations. As mentioned above, two studies have shown the effectiveness of such ventilated enclosures. Cecala et al. (2005) demonstrated that concentrations of respirable dust inside the operator cab can be reduced by an average of 96 percent when cabs are clean; are sealed (effective door gaskets and no cracks or holes); and have a properly designed, installed, and maintained filtration and pressurization system. NIOSH investigators reported respirable dust exposure reductions of 97 and 98 percent inside enclosed cabs (NIOSH HETA 92-0311).

[76] This exposure reduction is based on a study (discussed previously in the Furnace Operations subsection) conducted in a foundry environment in which silica exposure was reduced through housekeeping efforts. It is uncertain that a similar exposure reduction could be achieved in a beryllium manufacturing plant because the beryllium concentration of the materials handled during beryllium production is inherently higher than it is for those beryllium-containing alloys handled in melting and casting operations in foundries. However, this example demonstrates the extent to which worker exposures can be influenced by diligent housekeeping (OSHA SEP Inspection Report 303207518).

Feasibility Conclusion for Scrap Recycling—Production Support

Beryllium Production Appendix 2 shows that 36 percent of exposures in the scrap recycling area are already at or below the proposed 0.2 µg/m^3 PEL. Based on the availability of control methods to reduce exposures for each of the major sources of exposure in scrap recycling, OSHA preliminarily concludes that exposures at or below the proposed 0.2 µg/m^3 PEL can be achieved in most scrap recycling operations most of the time. OSHA seeks additional information and exposure data through the rulemaking process to further evaluate the effectiveness of the control methods described above, and determine whether an alternative PEL of 0.1 µg/m^3 can be considered feasible for scrap recycling operations.

Maintenance workers are primarily exposed when working in production areas. According to Table IV-6, the median beryllium exposure for furnace and tool maintenance workers is 0.53 µg/m^3, and the mean exposure is 1.73 µg/m^3, with a maximum exposure of 14.62 µg/m^3. Thus, additional controls are required to reduce maintenance worker exposures to the proposed PEL of 0.2 µg/m^3 or below.

The highest exposure for maintenance personnel occur during furnace repair and rebuild operations, with a median exposure level of 0.53 µg/m^3. The frequency with which furnaces require maintenance (rebuilding) can vary from two weeks to two months and depends on the type of furnace and the number of heat cycles it has operated. For example, in the New Cast Shop, furnaces require rebuilding about every 30 to 60 heat cycles and may operate for four heat cycles per day. Because of the approximately 40 furnaces located at the Elmore facility, furnace rebuilding is done on a daily basis. Although some repairs are done in place, most furnaces are not rebuilt in place. For repair-in-place, maintenance workers rely on the furnace's LEV for exposure control. All other furnaces are moved to a segregated rebuilding control room equipped with several bays for working on multiple furnaces simultaneously.

The furnace rebuild room is ventilated (about one air change per minute), and maintenance workers have high exhaust flow LEV hose drops (approximately 10,000 cubic feet per minute of exhaust air per two hose drops) and HEPA filter vacuums (centralized and portable diesel-powered) available for use during rebuilding activities. Additionally, wet methods are reportedly used during demolition activities. Worker exposures are primarily associated with two activities: 1) cleaning contaminated furnaces prior to rebuilding; and 2) mechanically generating beryllium aerosols during repair and reconditioning activities (e.g., manually demolishing furnace linings). Demolition activities probably contribute the most to worker exposures (about 90 percent), whereas cleaning activities may account for about 10 percent of total exposure. In the past, workers reportedly were not properly decontaminating furnaces prior to rebuilding (Kent, 2004).

Based on the available information, an additional control would be using jackhammers equipped with a controlled water spray at the chisel point. Jackhammering on furnace liners is likely the most significant source of exposures in furnace maintenance. Various studies have reported significant respirable dust exposure reductions ranging from 70 to 90percent when jackhammering with water-supplied jackhammers compared with dry jackhammering (NIOSH EPHB 282-11a; Williams and Sam, 1999). NIOSH investigated a water spray dust control used by workers breaking concrete with 60- and 90-pound jackhammers (EPHB 282-11a). Using both a direct-reading (real-time) instrument and a high-flow cyclone with filter media, NIOSH collected 10-minute readings with and without the water spray activated. Compared with uncontrolled concrete pavement-breaking, PBZ respirable dust concentrations were between 72 and 90 percent lower when the water spray was used. Similarly, Williams and Sam (1999) report that a hand-held pneumatic chipper equipped with a water spray nozzle reduced worker exposure to respirable crystalline silica by 70 percent during concrete truck drum cleaning. Workers periodically spray the interior surface of the drum and have a continuous water spray directed at the chisel point during chipping. The water flow rate is operator adjusted and is described as a controlled mist that does not generate excess water (Sam, 2004).

The use of water-supplied jackhammers during demolition of furnace linings can likely reduce worker exposures associated with demolition activities by at least 70 percent (NIOSH EPHB 282-11a; and Williams and Sam, 1999). OSHA notes that although the facility uses wet methods during demolition activities, it is not clear to what extent this control is currently successful in suppressing dust given the high exposures reported. Similarly, the LEV has high-flow capacity but it is not certain whether it is employed at the point of operation. OSHA believes that a water delivery system that is consistently suppressing dust at the point of operation will allow for similar reductions reported by the NIOSH (EPHB 282-11a) and Williams and Sam (1999) studies. See Section 2—Methodology of this PEA for detailed discussions on how some of the same controls methods available for one of these contaminants (silica) will also help control the other (beryllium).

In addition to furnaces, maintenance workers must also maintain (rebuild) contaminated furnace tools. These tools are fabricated in-house and include furnace rub bars and dross rakes that are 10 to 12 feet long. Maintenance workers cut off the contaminated sections of these tools and weld on new sections. Cut-off saws, grinders, and welders are used to repair these tools. Workers utilize operator-positioned LEV hose drops (some with hoods and some without) during these repair activities. Other exposure controls available to furnace maintenance workers include the use of HEPA filter vacuum systems (centralized and portable) and wet methods for cleaning work areas.

Other production support workers who have potential exposure to beryllium during their work activities include R&D and QA/QC/inspection workers. These workers ensure that the production process runs appropriately so as to ensure quality output. Additionally, these workers ensure that the materials sent to downstream users meet the quality standards set by the company. Exposures during these activities are generally well controlled, however. Table IV-6 shows that R&D and QA/QC/inspection workers have mean values of 0.11 $\mu g/m^3$ and 0.05 $\mu g/m^3$ and median values of 0.14 $\mu g/m^3$ and 0.05 $\mu g/m^3$, respectively.

Beryllium Production Appendix 2 shows that 64 percent of maintenance workers' exposures, 89 percent of R&D workers' exposures, and 95 percent of QA/QC/inspection workers' exposures are equal to or less than the proposed PEL. Table IV-11 presents the control measures that have already been implemented for these workers.

Table IV-11—Baseline Controls for Maintenance, R&D, and QA/QC Workers	
Work Group	**Baseline Exposure Controls**
Maintenance of Production Equipment, Molds and Dies	• *Decontamination/cleaning of equipment prior to repair/reconditioning.* • *LEV (hose drops, some with exhaust hoods) during activities/tasks having potential for beryllium exposure, such as demolition activities.* • *Housekeeping program to minimize dust accumulation and migration.* • *Cleaning with HEPA filter vacuums (centralized and portable) and wet methods.* • *Work uniforms, gloves, and respiratory protection.*
R&D	• *Devoted process exhaust ventilation systems with specially designed hoods and enclosures.* • *Activities reviewed and investigated on case-by-case basis by site safety/industrial hygiene staff for potential exposure and control alternatives.* • *Work uniforms.*
QA/QC/Inspection	• *Written analytical procedures.* • *Laboratory exhaust hoods.* • *Decontamination of parts and assemblies prior to inspection.* • *Work uniforms.*

The exposures to maintenance, R&D, and QA/QC/inspection workers also result from conditions that exist in beryllium production areas of the plant where these workers occasionally perform their duties. As exposures in these areas are reduced through engineering controls and additional housekeeping, maintenance, R&D, and QA/QC/inspection workers' exposures should also be reduced.

Feasibility Conclusion for Maintenance, R&D, and QA/QC Operations—Production Support
Based on the exposure profile, OSHA preliminarily concludes that the proposed PEL of 0.2 μg/m^3 and an alternative PEL of 0.1 μg/m^3 are feasible for R&D and QA/QC/inspection workers. It is not clear whether exposures at or below the proposed PEL and an alternative PEL of 0.1 μg/m^3 will be consistently achieved using wet methods for furnace and tool maintenance workers. The workers engaged in this high-exposure activity will likely need to rely on respiratory protection during these maintenance operations (e.g., a tight-fitting powered air purifying respirator would offer a protection factor of 1,000 and protect workers from beryllium concentrations up to 200 μg/m^3).

Site Support

For this analysis, site support workers include those involved in nonproduction related activities such as laundry, janitorial, decontamination, facility/site operations (e.g., boilers, maintenance, wastewater treatment), shipping/receiving/material handling, supply room, analytical laboratory, security, and cafeteria work. As shown in Table IV-6, the exposure profile for the site support job category is characterized by a median of 0.05 μg/m^3, a mean of 0.11 μg/m^3, and a range from 0.05 μg/m^3 to 4.22 μg/m^3. Of the 879 full-shift PBZ total beryllium sample results reported for workers categorized in the site support work group, 92 percent were at or below 0.2 μg/m^3 and 81 percent were less than 0.1 μg/m^3.

Site support workers are not directly involved with beryllium production but may occasionally be exposed when they enter beryllium manufacturing areas or when they handle beryllium-containing materials or materials that have become contaminated with beryllium. Site support workers have significant controls in place.

The Agency believes that the controls installed in the manufacturing operations to achieve compliance with the proposed PEL in those areas will also reduce exposures to the site support workers such that exposures above the PEL will not occur in 10 of 13 site support jobs. The controls that existed at the time of sampling for these 10 support jobs are listed in Table IV-12.

Table IV-12—Baseline Controls for Site Support Jobs

Work Group	Baseline Exposure Controls
Laundry	• *Water sprays (on a timer) and canopy hoods over dirty clothing hampers.* • *HEPA filter vacuum cleaners for floor cleaning.* • *Routine housekeeping in dirty locker rooms.* • *Work uniforms.* • *Half-mask air-purifying respirators (when removing dirty clothing from hampers).*
Janitorial	• *Written procedures to keep areas clean of beryllium and minimize the risk of beryllium migration.* • *Wet cleaning methods and HEPA filter vacuum cleaners.* • *Supplemental HEPA filter vacuums for servicing vacuums (e.g., changing the filters).* • *Work uniforms.* • *Half-mask air-purifying respirators (when emptying disposable/dirty personal protective equipment [PPE] receptacles and for vacuum maintenance/service).*
Landfill	• *Store and decontaminate solid waste prior to delivery to the landfill.* • *Established facility practices and procedures regarding the handling and deposit of material delivered to the landfill.* • *Work uniforms.*
Facility Maintenance	• *Cleaning before maintenance with wet cleaning methods and HEPA filter vacuums (centralized and portable).* • *Exhaust hoods in maintenance shops.* • *Wet commercial road sweepers.* • *Large-scale equipment decontamination (in segregated area).* • *Established facility practices and procedures.** • *Work uniforms, gloves, and respiratory protection.*
Analytical Laboratories	• *Standardized work practices for tasks relevant to their job description.* • *Laboratory exhaust hoods (for cutting operations, handling powders).* • *HEPA filter vacuums (centralized and portable).* • *Wet processing techniques (e.g., water polishing).* • *Splash guards on polishing wheels.* • *Work uniforms and respiratory protection (e.g., when cutting copper-beryllium samples).*
Shipping/Receiving	• *Wet cleaning methods and HEPA filter vacuums (to clean shipping department).* • *Materials and equipment are containerized or decontaminated prior to delivery to shipping/receiving. Potentially contaminated equipment is cleaned and visually inspected prior to offsite shipment.* • *Work uniforms.*

Table IV-12—Baseline Controls for Site Support Jobs	
Work Group	**Baseline Exposure Controls**
Supply Rooms	• *Work uniforms.* • *Established facility practices and procedures relevant to the tasks they perform, such as storing materials used by other site support workers.*
Security	• *Work uniforms.* • *Established facility practices and procedures.**
Facility Engineering	• *Work uniforms.* • *Established facility practices and procedures.**
Cafeteria	• *Aprons (over personal clothes).* • *Lab coat (cashier).* • *Wet cleaning methods to clean kitchen.*
* *Materion did not specify what these practices and procedures are for these individual work groups.*	

Three other site support jobs have exposures that are somewhat higher, and the occurrence of exposures above the proposed 0.2 μg/m^3 PEL is more frequent. These jobs are:

- Decontamination
- Boiler operators
- Wastewater treatment

Decontamination workers perform large-scale surface cleaning in places that do not get cleaned frequently, such as room and equipment surfaces that are over 8 feet high in the regulated (production) work areas. Entire areas are shut down for cleaning based on a predetermined work schedule. Decontamination workers do not perform cleaning tasks typically associated with the janitorial staff, such as cleaning offices, meeting/break rooms, and toilets. Currently, the decontamination crew consists of four to six workers who primarily perform large equipment decontamination. This equipment includes cranes that need to be serviced or inspected and equipment, such as electric motors, heavy equipment (e.g., a front-end loader), and vehicles, that needs to leave the site for service or repair. Decontamination is a daily activity for these workers. For example, at least one crane is decontaminated nearly every day because the site has approximately 300 cranes that must be serviced and inspected. Decontamination workers clean contaminated equipment surfaces by removing surface contamination with one or more cleaning techniques, including HEPA filter vacuuming and various wet cleaning methods (e.g., wet wiping, high- and low-pressure water washing). A high-power, diesel vacuum mounted on a trailer is also available for cleaning extensive gross surface contamination. Decontamination workers presumably receive higher exposures when cleaning more heavily contaminated equipment. Higher exposures might also be associated with the level of beryllium contamination of the work environment, worker technique, and/or improper work practice, such as using high-pressure water washing before initial gross cleaning by vacuuming and wet wiping.

As shown in Table IV-6, the median exposure for decontamination workers is 0.18 μg/m^3 and the mean is 0.47 μg/m^3, with a range of .05 μg/m^3 to 4.22 μg/m^3. Based on these data, OSHA concludes that the 0.2 μg/m^3 PEL can be achieved in this operation most of the time. However, additional controls will be required to reduce exposures in some cases.

It is difficult to predict the amount of decontamination work that will need to be performed with the improvement of engineering controls in beryllium manufacturing operations. Assuming that the frequency of decontamination remains the same, improvements in process controls and dust collection in the beryllium production operations will result in reduced deposition of beryllium-containing dust on surfaces and equipment. OSHA has no data that indicate the extent to which decontamination workers' exposures will be reduced when the beryllium production operations have better dust control.

Additional measures (not currently installed) for site support workers may offer further exposure reductions. For example, small equipment can be decontaminated in enclosed/sealed cleaning cabinets (NIOSH Testimony, 1977). Using such equipment, decontamination workers' exposures would be greatly reduced. An industry consultant suggests that perhaps 20 percent of the equipment that is decontaminated (e.g., engines) could be cleaned in a leak-tight decontamination chamber (Corbett, 2004).

Improved work practices can further reduce exposures. For example, ensuring that workers remove gross contamination with HEPA-filtered vacuums prior to wet wiping will reduce the amount of airborne contamination created during the decontamination process. Ensuring that workers consistently follow established procedures will reduce the frequency of occasional high exposures. No data exist that suggest the extent to which exposure levels can be reduced through work practices. However, a Materion industrial hygienist at the Elmore plant estimated that beryllium exposures can typically be reduced by approximately 20 to 50 percent through improved work practices or engineering controls (Kent, 2005).

Boiler operators monitor boilers that provide steam to other areas of the plant. The boilers are not themselves a source of beryllium contamination, but higher exposures than would normally be expected occur in these workers because the facility boilers are physically located near several high-exposure operations (i.e., the boilers are out in the open, there is no boiler "room"). Operators monitor the boilers from a small control room equipped with a window air-conditioning unit. Because of the proximity of the boiler control room to high-exposure operations (i.e., the pebble plant, beryllium oxide furnaces, and resource recovery recycling operation), contaminated air infiltration is the primary contributor to the higher exposure levels reported for boiler operators.

According to Table IV-6, boiler operators have a range of exposures from 0.05 μg/m^3 to 0.48 μg/m^3, with a mean of 0.23 μg/m^3 and a median of 0.16 μg/m^3. Subsequent to the 1999 baseline exposure monitoring, the boilers were physically isolated from two operations with higher exposures: the pebble plant and the beryllium oxide furnaces. Additionally, HEPA air filtration was introduced to all operator work stations (pulpits), including the boiler control room. Boiler operator exposures are now significantly lower and are estimated to be approximately one-tenth of what they were prior to HEPA filtration (Kent, 2005). The highest exposure level measured for boiler operators in 1999 was 0.48 μg/m^3 (Table IV-6). Assuming the Kent (2005) estimate is correct, the maximum exposure of boiler operators is 0.048 μg/m^3 or less, and no additional controls are needed to reduce exposures to, or below, the proposed PEL of 0.2 μg/m^3 or below an alternative PEL of 0.1 μg/m^3.

Wastewater treatment takes place in a separate building, so there is no co-location issue associated with worker exposures, as noted with the boiler operators. Worker exposures result from beryllium contamination in the water that enters the treatment plant and might primarily be associated with the sludge cake operation (operating and cleaning the filter presses and monitoring bag filling). Sludge contamination that has been allowed to dry can become airborne very easily and is a potential source of beryllium exposure. Higher exposures for wastewater treatment workers are reportedly due to improper work practices and inadequate housekeeping (Kent, 2005). Exposure controls within the wastewater treatment plant include enclosed and ventilated tanks for certain processes, as well as ventilated sludge presses.

Beryllium Production Appendix 2 indicates that wastewater treatment workers have a median beryllium exposure of 0.09 μg/m^3 and a mean exposure of 0.17 μg/m^3. Only 24 percent of the exposure levels are greater than 0.2 μg/m^3. As control of beryllium emissions in the beryllium production operations improves, the beryllium content in the wastewater and sludge will be reduced similarly. This will, in turn, reduce wastewater treatment plant workers' exposures. In the event that exposures are not reduced to or below the proposed 0.2 μg/m^3 PEL, improved housekeeping and work practices may be needed.

Sludge contamination in the wastewater treatment plant that is or has been allowed to dry (and accumulate) can become airborne very easily and is a potential source of beryllium exposure. Enhancing work practices through operator training, work practice modifications, and/or better supervision will minimize exposures associated with the sludge cake operation. For example, operators need to limit the number of times the sludge cake is pressed to avoid making it too dry. A dry cake can increase the amount of dust generated during sludge bag filling and directly affect worker exposure and/or contaminate the work environment.

Diligent housekeeping limits the amount of beryllium dust on floors, equipment, and other surfaces. NIOSH repeatedly recommends effective housekeeping and appropriate cleaning techniques (such as wet cleanup methods and/or vacuuming with an approved HEPA filter vacuum) as methods to minimize worker exposure to hazardous air contaminants such as asbestos, crystalline silica, and heavy metals (NIOSH HETA 89-270-2080; HETA 91-0093-2126; HETA 2003-0114-2924).

Feasibility Conclusion for Site Support Operations

In general, site support workers have very low beryllium exposures. Ninety-two percent of exposures are less than or equal to the proposed 0.2 μg/m^3 PEL, and 81 percent of exposures are less than 0.1 μg/m^3. Beryllium exposures in all site support activities will be reduced as a result of the general reduction in beryllium contamination that will occur as the plant complies with the provisions of the proposed rule. Even for decontamination, boiler operations, and wastewater treatment, exposures can be reduced by using engineering controls and work practices such as improved housekeeping and following established procedures. OSHA preliminarily concludes that beryllium exposures in most site support activities can be controlled to the proposed 0.2 μg/m^3 PEL or below, as well as below a 0.1 μg/m^3 alternative PEL, most of the time.

Administrative Personnel

As shown in Table IV-6, the exposure profile for the administrative job category is characterized by a median of 0.05 $\mu g/m^3$, a mean of 0.1 $\mu g/m^3$, and a range from 0.05 $\mu g/m^3$ to 4.54 $\mu g/m^3$. These values represent 981 full-shift PBZ total beryllium sample results reported for workers categorized in administrative work groups. For this analysis, administrative workers include managers, supervisors, secretaries, office workers, and professional support staff such as engineering, production planning, medical, and environmental health and safety personnel. Ninety-four percent of the samples for administrative personnel were equal to or less than 0.2 $\mu g/m^3$, indicating that only on rare occasions will administrative personnel have exposures that exceed the proposed PEL. And, 85% of the samples were less than the alternative PEL of 0.1 $\mu g/m^3$.

Administrative workers typically have their offices in administrative buildings and may or may not interface with production operations by entering regulated work areas of the facility. These workers do not work directly with beryllium. Administrative workers who enter production areas of the facility must abide by the same exposure controls and procedures applicable to production workers, including using company-provided work clothing (that is laundered on site) and respiratory protection and showering at the end of the work shift and/or when leaving regulated work areas. Beryllium contamination that could be transferred from regulated areas of the facility to administrative areas is controlled through migration control procedures. Examples of beryllium migration control techniques in place at the time the 1999 samples were taken include the following:

- Transition zones that provide a designated area for donning clean PPE before entering a regulated area and removing dirty PPE upon exiting.[77]
- Personal protective clothing (e.g., work clothing and shoes, coveralls, lab coats, gloves, head and shoe coverings).
- Shoe cleaners and tack (sticky) mats.
- Air showers (not plantwide).
- Personal hygiene (e.g., hand washing and showering at the end of the shift).
- Housekeeping (HEPA filter vacuum systems and wet methods; work surfaces and equipment "visibly" clean).
- Other (fabric-covered office furniture minimized; carpeting eliminated).

Because administrative workers do not work directly with beryllium, the few exposures that exceed the PEL result from occasional visits to the beryllium manufacturing operations or from handling materials that may be contaminated. The Agency believes that the controls that will be installed in the manufacturing operations to achieve compliance with the proposed PEL in those areas will also reduce the beryllium exposures of the administrative staff such that exposures

[77] In some areas, transition zones may separate the general office area from respirator-required plant areas.

above the PEL will not occur. As a result, no additional controls specifically designed to reduce administrative personnel exposures will be needed.

Feasibility Conclusion for Administrative Personnel Operations
OSHA preliminarily concludes that the proposed PEL of 0.2 μg/m^3 and an alternative PEL of 0.1 μg/m^3 have already been achieved for most administrative operations most of the time. Furthermore, an exposure level less than or equal to the proposed 0.2 μg/m^3 PEL can likely be achieved for these operations all of the time once additional control measures are installed in beryllium production areas.

Summary of Technological Feasibility Findings for Beryllium Production

Only one primary beryllium production facility is currently in operation in the United States, a plant owned and operated by Materion Corporation, located in Elmore, Ohio. OSHA identified eight job groups at this facility in which workers are exposed to beryllium: chemical operations, powdering operations, production support, cold work, hot work, site support, furnace operations, and administrative work.

The Agency developed an exposure profile for each of these eight job groups to represent the distribution of exposure levels associated with primary beryllium production. The job exposure profiles are based primarily on full-shift personal breathing zone (PBZ) (lapel-type) sample results from air monitoring conducted by Brush Wellman in 1999 at the Elmore primary production facility (Brush Wellman Elmore, 2004). Starting in 2000, the company developed the Materion Worker Protection Program (MWPP), a multi-faceted beryllium exposure control program designed to reduce airborne exposures for the vast majority of workers to 0.2 μg/m^3 or less in most operations most of the time. According to information provided by Materion, a combination of engineering controls, work practices, and housekeeping, were used together to reduce average exposure levels to or below 0.2 μg/m^3 for the majority of workers (Materion Information Meeting, 2012). Also, two operations with historically high exposures, the wet plant and pebble plants, were decommissioned in 2000, thereby reducing average exposure levels. Therefore, the samples taken prior to 2000 may overestimate current exposures, but OSHA has not been provided with more recent sampling data to verify the effects of the exposure control program and plant changes, or to determine what exposure levels currently exist in the Elmore facility.

In five of the primary production job groups (i.e., hot work, cold work, production support, site support, and administrative work), the baseline exposure profile indicates that most exposures are already lower than the proposed PEL of 0.2 μg/m^3 and the alternative PEL of .1 μg/m^3. Median exposure values for these job groups range from non-detectable to 0.08 μg/m^3.

For three job groups (chemical operations, powdering, and furnace operations), the median exposure level exceeds the proposed PEL of 0.2 μg/m^3. Median exposure values for these job groups are 0.47, 0.37, and 0.68 μg/m^3 respectively, and only 15% to 29% of the available measurements are less than or equal to 0.2 μg/m^3 for these three job groups. Therefore, additional control measures would be required to achieve compliance with the proposed PEL for these job groups.

OSHA has identified several engineering controls the Agency preliminarily concludes can reduce exposures in chemical processes and powdering operations to less than or equal to 0.2 $\mu g/m^3$. In chemical processes, these include fail-safe drum-handling systems, full enclosure of drum-handling systems, ventilated enclosures around existing drum positions, automated systems to prevent drum overflow, and automated systems for container cleaning and disposal such as those designed for hazardous powders in the pharmaceutical industry. Similar engineering controls would reduce exposures in powdering operations. In addition, installing remote viewing equipment (or other equally effective engineering controls) to eliminate the need for workers to enter the die-loading hood during die filling will reduce exposures associated with this powdering task and reduce powder spills. Based on the availability of control methods to reduce exposures for each of the major sources of exposure in chemical and powdering operations, OSHA preliminarily concludes that exposures at or below the proposed 0.2 $\mu g/m^3$ PEL can be achieved in most chemical and powdering operations most of the time. OSHA preliminarily concludes that furnace operators' exposures can be reduced using appropriate ventilation, fume capture hoods, and other controls to reduce overall beryllium levels in foundries, but is not certain whether they can be reduced to the proposed PEL with currently available technology. OSHA requests additional information on current exposure data and potential control measures for primary beryllium production operations to further refine this analysis, and in particular information to demonstrate the feasibility of reducing exposures to or below the alternative PEL of 0.1 $\mu g/m^3$.

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SECTION 3—BERYLLIUM PRODUCTION, APPENDIX 1

Table IV-13—Supporting Personal Exposure Profile in the Beryllium Production Industry (2007–2008) (NAICCS 331419)[a,b,c,d,e]

Job Category and Work Group	No. of Full-Shift PBZ Samples[f]	Range (μg/m^3)	Mean (μg/m^3)	Median (μg/m^3)
ADMINISTRATIVE	*NO DATA*			
SITE SUPPORT	*NO DATA*			
PRODUCTION SUPPORT	*42*	*0.01 to 9.24*	*1.42*	*0.40*
Mix Makeup (furnace charge material)	*5*	*0.02 to 0.57*	*0.33*	*0.41*
Scrap Recycling	*19*	*0.01 to 9.24*	*2.40*	*2.00*
Inventory Control Center	*2*	*0.09 to 0.39*	*0.24*	*0.24*
Scrap Reclamation	*9*	*0.01 to 9.24*	*3.63*	*2.93*
Leaching	*3*	*2.10 to 4.59*	*3.74*	*4.53*
Resource Recovery	*5*	*0.07 to 0.61*	*0.26*	*0.19*
Maintenance	*17*	*0.04 to 5.90*	*0.74*	*0.27*
Production Equipment	*11*	*0.05 to 5.90*	*1.00*	*0.30*
Furnaces and Tools	*3*	*0.08 to 0.69*	*0.35*	*0.27*
Molds and Dies	*3*	*0.04 to 0.36*	*0.16*	*0.08*
Research and Development	*NO DATA*			
QA/QC/Inspection	*1*	*0.03*	*0.03*	*0.03*
COLD WORK	*70*	*0 to 2.91*	*0.30*	*0.09*
Rolling	*8*	*0 to 0.02*	*0.01*	*0.01*
Straightening	*NO DATA*			
Drawing	*NO DATA*			
Machining	*62*	*0.02 to 2.91*	*0.33*	*0.11*
Billet Preparation	*8*	*0.02 to 0.38*	*0.17*	*0.15*
Alloys	*14*	*0.03 to 0.23*	*0.07*	*0.05*
High Beryllium	*40*	*0.03 to 2.91*	*0.46*	*0.24*
HOT WORK	*33*	*0.01 to 1.30*	*0.13*	*0.06*
Hot Rolling/Extrusion	*17*	*0.03 to 0.61*	*0.13*	*0.08*
Annealing	*11*	*0.02 to 1.30*	*0.17*	*0.03*
Welding	*NO DATA*			
Pickling (elevated bath temperatures)	*4*	*0.01 to 0.05*	*0.03*	*0.03*
Degreasing (elevated solvent temperature)	*1*	*0.07*	*0.07*	*0.07*
POWDERING	*22*	*0.11 to 11.57*	*2.60*	*1.50*
Operator/Impact Grinding	*11*	*0.28 to 11.57*	*2.98*	*1.57*
Compact Loading/Sintering	*7*	*0.63 to 7.45*	*3.37*	*3.15*
Near Net Shape (operator and welder)	*4*	*0.11 to 0.31*	*0.19*	*0.18*
CHEMICAL OPERATIONS	*3*	*0.16 to 0.44*	*0.27*	*0.24*
Be Sulfate (GC salt & wet screening operators)[e]	*3*	*0.16 to 0.44*	*0.27*	*0.24*

Table IV-13—Supporting Personal Exposure Profile in the Beryllium Production Industry (2007–2008) (NAICCS 331419)[a,b,c,d,e]				
Job Category and Work Group	**No. of Full-Shift PBZ Samples[f]**	**Range (µg/m³)**	**Mean (µg/m³)**	**Median (µg/m³)**
FURNACE OPERATIONS	*24*	*0.01 to 9.24*	*1.19*	*0.62*
Alloy Induction	*11*	*0.03 to 1.00*	*0.42*	*0.33*
Alloy Arc	*2*	*0.69 to 0.89*	*0.79*	*0.79*
High Beryllium Vacuum Casting	*3*	*0.22 to 2.30*	*1.21*	*1.11*
High Beryllium Atomization	*NO DATA*			
Beryllium Oxide	*8*	*0.01 to 9.24*	*2.35*	*0.93*

[a] *This supporting profile is a summary of the NIOSH 2007–2008 full-shift PBZ (lapel-type) total beryllium exposure results for workers at the Brush Wellman, Inc., Elmore, Ohio, plant (NIOSH Elmore database, 2011).*

[b] *Full-shift sample results are based on the actual sample duration. These sample durations are of 360 minutes or longer. Exceptions were made for several job categories due to the limited number of samples, and samples greater than 300 minutes were included for Production Support (i.e., Inventory Control Center, Furnaces and Tools, and Molds and Dies work groups).*

[c] *Samples were analyzed by NIOSH Method 7102 (Beryllium and compounds, as Be) or 7300 (Elements by ICP), and the analytical LOD was reported to be 0.1 µg per filter. For sample results below the LOD, a sample weight of 0.05 µg (one-half the analytical LOD) was used to calculate the volume-adjusted nondetectable sample concentrations.*

[d] *No sampling data was available for the following job categories and work groups: Administrative, Site Support, Production Support (Research and Development), Cold Work (Straightening, and Drawing), Hot Work (Welding), Furnace Operations (High Beryllium Atomization).*

[e] *Three outliers were excluded: a 321 µg/m³ sample for Production Support (Leaching), a 33 µg/m³ sample for Powdering (Impact Grinding), and a 29 µg/m³ sample for Powdering (Compact Loading).*

[f] *PBZ means personal breathing zone (lapel-type) samples.*

Source: NIOSH Elmore database, 2011

Table IV-14—Distribution of Supporting Full-Shift PBZ Exposure Results for Total Beryllium in the Beryllium Production Industry (2007–2008) (NAICCS 331419)[a,b,c,d,e]							
Job Category and Work Group	**Number of Full-Shift PBZ Sample Results in Range (µg/m³)**						**Total No. of Samples**
	< 0.1	**≥ 0.1 to ≤ 0.2**	**> 0.2 to ≤ 0.5**	**> 0.5 to ≤ 1.0**	**> 1.0 to ≤ 2.0**	**> 2.0**	
ADMINISTRATIVE	*NO DATA*						
SITE SUPPORT	*NO DATA*						
PRODUCTION SUPPORT	*12 (32%)*	*3 (8%)*	*5 (13%)*	*3 (8%)*	*4 (11%)*	*11 (29%)*	*38 (100%)*
Mix Makeup (furnace charge)	*1 (20%)*	*1 (20%)*	*2 (40%)*	*1 (20%)*	*0 (0%)*	*0 (0%)*	*5 (100%)*
Scrap Recycling	*1 (11%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*1 (11%)*	*7 (78%)*	*9 (100%)*
Inventory Control Center	*0 (0%)*	*1 (50%)*	*1 (50%)*	*0 (0%)*	*0 (0%)*	*0 (6%)*	*2 (100%)*
Scrap Reclamation	*3 (11%)*	*2 (8%)*	*9 (35%)*	*4 (15%)*	*5 (19%)*	*3 (12%)*	*26 (100%)*
Leaching	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*3 (100%)*	*3 (100%)*
Resource Recovery	*1 (20%)*	*2 (40%)*	*1 (20%)*	*1 (20%)*	*0 (0%)*	*0 (0%)*	*5 (100%)*

Table IV-14—Distribution of Supporting Full-Shift PBZ Exposure Results for Total Beryllium in the Beryllium Production Industry (2007–2008) (NAICCS 331419)[a,b,c,d,e]

Job Category and Work Group	Number of Full-Shift PBZ Sample Results in Range (μg/m³)						Total No. of Samples
	< 0.1	≥ 0.1 to ≤ 0.2	> 0.2 to ≤ 0.5	> 0.5 to ≤ 1.0	> 1.0 to ≤ 2.0	> 2.0	
Maintenance	*8 (47%)*	*0 (0%)*	*3 (18%)*	*2 (12%)*	*3 (18%)*	*1 (6%)*	*17 (100%)*
Production Equipment	*5 (45%)*	*0 (0%)*	*1 (9%)*	*1 (9%)*	*3 (27%)*	*1 (9%)*	*11 (100%)*
Furnaces and Tools	*1 (33%)*	*0 (0%)*	*1 (33%)*	*1 (33%)*	*0 (0%)*	*0 (0%)*	*3 (100%)*
Molds and Dies	*2 (67%)*	*0 (0%)*	*1 (33%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*3 (100%)*
Research and Development	*NO DATA*						
QA/QC/Inspection	*1 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*1 (100%)*
COLD WORK	*36 (51%)*	*9 (13%)*	*15 (21%)*	*5 (7%)*	*3 (4%)*	*2 (3%)*	*70 (100%)*
Rolling	*8 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*8 (100%)*
Straightening	*NO DATA*						
Drawing	*NO DATA*						
Machining	*28 (45%)*	*9 (15%)*	*15 (24%)*	*5 (8%)*	*3 (5%)*	*2 (3%)*	*62 (100%)*
Billet Preparation	*3 (38%)*	*2 (25%)*	*3 (38%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*8 (100%)*
Alloys	*10 (71%)*	*3 (21%)*	*1 (9%)*	*0 (7%)*	*0 (0%)*	*0 (0%)*	*14 (100%)*
High Beryllium	*15 (38%)*	*4 (10%)*	*11 (28%)*	*5 (13%)*	*3 (8%)*	*2 (5%)*	*40 (100%)*
HOT WORK	*24 (73%)*	*5 (15%)*	*2 (6%)*	*1 (3%)*	*1 (3%)*	*0 (0%)*	*33 (100%)*
Hot Rolling/Extrusion	*10 (59%)*	*5 (29%)*	*1 (6%)*	*1 (6%)*	*0 (0%)*	*0 (0%)*	*17 (100%)*
Annealing	*9 (82%)*	*0 (0%)*	*1 (9%)*	*0 (0%)*	*1 (9%)*	*0 (0%)*	*11 (100%)*
Welding	*NO DATA*						
Pickling (elevated bath temperatures)	*4 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*4 (100%)*
Degreasing (elevated temperatures)	*1 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*1 (100%)*
POWDERING	*0 (0%)*	*3 (14%)*	*2 (9%)*	*3 (14%)*	*5 (23%)*	*9 (41%)*	*22 (100%)*
Operator/Impact Grinding	*0 (0%)*	*0 (0%)*	*1 (9%)*	*1 (9%)*	*5 (45%)*	*4 (36%)*	*11 (100%)*
Compact Loading/Sintering	*0 (0%)*	*0 (0%)*	*0 (0%)*	*2 (29%)*	*0 (0%)*	*5 (71%)*	*7 (100%)*
NNS (operator and welder)	*0 (0%)*	*3 (75%)*	*1 (25%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*4 (100%)*

Table IV-14—Distribution of Supporting Full-Shift PBZ Exposure Results for Total Beryllium in the Beryllium Production Industry (2007–2008) (NAICCS 331419)[a,b,c,d,e]

Job Category and Work Group	Number of Full-Shift PBZ Sample Results in Range (μg/m³)						Total No. of Samples
	< 0.1	≥ 0.1 to ≤ 0.2	> 0.2 to ≤ 0.5	> 0.5 to ≤ 1.0	> 1.0 to ≤ 2.0	> 2.0	
CHEMICAL OPERATIONS	*0 (0%)*	*1 (33%)*	*2 (67%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*3 (100%)*
Beryllium Sulfate Salt (GC salt and wet screen operators)	*0 (0%)*	*1 (33%)*	*2 (67%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*3 (100%)*
FURNACE OPERATIONS	*5 (21%)*	*1 (4%)*	*4 (17%)*	*9 (38%)*	*1 (4%)*	*4 (17%)*	*24 (100%)*
Alloy Induction	*2 (5%)*	*1 (13%)*	*3 (32%)*	*5 (27%)*	*0 (14%)*	*0 (9%)*	*11 (100%)*
Alloy Arc	*0 (0%)*	*0 (0%)*	*0 (0%)*	*2 (100%)*	*0 (0%)*	*0 (0%)*	*2 (100%)*
High-Beryllium Vacuum Cast	*0 (0%)*	*0 (0%)*	*1 (33%)*	*0 (0%)*	*1 (33%)*	*1 (33%)*	*3 (100%)*
High-Beryllium Atomization	*NO DATA*						
Beryllium Oxide	*3 (38%)*	*0 (0%)*	*0 (0%)*	*2 (25%)*	*0 (0%)*	*3 (38%)*	*8 (100%)*

[a] This supporting profile is a summary of the NIOSH 2007–2008 full-shift PBZ (lapel-type) total beryllium exposure results for workers at the Brush Wellman, Inc., Elmore, Ohio, plant (NIOSH Elmore database, 2011).

[b] Full-shift sample results are based on the actual sample duration. These sample durations are of 360 minutes or longer. Exceptions were made for several job categories due to the limited number of samples, and samples greater than 300 minutes were included for Production Support (i.e., Inventory Control Center, Furnaces and Tools, and Molds and Dies work groups).

[c] Samples were analyzed by NIOSH Method 7102 (Beryllium and compounds, as Be) or 7300 (Elements by ICP), and the analytical LOD was reported to be 0.1 μg per filter. For sample results below the LOD, a sample weight of 0.05 μg (one-half the analytical LOD) was used to calculate the volume-adjusted nondetectable sample concentrations.

[d] No sampling data was available for the following job categories and work groups: Administrative, Site Support, Production Support (Research and Development), Cold Work (Straightening, and Drawing), Hot Work (Welding), Furnace Operations (High Beryllium Atomization).

[e] Three outliers were excluded: a 321 μg/m³ sample for Production Support (Leaching), a 33 μg/m³ sample for Powdering (Impact Grinding), and a 29 μg/m³ sample for Powdering (Compact Loading).

Source: NIOSH Elmore database, 2011

SECTION 3—BERYLLIUM PRODUCTION, APPENDIX 2

Table IV-15—Detailed Distribution of Full-Shift PBZ Exposure Results for Total Beryllium in the Beryllium Production Industry (1999) (NAICCS 331419)[a,b,c]

Job Category and Work Group	Number of Full-Shift PBZ Sample Results in Range (μg/m^3)						Total No. of Samples
	< 0.1	≥ 0.1 to ≤ 0.2	> 0.2 to ≤ 0.5	> 0.5 to ≤ 1.0	> 1.0 to ≤ 2.0	> 2.0	
ADMINISTRATIVE	*833 (85%)*	*90 (9%)*	*39 (4%)*	*10 (1%)*	*6 (0.5%)*	*3 (0.5%)*	*981 (100%)*
Operations/Management	*368 (84%)*	*45 (10%)*	*20 (4.5%)*	*4 (1%)*	*2 (0.5%)*	*1 (0%)*	*440 (100%)*
Human Resources	*48 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*48 (100%)*
Information Systems	*45 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*45 (100%)*
Credit Union	*15 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*15 (100%)*
Environmental Health & Safety	*119 (90%)*	*11 (8%)*	*1 (1%)*	*0 (0%)*	*1 (1%)*	*0 (0%)*	*132 (100%)*
Medical	*48 (92%)*	*4 (8%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*52 (100%)*
Training	*14 (93%)*	*0 (0%)*	*1 (7%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*15 (100%)*
Production Planning	*106 (79%)*	*16 (12%)*	*4 (3%)*	*4 (3%)*	*2 (1.5%)*	*2 (1.5%)*	*134 (100%)*
Engineering	*70 (70%)*	*14 (14%)*	*13 (13%)*	*2 (2%)*	*1 (1%)*	*0 (0%)*	*100 (100%)*
SITE SUPPORT	*711 (81%)*	*100 (11%)*	*45 (5%)*	*15 (2%)*	*6 (1%)*	*2 (0%)*	*879 (100%)*
Laundry	*42 (88%)*	*5 (10%)*	*1 (2%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*48 (100%)*
Janitorial	*52 (80%)*	*11 (17%)*	*1 (1.5%)*	*1 (1.5%)*	*0 (0%)*	*0 (0%)*	*65 (100%)*
Landfill	*29 (97%)*	*1 (3%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*30 (100%)*
Facility Maintenance	*96 (74%)*	*21 (16%)*	*9 (7%)*	*3 (2%)*	*1 (1%)*	*0 (0%)*	*130 (100%)*
Analytical Laboratories	*144 (86%)*	*14 (8%)*	*8 (5%)*	*0 (0%)*	*1 (1%)*	*0 (0%)*	*167 (100%)*
Ship/Receive/Material Handle	*122 (92%)*	*10 (8%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*132 (100%)*
Wastewater Treatment	*27 (59%)*	*8 (17%)*	*9 (20%)*	*2 (4%)*	*0 (0%)*	*0 (0%)*	*46 (100%)*
Store (supply) Rooms	*31 (97%)*	*1 (3%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*32 (100%)*
Security	*27 (87%)*	*3 (10%)*	*1 (3%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*31 (100%)*
Boiler Operators	*5 (28%)*	*5 (28%)*	*8 (44%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*18 (100%)*
Facility Engineering	*105 (90%)*	*7 (6%)*	*1 (1%)*	*2 (2%)*	*1 (1%)*	*0 (0%)*	*116 (100%)*

Table IV-15—Detailed Distribution of Full-Shift PBZ Exposure Results for Total Beryllium in the Beryllium Production Industry (1999) (NAICCS 331419)[a,b,c]

Job Category and Work Group	Number of Full-Shift PBZ Sample Results in Range (μg/m³)						Total No. of Samples
	< 0.1	≥ 0.1 to ≤ 0.2	> 0.2 to ≤ 0.5	> 0.5 to ≤ 1.0	> 1.0 to ≤ 2.0	> 2.0	
Cafeteria	*14 (88%)*	*2 (12%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*16 (100%)*
Decontamination	*17 (35%)*	*12 (25%)*	*7 (15%)*	*7 (15%)*	*3 (6%)*	*2 (4%)*	*48 (100%)*
PRODUCTION SUPPORT	*484 (56%)*	*129 (15%)*	*105 (12%)*	*54 (6%)*	*43 (5%)*	*46 (6%)*	*861 (100%)*
Mix Makeup (furnace charge)	*14 (27%)*	*9 (18%)*	*17 (33%)*	*5 (10%)*	*5 (10%)*	*1 (2%)*	*51 (100%)*
Scrap Recycling	*14 (13%)*	*26 (23%)*	*30 (27%)*	*14 (13%)*	*11 (10%)*	*16 (14%)*	*111 (100%)*
Inventory Control Center	*3 (19%)*	*7 (44%)*	*5 (31%)*	*0 (0%)*	*0 (0%)*	*1 (6%)*	*16 (100%)*
Scrap Reclamation	*3 (11%)*	*2 (8%)*	*9 (35%)*	*4 (15%)*	*5 (19%)*	*3 (12%)*	*26 (100%)*
Leaching	*1 (17%)*	*0 (0%)*	*2 (33%)*	*1 (17%)*	*0 (0%)*	*2 (33%)*	*6 (100%)*
Resource Recovery	*7 (11%)*	*17 (27%)*	*14 (22%)*	*9 (14%)*	*6 (10%)*	*10 (16%)*	*63 (100%)*
Maintenance	*155 (45%)*	*65 (19%)*	*43 (12%)*	*29 (8%)*	*26 (8%)*	*27 (8%)*	*345 (100%)*
Production Equipment	*109 (47%)*	*50 (21%)*	*25 (11%)*	*16 (7%)*	*21 (9%)*	*11 (5%)*	*232 (100%)*
Furnaces and Tools	*6 (10%)*	*5 (9%)*	*16 (27%)*	*12 (21%)*	*5 (9%)*	*14 (24%)*	*58 (100%)*
Molds and Dies	*40 (73%)*	*10 (18%)*	*2 (4%)*	*1 (2%)*	*0 (0%)*	*2 (3%)*	*55 (100%)*
Research and Development	*91 (76%)*	*15 (13%)*	*10 (8%)*	*2 (2%)*	*0 (0%)*	*1 (1%)*	*119 (100%)*
QA/QC/Inspection	*210 (89%)*	*14 (6%)*	*5 (2%)*	*4 (2%)*	*1 (0.5%)*	*1 (0.5%)*	*235 (100%)*
COLD WORK	*335 (61%)*	*107 (19%)*	*74 (13%)*	*13 (2%)*	*17 (3%)*	*9 (2%)*	*555 (100%)*
Rolling	*24 (80%)*	*2 (7%)*	*3 (10%)*	*0 (0%)*	*1 (3%)*	*0 (0%)*	*30 (100%)*
Straightening	*42 (75%)*	*7 (12%)*	*3 (5%)*	*2 (4%)*	*2 (4%)*	*0 (0%)*	*56 (100%)*
Drawing	*26 (84%)*	*5 (16%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*31 (100%)*
Machining	*243 (55%)*	*93 (21%)*	*68 (16%)*	*11 (3%)*	*14 (3%)*	*9 (2%)*	*438 (100%)*
Billet Preparation	*38 (42%)*	*29 (32%)*	*13 (15%)*	*4 (4.5%)*	*4 (4.5%)*	*2 (2%)*	*90 (100%)*
Alloys	*151 (70%)*	*40 (18%)*	*20 (9%)*	*1 (1%)*	*2 (1%)*	*2 (1%)*	*216 (100%)*
High Beryllium	*54 (41%)*	*24 (18%)*	*35 (26%)*	*6 (5%)*	*8 (6%)*	*5 (4%)*	*132 (100%)*

Table IV-15—Detailed Distribution of Full-Shift PBZ Exposure Results for Total Beryllium in the Beryllium Production Industry (1999) (NAICCS 331419)[a,b,c]

Job Category and Work Group	Number of Full-Shift PBZ Sample Results in Range (µg/m³)						Total No. of Samples
	< 0.1	≥ 0.1 to ≤ 0.2	> 0.2 to ≤ 0.5	> 0.5 to ≤ 1.0	> 1.0 to ≤ 2.0	> 2.0	
HOT WORK	*205 (69%)*	*56 (19%)*	*29 (10%)*	*6 (2%)*	*0 (0%)*	*1 (0%)*	*297 (100%)*
Hot Rolling/Extrusion	*109 (73%)*	*33 (22%)*	*7 (4%)*	*1 (1%)*	*0 (0%)*	*0 (0%)*	*150 (100%)*
Annealing	*37 (58%)*	*16 (25%)*	*10 (16%)*	*1 (1%)*	*0 (0%)*	*0 (0%)*	*64 (100%)*
Welding	*0 (0%)*	*4 (27%)*	*6 (40%)*	*4 (27%)*	*0 (0%)*	*1 (6%)*	*15 (100%)*
Pickling	*40 (85%)*	*3 (6%)*	*4 (9%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*47 (100%)*
Degreasing	*19 (90%)*	*0 (0%)*	*2 (10%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*21 (100%)*
POWDERING	*8 (11%)*	*13 (18%)*	*22 (31%)*	*14 (19%)*	*11 (15%)*	*4 (6%)*	*72 (100%)*
Operator/Impact Grinding	*5 (19%)*	*1 (4%)*	*6 (23%)*	*6 (23%)*	*7 (27%)*	*1 (4%)*	*26 (100%)*
Compact Loading/Sintering	*3 (16%)*	*6 (32%)*	*5 (26%)*	*0 (0%)*	*3 (16%)*	*2 (10%)*	*19 (100%)*
Near Net Shape (operator & welder)	*0 (0%)*	*6 (22%)*	*11 (41%)*	*8 (29%)*	*1 (4%)*	*1 (4%)*	*27 (100%)*
CHEMICAL OPERATIONS	*1 (5%)*	*2 (10%)*	*10 (50%)*	*4 (20%)*	*2 (10%)*	*1 (5%)*	*20 (100%)*
Beryllium Sulfate Salt (GC salt and wet screen operators)	*1 (5%)*	*2 (10%)*	*10 (50%)*	*4 (20%)*	*2 (10%)*	*1 (5%)*	*20 (100%)*
FURNACE OPERATIONS	*8 (5%)*	*20 (12%)*	*42 (24%)*	*46 (27%)*	*25 (14%)*	*31 (18%)*	*172 (100%)*
Alloy Induction	*5 (5%)*	*13 (13%)*	*31 (32%)*	*26 (27%)*	*13 (14%)*	*9 (9%)*	*97 (100%)*
Alloy Arc	*0 (0%)*	*1 (3%)*	*6 (16%)*	*14 (37%)*	*7 (18%)*	*10 (26%)*	*38 (100%)*
High Beryllium Vacuum Cast	*0 (0%)*	*3 (34%)*	*2 (22%)*	*1 (11%)*	*2 (22%)*	*1 (11%)*	*9 (100%)*
High Beryllium Atomization	*0 (0%)*	*0 (0%)*	*0 (0%)*	*4 (31%)*	*0 (0%)*	*9 (69%)*	*13 (100%)*
Beryllium Oxide	*3 (20%)*	*3 (20%)*	*3 (20%)*	*1 (7%)*	*3 (20%)*	*2 (13%)*	*15 (100%)*

[a] *The beryllium production exposure profile is a summary of the 1999 full-shift PBZ (lapel-type) total beryllium exposure results for workers at the Brush Wellman, Inc., Elmore, Ohio, plant.*

[b] *Full-shift sample results are based on the actual sample duration. Full-shift samples have a duration of 360 minutes or longer (in dataset, all samples are at least 400 minutes duration).*

[c] *Samples were analyzed by NIOSH Methods 7102 (Beryllium and compounds, as Be) or 7300 (Elements by ICP), and the analytical LOD was reported to be 0.1 µg per filter. In the dataset received by OSHA, a value had been assigned to each sample result that was below the LOD; a sample weight of 0.05 µg (one-half the analytical LOD) was used to calculate the volume-adjusted nondetectable sample concentrations (i.e., every sample was assigned a value). Samples with results below the LOD were not identified.*

Source: Brush Wellman, 2004

SECTION 4—BERYLLIUM OXIDE CERAMICS AND COMPOSITES

Beryllium oxide ceramics and beryllium oxide-metal matrix composites are used to manufacture materials with unique physical, thermal, and electrical properties for use in electronic equipment in the aerospace and other industries (Parsonage, 2011).[78] The U.S. Geological Survey estimates that beryllium oxide applications accounted for more than 15 percent of the beryllium consumed in the United States in 1996 (Cunningham, 2004). Industry representatives indicate that 90 to 95 percent of beryllium oxide is used for ceramic electronic applications; the remainder is used for metal matrix composite applications (Facility A-1, 2000; Facility B-1, 2000; Facility C-1, 2000; Facility H-1, 2000; Facility I-1, 2000; Facility M-1, 2000; Facility N-1, 2000).[79] This section focuses on the processes used to manufacture beryllium oxide ceramics and beryllium oxide-metal matrix composites.

Beryllium oxide products are prepared, shaped, and then fired by methods similar to those used with other ceramic materials, such as aluminum oxide (clay). To form the precise shapes required, manufacturers typically finish products using precision machining methods. Beryllium oxide product manufacturing involves the following categories of employees: material preparation operators, forming operators, kiln operators, machining operators, metallization workers, production support workers, and administrative staff.

Beryllium oxide-metal matrix composites are mixtures of beryllium metal and beryllium oxide created with different ratios of the two materials to obtain the desired physical, thermal and mechanical properties. The materials are produced by blending beryllium and beryllium oxide powders into a homogeneous mixture, which is formed into blocks using processes similar to those used for beryllium ceramics. The blocks are sliced into cards, which are then sawn to specified sizes, lapped and machined to final dimensions. The parts can then be plated with different types of metal as well. Beryllium oxide-metal matrix composites are used primarily for aircraft and satellite avionic packaging, and represent a relatively small fraction (5-10%) of annual beryllium oxide used in the US. They are produced using similar production processes and exposure control methods as those used for beryllium oxide ceramics (Parsonage, 2011). OSHA assumes that the control methods used for beryllium oxide ceramics will also reduce exposures when manufacturing and processing beryllium oxide-metal matrix composites. Accordingly, OSHA's preliminary technological feasibility conclusions apply whether a particular task is performed with beryllium oxide ceramic material or with beryllium oxide-metal matrix composite material. OSHA requests exposure data specifically associated with beryllium oxide-metal matrix composites.

The initial portion of this section describes the industries that produce beryllium oxide ceramic products, the estimated total number of establishments involved, and their employment numbers.

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[78] Beryllium oxide-metal matrix composite is produced in a similar manner to the way beryllium metal powder is consolidated into billets. This general process of powder densification into billets is described in Section 3—Beryllium Production.

[79] The level of beryllium oxide in the metal matrix composite varies between 28 and 71 percent by weight, forming three variations of matrix composites (with the trade names E-20, E-40, and E-60) [Source: Brush Ceramic Products Material Safety Data Sheet—No. C20. Beryllium Metal–Matrix Composite (E20, E-40, and E-60). Revised January 1, 2010.]

Later portions of this section present the exposure profiles for the various categories of workers described above, as well as a discussion of the technological feasibility of reducing worker exposures in beryllium oxide ceramics and composite production activities.

Industry profile information was obtained through discussions with fabricators and finishers of beryllium oxide products, distributors of beryllium oxide raw materials, professional society board members, ceramic engineers, industrial hygienists, and research scientists. Other information sources included relevant scientific reports and trade literature. The exposure profile and technological feasibility data came from information provided to OSHA by the affected industries, from site visits to two primary beryllium oxide ceramic producers, and from discussions with industry consultants. The following paragraphs provide estimates of the number of affected establishments and the number of workers at these establishments that produce beryllium oxide ceramic and composite products.

NUMBER OF ESTABLISHMENTS

OSHA identified only two U.S. facilities that process beryllium oxide powder into various forms for further manufacturing. This section discusses these two sites as Site 3 (ERG Beryllium Site 3, 2003) and Site 10 (ERG Beryllium Site 10, 2006: Brush Ceramic Products in Tucson, Arizona, a subsidiary of Materion Brush, Inc., formerly Brush Wellman Incorporated).[80] These facilities are the primary beryllium oxide ceramic producers. They process “green” (unfired) beryllium oxide powder and then fire it.[81] Thus, these facilities perform the powder material handling, pressing/forming, and kiln operations described below. They also ship beryllium oxide ceramic products as unfinished formed shapes to approximately 100 other manufacturing facilities for processing into various ceramic parts. According to reports from a major beryllium manufacturer, beryllium oxide ceramic products were sold to 102 different companies as unfinished shapes (Kolanz, 2001). OSHA estimates that 92 establishments within these 102 companies are working with beryllium oxide today. OSHA has classified these 92 establishments into eight NAICS codes. These establishments are presented in Table IV-16. Please refer to Chapter III, Industrial Profile, of the Preliminary Economic Analysis (PEA) for details on OSHA’s methodology in the distribution of affected establishments within these NAICS codes.

The two primary beryllium oxide ceramic producers and the downstream establishments that fabricate porcelain electronic and electrical insulators, molded porcelain parts for electrical devices, beryllium oxide composites, and other supplies are classified in Porcelain Electrical Supply Manufacturing (NAICS code 327113). Major customers of these facilities include aerospace and military hardware manufacturers. The 2010 County Business Patterns reported a total of 106 establishments in NAICS code 327113. The 2002 Census listed 18 of the 120 firms in this NAICS code (with shipments of $100,000 or more) as manufacturing beryllium oxide, titanate, and other ceramic electrical products and components for electronic applications (U.S.

[80] Materion Corporation used to be called Brush Wellman. In 2011, however, subsequent to the collection of the information presented in this chapter, the name changed. “Brush Wellman” is used whenever the data being discussed pre-date the name change.
[81] Unfired beryllium oxide is called “green” because it has a greenish tinge.

Census Bureau, 2002).[82] These firms also engage in metallizing operations, in which a coating of metal is placed on the beryllium oxide ceramic or composite pieces, and many also perform some machining operations, such as grinding, cutting, or polishing (Pekrul, 2004). Discussions with industry personnel suggest that the actual number of domestic manufacturers of beryllium oxide ceramic products, including the primary beryllium oxide producers is less than 18 firms, possibly as low as one-half this number (Pekrul, 2004). OSHA estimates that there are 2 primary beryllium oxide producers' establishments and 14 downstream establishments in the Porcelain Electrical Supply Manufacturing NAICS code. Refer to PEA Chapter III, Industry Profile, for details on OSHA's methodology used to obtain this estimate.

Beryllium oxide ceramics are also used to produce other specialty products, such as traveling wave tubes used in microwave applications. These manufacturers braze beryllium oxide over a metal helix and assemble the tubes with finished beryllium oxide ceramic parts (Facility D-1, 2000). The 2010 County Business Patterns reports 79 establishments in the relevant NAICS code 334411 (Electron Tube Manufacturing) (U.S. Census Bureau, 2010), but industry contacts indicated that a relatively small number of firms in this industry produce traveling wave tubes using beryllium. One contact estimated that 20 to 30 companies produce these tubes (Facility J-1, 2000). Neither the 2002 nor 2007 Censuses provide disaggregated statistics regarding the number of establishments that manufacture traveling wave tubes, but the 2007 Census reported an overall total of 70 firms in this NAICS code industry (U.S. Census Bureau, 2002; U.S. Census Bureau, 2007). OSHA did not identify any other information that provided profile statistics on this group of firms, and the Agency estimates that 21 firms produce traveling wave tubes with beryllium. Refer to PEA Chapter III, Industry Profile, for details on OSHA's methodology used to obtain this estimate.

From OSHA's estimated total of 92 downstream users, this leaves 55 remaining users to be distributed among relevant industries. Based on Materion's description of customers for beryllium oxide, OSHA believes that the remaining 55 customers use beryllium oxide ceramics in the production of four types of electrical and electronic products: (1) wireless base stations (such as cell towers); (2) various electronics devices (including resistor cores, heat sinks for satellites, and automotive ignitions); (3) medical laser devices; and (4) lasers used in entertainment devices.

Product manufacturers for these electronics products are classified in six different NAICS codes: NAICS 334415: Electronic Resistor Manufacturing; NAICS 334419: Other Electronic Component Manufacturing; NAICS 336322: Other Motor Vehicle Electrical and Electronic Equipment Manufacturing; NAICS 334220: Radio and Television Broadcasting and Wireless Communications Equipment Manufacturing; NAICS 334510: Electromedical and Electrotherapeutic Apparatus Manufacturing; and NAICS 334310: Audio and Video Equipment Manufacturing.

OSHA has preliminarily concluded that the remaining 55 customers purchasing beryllium oxide from Materion will fall within these six industries. These companies were distributed among these six NAICS codes based on Materion customer survey report descriptions and NAICS titles.

[82] Similarly disaggregated information for this industry is not provided by the 2007 Economic Census, so the 2002 numbers are presented here.

In addition, a UK company (Consolidate Beryllium Limited) also sells beryllium oxide products in the U.S. market. The customers contacted generally noted that they purchased products from Materion Corporation as well as its domestic and UK competitors. Thus, the assumption that Materion Corporation's customers represent virtually all customers in these industries should generally hold. Based on the Brush Wellman customer survey report descriptions, the Brush Wellman distribution of customers not already accounted for, and NAICS titles, the affected establishments in all of the 92 downstream users were distributed among several NAICS codes, as shown in Table IV-16. Some of the companies that work with beryllium oxide do so only occasionally (Facility B-1, 2000). Not all these establishments perform significant processing of beryllium oxide parts; some might only be assembling components.

Table IV-16—Distribution of Affected Beryllium Oxide Ceramic Industries by NAICS Category

NAICS		Number of Establishments
327113	*Porcelain electrical supply manufacturing (SIC 3264)—Total beryllium oxide, titanate, and other ceramic electrical products and components for electronic applications, n.e.c.*	*16*
334411	*Electron tube manufacturing—Total beryllium oxide-based traveling wave tubes. (SIC 3671)*	*21*
334415	*Electronic resistor manufacturing (SIC 3676)*	*12*
334419	*Other electronic component manufacturing (SIC 3679)*	*9*
336322	*Other motor vehicle electrical and electronic equipment manufacturing (SIC 3694 and 3714)*	*10*
334220	*Cellular telephones manufacturing (SIC 3663 and 3679)*	*10*
334510	*Electromedical equipment manufacturing (SIC 3845)*	*9*
334310	*Compact disc players manufacturing (SIC 3651 and 3679)*	*5*
Total		**92**

Sources: U.S. Census Bureau, 2002; U.S. Census Bureau, 2010; OSHA Office of Regulatory Affairs

NUMBER OF EMPLOYEES

Although the Brush Wellman customer survey provides fairly current information about the number of employees in beryllium oxide-related manufacturing operations, historical data are limited. However, the National Institute for Occupational Safety and Health's (NIOSH) 1981-1983 National Occupational Exposure Survey (NOES) offers some information. Based on survey data, NIOSH estimated that 4,305 workers were exposed to beryllium oxide in the workplace (NIOSH NOES, 1989). According to industry representatives, fewer firms are working with beryllium oxide due to its potential toxicity and the reduced availability of beryllium oxide powder, thus the number has mostly like declined since the 1980's (Facility B-1, 2000; Facility C-1, 2000; Facility D-1, 2000; Facility H-1, 2000; Facility J-1, 2000; Facility K-1, 2000; Facility L-1, 2000).

In the absence of more concrete information, OSHA estimates that the total number of affected employees is 5,722 among the 92 affected establishments. This estimate was derived from the average number of employees in an establishment in a particular NAICS code multiplied by the number of affected establishments estimated to be in this same NAICS code. The Agency may be over-counting the number of employees by using the average number of employees per establishment to estimate the total. Refer to PEA Chapter III, Industry Profile, for details on OSHA's methodology used to obtain this estimate.

Table IV-17—Distribution of Affected Beryllium Oxide Ceramic Employees by NAICS Category

NAICS		Affected Employees
327113	*Porcelain electrical supply manufacturing (SIC 3264)—Total beryllium oxide, titanate, and other ceramic electrical products and components for electronic applications, n.e.c.*	*689*
334411	*Electron tube manufacturing—Total beryllium oxide-based traveling wave tubes. (SIC 3671)*	*1,298*
334415	*Electronic resistor manufacturing (SIC 3676)*	*732*
334419	*Other electronic component manufacturing (SIC 3679)*	*372*
336322	*Other motor vehicle electrical and electronic equipment manufacturing (SIC 3694 and 3714)*	*605*
334220	*Cellular telephones manufacturing (SIC 3663 and 3679)*	*984*
334510	*Electromedical equipment manufacturing (SIC 3845)*	*946*
334310	*Compact disc players manufacturing (SIC 3651 and 3679)*	*95*
Total		**5,722**

Sources: U.S. Census Bureau, 2002; U.S. Census Bureau, 2010; OSHA Office of Regulatory Affairs

Industry contacts verified that most beryllium oxide handling operations at these producers are small and suggested that the fabrication facilities are among the smaller firms in the customer population. Most establishments employ between five and 20 production workers (Facility B-1, 2000; Facility E-1, 2000; Facility G-1, 2000; Facility H-1, 2000). One firm employs 50 to 60 production workers, but not all of them work on beryllium oxide projects (Facility O-1, 2000).

PROCESS DESCRIPTION

ERG visited the two primary beryllium oxide ceramics production facilities and surveyed a number of operations in which beryllium exposures are possible. For the purposes of this analysis, these facilities are identified as Site 3 (ERG Beryllium Site 3, 2003) and Site 10 (ERG Beryllium Site 10, 2006). At Site 3, ERG also conducted air monitoring. Additional information on the industry was obtained from industry consultants familiar with beryllium oxide operations (Frigon, 2004).

The first step in producing beryllium oxide ceramic products involves material preparation. Pure beryllium oxide arrives at the plant as a crystalline powder in 45-gallon drums.[83] Material preparation operators process the raw beryllium oxide powder into formulated ceramic powders that will be used to make beryllium oxide components that meet product and customer specifications. Material preparation typically involves mixing, screening, milling, spray drying, blending, and otherwise treating the raw beryllium oxide powder and any other ingredients. Forming operators shape the beryllium oxide powder using a variety of forming methods, such as pressing and extrusion. Kiln operators then heat (fire) the formed product in a kiln or furnace at high temperatures to fuse the material into shaped ceramic products.

At subsequent stages of production, machining operators precision-cut, lathe, and grind the ceramic product to refine its shape. Fired ceramics can also be metalized by applying a metal layer that provides a bonding surface for subsequent attachment of metal parts or chips (ASME, 2002).

Some parts are machined before firing because the compacted ceramic is soft and easier to shape with machine tools. This process is termed "green machining" and includes a variety of complex (precision) machining operations, such as lapping (e.g., cylindrical, centerless, and surface grinding), dicing, and drilling, that help the manufacturer meet customers' dimensional specifications (ASME, 2002).[84]

Production support workers perform tasks such as packaging and maintenance. These activities produce little or no beryllium dust; however, production support workers may be exposed to beryllium when they perform occasional special services, when they are co-located with production activities, or when dust is inadvertently transferred to their work areas from the production areas of the plant.

Downstream facilities that purchase beryllium oxide ceramics to manufacture custom parts for various industries do not prepare raw beryllium oxide powder or fire green ceramic materials; only the two primary beryllium oxide ceramics producers process raw beryllium oxide powder. The downstream facilities might, however, process fired ceramic products, which could consist of metallization; a second firing in a tunnel-type kiln or furnace; machining of the ceramics into precise shapes (e.g., lapping and polishing, laser machining, dicing); and other operations (Berakis, 2009).

Affected Occupations

Material Preparation Operators (Primary Beryllium Oxide Ceramics Producers Only)

Material preparation operators mix beryllium oxide powder through a series of dry and wet processing steps to create materials with the properties necessary for subsequent forming/shaping

[83] The 45-gallon raw powder drums are overpacked in 55-gallon drums.
[84] Compacting a loose powder produces a green compact. The machining of a green compact or ceramic in the unfired state is called green machining.

operations. The material preparation operator receives bulk beryllium oxide powder in drums and transfers the material—either automatically or manually—into mixing equipment to form an aqueous suspension of beryllium oxide, binder additives, and water. The bulk material is vacuum-conveyed through an isolated piping delivery system to the mixing containers (ERG Beryllium Site 10, 2006). Site 10 previously used a drum tipper to transfer powder to mixing containers, but in 1998, workers began placing the drum inside a partially enclosed local exhaust ventilation (LEV) hood when transferring powder. The operator removes the top of the drum and uses a vacuum lance to extract powder from the drum.[85] The worker remains outside the hood with only his hands (gloved) and arms (covered in protective sleeves) inside the enclosure.

The mixing equipment is used to homogenize the aqueous suspension into a slurry. Some formulations require the operator to mill the ingredients (e.g., in a ball mill or similar equipment) to reduce the particle size as part of the mixing process. Before the beryllium oxide material is shaped using a pressed-powder process, the material preparation operator must generate a specially prepared powder by pumping the slurry to a spray dryer that disperses material under a high-pressure airstream for rapid drying inside an enclosed chamber. Spray drying prepares the beryllium oxide powder by producing a consistent particle size (essential for product quality) and reducing the moisture content so that the powder will consolidate when compressed. Material preparation workers may also screen the spray-dried powder as an added step of quality control to ensure uniform size.

At Site 3, material preparation was performed manually inside a hood, although not all operations (such as spray drying) were performed while ERG investigators were on site (ERG Beryllium Site 3, 2003). The material preparation tasks that ERG observed included powder transfer from a vendor container into intermediate milling containers and the loading of powder into the rotational beryllium oxide powdering mill. Thus, the material preparation operator was potentially exposed during manual loading and unloading of bulk product containers and the rotational mill, when disconnecting product drums from the bottom of the spray dryer, and when servicing and maintaining associated equipment.[86]

Forming Operators (Primary Beryllium Oxide Ceramics Producers Only)

After material preparation, the next step is the forming operation, during which the beryllium oxide materials are shaped into a variety of small specialty ceramic products, ranging in size from a few millimeters to several inches). These forming operations occur at the two primary beryllium oxide ceramics producers' facilities. The forming processes include a variety of techniques common to the ceramics industry. Forming operators typically mold beryllium oxide using one of the following processes:[87]

[85] Beryllium oxide powder is not considered an explosion hazard, so explosion prevention controls are not necessary. The Brush Ceramic Products' Beryllia Ceramic Material Safety Data Sheet lists the explosion hazard as "not applicable" (Brush Ceramic Products, 2006b).

[86] As noted, the spray-drying operation was not observed during the ERG Beryllium Site 3 visit. Nevertheless, the spray-drying operation is anticipated to generate exposures when the worker performs container changes, similar to those observed at ERG Beryllium Site 3.

[87] Another forming operation previously performed by forming operators—***tape casting***—produced thin, flat ceramics from a solution containing moistened beryllium oxide powder. There is no indication that this process is currently being used in any facility.

- ***Dry (powder) pressing:*** A process in which forming operators use equipment to compress spray-dried, low-moisture beryllium oxide powder material into a die with a ram.
- ***Isostatic pressing:*** An advanced powder compaction process in which hydrostatic forming equipment applies even pressure on all sides of a liquid-tight rubber die containing beryllium oxide powder to form ceramic parts.
- ***Hot pressing:*** A process whereby beryllium oxide powder is simultaneously subjected to high temperature and high pressure in heated dies. This process is used for making parts with large diameters (24 inches) and limited complexity.
- ***Extrusion:*** A conventional mechanical process in which moist, paste-like beryllium oxide material is forced through a shaped orifice or die. This process is used for creating thick-walled ceramic tubes, rods, and other parts with small cross-sections.

During ***dry pressing,*** the forming operator starts by connecting the automated pressing equipment to containers filled with spray dried ceramic powder produced by the material preparation operators. At Site 10, visited by ERG in 2006, the beryllium oxide powder is brought into the forming area in 12-gallon plastic bottles. With the bottle upright, the forming operator removes the bottle cap and replaces it with a second cap that includes a feed mechanism. The operator also wraps vinyl tape around the cap to ensure a good seal on the bottle top. The operator then inverts the beryllium oxide powder container (a second worker may assist with the process), allowing powder to flow into a holding bin within the press. A measured amount of powder is positioned in the die, and the hydraulic press compacts the powder to form a firm cake in the shape of the product, which is then removed by the operator or ejected into a holding tray. The forming operator will then inspect, weigh, and vacuum the products before placing them on a tray for firing or other processing (ERG Beryllium Site 10, 2006).

Some presses run automatically so that one operator can tend a number of presses. The operator generally spends most of the shift working in the immediate vicinity of the presses. On certain product lines, the forming operator might also operate a dry, abrasive cut-off saw to remove unwanted material from the shapes formed during the pressing process.

For ***isostatic press*** operations, forming operators take the bottle of prepared beryllium oxide powder and place it inside a large LEV hood. Then they remove the cap and use a vacuum wand to empty the powder into a hopper on top of the hood. From the hopper, the powder is dispensed into a liquid-tight rubber mold within the hood. The operators then immerse the mold in a noncompressible fluid (oil or water) contained in a pressure vessel. The operator pressurizes the fluid in the vessel, which causes all surfaces of the mold to receive equal pressure. The result is a molded product shape with uniform density. To release the product shape, the forming operator removes the mold from the pressure vessel and disassembles it under an LEV hood. The operator also cleans the shape by hand.

During the material preparation activities observed at Site 3, the worker performed the manual operations (including product shape-washing) inside a long, laboratory-style exhaust hood equipped with running water and both back- and downdraft exhaust air flow. After washing, the product was placed in a covered container for transfer outside the hood (ERG Beryllium Site 3, 2003). Industry information indicates that isostatic pressing is used for both ceramic and beryllium oxide-metal matrix blends (Materion, 2011).

Pressing methods might also include ***hot pressing***. At one of the primary beryllium oxide ceramics producers' facility, beryllium oxide powder is hot pressed by simultaneously subjecting it to high temperature and pressure in heated graphite dies (ABI, 2006). Hot pressing is used only for special ceramic combination requirements.

As an alternative to pressing, the forming operator can ***extrude*** beryllium oxide material that is of a paste-like consistency. The paste is forced through a die (i.e., extruded) to form the dimensions of the product. The operator manually cuts and removes the product pieces from the die as they are being extruded and places the pieces on a product transfer cart for subsequent firing or other processing.

Overall, forming operators might be exposed to beryllium during several tasks, although the extent of potential exposure varies with the specific forming operation. The potential exposure points are when: 1) loading and connecting beryllium oxide powder material feed containers to the press, 2) loading the die with beryllium oxide powder, 3) pressing the part, 4) removing parts from the press, 5) removing excess material from the parts with a saw; and 6) unloading and disconnecting empty beryllium oxide powder product-feed containers. Additional potential exposure occurs during cleaning, service, and maintenance of the press and extrusion equipment.

Kiln Operators (Primary Beryllium Oxide Ceramics Producers and Downstream Users)

The kiln operator ensures that the kiln is working properly and that material is fired properly. Kiln operators place formed shapes inside the firing containers (called saggers). The saggers are manually placed on carts that are then rolled inside the kilns. The kiln is sealed, and formed products are fired/sintered at temperatures of 1,300°C to 1,400°C.[88] After the firing cycle is complete (e.g., during the next shift or the next day), the kiln operator opens the kiln and wheels the cart partially out of the kiln. The cart may then be left just outside the kiln until it cools sufficiently. Kiln operators enter and leave the kiln room throughout the work shift and might also leave the area and perform other tasks while waiting for fired parts to cool.

In some cases, the flash (excess ceramic material that forms along the edge of the part at the seam where molding materials meet) must be removed from the sintered parts. Kiln operators place the parts in a large drum with water and tumble them to remove the excess material. Then the parts must be finished (by machining operators) to achieve the dimensional requirements specified for the product (Facility B-1, 2000; Facility I-1, 2000).

One firm uses beryllium oxide chips as the raw material to make traveling wave tubes. These chips can be made by machining beryllium oxide ceramic blocks or other shapes made by forming operators. In this process, kiln operators pour beryllium oxide chips into a jigged furnace with other brazing materials and then raise the temperature. The beryllium oxide brazes onto the outside wall of copper helixes, which are then suspended in airtight tubes (Facility D-1, 2000).

[88] Sintering is a method for making objects from powder products by heating the material (below its melting point) until its particles adhere to each other (Wikipedia, 2006). During the sintering process, the strength of the powder mass increases, electrical resistivity and porosity decrease, and density increases (Johnson, 2000).

Machining Operators (Primary Beryllium Oxide Ceramics Producers and Downstream Users)

Machining of beryllium oxide ceramics and composites involves both large- and small-scale machining processes. Exposures occur when beryllium-containing particles become airborne as a result of the mechanical energy used to manipulate the formed shapes. In some cases, both for large- and small-scale operations, machining operators receive sintered beryllium oxide shapes in the form of blocks that must be shaped to precise sizes. For ***larger scale*** machining jobs, machining operators might oversee automated electrostatic discharge machines. These enclosed machines use jigs that operate under water to convert large ceramic blocks received from kiln operations into finished shapes. In other cases, machining operators receive the ceramics in "near-net-shapes"[89] that require only ***small-scale*** machining to meet final product specifications. Such small-scale machining processes include grinding, lapping, drilling, laser cutting/scribing, trimming, diamond dicing, water cutting, sanding, abrasive cutting, polishing, and chemical etching.

Machining operations may also be conducted with slurry-cutting machines. Once the product is machined, operators can then mill the emerging shapes with a diamond cutter and, when necessary, use a hole-burning machine.

Machining operators typically use wet methods and ventilation for machining fired ceramics (in contrast, green machining is typically performed dry). The operator manually loads the beryllium oxide products into the machining centers. Finished parts are manually removed from the machining centers, cleaned, and placed in holding containers. Some beryllium oxide operations use lasers for scribing onto beryllia plates that would be formed by a press. Although scribing is no longer performed at Site 10, at one time this facility used enclosed carbon dioxide lasers for scribing. The laser chamber had interlocking doors and was under LEV. The laser head moved down into the enclosure to operate, and the beryllium oxide piece was on a movable platform; once in position, the laser head was fixed and the part was moved (ERG Beryllium Site 10, 2006).

At Site 3, investigators observed precision grinding operations on beryllium oxide ceramic material parts. The precision grinding machining operator was running a surface grinder, which was fully enclosed and under LEV. The operator performed the cutting action as a wet process, under a flood of coolant. The worker positioned the part in the grinder enclosure, cycled the machine to cut the part (cycle time was approximately 3 minutes), and removed the part when the cycle was complete. Then, the machining operator rinsed the part in a tray of water, wiped it off with a sponge, and placed it in a parts tray. Both manual and automatic grinding techniques are used to achieve precise physical dimensions. Another available method in the shop includes cylindrical grinding. This grinding method used diamond wheels to machine a solid or hollow cylinder and is capable of removing material from any surface are of the cylinder. This technique can be performed dry (green machining) or wet through the application of metalworking fluid.

Additional discussions of precision machining (for beryllium and beryllium alloy products) are provided in Section 7—Precision Turned Products. In general, the machining of beryllium oxide ceramics is similar to machining of other beryllium materials (e.g., alloys). OSHA has no

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[89] These shapes are produced when beryllium oxide powder is loaded into dies and consolidated into preformed shapes with pressing techniques.

evidence that allows a comparison of the relative hazards of machining on beryllium oxide ceramics or metallic beryllium materials, although the hazards are thought to be similar. Beryllium oxide ceramic materials might generate more particulate during machining because the ceramics are more easily reduced to dust than solid beryllium metal, but this has not been confirmed in the technical literature.[90] In general, the same control measures are applied to machining beryllium oxide, metallic beryllium, and beryllium alloy materials.[91]

Metallization Workers (Primary Beryllium Oxide Ceramics Producers and Downstream Users)

Some beryllium oxide ceramics and composites are metallized, which involves plating or brazing with metal to permit the joining of the ceramic part to other pieces of equipment. Because the beryllium oxide ceramics are being coated but not cut or degraded in this step, there is generally no beryllium exposure during this process.[92]

The manufacture of laser bores exemplifies metallization work. During the manufacture of laser bores, workers first place the part in an enclosed metallizing machine and then take the part to a small kiln to bake on the metallization. Thus, these workers rotate among metallizing and kiln operations. They also transfer the parts to the lapping department as needed.

Production Support Workers (Primary Beryllium Oxide Ceramics Producers and Downstream Users)

This category includes packaging and maintenance jobs. Packaging workers receive finished parts from the production area, perform visual/dimensional inspections, and then package the products for shipment. Maintenance involves all types of repair tasks on production equipment and facilities, as well as janitorial work.

Administrative Staff (Primary Beryllium Oxide Ceramics Producers and Downstream Users)

This category includes front office, engineering, and research and development staff. These workers typically do not handle beryllium products directly during the manufacturing process, nor do they perform tasks that might generate beryllium dust. Some facilities allow administrative staff to pass through production areas or perform activities co-located near production areas, but others do not (ERG Beryllium Site 3, 2003; ERG Beryllium Site 10, 2006). Beryllium dust might also unwittingly be transported from production areas to administrative workspaces on paper, clothing, and other items, although facilities have taken measures to prevent transfer to nonproduction areas, as discussed below.

[90] Beryllium oxide contains a higher concentration of beryllium than beryllium alloys, but less than pure beryllium metal.
[91] For example, use of cutting fluids for cooling and dust control on machine tools is a uniform practice throughout materials machining industries (many machine tools come fitted for cutting fluid application regardless of the material to be worked, whether metal, ceramic, composites, or other materials). Additionally, wet control methods are widely used in other ceramic cutting operations (e.g., as a standard feature, saws used for tile and masonry cutting/shaping are designed for use with water applied to the abrasive cutting blade).
[92] The exposure profile indicates that some metallization workers are occasionally exposed to beryllium, which is why they are discussed in this analysis; however, no evidence indicates that these workers are directly exposed from their own operations.

Number of Workers by Job Category

Table IV-18 presents the distribution of beryllium oxide ceramic workers by job category. This distribution is based on information obtained during ERG's site visit to a primary beryllium oxide ceramics producer facility (Site 3 and Site 10) and from discussions with project consultants and other industry contacts (ERG Beryllium Site 10, 2006; ERG Beryllium Site 3, 2003; Frigon, 2004, 2005; Kolanz, 2001).

Table IV-18—Number of At-Risk Beryllium Oxide Workers by Job Category

Job Category	Number of Workers	Percent
Material Preparation Operators	*8*	*0.6%*
Forming Operators	*63*	*4.9%*
Kiln Operators	*22*	*1.7%*
Machining Operators	*433*	*33.6%*
Metallization Workers	*66*	*5.1%*
Production Support	*208*	*16.1%*
Packaging Operator	*14*	*1.1%*
Maintenance	*169*	*13.1%*
Janitor	*25*	*1.9%*
Administrative Staff	*489*	*38.0%*
Total	*1,289*	*100.0%*
Sources: ERG Beryllium Site 3, 2003; ERG Beryllium Site 10, 2006; Frigon, 2004, 2005; Kolanz, 2001		

EXPOSURE PROFILE

Data Sources

Four sources of exposure measurement data were used to determine the exposure profile for the beryllium oxide ceramic industry:

4. Personal breathing zone (PBZ) (lapel-type) air-sampling results taken between 1994 and 2003 at Site 10, a large beryllium oxide ceramics facility[93] (OSHA-H005C-2006-0870-0094). The docket submittal was made by Brush Wellman in 2003 and is presumed to represent exposure data from the facility termed Site 10 in this technological feasibility analysis.

[93] Lapel-type air sample refers to a PBZ sample. This terminology (i.e., lapel) was adopted by the beryllium industry to avoid confusion with high-volume (i.e., fixed area) air samples collected at breathing zone height. These and other fixed area samplers were used to calculate daily weighted average beryllium exposures in accordance with the Atomic Energy Commission method of monitoring.

5. A published report that provides information on beryllium oxide ceramics product manufacturing for a slightly earlier time period at Site 10 (Kreiss et al., 1996).[94]

6. PBZ and hand/surface contamination results obtained during a site visit to a primary beryllium oxide ceramics producer (Site 3).

7. PBZ exposure data from OSHA's Integrated Management Information System (IMIS) (OSHA, 2009).

No exposure information was obtained specifically for beryllium oxide metal composites, however, OSHA assumes that the potential for exposure is similar for both ceramics and composites.

The majority of the full-shift PBZ air-sampling results are from data associated with beryllium oxide operations at Site 10. Additional PBZ air-sampling results were collected during the visit to Site 3. OSHA acknowledges that the exposure profile for this sector might not represent the entire industry because it is primarily based on the results of one facility (Site 10); however, it represents the best available data. It is possible that the exposure profile might overestimate current exposures for some job categories at Site 10 because the facility has reportedly made enhancements to engineering, work practice, and migration controls since the samples were taken. It is also possible that the exposure profile underestimates potential exposures at other firms in this sector that might not have the level of controls employed at Site 10 or Site 3. However, no downstream users handle beryllium oxide powder or fire green materials, two processes that have high exposure potential.

The sampling results are organized into the seven major job categories described in the Process Description sub-section (i.e., material preparation operators, forming operators, kiln operators, machining operators, metallization workers, production support workers, and administrative staff).

ERG Beryllium Site 10 (1994–2003)

Exposure data includes 1,214 full-shift PBZ beryllium sample results obtained from 1994 through 2003 for workers at Site 10. These exposure data for Site 10 are included in unpublished data provided to ERG (Brush Wellman Tucson, 2004). Although the sample results were obtained over a 10-year period, nearly 50 percent of the samples were collected in 2001, when production levels peaked.[95] All results were obtained while workers produced beryllium oxide ceramic products, so all results are associated with essentially 100 percent beryllium oxide.[96]

Air samples were analyzed by NIOSH Method 7102 (Beryllium and compounds, as Be) or 7300 (Elements by ICP). The analytical limit of detection (LOD) was reported to be 0.1 micrograms (µg) beryllium per filter, which corresponds to an airborne concentration of approximately 0.1

[94] Kreiss et al. (1996) do not explicitly state that the beryllium ceramics plant in their investigation is Site 10. In NIOSH's Beryllium Research (2005) highlights newsletter, however, NIOSH indicates that the ceramics facility is the same facility termed Site 10 in this technological feasibility analysis.

[95] Around the 2000-2001 time-frame a major competitor of Site 10 ceased producing beryllium oxide powder. Site 10's business surged and the plant's production doubled.

[96] Where beryllium oxide is handled, it is generally 100 percent beryllium oxide or in combination with beryllium metal.

μg/m^3 for an 8-hour sample. For sample results below the LOD, a sample weight of 0.05 μg (one-half the analytical LOD) was used to calculate the volume-adjusted, nondetectable sample concentration. (For further information on the handling of nondetectable samples, see the discussion in Section 2—Methodology.) All samples are full shift and represent a minimum sampling duration of at least 400 minutes. Sample concentrations are based on the actual sampling durations rather than 8-hour time-weighted averages (TWAs).

Earlier Information on Site 10 (Prior to 1994)

Kreiss et al. (1996) provide additional information and commentary on airborne exposures at the Site 10 facility. As noted, the publication does not name the facility under study, but NIOSH's beryllium research newsletters identify it as the facility termed Site 10 in this technological feasibility analysis (NIOSH Beryllium Research, 2005).[97] Kreiss et al. addressed a time period earlier than that represented by the exposure profile data (i.e., prior to 1994). The purpose of the earlier study was to examine the risk of beryllium disease and sensitization among workers with median exposures below 2.0 μg/m^3. The researchers noted that the occasional exposures over 2.0 μg/m^3 occurred primarily in machining operations. The Kreiss et al. (1996) investigation did not find the same level of exposures (e.g., > 1.0 μg/m^3) for material preparation workers as the exposure data used here. The authors stated that their study of general area and PBZ samples for this beryllium oxide ceramics facility indicated that exposures had been decreasing over the 12 years of plant operation prior to the time of the study **(**Kreiss, 1996**)**. OSHA did not incorporate these exposure results because the study reported their findings as summary rather than individual data. Additionally, modifications have been made to this facility since this study, so these samples would not be representative of current conditions. More recent information is used in the exposure profile instead.

ERG Beryllium Site 3

Four full-shift PBZ total beryllium air samples were collected during a visit to Site 3 (2003). OSHA's Salt Lake City Laboratory performed the laboratory analyses. Beryllium mass was determined using OSHA Method No. ID-125G, inductively coupled argon plasma–atomic emission spectroscopy. Field and media blanks made up 10 percent and 5 percent of the samples analyzed, respectively. The analytical reporting limit for air samples was 0.02 μg beryllium per filter. The four full-shift samples are included in the exposure profile.

During this site visit, an attempt was made to survey as many of the potential beryllium-handling activities as possible. Due to weak product demand at the time of the visit, however, the facility was operating at only 10 percent of capacity. Sample results were obtained from the four workers participating in the beryllium oxide operations at the time of the ERG visit (i.e., all workers potentially exposed to beryllium oxide were sampled; the workers were engaged in material preparation, forming, and machining). All four of the air-sampling results were 0.1 μg/m^3 or less. ERG's investigators noted that these results were due to well-practiced work procedures for keeping beryllium oxide dust within the process enclosures and ventilation hoods, diligent housekeeping, and process enclosures designed to promote effective cleaning (e.g., stainless steel framed/Plexiglas construction; hoods with running water, drains, and both back- and downdraft airflow designs; minimization of horizontal surfaces inside hoods). Based on the results of the air-sampling data, these efforts appeared to be successful at containing airborne particulates.

[97] Brush Wellman acknowledged that the facility is the Site 10 visited by ERG (ERG Beryllium Site 10, 2006).

In addition to taking full-shift samples, ERG investigators measured short-term worker exposures during two tasks, each of which has relatively high potential for beryllium exposure. The task-specific samples represent a more focused examination of exposures that occur during individual tasks primarily associated with the job category.[98] One measurement was taken for a material preparation operator and another for an isopress forming operator. These short-term samples provide further evidence that the operations sampled were well controlled: both of these results are below the analytical LOD (in this case 0.01 μg/m^3 for the material preparation operator and 0.004 μg/m^3 for the forming operator). The two task samples were not used in the personal exposure profile because they are not full-shift samples and were not collected using a validated sampling method. In an attempt to meet the minimum air volume required to detect the presence of beryllium, the task samples were collected at a high flow rate of 25 liters per minute (lpm) (ERG Beryllium Site 3, 2003). In contrast, the flow rates specified for validated OSHA and NIOSH sampling methods range from 1 lpm to 4 lpm.

The beryllium concentrations were low for both personal full-shift and task samples obtained during this survey. The dust collected in these samples generally contained less than 1 percent beryllium, indicating that the beryllium oxide handled at the plant was controlled sufficiently enough to severely limit beryllium dust during material transfer in material preparation, and during pressing operations to form beryllium oxide shapes.

OSHA IMIS Database

Only 14 results of a total of 317 PBZ samples in the IMIS database had detectable beryllium (OSHA, 2009). These data are characterized by a median of 0.18 μg/m^3, a mean of 0.54 μg/m^3, and a range of 0.05 μg/m^3 to 2.0 μg/m^3. The sampling results in which beryllium was detected are associated with racing engine manufacturing (one sample, 0.26 μg/m^3); soldering (five samples ranging from 0.1 μg/m^3 to 1.0 μg/m^3); welding (seven samples ranging from 0.05 μg/m^3 to 2.0 μg/m^3); and maintenance (one sample, 0.2 μg/m^3). Nearly all the positive IMIS results are older (i.e., from 1981 to 1991) than the other exposure data available (i.e., prior to 1994, 1994 to 2003, 2003). Only one sample is relatively recent and was obtained in 2006 (reported in IMIS as racing engine manufacturing sample). Interpretation of the IMIS results is limited because the data do not report the sample durations, the exact circumstances of the sampling, or the analytical LOD. Because of these limitations, the IMIS data provide supporting data but are not included in the exposure profile.

Personal Exposure Profile for Beryllium Oxide

Tables IV-19 and IV-20 represent the exposure profile for beryllium oxide ceramics industry workers. Table IV-19 presents the number, range, mean, and median of the samples by job category. Table IV-20 presents the distribution of the results by job category in relation to the proposed permissible exposure limit (PEL) options of 0.1 μg/m^3, 0.2 μg/m^3, 0.5 μg/m^3, and 1.0 μg/m^3.

[98] For a short-term, task-based sample, exposure during the task is not averaged with presumably lower exposures that occur during time spent between tasks, on breaks, or performing administrative work.

Table IV-19—Details of Personal Exposure in the Beryllium Oxide Ceramics Industry (1994–2003)

Job Category and Work Group	No. of Full-Shift PBZ Samples[a]	Range (μg/m³)	Mean (μg/m³)	Median (μg/m³)
Material Preparation Operator	*77*	*0.02 to 10.6*	*1.01*	*0.41*
Forming Operator[b]	*408*	*0.02 to 53.2*	*0.48*	*0.18*
Kiln Operator	*3*	*0.22 to 0.36*	*0.28*	*0.25*
Machining Operator	*355*	*0.01 to 5.0*	*0.32*	*0.15*
Metallization Worker	*36*	*0.02 to 0.62*	*0.15*	*0.06*
Production Support Worker	*119*	*0.02 to 7.7*	*0.21*	*0.05*
Packaging Operator	*37*	*0.020 to 0.50*	*0.09*	*0.05*
Maintenance	*81*	*0.02 to 7.70*	*0.26*	*0.05*
Janitor	*1*	*0.80*	*0.80*	*0.80*
Administrative Staff	*185*	*0.02 to 1.2*	*0.06*	*0.05*
Total	**1,218**	**0.01 to 53.2**	**0.36**	**0.11**

[a] *The exposure profile is based on full-shift PBZ (lapel) total beryllium sample results. Full-shift sample results represent a sampling duration of 360 minutes or longer and have not been time-weighted for 8 hours (i.e., full-shift sample results are based on the actual sampling duration). Most samples (1,214 samples) were analyzed by NIOSH Method 7102 (Beryllium and compounds, as Be) or 7300 (Elements by ICP), and the analytical LOD was reported to be 0.1 μg beryllium per filter. For sample results below the analytical LOD, a sample weight of 0.05 μg (one-half the analytical LOD) was used to calculate the volume-adjusted nondetectable sample concentration. Four samples were analyzed using OSHA Method 125G, with a reporting limit of 0.02 μg per filter. Results reported as less than 0.02 μg are incorporated into the exposure profile as volume-adjusted reporting limit concentrations.*

[b] *Twenty-eight samples (7 percent of all forming operator samples) associated with tape casting are included, although tape casting is not currently performed.*

Sources: Brush Wellman Tucson, 2004 (presenting data for ERG Beryllium Site 10); ERG Beryllium Site 3, 2003.

Table IV-20—Distribution of Full-Shift PBZ Exposure Results for Total Beryllium in the Beryllium Oxide Ceramics Industry (1994–2003)

Job Category and Work Group	Number of Full-Shift PBZ Sample Results in Range [a] (μg/m³)						Total No. of Samples
	< 0.1	≤ 0.1 to ≤ 0.2	> 0.2 to ≤ 0.5	> 0.5 to ≤ 1.0	> 1.0 to ≤ 2.0	> 2.0	
Material Preparation Operator	*10 (13%)*	*12 (14%)*	*24 (33%)*	*15 (20%)*	*8 (10%)*	*8 (10%)*	*77 (100%)*
Forming Operator [b]	*110 (27%)*	*118 (29%)*	*115 (28%)*	*43 (11%)*	*15 (4%)*	*6 (1%)*	*408 (100%)*
Kiln Operator	*0 (0%)*	*0 (0%)*	*3 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*3 (100%)*
Machining Operator	*142 (37%)*	*102 (26%)*	*87 (22%)*	*40 (10%)*	*11 (3%)*	*8 (2%)*	*390 (100%)*
Metallization Operator	*20 (55%)*	*5 (14%)*	*10 (28%)*	*1 (3%)*	*0 (0%)*	*0 (0%)*	*36 (100%)*
Production Support Worker	*81 (68%)*	*24 (20%)*	*8 (7%)*	*3 (2%)*	*1 (1%)*	*2 (2%)*	*119 (100%)*
Packaging Operator	*27 (73%)*	*8 (22%)*	*2 (5%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*37 (100%)*
Maintenance	*54 (67%)*	*16 (20%)*	*6 (8%)*	*2 (2%)*	*1 (1%)*	*2 (2%)*	*81 (100%)*
Janitor	*0 (0%)*	*0 (0%)*	*0 (0%)*	*1 (100%)*	*0 (0%)*	*0 (0%)*	*1 (100%)*

Table IV-20—Distribution of Full-Shift PBZ Exposure Results for Total Beryllium in the Beryllium Oxide Ceramics Industry (1994–2003)

Job Category and Work Group	Number of Full-Shift PBZ Sample Results in Range [a] (μg/m³)						Total No. of Samples
	< 0.1	≤ 0.1 to ≤ 0.2	> 0.2 to ≤ 0.5	> 0.5 to ≤ 1.0	> 1.0 to ≤ 2.0	> 2.0	
Administrative Staff	*172 (93%)*	*9 (5%)*	*2 (1%)*	*1 (0.5%)*	*1 (0.5%)*	*0 (0%)*	*185 (100%)*
Total	*535 (44%)*	*270 (22%)*	*249 (20%)*	*103 (9%)*	*36 (3%)*	*25 (2%)*	*1,218 (100%)*

[a] *The exposure profile is based on full-shift PBZ (lapel) total beryllium sample results. Full-shift sample results represent a sampling duration of 360 minutes or longer and have not been time-weighted for 8 hours (i.e., full-shift sample results are based on the actual sampling duration). Most samples (1,214 samples) were analyzed by NIOSH Method 7102 (Beryllium and compounds, as Be) or 7300 (Elements by ICP), and the analytical LOD was reported to be 0.1 μg beryllium per filter. For sample results below the analytical LOD, a sample weight of 0.05 μg (one-half the analytical LOD) was used to calculate the volume-adjusted nondetectable sample concentration. Four samples were analyzed using OSHA Method 125G, with a reporting limit of 0.02 μg per filter. Results reported as less than 0.02 μg are incorporated into the exposure profile as volume-adjusted reporting limit concentrations.*

[b] *Twenty-eight samples (7 percent of all forming operator samples) associated with tape casting are included, although tape casting is not currently performed.*

Sources: Brush Wellman Tucson, 2004 (presenting data for ERG Beryllium Site 10); ERG Beryllium Site 3, 2003.

OSHA has reviewed data for each of the major process steps at beryllium oxide ceramic operations for both a large industrial setting and a small facility setting. Site 10 is the only fairly large operation in this sector, so the findings may have limited applicability to other facilities. The operations observed at Site 3 are judged to be reflective of well-designed operations at a small job facility. Accordingly, the Site 3 observations are assumed to be applicable to other beryllium-oxide-using customers of these facilities. The low level of operations observed at Site 3, however, might underestimate the exposures for the broader population of beryllium oxide machining and other operations. Thus, average exposures for typical beryllium oxide machining and other operations might be higher than those at Site 3.

As shown in Table IV-19, the median values are below the mean for all job categories, reflecting the occasional high measurements obtained for some job categories. Table IV-20 also shows that exposures exceeding 1.0 μg/m^3 have occurred in most job categories (with the exception of kiln operators and metallization). However, other than material preparation operators and kiln operators, the median values for each job category fall within the range of 0.05 μg/m^3 to 0.2 μg/m^3.

A limited number of facilities are involved in beryllium oxide ceramic production. The two facilities (Site 3 and Site 10) for which exposure observations were obtained represent the primary commercial activity involving beryllium oxide ceramic powder preparation and firing of "green" materials. Thus, the exposure profile is the best estimate of baseline exposure levels for those jobs unique to the primary beryllium oxide ceramic producers, such as material preparation and forming operators (i.e., employees working with unfired beryllium oxide ceramic powder). These plants and the customers of these primary beryllium oxide ceramics producers might perform additional firing and processing of the ceramic material, such as metallization, lapping and polishing, and laser machining and dicing.

TECHNOLOGICAL FEASIBILITY

This section presents the general and operation-specific exposure controls used in beryllium oxide ceramic and composite facilities and possible additional controls that could further reduce worker exposures.

Material Preparation Operators

Material Preparation Operators—Baseline Controls

Material preparation operators convert pure beryllium oxide powder into a paste or powder having the necessary consistency and chemistry to be formed into various shapes to meet product specifications. Potential exposures occur while unloading bulk product containers; disconnecting product drums from the spray dryer or material transfer equipment; and cleaning, servicing, and maintaining associated equipment.

Engineering controls for material preparation operations include installing partially enclosed LEV hoods at material transfer points (e.g., unloading beryllium oxide powder from containers or drums, connecting/disconnecting collection containers at the base of the spray dryer) and using fully enclosed and ventilated material transfer systems to convey material from one process step to another (e.g., material screening, milling, storage). Other controls include careful work practices, wet cleaning methods (for housekeeping and equipment cleaning), and frequent housekeeping.

The two facilities that include primary beryllium oxide production processes utilize substantial ***LEV and operating enclosures*****.** At Site 10, the material preparation operation is located in an isolated room and is separated from the rest of the plant by an airlock. To transfer material from product-feed drums to the holding bins, the material preparation operator reaches into a partially enclosed transfer hood to open product feed drums and vacuum-convey (through the use of a vacuum wand) beryllium powder through an enclosed system into the holding bin. Workers remain outside the hood; only their arms, which are covered with protective sleeves, enter open drums to manipulate the vacuum wand during transfer of the powder (ERG Beryllium Site 10, 2006).

Similarly, all powder-transfer tasks are performed in a partially enclosed LEV hood or containerized in a seal-tight enclosure. ERG observed highly disciplined work practices. The material preparation operator cleans all potentially contaminated surfaces (e.g., containers, bags, gloves, hands, skin) with running water and sponges before removing them from the exhaust hood. Hoods are engineered for easy cleaning (e.g., stainless steel and Plexiglas construction, minimization of horizontal surfaces), with clean running water and drainage capability to facilitate cleaning before anything is removed from the hood. The material preparation operator also performs general housekeeping tasks.

Site 10 has made changes to specific equipment and processing techniques over time to reduce exposures (ERG Beryllium Site 10, 2006). First, facility personnel reorganized production so that similar ceramic mixes are processed in sequence, reducing the frequency of worker cleanouts of the spray-drying equipment. Currently, during routine production, the spray dryer is reportedly cleaned two to three times per week. The amount of time spent cleaning typically ranges from 15 to 30 minutes (ERG Beryllium Site 10, 2006). Much of the operator exposure associated with this task occurs when the worker leans over and/or into the dryer hatch for cleaning. The spray-dryer operating action was modified to reduce the amount of material left in the equipment after a production cycle. The facility reported that the reconfiguration had reduced the amount of material left in the spray dryer by a factor of 6 or 7.[99] Further, the facility changed the spray-dryer cleaning method from hand scraping to wet cleaning with a pressure washer. The facility reported that the combination of changes decreased cleaning frequency overall and reduced exposures during cleaning (ERG Beryllium Site 10, 2006); however, no data were available to estimate the extent of the reduction.

Additionally, spray drying occurs in a segregated portion of this particular plant. Specially designed valves and LEV control the release of beryllium oxide ceramic particles when the operator disconnects the drums of prepared material from the bottom of the spray dryer. As an added precaution, operators use impermeable gloves and disposable sleeves and coveralls when breaking the plane of exhaust-hood enclosures. Impervious body aprons are worn when workers are likely to contact solutions containing beryllium oxide ceramic material.

Housekeeping is a critical part of overall exposure control. Housekeeping practices have been enhanced in recent years. At Site 3, the facility has a documented housekeeping schedule (daily, weekly, monthly, and quarterly), and activities are tracked to ensure that housekeeping requirements are completed. The site employs one full-time maintenance worker who is dedicated to and responsible for completing the housekeeping schedule. All operators are responsible for keeping their work surfaces and themselves clean throughout the shift, and they are to use the last 15 minutes of the shift to perform a thorough cleaning of their work areas. One central vacuum system and four portable HEPA filter vacuums are available to facilitate housekeeping efforts (ERG Beryllium Site 3; ERG Beryllium Site 9[100]). Since 2000, Site 10 has also made housekeeping improvements in accordance with the Materion Worker Protection Model discussed in this PEA at Chapter IV, Methodology Appendix 1. Site 10 housekeeping procedures now include daily housekeeping requirements by all shifts in addition to more in-depth cleaning of production areas on a monthly basis. Cleaning must be conducted with either HEPA-filtered vacuums or wet methods (wet mop stations or automated floor cleaning machines). Wet mop stations are designed so that floor mops can be rinsed with clean water every time.

Material Preparation Operators—Additional Controls

As shown in Table IV-19, the median exposure level (exposure profile) for material preparation operators is 0.41 µg/m^3 and the mean is 1.01 µg/m^3. Table IV-20 indicates that 13 percent (10 of the 77 total) sample results for material preparation operators are less than 0.1 µg/m^3 and 73 percent are greater than 0.2 µg/m^3. Therefore, additional controls will be required to achieve lower levels of exposure.

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[99] For example, during the 1999/2000 timeframe, approximately 23 to 25 pounds of material was cleaned off the inside of the spray dryer. After the scheduling and equipment changes were implemented, the material removed was reduced to 3 to 4 pounds.

[100] Site 3 and Site 9 are the same facility. The Site 3 visit took place in 2003, and the Site 9 visit took place in 2004.

OSHA notes that the exposure profile for material preparation operators is primarily based on 10 years of exposure data (1994 to 2003). Information pertaining to worker activities is not available for these data, and there are inconsistencies in the number of samples obtained each year. For example, for both 1994 and 1995, only one sample result is available. For 2002 and 2003, four and five sample results, respectively, were obtained (compared to over 30 results obtained in 2001). Furthermore, in most cases OSHA is not able to match exposure data with the information on engineering controls obtained from Site 10, which is the most robust data source for this industry (ERG Beryllium Site 10, 2006). Thus, for most samples in the exposure profile, the Agency does not have the information necessary to correlate exposure results with tasks performed and controls in place at the time of sampling from 1994 through 2003. An exception, however, does exist as described in the following paragraphs.

OSHA does have one sample (obtained at Site 3) for which the Agency has obtained detailed information on the tasks performed and specific engineering controls in place at the time of sampling. This result was reported as < 0.02 $\mu g/m^3$. As discussed previously, this facility was operating at 10 percent of capacity, and the material preparation operator sample did not perform all the tasks associated with the job description. Specifically, this worker did not perform spray drying or maintenance of the spray chamber.

Despite this limitation of the available sample data, based on information about the tasks performed and engineering controls in place at the time of sampling, OSHA is able to infer the extent to which engineering controls are efficient for managing exposures during the specific tasks performed when this sample was taken. At the time of sampling, the Site 3 worker transferred beryllium oxide powder from vendor containers to intermediate milling containers and then to a powdering mill. ERG investigators noted that this sample result was associated with process enclosures, ventilation hoods, and diligent housekeeping (ERG Beryllium Site 3, 2003). These findings are consistent with the information provided by the Site 10 personnel regarding exposure controls at the Site 10 facility (ERG Beryllium Site 10, 2006).

The correlation between controls used at Site 3 and Site 10 is significant because key sources of worker exposure at both sites occur during material transfer and container-filling operations. The information from Site 3 offers evidence that activities involving material transfer points that require workers to handle and manipulate beryllium oxide powders and to fill containers can be well controlled by the control methods in place at Site 3 (i.e. process enclosures, ventilation hoods, and diligent work practices, including housekeeping). OSHA has evidence that facilities performing these tasks in this manner can achieve exposure levels below 0.1 $\mu g/m^3$ (ERG Beryllium Site 3, 2003). OSHA notes that other controls are also available for these processes, and recommends that the enclosed transfer hood where drums are emptied be equipped with a solid door with a viewing port and gloves. Workers typically must stand immediately outside the hood while reaching into the hood to remove the lid, operate the vacuum wand, and clean the container and the inside of the hood. A solid door with viewing ports extending into the hood would provide a physical barrier separating the operator from the source of contamination. For small-scale operations where smaller containers are emptied, ventilated glove boxes, such as those shown to reduce exposures to pharmaceutical chemicals to 0.1 $\mu g/m^3$, would likely be an effective control measure (Hosokawa Micron Group, 2005).

As noted above, documentation indicates that controls similar to those in place at Site 3 (process enclosures, ventilation hoods, and diligent housekeeping) were also in use at Site 10. The information from Site 3 does not, however, offer information on exposures that occur during spray drying or maintenance of the spray drier, tasks that OSHA infers were routinely conducted at Site 10 during the periods sampled.

Although OSHA does not have exposure data specific to spray drying, spray drying operations can be conducted in an enclosure (ERG Beryllium Site 10, 2006). Therefore, to the extent this isolation method works effectively, OSHA anticipates that exposures during spray drying operations can be maintained below 0.1 $\mu g/m^3$.

OSHA does not have evidence that exposure levels below 0.2 $\mu g/m^3$ can be achieved on shifts when workers perform maintenance of the spray chamber. Despite information from the Site 10 facility regarding improvements during maintenance of the spray chamber, no exposure data demonstrate the effect of these modifications on worker exposures. Based on the information presented here, OSHA acknowledges that maintenance of the spray chamber is potentially the greatest source of exposure for material preparation operators. The exposure profile suggests that this task contributes significantly to exposures and was performed routinely during sampling at Site 10. Despite having only limited information about the tasks performed, OSHA did obtain a description of the process indicating that, during normal operations, maintenance of the spray chamber was typically performed for approximately 30 minutes three days per week (e.g., after each production run) because the material tends to clump in the bottom of the spray drier and must be removed regularly (ERG Beryllium Site 10, 2006). Additionally, as described in the process description for this industry, spray drying is an essential step in producing beryllium oxide powder, therefore the frequency of spray drying (and related equipment servicing and maintenance) must increase as beryllium oxide powder production increases. Furthermore, OSHA knows, from site personnel and reported sampling dates, that nearly 50 percent of the Site 10 samples were collected in the year 2001, a period when production levels were near peak (i.e., a time when spray drying was by necessity commonplace due to high production demand). From this information, OSHA finds it reasonable to infer that spray dryer maintenance was regularly included in activities sampled in 2000 and 2001.

In summary, sampling data indicate that exposure from transferring and filling operations can be minimized with adequate controls because an exposure measurement taken when only these tasks were performed (i.e., when no spray drying or spray dryer maintenance were conducted) was below 0.1 $\mu g/m^3$. OSHA also believes exposures during spray drying can be maintained at or below 0.1 $\mu g/m^3$ because spray drying occurs in a ventilated enclosure. However, despite these controls for transferring, filling, and spray drying operations, the exposure profile shows that 73 percent of exposures remained elevated (above 0.2 $\mu g/m^3$). Therefore, OSHA preliminarily concludes that primary source of exposures above 0.1 $\mu g/m^3$ for material-handling operations is maintenance of the spray chamber. This task is performed for approximately 30 minutes three days per week, which means that this task causes elevated peak exposures to the point that the proposed PEL of 0.2 $\mu g/m^3$ is exceeded. In Section 12—Short-Term Exposures of Chapter IV of the Preliminary Economic Analysis of the Beryllium Proposed Standard, OSHA explains that having an exposure of 2.1 $\mu g/m^3$ for 30 minutes (note that the proposed short-term exposure limit [STEL] is 2.0 $\mu g/m^3$)—assuming no exposure for the remainder of the work shift—results in an 8-hour TWA exposure of 0.13 $\mu g/m^3$. In light of this information, OSHA believes that the exposure profile for material preparation, although limited, reveals that peak exposures during maintenance of the spray chamber are driving the 8-hr TWA to levels at or above the proposed PEL.

Recent modifications to the maintenance process may result in lower exposures; however, OSHA does not have the information needed to quantify the extent of the reduction. As such, respiratory protection may be necessary for servicing and maintenance of the spray chamber.

Material Preparation Operators—Conclusion

Based on the information presented in the additional controls section, OSHA preliminarily concludes that exposures resulting from material transfer, loading, and spray drying can be reduced to below 0.1 µg/m^3 with process enclosures, ventilation hoods, and diligent housekeeping. Accordingly, OSHA also preliminarily concludes that the proposed PEL of 0.2 µg/m^3 can be achieved most of the time for the majority of material preparation operators performing these tasks.

For maintenance of the spray chamber, however, OSHA's evidence indicates that peak exposures during these tasks result in 8-hour TWA exposures greater than 0.2 µg/m^3 most of the time. The Site 10 facility has reportedly modified this process to reduce worker exposures, but OSHA has no data to quantify this reduction. OSHA is requesting additional information that demonstrates the extent of the exposure reduction associated with modifications made to the spray-drying process.

Accordingly, OSHA is less certain that the proposed PEL of 0.2 µg/m^3 (or an alternative PEL of 0.1 µg/m^3) can be achieved on shifts when all of material preparation activities are performed, i.e., material transfer, loading, spray drying, and maintenance of the spray chamber. On shifts when TWA exposures exceed 0.2 µg/m^3 despite the implementation of all feasible engineering controls, employees will need to wear respiratory protection during high exposure tasks, such as maintenance of the spray chamber. For workers whose exposures are below the current PEL of 2.0 µg/m^3, a respirator with an assigned protection factor (APF) of 10 will be sufficient. These respirators (e.g., half-facepiece respirators) offer protection up to an exposure level of 2.0 µg/m^3. For more elevated exposures, above 2.0 µg/m^3, a respirator that offers a minimum APF of 50 is necessary. Such respirators (e.g., full-facepiece respirators) provide protection against airborne beryllium concentrations of up to10 µg/m^3.

Forming Operators

This job category includes the forming operators who control *pressing* (dry and isopressing) and *extrusion* workstations. The initial paragraphs address forming operators who perform dry pressing. For the technological feasibility analysis on forming operators who work with extrusion equipment, refer to subsequent paragraphs on forming operators grouped as extrusion operators, also within this subsection on forming operators.

Forming Operators—Press Operators (Dry Pressing)—Baseline Controls

Workers can be exposed when they load and connect beryllium oxide ceramic powder containers to the press, load the die with ceramic powder, press the parts, remove the parts from the press, and unload and disconnect empty powder product-feed containers. Exposures can also occur during cleaning, servicing, and maintenance tasks on associated equipment. The sources of exposure are similar for the various kinds of press operations discussed below.

At Site 10, small presses have been enclosed with Plexiglas and ventilated since the late 1990s. To achieve low exposures in its dry-pressing operations, the facility employs low-volume high-velocity (LVHV) LEV pickups at the die press point of operation (vacuum hood is within inches of the die press), and it has fully enclosed and ventilated the small-press operations. Since 1999, the facility also has had full enclosures with LEV at the beryllium oxide powder-feed connections to presses. The powder transfer from the feed container to the press die is isolated within the machine-piping system and enclosures. Further, the facility has two LEV systems around the small presses: one capturing air through the operating envelope (this includes the die/ram press area, the area to which the parts are ejected, and the area of the hood into which the operator reaches to retrieve parts) and an LVHV central vacuum system for close capture of beryllium oxide particles from the newly pressed parts before the parts are removed from the ventilated enclosure. The small-press enclosures are custom-designed by outside vendors to accommodate press wiring and the mode of operation.

The two large presses at Site 10 are not enclosed but do have an LVHV vacuum pickup attached to the ram and positioned within inches of the die. This system provides close capture of powder that is released when the ram comes down into the die. The large presses also have ventilated devices called de-dusters that operators use to remove loose particles from pressed parts. A de-duster is a small, rectangular box under negative pressure with a series of holes on the top through which exhaust air is pulled. Workers manually swipe their parts over the top of the de-duster to remove loose particles after pressing. The exhaust ventilation is provided through a small, flexible exhaust duct connected to the side of the de-duster. Workers periodically disconnect the exhaust duct from the de-duster and use it to vacuum up loose material on the press.

The isopress operation is located in a separate room. The powder-filling station for this operation is partially enclosed with Plexiglas and ventilated. The operator works with his hands inside the enclosure and uses an open-face exhaust duct for cleaning. Some powder leakage occurs within the enclosure when molds are filled.

The facility has also attempted to optimize work procedures for exposure control. For example, when press operators must clean out the die area to prevent accumulations of powder, operators use wet methods to rehydrate materials and limit exposures during cleanup. Additionally, as an alternative to vacuuming, parts are sometimes wet-cleaned (e.g., with water and sponges) after each potentially dusty processing step (including pressing).

At Site 3, dry pressing is conducted inside a partial enclosure (open in the front) under LEV. In addition to performing dry pressing, the dry-press operator operates a dry abrasive cut-off saw for a separate line of parts. The saw is positioned inside a separate, partially enclosed and ventilated hood with an LEV pickup (plain opening exhaust duct) positioned close to the point of operation. Parts are removed from a holding tray and placed in position to be cut. The operator then cycles the semi-automated machine to perform the cutting action and loads the parts onto another storage tray in preparation for firing. The operator frequently uses a wet sponge to clean potentially contaminated surfaces, hands, and skin before removing anything from the enclosure.

During the site visit, ERG investigators observed the dry-press operator wash his hands at least 16 times during the shift.

The isopress operator at Site 3 places prepared ceramic powder in a liquid-tight rubber mold inside a partially enclosed LEV hood (open in the front). The laboratory-type hood is about 10 feet long and has running water and both back- and downdraft exhaust flow. Molds that are removed from the isopress are positioned back inside the hood and disassembled, and then the parts are cleaned and stored in a covered container. The operator was observed using meticulous work practices to carefully clean all potentially contaminated surfaces with running water, a sponge, and a small bristled brush prior to removal from the hood. The worker traversed the entire length of the hood and was careful not to remove her contaminated hands prior to cleaning them.

Forming Operators—Press Operators (Dry Pressing)—Additional Controls

Table IV-19 shows that press operators have a median exposure level of 0.18 $\mu g/m^3$ and a mean of 0.48 $\mu g/m^3$. As shown in Table IV-21 of Beryllium Oxide Ceramics and Composites Appendix 1, the median exposure levels for small-press and large-press operators are 0.18 $\mu g/m^3$ and 0.2 $\mu g/m^3$, respectively. The exposure profile also includes three full-shift PBZ sample results for "press setup" that are characterized by a median of 0.2 $\mu g/m^3$. The isopress median exposure level is significantly higher at 0.83 $\mu g/m^3$. Six of the seven isopress sample results were taken at Site 10 in 1995, however, and it is likely that exposures are lower now due to process, work practice, and migration control enhancements. The remaining isopress sample was collected on the isopress operator at Site 3 in 2003 and was nondetectable (below 0.06 $\mu g/m^3$) with the exposure controls in place at that facility (described above in the discussion of Baseline Controls).

The exposure profiles for small- and large-press operators are based primarily on 305 full-shift PBZ samples obtained over 10 years (1994 to 2003) at Site 10. This facility has reportedly made engineering, work practice, and beryllium migration control improvements over time. More recent efforts have been focused on refining work practices. In 2003, the median exposure levels for small-press (0.082 $\mu g/m^3$) and large-press operators (0.04 $\mu g/m^3$) were both less than 0.1 $\mu g/m^3$, although the number of sample results for large-press operators is limited (i.e., three sample results in 2003). Additionally, plant personnel report that exposures for small- and large-press operators in 2004 have generally been below 0.1 $\mu g/m^3$, although one recent observation was 0.24 $\mu g/m^3$ (Frigon, 2004). Based on this information, it seems likely that the exposure profile overestimates the current baseline exposure level for small- and large-press operators, and that 0.1 $\mu g/m^3$ may be a better estimate of the baseline exposure level for these workers. If indeed the current baseline exposure level is 0.1 $\mu g/m^3$, no additional controls would be required.

However, if the exposure profile accurately reflects current exposures, additional exposure reductions might be possible with improved work practices and machine interlocks to prevent workers from opening enclosures too soon or too rapidly after the operating cycle ends. For example, Brush Wellman personnel have noted that to avoid excessive turbulence, forming operators should be instructed not to open enclosures too soon after the operating cycle ends or too rapidly. If the enclosure is opened quickly, the vacuum created can overcome the ventilation inside the containment and release particles toward the worker (Frigon, 2004). Machine interlocks to prevent premature opening of the forming press enclosures would also help limit worker exposures. In a general sense, one industry expert suggests that combined engineering (e.g., machine interlocks) and work-practice improvements (e.g., opening enclosures carefully) typically reduce worker exposures by two to three times at beryllium oxide facilities (Kent, 2005).

Forming Operators—Press Operators—Conclusion

Table IV-22 of Beryllium Oxide Ceramics and Composites Appendix 1 shows that most exposures in small-press (57 percent), large-press (52 percent), and press setup (67 percent) operations are already less than or equal to the proposed 0.2 µg/m^3 PEL. In 2003 and 2004, one beryllium powder-forming facility reported that exposures for small- and large-press operators were generally below 0.1 µg/m^3. For those few exposures that exceed the proposed 0.2 µg/m^3 PEL, interlocks on enclosure doors and improved work practices could help to reduce exposures. The isopress operation sample results are higher at Site 10, with 72 percent of exposures greater than the proposed 0.2 µg/m^3 PEL. The primary control method at this plant was a ventilated Plexiglas enclosure at the powder-filling station. Installing a more complete enclosure for the entire isopress operation, as was implemented at Site 3, would reduce exposures substantially, in that the ventilated enclosure used at Site 3 resulted in exposures below 0.06 µg/m^3 (ERG Beryllium Site 3, 2003). Based on these results, OSHA preliminarily concludes that exposures less than or equal to the proposed 0.2 µg/m^3 PEL and an alternative PEL of 0.1 µg/m^3 can be achieved in most press operations most of the time.

Forming Operators—Extrusion Operators—Baseline Controls

Opportunities for exposure tend to be lower when forming beryllium oxide ceramics using an extrusion process rather than pressing. During the extrusion process, beryllium oxide powder is mixed with binders to produce a paste. Water is added to the paste, which is then extruded to form the dimensions of the product. At Site 10, the operator manually removes the still-damp flexible product from the press as it is being extruded, lays it on a table, breaks off the excess by hand, and drops the excess into a bucket (ERG Beryllium Site 10, 2006). Extruded parts are then transferred to other workstations for subsequent processing. The paste has moisture content that helps reduce the potential for airborne particulate generation during this operation.

Because of the binders incorporated into the material, however, workers may encounter dried clumps of beryllium oxide ceramic material when cleaning out the extruders. To help prevent dust generation during cleanout, workers rehydrate materials by spraying them with water and use wet methods for cleanup. LEV is installed on top of the extrusion machine where the powder flows into the machine.

Forming Operators—Extrusion Operators—Additional Controls

As shown in Table IV-21 of Beryllium Oxide Ceramics and Composites Appendix 1, the median exposure level (exposure profile) for extrusion operators is 0.17 µg/m^3. Table IV-22 of Beryllium Oxide Ceramics and Composites Appendix 1 indicates that 26 percent of the full-shift PBZ total beryllium sample results for extrusion operators are less than 0.1 µg/m^3 and 62 percent of exposures are less than or equal to the proposed 0.2 µg/m^3 PEL. These results are based on exposure data obtained from1996 to 2003 for extrusion operators.

Exposures during the extrusion operation are likely to occur during three processes: mixing of beryllium oxide powder with water and binders, the extrusion tooling operation, and machine cleaning. Control measures are available for each of these processes, although no data are available on the relative contribution of these processes to the overall worker exposure level. Additional ventilation of and enclosures for the powder-mixing operations would reduce fugitive emissions that contribute to exposures. For example, enhancing the existing ventilation or adding an additional exhaust hood at the tooling point of operation would serve to reduce exposures. Exposures might also be reduced through more frequent machine cleaning, more consistent wetting of dried ceramic residue, and/or the use of HEPA filter vacuums.

Forming Operators—Extrusion Operators—Conclusion

The exposure profile for the extrusion operations indicates that 62 percent of exposures are less than or equal to the proposed 0.2 $\mu g/m^3$ PEL. In addition, control measures for the most significant sources of exposure are available. Thus, OSHA concludes that exposures less than or equal to the proposed 0.2 $\mu g/m^3$ PEL can be achieved for the majority of extrusion operations most of the time. Whether these controls will reduce exposures to or below 0.1$\mu g/m^3$ is less certain, and the agency requests additional information that demonstrates that exposures can be reduced to that level most of the time.

Kiln Operators

Kiln Operators—Baseline Controls

Kiln operations occur at the two production facilities that fire “green” beryllium oxide powder and at downstream facilities that metallize ceramic materials and subsequently perform a second firing of the parts. As noted in the Brush Ceramic Products' Material Safety Data Sheet for beryllia ceramics, volatile beryllium hydroxide can be formed when solid beryllium oxide parts are fired at temperatures exceeding 900°C in a moist atmosphere, such as in a hydrogen atmosphere sintering furnace (Brush Ceramic Products, 2006). This process results in beryllium oxide exposure in kiln operations.

Site 10 sinters green ceramic parts in air atmosphere tunnel kilns or in batch kilns. In the press room, smaller batch kilns and a tunnel kiln are used to evaluate samples for product specifications. Tunnel kilns are also used to clean parts before shipping and to fire parts that have been metallized. Green parts are fired in air (i.e., the composition of kiln air is the same as work environment air), whereas metallized parts are typically fired in an inert or reducing atmosphere (e.g., hydrogen and nitrogen). Kilns are vented to the external environment (outside the workplace) without any special HEPA filtration. Batch kilns used for production operations have tapered slot hoods suspended above the length of the kiln doors to capture heat and odors associated with the firing process (ERG Beryllium Site 10, 2006).

Central and portable HEPA filter vacuums are available for housekeeping purposes. Portable HEPA filter vacuums may be common in downstream facilities. Other specialized cleaning practices may not be as widely used among downstream users of beryllium oxide ceramics. Managers at Site 10 describe using additional controls, such as central vacuums, wet-cleaning stations designed to reduce the redistribution of contaminated water, and a disciplined approach to cleaning work areas (e.g., twice per shift shutdown of operations for cleaning). Workplace contamination in the kiln areas can occur when ceramic parts break and/or saggers are not kept clean (ERG Beryllium Site 10, 2006).[101]

Kiln Operators—Additional Controls

Table IV-19 (exposure profile) shows that the median exposure level for kiln operators is 0.25 µg/m^3. These results are based on three full-shift PBZ samples obtained in 1995 for kiln operators at Site 10. As shown in Table IV-20, all three sample results exceed 0.2 µg/m^3. In addition, the OSHA beryllium docket contains summary statistics for six full-shift PBZ sample results for kiln operators at a beryllium oxide ceramic production and processing facility (OSHA-H005C-2006-0870-0094). These data are characterized by a mean of 0.31 µg/m^3 and range from 0.22 µg/m^3 to 0.57 µg/m^3. The median was not provided and cannot be determined because individual values were not reported.

More recent information suggests that current exposures for kiln operators are generally below 0.1 µg/m^3 (0.04 µg/m^3, 0.04 µg/m^3, 0.04 µg/m^3, 0.08 µg/m^3 [median = 0.04 µg/m^3; mean = 0.05 µg/m^3]) (Frigon, 2005). This improvement might be attributable to changes in operations that reduced the amount of time kiln operators spend in the immediate vicinity of the kilns and/or the discontinuation of a nearby dust-generating operation (tape casting) (Frigon, 2004, 2005). These data suggest that the median exposure level in the exposure profile for kiln operators might overestimate the baseline exposure level for this job category. Thus, the baseline exposure level for kiln operators is estimated to be below 0.25 µg/m^3.

Re-engineering the furnace operations to reduce beryllium emissions would be impeded to some degree by the lack of knowledge about the exact source or cause of beryllium emissions in these areas. While the moisture content of the materials fired apparently contributes to emissions, the exact chemical form of the emissions has not been documented, and there is some uncertainty as to what steps might be effective. Also, exposures might occur when the furnace doors are opened to remove products or during the firing process. If exposure occurs when the furnace doors are opened, LEV improvements to the area in front of the kiln might be effective. If beryllium particles become airborne during kiln firing, additional ventilation controls might be needed at the furnace leakage points. The kiln modifications will require an engineering study to avoid problematic impacts on the airflow around the kiln. Given the median (baseline) exposure level of 0.25 µg/m^3, any reduction greater than 20 percent would be sufficient to meet the proposed 0.2 µg/m^3 PEL. Improvements to the LEV could reduce exposures by approximately 20 to 50 percent (Kent, 2005).

In addition, contaminated saggers may be a source of exposure, and providing a HEPA-filtered vacuum to clean them would reduce exposures from this source.

Kiln Operators—Conclusion

The exposure profile for kiln operators is based on the results of three full-shift PBZ sample results obtained in 1995. The baseline exposure level for this job category is estimated to be less than the median exposure level of 0.25 µg/m^3. More recent data from Site 10 suggest that kiln operator exposures have already been controlled to levels below 0.1 µg/m^3 (ERG Beryllium Site

[101] Saggers are the protective (alumina) containers into which the green parts are placed before being rolled into the kilns and fired.

10, 2006). If necessary, operator exposures could be reduced through enhanced LEV systems for the kilns and HEPA-filtered vacuums for cleaning contaminated saggers. Based on these data, OSHA concludes that exposures less than or equal to the proposed 0.2 μg/m^3 can be achieved in the majority of kiln operations most of the time. Based on the more recent data from Frigon (Frigon, 2005), OSHA concludes that exposures below 0.1 μg/m^3 can also be achieved.

Machining Operators

Machining Operators—Baseline Controls

The engineering controls for machining operations at Site 3 and Site 10 are summarized below. These establishments have similar approaches to controlling exposures and OSHA found these controls to be associated with baseline practices: information from other establishments suggests that similar types of LEV (e.g., LVHV) and/or ventilated enclosures are widely employed (Facility B-1, 2000; Facility L-1, 2000; ERG Beryllium Site 3, 2003; ERG Beryllium Site 10, 2006). In addition to enclosures and ventilation systems, both beryllium oxide ceramic manufacturing facilities have established housekeeping programs to minimize and control workplace contamination (ERG Beryllium Site 3, 2003; ERG Beryllium Site 10, 2006).

Site 10 performs both wet and dry machining. Wet machining can be performed on hardened products that have already been fired in the kiln. Dry machining must be performed on non-fired (green) ceramic materials because wet machining would allow the material to absorb too much moisture. Dry machining is generally performed by positioning LVHV ducts as close to the point of operation as possible. Some hoods are close-fitting, custom-made hoods; others are plain-opening hoods. Control is achieved by positioning the hood and exhausting the air directly from the point of operation (where dust is generated). Capture velocities are very high, and small-diameter (e.g., 1 to 1.5 inches) flexible exhaust tubing must be positioned as close as possible (e.g., within 1 inch) to the point of operation. LVHV hoods are generally designed to have greater than 10,000 feet per minute (fpm) face velocities and configured such that they can be positioned within 1 inch of the source of generation. Capture velocity drops off dramatically with increased distance from the source. This means workers must carefully position LVHV hoods, because improperly locating a hood by just a small distance (e.g., by a few centimeters) can have a profound effect on the capture efficiency of the exhaust system (ERG Beryllium Site 10, 2006).

Wet machining is performed on fired ceramic materials and is typically performed inside exhausted enclosures equipped with sliding doors. Machining fluids/coolants are cleaned by one centralized filtration system to reduce the accumulation of beryllium oxide particulate, and the fluid/coolant reservoirs are also enclosed and under LEV.

Lapping and plate polishing are among the more difficult exposure control challenges for machining operators. [102] Site 10 performs lapping and polishing wet with no LEV or enclosures (ERG Beryllium Site 10, 2006). Operators wear gloves, rubber boots, full-body disposable coveralls (Saranex™), and disposable Tyvek® sleeves. Impervious aprons are also worn when the potential for contact with machining solution exists.

[102] Lapping is a type of precision grinding and is performed using two rotating plates with an abrasive between them. Plate polishing is similar to lapping, only the grit of the abrasive differs between the two processes.

Lapping is a wet and inherently sloppy operation and was originally performed with a water-based lapping fluid (i.e., grinding media mixed with a water-based carrying fluid). Polishing can also be performed with a fluid. To help lower airborne exposures associated with workplace contamination, Site 10 currently uses an oil-based lapping fluid. The oil-based fluid provides a "wet method" for reducing emissions from the machine but creates substantial housekeeping concerns. Oil- or water-based lapping fluids can be used, but both become infused with beryllium particles that are then sprayed around the machine as a result of the mechanical energy from grinding. Additionally, the water-based fluid can evaporate and leave a beryllium-containing dust that can become airborne. The oil system dries more slowly, decreasing the rate at which beryllium particulate might dry and become airborne. Although Site 10 currently uses oil-based fluids, (Frigon, 2005) noted that other facilities often still use water-based lubricating systems (Frigon, 2005).

Due to the potential for workplace contamination, Site 10 isolated lapping and polishing activities in a dedicated work suite, thereby lowering exposures in nearby operations (e.g., extruding) (ERG Beryllium Site 10, 2006). Although some establishments have isolated lapping operations, others have kept these operations out on the production floor. For example, at one production machine shop ERG visited (Site 9), the lapping machine sat amidst other machining operations. The lapping machine was observed to be enclosed and ventilated, however. This facility was a general metallic beryllium machining operation, not one specific to beryllium oxide machining (ERG Beryllium Site 9, 2004).

Specific work practices also vary with wet or dry machining. The machining operator running the dry-machining center vacuums finished parts before placing them in the storage container. After machining parts using wet methods, the operator wiped them dry before placing them in the storage container.

Site 3 makes extensive use of full-machine enclosures. There are approximately 60 beryllium oxide machining centers at Site 3, and each is fitted with LEV and fully enclosed with a stainless steel frame and Plexiglas enclosure. At the time of the site visit, the machining operator was observed running a surface grinder under a flood of coolant (in a fully enclosed and ventilated machining center). After completing the machining cycle (approximately three minutes), the worker removed the part, rinsed it in a tray of water, wiped it off with a sponge, and placed it in a part tray (ERG Beryllium Site 3, 2003).

Machining enclosures and LEV hoods throughout the facility are served by 12 LVHV exhaust ventilation systems connected to HEPA filter dust collection units. Eight are rated at 3,000 cubic feet per minute (cfm) and four are rated at 2,000 cfm. There is also one LVHV HEPA filter collection system dedicated to the machining department. Machine controls are reportedly linked to the operation of the ventilation system, and critical alarms are installed to indicate system malfunction. Differential pressure gauges across the filters are installed, checked, and routinely recorded. Internal personnel service and maintain the ventilation system on an annual basis (ERG Beryllium Site 3, 2003).

Machining Operators—Additional Controls

As shown in Table IV-21 of Beryllium Oxide Ceramics and Composites Appendix 1, the exposure profile for machining operators includes sample data for a variety of machining tasks and is characterized by an overall range of 0.01 $\mu g/m^3$ to 5.0 $\mu g/m^3$, a mean of 0.32 $\mu g/m^3$, and a median of 0.15 $\mu g/m^3$. Seven of nine machining operations have low exposures:

- Ignition module machining (71 percent of exposures are less than or equal to 0.2 $\mu g/m^3$)
- Surface grinding (100 percent of exposures are less than or equal to 0.2 $\mu g/m^3$)
- Laser scribing (81 percent of exposures are less than or equal to 0.2 $\mu g/m^3$)
- Complex (precision) machining (76 percent of exposures are less than or equal to 0.2 $\mu g/m^3$)
- Drilling (100 percent of exposures are less than or equal to 0.2 $\mu g/m^3$)
- Machining resister cores (67 percent of exposures are less than or equal to 0.2 $\mu g/m^3$)
- Dry (green) machining (69 percent of exposures are less than or equal to 0.2 $\mu g/m^3$)

Drilling, machining resistor cores, and dicing all have median exposure levels that exceed 0.1 $\mu g/m^3$. The number of full-shift PBZ sample results for each of these machining activities is quite limited (i.e., one to three samples each), and in all cases, these data represent samples obtained more than 10 years ago. Note that both lapping and plate polishing and dry (green) machining also have median exposures above 0.1 $\mu g/m^3$; however, many more samples are available for these operations (60 and 180 samples, respectively).

Given the reported improvements in exposure control at this facility over time, the baseline exposure levels for drilling, machining resistor cores, and dicing would likely be lower than the exposure profile indicates. In those circumstances where exposures in the above-listed operations exceed the proposed 0.2 $\mu g/m^3$ PEL, additional controls would include ensuring that existing control measures are working properly and that proper procedures are being followed.

Green machining (primarily laser bores) and lapping and plate polishing comprise the bulk of the machining sample results for which additional controls are required. The exposure profiles for these operations are based on 240 full-shift PBZ samples obtained over a 10-year period (1994 to 2003) at Site 10. The median exposure levels (exposure profile) for green machining and lapping and polishing are 0.16 $\mu g/m^3$ and 0.29 $\mu g/m^3$, respectively. Site 10 has reported improvements in exposure controls over time. Exposure control improvements include isolating lapping and polishing from the rest of production in two separate, enclosed areas; switching to an oil-based lapping abrasive; revising personal protective equipment (PPE) requirements; adding additional air-conditioning capacity to lapping areas to address PPE heat stress issues; covering machine coolant containers; filtering machining fluid and lapping abrasives to remove beryllium particulate; and addressing work practice issues (Frigon, 2005). Data showing to what extent exposures have been reduced are not available. Nonetheless, since the median exposures for green machining are already below the proposed 0.2 $\mu g/m^3$ PEL, and the median exposures for lapping and polishing are only slightly above the proposed 0.2 $\mu g/m^3$ PEL, only modest reductions were needed. It seems likely that the controls that have been implemented are sufficient to reduce exposures in these operations most of the time.

Where machining operator exposures continue to exceed 0.2 μg/m^3, additional controls will be needed. Physical enclosures around lapping equipment might be helpful for further limiting the migration of lapping fluid. The barriers would help prevent lapping fluid from escaping from the equipment and splashing onto worker clothing, equipment, and work surfaces in close proximity. This additional control also would limit the amount of workplace and worker contamination and reduce exposures associated with the contamination. As noted in the section on Machining Operators—Baseline Controls, during a visit to a beryllium machine shop (Site 9), investigators observed that a double-sided lapper used for production machining was enclosed and ventilated. Exposures associated with lapping and other wet-machining operations might also be reduced by adding enclosures and/or LEV at points of fluid agitation or effervescing that are not already contained and ventilated.

Machining Operators—Conclusion

In general, exposure during machining operations is low. Overall, 63 percent of exposures in these operations are less than or equal to the proposed 0.2 μg/m^3 PEL. For most operations, ensuring that existing controls are working properly and that appropriate procedures are followed consistently will address the few exposures that exceed the proposed 0.2 μg/m^3 PEL. Additional controls for the lapping and polishing operations have been installed at Site 10 and are believed to be effective in reducing exposures. In addition, enclosing the lapping operations to reduce the migration of contaminated fluids will reduce the level of beryllium contamination and thus, reduce worker exposures. Because only modest reductions are needed to achieve exposures at or below the proposed 0.2 μg/m^3 PEL, OSHA preliminarily concludes that exposures at or below the proposed 0.2 μg/m^3 PEL can be achieved in the majority of machining operations most of the time. Sixty-three percent of the exposures in machining operations are greater than or equal to 0.1 μg/m^3. Based on available information, OSHA believes that achieving an alternative PEL of 0.1 μg/m^3 for this job category most of the time with the use of engineering and work practices would be challenging. Therefore, the Agency requests additional information, including exposure data and effectiveness of controls, to make a determination on the feasibility of an alternative PEL of 0.1 μg/m^3.

Metallization Workers

Metallization Workers—Baseline Controls

Metallization workers operate the metallizing equipment and then transfer parts to a kiln for firing (or re-firing). While metallizing operations do not generate beryllium dust, the firing process can generate beryllium-containing emissions.

Metallizing typically occurs within an enclosed chamber and involves coating all or part of the ceramic with a molybdenum-manganese material by roll-coating, spraying, or screen printing. Thus, dust generation is not normally an issue. After metallization, parts are nickel-plated and fired (sintered) at high temperatures in a furnace with a reducing atmosphere. Worker exposure can occur if the furnace lacks sufficient ventilation.

Metallization Workers—Additional Controls and Conclusion

As shown in Table IV-19, the median exposure level for metallization workers is 0.06 μg/m^3. Table IV-20 shows that 69 percent of exposures during metallizing activities are less than or equal to the proposed 0.2 μg/m^3 PEL, and 55 percent of exposures are less than 0.1 μg/m^3, based on 36 full-shift PBZ sample results obtained at Site 10 from 1996 to 2003. In those infrequent instances when exposures exceed these levels, OSHA believes that ensuring that existing controls are working as intended, that proper work procedures are followed, and that housekeeping is maintained will reduce exposures. Based on these data, OSHA preliminarily concludes that exposures less than or equal to the proposed 0.2 μg/m^3 PEL can be achieved in the majority of metallizing operations most of the time, and that exposures less than 0.1 μg/m^3 can also be achieved most of the time.

Production Support Workers

Production Support Workers—Baseline Controls

This job category primarily includes packaging and maintenance workers. At Site 10, packaging is conducted in one room in a nonproduction area of the facility. Packaging operators receive cleaned and finished parts from the production area through a "pass-through" airlock. They perform visual/dimensional inspections and packaging of parts under laboratory-type LEV hoods.

Maintenance work includes building and grounds maintenance as well as production maintenance. At Site 10, workers conduct maintenance work on uncontaminated equipment and parts in a central maintenance shop. For production-related work, two smaller satellite maintenance shops are available in production areas of the plant (wastewater treatment and material preparation). Maintenance workers must follow facility policies and procedures when working in production (regulated) areas. These procedures include using PPE (e.g., work clothing, disposable coveralls, gloves, shoes and socks, shoe covers, loose-fitting powered air-purifying respirators) and following personal hygiene requirements (e.g., strict handwashing, taking showers after exiting production areas). Maintenance workers and other production support workers, such as janitors, have wet-cleaning methods and HEPA-filter vacuums (central and portable) available for housekeeping and equipment decontamination.

Production Support Workers—Additional Controls and Conclusion

As shown in Table IV-19, the median exposure level for production support workers is 0.05 μg/m^3. Table IV-20 shows that 88 percent of production support workers' exposures are less than or equal to the proposed 0.2 μg/m^3 PEL, and 68 percent of exposures are less than 0.1 μg/m^3, based on 119 full-shift PBZ sample results obtained at Site 10 from 1996 to 2003. OSHA believes that the infrequent exposures above 0.2 μg/m^3 are a result of maintenance activities that occur in the production areas, and that production support workers' exposures will be reduced as the general level of contamination decreases in the course of lowering other workers' exposures. Thus, no additional controls will be needed specifically for production support workers. Based on these data, OSHA preliminarily concludes that exposures less than or equal to the proposed 0.2 μg/m^3 PEL can be achieved in the majority of production support operations most of the time, and that exposures below 0.1 μg/m^3 also can be achieved in these operations most of the time.

For some unusual maintenance activities, the varied work requirements make finding an effective control problematic. For these tasks, maintenance workers will need to continue using appropriate PPE, including respiratory protection. For workers whose exposures are below the current PEL of 2.0 μg/m^3, a respirator with an assigned protection factor (APF) of 10 will be sufficient. These respirators (e.g., half-facepiece respirators) offer protection up to an exposure level of 2 μg/m^3. For situations that can create more elevated exposures (e.g., upset conditions, such as a spill of beryllium oxide-containing material), a respirator that offers a minimum APF of 50 is necessary. Such respirators (e.g., full-facepiece respirators) provide protection against airborne beryllium concentrations of up to 10 μg/m^3. Thus, for example, if the PEL is set at the proposed level of 0.2 μg/m^3, a production support worker with an exposure of 7.70 μg/m^3 (the highest exposure level in OSHA's exposure profile for this job category) would require a respirator with an APF of 50. A tight-fitting powered air purifying respirator (PAPR) (with an APF of 1,000) would also be acceptable.

Administrative Staff—Technological Feasibility

Administrative Staff—Baseline Controls

At Site 10, administrative workers are no longer allowed to freely enter production areas. Access to production work areas requires compliance with facility policies and procedures, including using PPE (clothing and loose-fitting powered air-purifying respirators) and personal hygiene practices (handwashing and showers). Site 10 has designated zones of control: administrative zone, production zones, and interplant lab/office/break area zones. Transition zones separate production zones from interplant office/break zones. The transition zones are equipped with sticky floor mats, HEPA-filtered air showers, and facilities for donning/doffing a second set of gloves and shoe covers. Where appropriate, material/product/ paper "pass-throughs" and inter-zone intercoms were installed to minimize worker traffic between production and interplant lab/office/break areas (ERG Beryllium Site 10, 2006).

For other establishments in the industry, migration control measures may not be as consistent. Site visit data for other sectors (e.g., beryllium production) also suggest that production and administrative areas might not be well separated. For example, at Site 3, the employer does relatively little to separate administrative workers from production areas. Administrative personnel enter the production areas of the facility in street clothes and shoes without any special precautions. Production workers are permitted in the office environment but enter only infrequently.

Administrative Staff—Additional Controls and Conclusion

As shown in Table IV-19, the median exposure level (exposure profile) for administrative workers is 0.05 μg/m^3. Table IV-20 shows that 98 percent of administrative staff exposures are less than or equal to the proposed 0.2 μg/m^3 PEL and 93 percent are less than 0.1 μg/m^3. This finding is based on 185 full-shift PBZ sample results obtained for office, engineering, and R&D personnel from 1995 to 2003 at Site 10. The low exposures achieved in this plant are the result of reasonable approaches to limit access to potentially hazardous areas and to minimize the migration of contamination from the production areas of the plant. Other facilities should be able to achieve the same results with the same or similar measures. Therefore, OSHA preliminarily concludes that administrative staff exposures less than or equal to the proposed 0.2 μg/m^3 PEL can be achieved in the majority of administrative operations most of the time, and that exposures less than 0.1 μg/m^3 can also be achieved most of the time.

SUMMARY

OSHA identified seven beryllium oxide ceramics production job groups with beryllium exposure: material preparation operator, forming operator, machining operator, kiln operator, production support, metallization, and administrative work. Four of these jobs (i.e. material preparation, forming operator, machining operator and kiln operator) work directly with beryllium oxides, and therefore these jobs have a higher potential for exposure. The other three job groups (i.e. production support work, metallization, and administrative work) have primarily indirect exposure that occurs only when production support, metallization, and administrative workers enter production areas and are exposed to the same sources to which material preparation, forming, machining and kiln operators are directly exposed. However, some production support and metallization activities do require workers to handle beryllium directly, and these workers may therefore at times be directly exposed to beryllium.

The Agency developed exposure profiles for these jobs based on air-sampling data from three sources: 1) samples taken between 1994 and 2003 at a large beryllium oxide ceramics facility, 2) air-sampling data obtained during a site visit to a primary beryllium oxide ceramics producer, 3) a published report that provides information on beryllium oxide ceramics product manufacturing for a slightly earlier time period, and 4) exposure data from OSHA's Integrated Management Information System (IMIS) (OSHA, 2009). The exposure profile indicates that the three job groups with mostly indirect exposure (production support work, metallization, and administrative work) already achieve the proposed PEL of 0.2 $\mu g/m^3$. Median exposure sample values for these job groups did not exceed 0.06 $\mu g/m^3$.

The four job groups with direct exposure had higher exposures. In forming operations and machining operations, the median exposure levels are slightly below the proposed PEL (0.18 and 0.15 $\mu g/m^3$, respectively), while the median exposure levels for material preparation and kiln operations exceed the proposed PEL (0.41 $\mu g/m^3$ and 0.25 $\mu g/m^3$, respectively).

OSHA preliminarily concludes that the profile for the directly exposed jobs may overestimate exposures due to the preponderance of data from the mid-1990s, a time period prior to the implementation of a variety of exposure control measures introduced after 2000. In forming operations, 44% of sample values in the exposure profile exceeded 0.2 $\mu g/m^3$. However, the median exposure levels for some tasks, such as small-press and large-press operation, based on sampling conducted in 2003 were below 0.1 $\mu g/m^3$. The exposure profile for kiln operation was based on three samples taken from a single facility in 1995, all above 0.2 $\mu g/m^3$. Since then, exposures at the facility may have declined due to changes in operations that reduced the amount of time kiln operators spend in the immediate vicinity of the kilns, and the discontinuation of a nearby high-exposure process. More recent information communicated to OSHA suggests that current exposures for kiln operators at the facility are currently below 0.1 $\mu g/m^3$, as discussed in the Exposure Profile for the Nonferrous Foundries section of this PEA (OSHA, 2014). Exposures in machining operations, most of which were already below 0.2 $\mu g/m^3$ during the 1990s, may have been further reduced since then through improved work practices and exposure controls (PEA Chapter IV Section 7—Precision Turned Products). For forming, kiln, and machining operations, OSHA preliminarily concludes that the installation of additional controls such as machine interlocks (for forming) and improved enclosures and ventilation will reduce

exposures to or below the proposed PEL most of the time. OSHA requests information on recent exposure levels and controls in beryllium oxide forming and kiln operations to help the Agency evaluate the effectiveness of available exposure controls for this application group.

In the exposure profile for material preparation, 73% of sample values exceeded 0.2 μg/m^3. As with other parts of the exposure profile, exposure values from the mid-1990s may overestimate airborne beryllium levels for current operations. During most material preparation tasks, such as material loading, transfer, and spray drying, OSHA preliminarily concludes that exposures can be reduced to or below 0.2 μg/m^3 with process enclosures, ventilation hoods, and improved housekeeping procedures. However, OSHA acknowledges that peak exposures from some short term tasks such as maintenance of the spray chamber might continue to drive the TWA exposures above 0.2 μg/m^3 on shifts when this task is performed, and that respirators may be needed to protect workers from exposures above the proposed PEL during this task.[103] OSHA notes that material preparation for production of beryllium oxide ceramics currently takes place at only two facilities in the United States.

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SECTION 4—BERYLLIUM OXIDE CERAMICS AND COMPOSITES, APPENDIX 1—PERSONAL EXPOSURE DETAILS

Table IV-21—Details of Personal Exposure in the Beryllium Oxide Ceramics Industry (1994–2003)

Job Category and Work Group	No. of Full-Shift PBZ Samples [a]	Range (µg/m³)	Mean (µg/m³)	Median (µg/m³)
Material Preparation Operator	*77*	*0.02 to 10.6*	*1.01*	*0.41*
Forming Operator	*408*	*0.02 to 53.2*	*0.48*	*0.18*
Tape casting [b]	*28*	*0.03 to 5.6*	*0.62*	*0.14*
Extrusion	*65*	*0.04 to 0.88*	*0.23*	*0.17*
Small press	*190*	*0.02 to 53.2*	*0.62*	*0.18*
Press setup	*3*	*0.15 to 0.25*	*0.20*	*0.20*
Large press	*115*	*0.02 to 6.3*	*0.36*	*0.20*
Isopress	*7*	*0.06 to 1.0*	*0.59*	*0.83*
Kiln Operator	*3*	*0.22 to 0.36*	*0.28*	*0.25*
Machining Operator	*355*	*0.01 to 5.0*	*0.32*	*0.15*
Ignition module machining	*35*	*0.03 to 1.8*	*0.22*	*0.10*
Surface grinding	*2*	*0.03 to 0.05*	*0.04*	*0.04*
Laser scribing	*27*	*0.02 to 0.51*	*0.12*	*0.09*
Complex machining	*80*	*0.02 to 4.9*	*0.22*	*0.10*
Drilling	*2*	*0.18 to 0.20*	*0.19*	*0.19*
Machining resistor cores	*3*	*0.20 to 0.44*	*0.28*	*0.20*
Lapping/Plate polishing	*60*	*0.02 to 3.4*	*0.58*	*0.29*
Dry (green) machining	*180*	*0.01 to 4.99*	*0.32*	*0.16*
Dicing	*1*	*0.36*	*0.36*	*0.36*
Metallization Worker	*36*	*0.02 to 0.62*	*0.15*	*0.06*
Production Support Worker	*119*	*0.02 to 7.7*	*0.21*	*0.05*
Packaging operator	*37*	*0.020 to 0.50*	*0.09*	*0.05*
Maintenance	*81*	*0.02 to 7.70*	*0.26*	*0.05*
Janitor	*1*	*0.80*	*0.80*	*0.80*
Administrative Staff	*185*	*0.02 to 1.2*	*0.06*	*0.05*
Office	*172*	*0.02 to 1.2*	*0.06*	*0.05*
Engineering and R&D	*13*	*0.03 to 0.06*	*0.05*	*0.06*
Total	**1,218**	**0.01 to 53.2**	**0.36**	**0.11**

[a] *The exposure profile is based on full-shift PBZ (lapel) total beryllium sample results. Full-shift sample results represent a sampling duration of 360 minutes or longer and have not been time-weighted for 8 hours (i.e., full-shift sample results are based on the actual sampling duration). Most samples (1,214 samples) were analyzed by NIOSH Method 7102 (Beryllium and compounds, as Be) or 7300 (Elements by ICP), and the analytical LOD was reported to be 0.1 µg beryllium per filter. For sample results below the analytical LOD, a sample weight of 0.05 µg (one-half the analytical LOD) was used to calculate the volume-adjusted nondetectable sample concentration. Four samples were analyzed using OSHA Method 125G, with a reporting limit of 0.02 µg per filter. Results reported as less than 0.02 µg are incorporated into the exposure profile as volume-adjusted reporting limit concentrations.*

[b] *The 28 samples (7 percent of all forming operator samples) associated with tape casting are included, although tape casting is not currently performed.*

Sources: Brush Wellman Tucson, 2004 (presenting data for ERG Beryllium Site 10); ERG Beryllium Site 3, 2003.

Table IV-22—Details Regarding Distribution of Full-Shift PBZ Exposure Results for Total Beryllium in the Beryllium Oxide Ceramics Industry (1994–2003)							
Job Category and Work Group	**Number of Full-Shift PBZ Sample Results in Range [a] (μg/m^3)**						**Total No. of Samples**
	< 0.1	**≥ 0.1 to ≤ 0.2**	**> 0.2 to ≤ 0.5**	**> 0.5 to ≤ 1.0**	**> 1.0 to ≤ 2.0**	**> 2.0**	
Material Preparation Operator	*10 (13%)*	*12 (14%)*	*24 (33%)*	*15 (20%)*	*8 (10%*	*8 (10%)*	*77 (100%)*
Forming Operator	*110 (27%)*	*118 (29%)*	*115 (28%)*	*43 (11%)*	*15 (4%)*	*6 (1%)*	*408 (100%)*
Tape casting [b]	*11 (39%)*	*6 (21%)*	*6 (22%)*	*0 (0%)*	*2 (7%)*	*3 (11%)*	*28 (100%)*
Extrusion	*17 (26%)*	*23 (36%)*	*19 (29%)*	*6 (9%)*	*0 (0%)*	*0 (0%)*	*65 (100%)*
Small press	*56 (30%)*	*51 (27%)*	*53 (28%)*	*21 (11%)*	*6 (3%)*	*3 (1%)*	*190 (100%)*
Press setup	*0 (0%)*	*2 (67%)*	*1 (33%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*3 (100%)*
Large press	*25 (22%)*	*35 (30%)*	*35 (31%)*	*12 (10%)*	*7 (6%)*	*1 (1%)*	*115 (100%)*
Isopress	*1 (14%)*	*1 (14%)*	*1 (14%)*	*4 (58%)*	*0 (0%)*	*0 (0%)*	*7 (100%)*
Kiln Operator	*0 (0%)*	*0 (0%)*	*3 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*3 (100%)*
Machining Operator	*142 (37%)*	*102 (26%)*	*87 (22%)*	*40 (10%)*	*11 (3%)*	*8 (2%)*	*390 (100%)*
Ignition module machining	*17 (48%)*	*8 (23%)*	*6 (17%)*	*3 (9%)*	*1 (3%)*	*0 (0%)*	*35 (100%)*
Surface grinding	*2 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*2 (100%)*
Laser scribing	*15 (55%)*	*7 (26%)*	*4 (15%)*	*1 (4%)*	*0 (0%)*	*0 (0%)*	*27 (100%)*
Complex machining	*36 (45%)*	*25 (31%)*	*15 (19%)*	*3 (4%)*	*0 (0%)*	*1 (1%)*	*80 (100%)*
Drilling	*0 (0%)*	*2 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*2 (100%)*
Machining resistor cores	*0 (0%)*	*2 (67%)*	*1 (33%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*3 (100%)*
Lapping/Plate polishing	*15 (25%)*	*9 (15%)*	*15 (25%)*	*11 (18%)*	*6 (10%)*	*4 (7%)*	*60 (100%)*
Dry (green) machining	*57 (32%)*	*49 (37%)*	*45 (25%)*	*22 (12%)*	*4 (2%)*	*3 (2%)*	*180 (100%)*
Dicing	*0 (0%)*	*0 (0%)*	*1 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*1 (100%)*
Metallization Operator	*20 (55%)*	*5 (14%)*	*10 (28%)*	*1 (3%)*	*0 (0%)*	*0 (0%)*	*36 (100%)*
Production Support Worker	*81 (68%)*	*24 (20%)*	*8 (7%)*	*3 (2%)*	*1 (1%)*	*2 (2%)*	*119 (100%)*
Packaging operator	*27 (73%)*	*8 (22%)*	*2 (5%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*37 (100%)*
Maintenance	*54 (67%)*	*16 (20%)*	*6 (8%)*	*2 (2%)*	*1 (1%)*	*2 (2%)*	*81 (100%)*

Table IV-22—Details Regarding Distribution of Full-Shift PBZ Exposure Results for Total Beryllium in the Beryllium Oxide Ceramics Industry (1994–2003)

Job Category and Work Group	Number of Full-Shift PBZ Sample Results in Range [a] (μg/m³)						Total No. of Samples
	< 0.1	≥ 0.1 to ≤ 0.2	> 0.2 to ≤ 0.5	> 0.5 to ≤ 1.0	> 1.0 to ≤ 2.0	> 2.0	
Janitor	*0 (0%)*	*0 (0%)*	*0 (0%)*	*1 (100%)*	*0 (0%)*	*0 (0%)*	*1 (100%)*
Administrative Staff	*172 (93%)*	*9 (5%)*	*2 (1%)*	*1 (0.5%)*	*1 (0.5%)*	*0 (0%)*	*185 (100%)*
Office	*159 (93%)*	*9 (5%)*	*2 (1%)*	*1 (0.5%)*	*1 (0.5%)*	*0 (0%)*	*172 (100%)*
Engineering and R&D	*13 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*13 (100%)*
Total	*574 (47%)*	*231 (19%)*	*249 (20%)*	*103 (9%)*	*36 (3%)*	*25 (2%)*	*1,218 (100%)*

[a] *The exposure profile is based on full-shift PBZ (lapel) total beryllium sample results. Full-shift sample results represent a sampling duration of 360 minutes or longer and have not been time-weighted for 8 hours (i.e., full-shift sample results are based on the actual sampling duration). Most samples (1,214 samples) were analyzed by NIOSH Method 7102 (Beryllium and compounds, as Be) or 7300 (Elements by ICP), and the analytical LOD was reported to be 0.1 μg beryllium per filter. For sample results below the analytical LOD, a sample weight of 0.05 μg (one-half the analytical LOD) was used to calculate the volume-adjusted nondetectable sample concentration. Four samples were analyzed using OSHA Method 125G, with a reporting limit of 0.02 μg per filter. Results reported as less than 0.02 μg are incorporated into the exposure profile as volume-adjusted reporting limit concentrations.*

[b] *The 28 samples (7 percent of all forming operator samples) associated with tape casting are included, although tape casting is not currently performed.*

Sources: Brush Wellman Tucson, 2004 (presenting data for ERG Beryllium Site 10); ERG Beryllium Site 3, 2003.

SECTION 5—NONFERROUS FOUNDRIES

INDUSTRY PROFILE

Aluminum and copper foundries produce a variety of cast products using alloyed and unalloyed copper, aluminum, and other metals that at some foundries include castings of copper-beryllium and, to a lesser extent, aluminum-beryllium. Aluminum and copper foundries that produce or process beryllium alloys are classified in the following industries as defined by 2007 NAICS:

- Aluminum foundries (except die-casting) (NAICS 331524 [SIC 3365]).
- Copper foundries (except die-casting) (NAICS 331525 [SIC 3366]).

Other foundries perform die-casting of aluminum, copper, and other nonferrous alloys:

- Aluminum die-casting foundries (NAICS 331521 [SIC 3363]).
- Nonferrous (except aluminum) die-casting foundries (NAICS 331522 [SIC 3364]).

Copper beryllium alloys average about 70 percent of U.S. annual consumption of beryllium, most which contain approximately 2% beryllium. Aluminum-beryllium alloys which contain 30% to 68% are used primarily in aerospace applications and account for less than 5% of annual consumption (Cunningham, 2004). Table IV-23 shows U.S. Census Bureau data describing the copper and aluminum foundry industries. At some of these establishments, pure beryllium is cast for specialized aerospace applications, however, the vast majority of beryllium is alloyed with other metals.[104] Most beryllium alloys contain 5 percent or less of beryllium. Products produced by casting beryllium alloys include alloy ingots; non-sparking hand tools; welding electrodes and other parts of the welding electrode assembly, such as holders and shanks; and specialized parts for the electronics and aerospace industries.

OSHA has limited information on the number of foundries that cast beryllium and beryllium alloys. Based on discussions with representatives of the American Foundry Society and the Non-Ferrous Founders' Society, the number is likely to be small (Robinson, 2001; NFFS, 2002). Other industry sources, including representatives from copper and aluminum foundries, a resistance welding electrode manufacturer, and a brass and copper rolling mill, also indicated that few foundries cast beryllium and beryllium alloys, although they could not estimate the number (Barbetti, 2002; Capozzi, 2002; Erickson, 2002; Specialloy, 2002).

[104] According to the U.S. Department of Energy, beryllium is alloyed with copper, aluminum, nickel, zinc, and zirconium (64 FR 66854, 68855-56). Copper-beryllium, aluminum-beryllium, and nickel-beryllium are cast in the United States. OSHA found no information about casting of zinc-beryllium or zirconium-beryllium alloys in the United States.

Table IV-23—Copper and Aluminum Foundries, 2010				
	NAICS 331525, copper foundries (except die-casting)	**NAICS 331524, aluminum foundries (except die-casting)**	**NAICS 331521, aluminum die-casting foundries**	**NAICS 331522, nonferrous (except aluminum) die-casting foundries**
No. of Establishments	*208*	*394*	*254*	*140*
Total Employees	*5,123*	*15,178*	*18,017*	*6,362*
Source: U.S. Census Bureau, 2007; U.S. Census Bureau, 2010.				

Copper Foundries

An analysis of sampling information from OSHA's Integrated Management Information System (IMIS) found that beryllium was detected in 20 percent of the 110 copper foundries where samples were taken during the period 1978 through 2008 (OSHA, 2009). An extrapolation of this percentage to the population of copper foundries (208) classified in NAICS 331525 suggests that about 42 such foundries work with copper-beryllium alloys. Industry contacts suggest that the number of foundries casting beryllium alloys has declined in recent years. Of seven foundries contacted that have used copper-beryllium, two have stopped using the material in recent years, therefore the current number is likely to be less than 42. (Dollard, 2002; Enviro, 2001; Johnson, 2002; Specialloy, 2002; Taylor, 2001; Tricast, 2001; Worldcast, 2001).

Table IV-24 shows data from the U.S. Census Bureau (2002) describing the number of copper foundries with shipments in categories that include copper-beryllium, specifically high-copper alloys.[105] The table shows that 25 firms produced copper and high-copper sand castings (NAICS 3315250416), and 25 firms also produced investment castings out of high-copper alloys (NAICS 33152505410. Fewer foundries produced high-copper mold, centrifugal, and other types of castings. These categories are not exclusive, however, and firms might be listed more than once, and therefore, the number of foundries using high-copper alloys is less than the total shown in the table (89). If the number of unique foundries represented in Table IV-24 is one-half the aggregate, then the Census data suggest that about 45 copper foundries might potentially work with beryllium alloys. This estimate is consistent with the findings from OSHA's IMIS database, given the decline in copper-beryllium use in the foundry industry in the last decade.

Table IV-24—Number of Foundries Producing High-Copper Alloy Castings by NAICS, 2002	
NAICS, Foundry Type, and Casting Method	**No. Foundries**
All Copper Foundries (331525)	*208*
33152504: Tin, bronze, copper, and high-copper alloy sand castings	
3315250416: Copper and high-copper sand castings (except bearings and bushings)	*25*
33152505: Other copper and copper-base alloy castings	

[105] Comparable data are not available from the 2007 Economic Census.

Table IV-24—Number of Foundries Producing High-Copper Alloy Castings by NAICS, 2002	
3315250531: Permanent and semi-permanent mold castings	*12*
3315250536: Centrifugal castings	*13*
3315250541: Investments castings	*25*
3315250546: Other castings	*10*
*33152506: Copper-base alloy bearings and bushings, nonmachined**	*4*
Total Firms Producing High-Copper Alloy Castings	*89*

**   Includes high-copper as well as other types of copper alloys.*

Source: U.S. Census Bureau, 2002: number of firms with $100,000 or more in shipments.

Aluminum Foundries

OSHA found little information on which to estimate the number of foundries in the United States that cast aluminum-beryllium alloys. The use of aluminum-beryllium alloys is much less common than the use of copper-beryllium. (Cunningham, 2004). Copper-beryllium alloys are used in a variety of applications, including electronic and computer products, whereas aluminum-beryllium alloys are used primarily in specialized applications, such as the aerospace industry. In addition, a representative of an aluminum foundry indicated an apparent trend away from the use of beryllium alloys in aluminum foundries (Barbetti, 2002).

Based on information from the U.S. Census Bureau and industry sources, OSHA estimates that 14 foundry companies cast aluminum-beryllium alloys (Kosto, 2002). Of these foundries, at least 12 are estimated to use aluminum-beryllium master alloys (Kosto, 2002). The remaining two foundries cast both pure beryllium and beryllium composite or hybrid products. These foundries make parts for specialized aerospace applications (MDA, 2011; Fedvendor.com, 2004-2005). For the purposes of this analysis, OSHA divided these establishments and assigned one half of the total, or seven establishments, to each of the two aluminum foundry industries (NAICS 331521 and 331524).

Nonferrous Die-casting Foundries (Except Aluminum)

OSHA found no information about beryllium alloy use among establishments classified in NAICS 331522 as nonferrous (non-aluminum) die-casting foundries. The U.S. Census Bureau, however, reported that 38 firms classified in this industry produce copper or copper-base alloy die-castings, including bearings and bushings (U.S. Census Bureau, 2002). Because these are the products most likely to contain beryllium, OSHA used this as an upper estimate of the number of such establishments that might work with copper-beryllium alloys.

Table IV-25 summarizes OSHA's estimates of the number of foundries that produce casts made from beryllium alloy metals. The number of employees are estimated based on the average employment sizes for the respective industries. OSHA, thus, estimates a total of 97 foundries with 3,601 employees.

Table IV-25—Foundries Casting Beryllium and Beryllium Alloys

Industry	Establishments	Total Employees
NAICS 331521, Aluminum die-casting foundries	*7*	*497*
NAICS 331522, Nonferrous (except aluminum) die-casting foundries	*38*	*1,727*
NAICS 331524, Aluminum foundries (except die-casting)	*7*	*270*
NAICS 331525, Copper foundries (except die-casting)	*45*	*1,108*
Total	*97*	*3,601*
Source: ERG estimates; see text (Industry Profile for Aluminum and Copper Foundries).		

Affected Job Categories

The metal casting industry uses many different casting processes for a wide variety of applications. The production of castings using beryllium alloys includes the following basic process steps: 1) preparing a mold into which the molten metal is poured, 2) melting and pouring the molten metal, and 3) cleaning the cooled metal casting to remove molding and extraneous metal (NIOSH 85-116). The primary job categories with potential for beryllium exposure in foundries are as follows:

- Molder (including sand mold-maker and permanent mold maintenance).
- Material handler.
- Furnace operator (also melt operator).
- Pouring operator.
- Shakeout operator (only in foundries using sand molds or cores).
- Abrasive blasting (shotblast) operator.
- Grinding/finishing operator.
- Maintenance operator (including furnace/ladle and ventilation system maintenance, housekeeping).

Furnace operators, pourers, and foundry supervisors[106] are present in the foundry areas of the facility during the entire work shift (NIOSH EPHB 326-16a). The other job categories spend some portion of the shift in the production areas.

[106] This NIOSH EPHB did not specify what tasks a foundry supervisor performs. This study did specify that 12 samples were collected at the green sand portion of the foundry for 1 furnace operator, 3 molders, and 2 pouring operators. Included in these twelve samples is a description of exposures of 0.1 μg/m^3 and 0.58 μg/m^3 for a foundry supervisor. Thus, it is likely that the foundry supervisor in this study supervised any or all of these three activities, and to the extent that the sources of exposure in these activities are controlled, so will exposures to the foundry supervisor.

The volume, size, and type of castings produced vary widely from one foundry to another, ranging from a few large specialized castings to thousands of small castings per shift. Depending on the size of the foundry, each task may be performed by a separate operator or one operator may be responsible for several tasks. In high-production foundries, workers are likely to be responsible for a single task (e.g., molder, pouring operator, or furnace operator); in small or highly automated shops, a single worker may be assigned to several operations, such as combined responsibilities for furnace operation and pouring (NIOSH 79-114).

In addition to the categories listed above, other operations may occur in foundries, including pattern making, core making, welding, and X-ray inspection of castings. Welding is the subject of a specific section of this analysis and is not further addressed here (see Section 10—Welding). Inspection and radiography/X-ray processes are not normally associated with exposure to airborne beryllium at concentrations greater than the proposed permissible exposure limit (PEL) of 0.2 micrograms per cubic meter ($\mu g/m^3$) (Interactive Guide Casting Alloys, 2012). Pattern and core making are precision processes typically involving new, uncontaminated non-metal materials (e.g., wood, sand, clay, plastic, Styrofoam, chemical agents) and are often performed in a separate foundry area, away from mold making and casting areas, with little potential for exposure. OSHA assumes these activities are not associated with significant exposure.[107] And therefore, pattern making, core making and inspection of castings are not discussed further in this report.

Table IV-26 summarizes the major activities of workers potentially exposed to beryllium in foundries. Figure IV-1 illustrates a typical plant layout with two foundries: an aluminum-beryllium and copper-beryllium ingot foundry, and a green sand foundry that primarily manufactures copper-beryllium hand tools (NIOSH EPHB 326-16a).

Table IV-26—Job Categories and Major Activities of Workers Potentially Exposed to Beryllium in Foundries

Job Category	Major Activities
Molder (mold maintenance, mold formation, sand systems operation)	*Maintains molds, removes metal deposits, and cleans molds in foundries with reusable molds. Monitors sand systems and molding machine operation in sand casting foundries. Applies mold parting/coating/release compounds.*
Material handler (forklift operator, crane operator)	*Operates a front-end loader, forklift, crane, or other material-moving equipment to transport metal, castings, or other materials. Assists other workers with manual handling activities (such as furnace charging).*

[107] Patterns are required to make molds. A pattern is a form made of wood, metal, plastic, or plaster that is the same shape as the final casting. Molding material is packed around the pattern to shape the mold cavity. Air contaminants associated with pattern-making typically include particulate emissions from cutting, grinding, and sanding pattern materials, and solvent and cleaner exposures associated with equipment cleaning (EPA 310-R-97-004; NIOSH 85-116).
Molds replicate the external shape of the pattern. If internal cavities are required, cores are placed inside the mold. Cores are typically made from sand and chemical binders and are formed inside a core box where the required materials are added and cured into the desired shape. Curing processes include heat, a chemical reaction, or a catalytic reaction (EPA 310-R-97-004). Air contaminants associated with core making include sand and chemical emissions from binding agents, resins, catalysts, and other materials used in core making processes (NIOSH 85-116).

Table IV-26—Job Categories and Major Activities of Workers Potentially Exposed to Beryllium in Foundries	
Job Category	**Major Activities**
Furnace operator (melt operator)	*Controls and monitors furnaces used to produce molten metal. Loads metal into furnaces and skims dross from molten metal.*
Pouring operator (ladle operator, casting operator)	*Transfers molten metal into ladle or holding furnace, and then into molds, typically via equipment supported by a cart, crane, or rail configuration.*
Shakeout operator	*In foundries using sand molds or cores, oversees operation of shakeout and knockout equipment to separate castings from molds. Contact with equipment and castings will depend on the degree of automation.*
Abrasive blasting operator (includes wheelabrator operator, rotoblast operator)	*Typically operates shotblasting cabinet; if very large casting, may blast on open floor or use compressed air to clean castings.*
Grinding/finishing operator (includes saw operator and sanding operator)	*Uses portable or bench tools such as chippers, grinders, and polishers or buffers to remove defects and adhered molding material from castings.*
Maintenance operator	*Repairs and maintains foundry and furnace equipment including repair and maintenance of ventilation system air cleaning devices and refractory lining on furnace, ladle, and tundish. Activities may also include housekeeping such as dry sweeping, vacuuming, and shoveling chips and metal splatter from floors and equipment.*

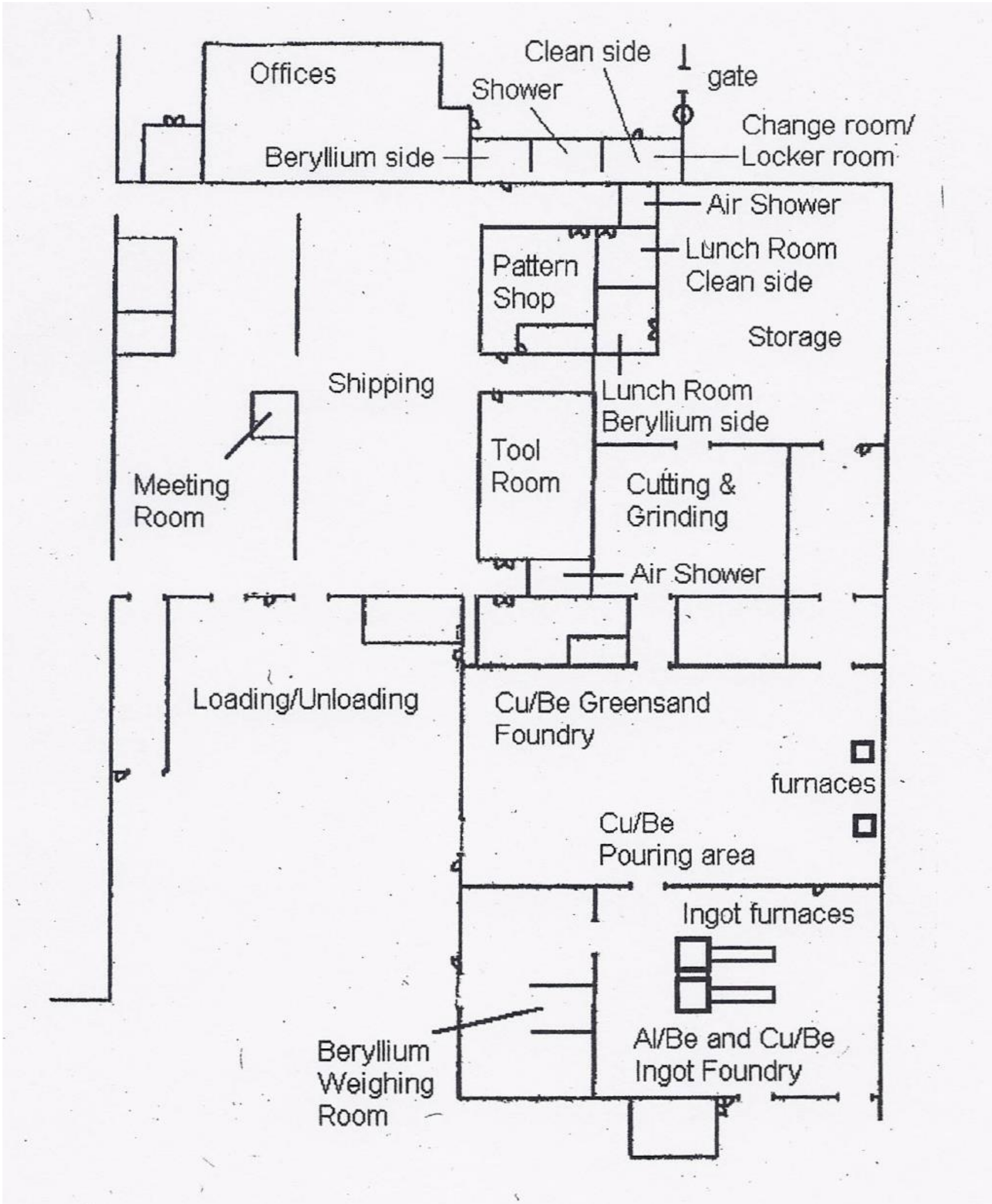

Figure IV-1. Plant layout of a facility with two foundries: an aluminum-beryllium and copper-beryllium ingot foundry and a green sand foundry that manufactures a variety of copper-beryllium hand tools (Source: NIOSH EPHB 326-16a).

OSHA used BLS Occupational Employment Statistics Survey data to estimate the percentages of foundry workers in each of these job classifications (BLS, 2008). The percentages were adjusted to account for occupations specific to sand casting foundries (shakeout operator) and to ensure a minimum number of employees per establishment (at least one) in each job classification. The resultant percentages were then applied to the employment totals to estimate the number of employees by job category in the affected establishments. These estimates are shown in Table IV-27.

Table IV-27—Distribution of Beryllium Alloy Foundry Employment by Affected Job Category

Job Category	Percentage of Employment	Number of Employees
Molder	*13.80%*	*497*
Material handler	*2.20%*	*79*
Furnace operator	*2.60%*	*94*
Pouring operator	*4.20%*	*151*
Shakeout operator	*1.14%*	*41*
Abrasive blasting operator	*2.40%*	*86*
Grinding/finishing operator	*7.20%*	*259*
Maintenance operator	*5.50%*	*198*
Total-affected job categories	*39.04%*	*1,406*
Other, non-affected occupations	*60.96%*	*2,195*
Total	**100.0%**	**3,601**

Sources: BLS, 2008; Table IV-25; and ERG estimates. See text (Affected Job Categories subsection in this on Aluminum and Copper Foundries).

DESCRIPTIONS OF AFFECTED JOB CATEGORIES

<u>Molder</u>

Molders prepare, clean, and maintain permanent and non-permanent molds. Permanent (reusable) molds, or dies, require little daily preparation other than assembly and cleaning (brushing out old mold release agent, sweeping, scraping, and minor grinding). Beryllium-containing residue (in the form of oxides and base metal) can build up on the molds during the casting process, and molders may be exposed to beryllium as they remove this material along with the residual mold release agents. When molds will be reused immediately, workers perform these tasks in the pouring area (in foundries with a small workforce, molder and pouring operator tasks may be performed by one worker). Molds can also be transported to other areas for maintenance.

In facilities that use non-permanent molds (e.g., sand casting foundries), molders typically prepare molds by shaping granular media (sand or similar substances) and a binder into shapes that will form molten metal, but will disintegrate to the original granular structure when casting is complete. Sand casting methods do little to minimize oxide formation, and sand castings may be covered with beryllium oxide (Corbett, 2004). As a result, reclaimed molding sand may become contaminated with oxide and beryllium alloy dislodged from the casting during shakeout activities. This process creates a source of beryllium exposure for workers handling the sand and preparing molds in foundries that cast beryllium alloys.

Sand molders usually work in an area of the foundry that is functionally separate from other foundry activities; however, air monitoring of other toxic metals, such as lead and cadmium, in copper and bronze sand casting foundries indicates that molders can experience secondary metal fumes and dust exposures when poorly balanced ventilation systems allow contaminated air to flow from melting and pouring spaces to the molding area (CCMA, 2000). Results from OSHA's IMIS database indicate that molders can also be exposed to beryllium (OSHA, 2009). However, job descriptions in the IMIS database generally do not permit differentiation between workers handling reusable molds and those working with expendable or sand molds. For example, out of 85 job descriptions associated with molding, only five indicated the nature of the molds handled (one green sand mold and four permanent mold operators). Additional process and exposure information is required to determine the extent to which workers performing these tasks should be differentiated in the future.

Material Handler (Heavy Equipment Operator, Crane Operator, Forklift Operator)

Material handlers transport materials and castings between workstations. For these workers, the primary sources of beryllium exposure include ineffectively controlled processes associated with other job categories that the material handler must pass by or work near, spilled and settled dusts disturbed by the transport equipment they operate (e.g., forklifts), dust and fumes released directly from loads being transported by the material handler (e.g., fuming ladles, open barrels of excess metal trimmed from casting), and beryllium fumes and dust that cause cross-contamination in areas frequented by material handlers. Forklift operators who charge furnaces and who move receptacles containing dross (a scum at the surface of the molten metal formed by oxides and other contaminants) and scrap can experience airborne beryllium exposure from these sources. Forklift and crane operators who move new castings may encounter beryllium oxide dust from these items or be exposed to fumes as they pass near active melting and pouring operations. As other studies have shown, forklift drivers' exposure often is related to areas they enter where other workers' activities generate elevated airborne concentrations of contaminants (ERG Silica_GenInd1v.2, 2008).

Furnace Operator (Melt Operator, Furnace Assistant)

Furnace operators charge furnaces with new and/or reused metal (foundry scrap returns), supervise the melting process, sparge molten metal in the furnace (i.e., adding a gas-generating substance to promote mixing), and skim dross using a scoop or wand. The tasks associated with managing dross are reportedly among those that generate the highest and most frequent potential beryllium exposures in foundries (Corbett, 2004).

Furnace operators spend the majority of their time melting metal. For more automated processes, the furnace operators frequently spend a substantial amount of their shift in an office or control booth, monitoring the melting process remotely and through periodic checks. Certain tasks, however, must be performed for each melt. For example, furnace charges (raw materials in the form of ingot or foundry returns) must be prepared (weighed) to create the desired mix, preheated, and placed in the furnace (more than one charge may be required per melt). Heating the charge usually occurs in a large specialized bucket placed in a separate furnace. In addition to dust that might be released during the transfer process, preheating can cause air currents that disturb beryllium-containing dust, particularly on foundry scrap returned to the furnace for melting (the previous melting/casting cycle may have caused beryllium oxides to form). Transfer of the charge to the furnace may be manual or automated, depending on the size of the furnace and level of foundry automation. Furnace operators often transfer the raw materials (brought by a material handler to the furnace area) from a transport container to the special bucket used for preheating the charge or making additions to the furnace.

Once the raw material is loaded into the furnace, the operator initiates the melting process. This involves several repetitive steps centered around the furnace. Induction furnaces, typically cylindrical without a refractory lid (open top), have been growing in popularity for a number of years and now are the most common type of equipment controlled by furnace operators. A furnace typically includes a small platform at the top for the operator. Some foundry designs also include a separate observation/control platform removed from the furnace or an enclosed control room.

Regardless of the furnace type or foundry design, most of the melting steps are similar. In one step, the furnace operator monitors the extent to which impurities in the metal and oxygen (from air at the molten metal surface) create dross. Furnace operators must remove this dross at regular intervals to improve the purity of the molten metal and prevent the newly forming oxides from becoming incorporated into the melt when it is stirred.

To skim the dross, the furnace operator typically uses a scoop on a long handle and reaches into the furnace to scoop the impurities from the surface. After emptying the scoop into a receptacle, typically a bucket, the operator repeats the process as many times as necessary. Extra beryllium may be added to the mix to compensate for beryllium lost as oxide and to ensure the final casting contains the correct percentage.[108] Furnace operators are exposed to beryllium when they manipulate molten metal in the furnace (fumes rising off molten metal), when they bring dross off the surface and move the scoop outside the furnace, and when they knock the dross from the scoop into the receptacle. They can also be exposed when they handle the dross receptacle to transport it or empty it into a larger storage container. In addition to the beryllium hazard, this work is physically demanding and hot.

Other activities associated with the melting process include sparging the molten metal to stir it (adding a gas-generating substance on a wand or using an automated process), collecting samples for analysis (again manipulating molten metal in the furnace), and cleaning the melt deck. Operators also visually check the melt frequently to determine whether other actions are needed. Once the metal is properly formulated, melted, drossed, and sparged, the furnace operator adjusts the furnace for tapping (transferring molten metal out of the furnace for pouring). For example, in a typical operation, the furnace will be tipped to pour metal into a tundish (a refractory-lined vessel with one or more openings at the bottom for controlling metal flow into the molds) or a

[108] Beryllium has an affinity for oxygen, and the oxides that form on the surface of metal can have a substantially higher percentage of beryllium—by several times—than the alloy itself (Corbett, 2004).

ladle (a container used to transport molten metal to another area where it will be poured). This point marks the beginning of activities in the pouring operator job category.

In smaller or more automated foundries, the same person will often do a number of jobs; for example, furnace operators can control both the furnace and the pouring operations (ERG Beryllium Site 7, 2003). These jobs are generally separate in larger foundries, so exposures and controls relating to pouring activities are addressed under the pouring operator job category. Some furnace operators also maintain furnace refractory linings, which are contaminated with beryllium/oxide from contact with molten metal that impregnates the semi-porous refractory surface. This task, often performed by maintenance staff, is addressed under the maintenance operator (furnace maintenance) category. Additionally, furnace equipment (e.g., dross handling equipment, furnace hoods/enclosures, and furnace tools) can become contaminated with beryllium. Furnace operators can be exposed during cleaning and service activities associated with contaminated equipment.

Furnace operators frequently receive help from designated furnace operation assistants and employees who normally work in other job categories (e.g., material handlers), but are appointed as helpers during the melt process (ERG Beryllium Site 7, 2003). OSHA has considered these helpers to be doing work associated with the furnace operator job category during their time working in the furnace area.

Pouring Operator

Pouring operators supervise the transfer of molten metal from the furnace (and any intermediary ladles) into molds. Depending on the type of casting performed by the foundry, these workers oversee a wide range of common molding equipment. Examples include sand molds, permanent molds such as dies, vacuum molding equipment (pulls molten metal into the mold using vacuum pressure), centrifugal molds (spins molten metal to force it out into a mold or to coat the inside of a spinning cylinder—such as for manufacturing pipes), and water-chilled molds that quickly cool casting surfaces (Schleg and Kanicki, 2000). Depending on mold type, foundry staffing, and casting size, some or all duties may be shared by the furnace operator, the pouring operator, the molder, and/or the shakeout operator. One worker may perform all these jobs (ERG Beryllium Site 7, 2003).

Beryllium fumes can enter pouring operators' breathing zones as the fumes rise off molten metal in open ladles, tundishes, and molds. The American Foundry Society (AFS), in its *Foundry Ventilation Manual* (1985), notes: "Normally, copper and its alloying agents due to greater toxicity have lower allowable exposure levels (threshold limit values or permissible exposure levels) than ferrous metals and their alloying agents." Additionally, "copper-based alloys have a lower vapor pressure than ferrous metals. In the molten state, they produce more metallic fumes. Since the main reservoir for the molten metal is the ladle(s), the majority of emissions from these pouring operations emanates from that source, rather than the mold itself. Once copper-based alloys solidify, the emission of air contaminants drops to a very low level."

Fume escaping from any source into the work area contributes to background exposure levels in the pouring area and other areas where air currents transport the fumes. Other sources of beryllium exposure in the pouring area include any beryllium metal or oxide residue left on the molds (see molder job category) and refurbishing of the tundish and ladles (see maintenance operator job category). Adjacent operations can also influence employee exposure in the pouring area. For practical reasons, the pouring area is nearly always next to the furnace area, with minimal barriers between the two spaces. Beryllium fumes and dust released from the furnace area can be a substantial source of exposure for pouring operators. Shakeout areas, where new castings are separated from molds (particularly sand molds and cores), can also be adjacent to the molding area for convenience.

Exhaust ventilation systems are available for numerous types of equipment used in the pouring area; however, this equipment is not consistently installed in foundries. Additionally, some ventilation systems require special work practices and may be used improperly, which decreases their effectiveness.

Shakeout Operator

Shakeout operators separate molds from castings. If sand molds or sand cores are used in the casting process, shakeout operators use vibrating equipment to dislodge granular media ("sand"). This process is generally termed "shakeout." Under some casting conditions, beryllium oxide can form on the casting surface. In these cases, sand can be contaminated with residual beryllium oxide from contact with the cast metal surface.

Shakeout operators monitor equipment that separates castings from mold materials by mechanically vibrating or tumbling the casting. The castings, along with large lumps of molding sand and excess metal, remain on top, while fine materials (primarily molding sand) fall through grates. Sand separated during shakeout is transported away on a portion of the sand transport system and is frequently reused (overseen by another group of workers, molders). When melting and casting in the presence of oxygen in air, beryllium oxide typically forms on the casting surface. In these cases, sand can be contaminated with residual beryllium oxide from contact with the cast metal surface. Shakeout operators may tend automated equipment or perform manual operations, primarily loading and unloading the vibrating equipment. Additionally, in the case of large, heavy castings, a material handler (e.g., crane operator) may work in the shakeout area, hoisting the flask that contains the mold and then dumping it on a vibrating table.[109] During this operation, a second operator may be responsible for re-hooking the cast metal piece onto the crane for transfer to the finishing area (NIOSH 79-114, 1978). Shakeout operations vary from manually handling and turning over the mold to systems that are fully automated (AFS, 1985).

A National Institute for Occupational Safety and Health (NIOSH) study described a manual shakeout operation at a copper-base casting operation. At this facility, an oscillating shakeout was mobilized on a set of tracks for shakeout at the end of the five mold conveyor lines. Three workers operated the shakeout, two to dump the molds from the pouring conveyor and simultaneously retrieve the bottom board, and the other worker to hook the casting off the conveyor (NIOSH 79-114, 1978). Workers may also use sledgehammers and compressed air to move excess sand from castings (NIOSH HETA 92-090-2296). These high-energy processes

[109] A flask is a metal or wood frame without a top or a fixed bottom that is used to hold the sand from which a mold is formed. It usually consists of two parts, the cope and the drag. (Source: NIOSH 85-116.)

release substantial dust. If the molding materials are contaminated with beryllium, then beryllium dust could be released (Corbett, 2004).

Shakeout operators' duties frequently overlap with those of pouring operators and material handlers. For some casting methods that do not use granular media for molds or cores (e.g., extruded casting processes, or casting solid objects in permanent molds), the shakeout operator job category may be completely eliminated.

Abrasive Blasting Operator

Abrasive blasting operators clean castings to remove residual molding material (e.g., sand) and surface oxides, and to prepare the metal surface for additional treatment (e.g., painting). For the surface cleaning and preparation activities, these workers use abrasive media, usually steel shot or steel grit for the hardest alloys, or for softer alloys, a range of other organic and inorganic media (Belair, no date; Kramer, 2012). For smaller castings, abrasive blasting operators typically operate automated blasting machines (such as those made by Wheelabrator) or related equipment such as tumbling media mills or vibratory mills that perform a similar function in cleaning and preparing the casting surface. Large castings are abrasively blasted in booths, although castings too large to fit in a booth are typically blasted in large open areas with respiratory protection. However, very few foundries produce beryllium alloy castings this large. Some abrasives can themselves be a source of additional beryllium exposure due to beryllium content of the abrasive media, or contain other toxic substances such as crystalline silica, other metals (KTA-Tater-Phase-I, 1998).

Grinding/Finishing Operator—Description

Grinding/finishing operators perform any steps needed to finish castings. They can use saws to remove gates, sprues, and risers or trim the casting to specification. These workers also perform grinding to remove minor casting surface defects. They finish castings by polishing, buffing, sanding, or grinding pieces to customer specifications. Grinding/finishing operators can use abrasive cut-off saws, stationary or hand-held grinding equipment, sanding equipment, and machine tools (precision machining activities are also grouped with this category). All of these items remove metal from the casting and create beryllium metal dust. Some grinding and sanding is performed to remove beryllium-containing oxide that forms on the product during the casting process. This work can be performed using wet methods in aluminum and copper foundries to reduce the amount of dust (ERG Beryllium Site 7, 2003). Additionally, some abrasive media can themselves be a source of additional beryllium exposure (due to beryllium content of the abrasive media).

Maintenance Operator

Maintenance operators repair equipment throughout the facility. These workers can be exposed to beryllium when they service foundry ventilation systems, repair production equipment, and maintain refractory materials.

Maintenance operators encounter beryllium while adjusting and repairing industrial ventilation system components such as bag houses and filters, or when emptying portable vacuum cleaners used to capture dust that contains beryllium. For example, maintenance operators must periodically change the filter bags in bag houses and filters in other air cleaning devices. This process can be dusty, particularly during upset conditions when a bag has deteriorated to the point that it has begun leaking dust. NIOSH reported on maintenance operators who inspected vacuum cleaners and cleared cyclone dust separators at a facility that cast beryllium alloy (in this case not classified as a foundry, but performing some of the same activities) (NIOSH HHE 78-17-567, 1979).

Maintenance operators also encounter beryllium when they chip and scrape refractory ceramic linings that have been in contact with beryllium alloys (e.g., in a furnace, ladle, or tundish). Although new refractory ceramic material (usually a cementitious mineral product) does not contain appreciable beryllium, molten metal and metal oxides coat (and in some cases impregnate) the semi-porous refractory surface upon use (Corbett, 2004). Oxides of beryllium can contain appreciably higher beryllium content than the original alloy. The oxide that accumulates on furnace, ladle, and tundish walls can have a beryllium content that is several percent higher than the beryllium alloy itself. Because refractory ceramic linings can be damaged by the heating and cooling cycles to which they are subjected, maintenance operators in some foundries must repair cracks and thin spots on a daily basis. Furnace maintenance workers may use a hammer and chisel, or scraping tools, or use power equipment (pneumatic chipping tools) to chip away damaged/cracked refractory lining before patching (Refractory Services Provider A, 2003; ERG Silica_GenInd1v.2, 2008). In some foundries, furnace operators and pouring operators also perform this task. At an ERG foundry site visit, tundish maintenance was performed immediately after the metal was poured, while the metal on the tundish was still hot. Debris was removed from one or more square feet of surface area and placed in a ventilated receiving container. The furnace operator then patched and painted the tundish with a coating similar to a mold-release agent. During this process, the furnace operator was exposed to fumes as he moved in and out of the effective range of the exhaust ventilation in the pouring area (Corbett, 2005).

Some maintenance workers may perform housekeeping tasks. Sources of exposure include beryllium-containing dust disturbed during housekeeping, such as handling contaminated equipment, dry sweeping, dry wiping, moving dusty items, and chipping splattered metal. At one beryllium alloy facility with both ingot and green sand foundries, production workers clean and maintain their work stations throughout the day and at the end of the work shift (NIOSH EPHB 326-16a). High-efficiency particulate air (HEPA) filter vacuums are used to clean equipment and work surfaces. A centralized (stationary) HEPA vacuum system is used in the ingot foundry, while portable HEPA vacuums are used in the green sand foundry and in the cutting and grinding shop.

EXPOSURE PROFILE

Data Sources

For aluminum and copper foundries, OSHA examined the affected job categories, including mold maker, material handler, furnace operator, pouring operator, shakeout operator, abrasive blasting operator, grinding/finishing operator, and maintenance worker.

Limited information is available regarding worker exposure to beryllium in copper and aluminum foundries. The available sources of exposure information include:

- Eight reports containing individual exposure results.
- Surrogate exposure information from a primary beryllium producer.
- IMIS sampling results.

Individual Exposure Results

OSHA identified eight sources of individually reported exposure results:

- A 2003 ERG site visit conducted at a beryllium alloy casting facility hereafter referred to as ERG Beryllium Site 7 (ERG Beryllium Site 7, 2003). This facility uses direct chill casting methods to manufacture beryllium alloy casting and master alloy ingot (copper-beryllium, nickel-beryllium, and aluminum-beryllium). The beryllium content of the products range from 0.25 percent to 10.5 percent in the master alloys. A total of four personal breathing zone (PBZ) beryllium samples were obtained for three workers (furnace operator, furnace helper, and forklift operator) over two days. Casting was done during the night shift with only one casting done on a typical night. Because the workers were permitted to end the shift after they melted and poured one batch of alloy, the sampling periods for three of the four samples were less than 5 hours (i.e., 252 to 267 minutes), encompassing the employees' total exposure for a typical day. All four PBZ samples were positive for beryllium, with results ranging from 1.92 $\mu g/m^3$ to 14.08 $\mu g/m^3$. The air sampling rate was 2 liters per minute (lpm) and the samples were analyzed using OSHA Method 125G (Inductively Coupled Argon Plasma—Atomic Emission Spectroscopy (ICAP-AES)). The analytical limit of detection was reported to be 0.02 µg beryllium per sample.

- A 2007 NIOSH industrial hygiene evaluation conducted at a copper-beryllium foundry and machine shop that manufactures products for the metal die casting industry (NIOSH EPHB 326-11a). This foundry uses both sand mold and permanent mold systems in two different furnace operations and the products contain from 0.45 percent to 2.15 percent beryllium. Twenty-four PBZ and three general area air samples for beryllium were obtained over two consecutive days during normal plant operations.[110] Most samples were more than 8 hours in duration due to the plant's 10-hour work shift. Beryllium was detected in all samples collected with PBZ

[110] The samples were simultaneously analyzed for copper and other metals.

concentrations ranging from 0.13 μg/m^3 to 5.52 μg/m^3. The three area samples were all obtained in the machine shop and ranged from 0.06 μg/m^3 to 0.08 μg/m^3. Sixteen of the 24 samples exceeded the NIOSH Recommended Exposure Limit (REL) of 0.5 μg/m^3 and seven indicated airborne beryllium concentrations greater than the current PEL of 2 μg/m^3. The highest PBZ concentrations were associated with melting and casting, mold cleanout, sawing and grinding, and the machine shop. PBZ and general area samples were collected at a flow rate of 3 lpm and analyzed according to NIOSH Method 7300 (inductively coupled plasma spectroscopy).

- Another 2007 NIOSH industrial hygiene evaluation conducted at a facility with both an ingot foundry and a green sand foundry (NIOSH EPHB 326-16a). The ingot foundry manufactures aluminum-beryllium and copper-beryllium ingots containing 1 percent to 5 percent beryllium. The green sand foundry manufactures a variety of copper-beryllium products (including non-sparking hand tools) that contain a maximum of 4 percent beryllium. A total of 23 full-shift air samples were collected on two consecutive workdays for beryllium and other metals (17 PBZ and six general area air samples) during normal plant operations. PBZ concentrations ranged from less than 0.03 μg/m^3 to 1.07 μg/m^3 and general area samples ranged from 0.03 μg/m^3 to 0.15 μg/m^3. Three of the samples exceeded 0.5 μg/m^3 and none exceeded the current PEL of 2 μg/m^3. The highest PBZ concentrations were associated with the grinding room, the foundry supervisor, and the aluminum-beryllium ingot furnace operator. PBZ and general area samples were collected at a flow rate of 3 lpm and analyzed according to NIOSH Method 7300 (inductively coupled plasma spectroscopy).

- A site visit (Case History D) conducted in 1999 at a ferrous/non-ferrous centrifugal casting foundry by the California Cast Metals Association (CCMA, 2000). The case history includes a brief description of the pouring area and 10 PBZ air sampling results for beryllium for various job categories (such as melting and casting, abrasive blasting, machining, grinding, and others) obtained over several days.[111] Most samples were at least 7 hours in duration. One beryllium result (2.2 μg/m^3) during casting exceeded OSHA's current PEL for beryllium (2 μg/m^3), while all other results were well below the PELs for the metals evaluated (many of these results were also below the limits of detection). Information regarding sampling and analytical procedures was not provided.

- A 1983 NIOSH Health Hazard Evaluation (HHE) at a light-alloy foundry that manufactures aluminum and magnesium castings for the aircraft, missile, and aerospace industries (NIOSH HETA 83-015-1809). NIOSH investigators evaluated worker exposures to various chemical substances including beryllium in the foundry and welding areas of the facility. A chest X-ray obtained in 1982 of one beryllium-exposed employee showed findings consistent with sarcoidosis, a disease that can be difficult to differentiate from chronic beryllium disease. A total of 20 full-shift PBZ

[111] The samples were analyzed for beryllium and other metals, including arsenic, cadmium, chromium, lead, nickel and selenium.

samples were obtained for beryllium.[112] Thirteen of the samples were collected on furnace tenders (operators), five samples were collected on welders, and two samples were obtained on weld cleaners (removing unsightly burns, bluing, scale, discoloration and rust from welds). The metals were collected at a sampling flow rate of 2.0 lpm and analyzed by inductively coupled plasma-atomic emission spectroscopy. The analytical detection limit was 1 µg beryllium per sample. Although none of the samples contained detectable amounts of beryllium, NIOSH investigators reported that the sampling limit of detection (1 µg/m^3) was not low enough to adequately evaluate the presence of airborne beryllium (NIOSH HETA 83-015-1809). Further, it was not known whether beryllium-containing castings were being processed at the time of the NIOSH evaluation.[113] A description of the facility's engineering controls was limited to the pouring and cooling areas of the foundry. NIOSH noted the use of general dilution ventilation in these areas and a lack of LEV. Previous sampling conducted by a consultant to the company showed airborne concentrations of 0.2 µg/m^3 in the breathing zone of a pouring operator and concentrations of 1.1 µg/m^3 to 1.4 µg/m^3 in the breathing zone of a weld cleaner working on a casting containing 0.03 percent beryllium (by weight). No other information was reported.

- Two NIOSH HHEs conducted in 1975 and 1978 at a large beryllium extraction and manufacturing facility in Reading, Pennsylvania, that produced pure beryllium metal, beryllium oxide, and beryllium alloys (copper, nickel, and aluminum). The principal product produced, however, was copper-beryllium alloys (master alloy containing 4 percent beryllium and other forms containing 2 percent or less beryllium) including tools, wire, rod, tubing, strip, and sheet (NIOSH HHE 75-87-280; NIOSH HHE 78-17-567; Kriebel et al., 1988). Site processes included a foundry where alloys were cast into billets and sold as is or used to cast other alloys. The alloys were rolled or drawn to the proper dimensions and then tempered. During the 1975 evaluation, NIOSH investigators obtained 17 PBZ samples for beryllium in the foundry and melting and casting areas (NIOSH HHE 75-087-280). Sampling durations ranged from 306 minutes to 428 minutes and the air sampling rate was approximately 1.5 lpm. The samples were analyzed for beryllium using NIOSH Method P & CAM 121 with a beryllium limit of detection (LOD) of 1 µg per sample (NIOSH HHE 75-87-280; NIOSH HHE 78-17-567).[114] In addition to air monitoring for beryllium and other metals throughout the facility, NIOSH conducted a review of randomly selected employee medical records, which indicated that one employee experienced beryllium dermatitis, one employee had acute beryllium pneumonitis, and nine employees had chronic beryllium disease.

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[112] The samples were analyzed for beryllium and other metals, in this case including aluminum, barium, and magnesium.

[113] OSHA does not know if the nonferrous foundry also manufactured beryllium alloy castings at the time of the NIOSH site survey. However, small amounts of beryllium are commonly added to aluminum and magnesium alloys to improve the quality of the melt and the resulting castings. The beryllium additions are usually made by adding aluminum-beryllium, copper-beryllium, or magnesium-beryllium master alloy to the aluminum alloys. For magnesium alloys, beryllium is usually added in the form of magnesium-beryllium or aluminum-beryllium master alloy (Houska, 1988).

[114] The beryllium LOD for NIOSH Method P & CAM 121 is reported in NIOSH HHE 78-17-567.

- During the 1978 evaluation at the Reading facility (NIOSH HHE 78-17-567), NIOSH investigated the beryllium exposure of maintenance employees (called Hygiene Assistants) whose activities included emptying the waste material collected in central cyclone floor vacuums and local exhaust ventilation (LEV) systems (i.e., releasing and bagging wastes from the vacuum system and dust collectors), periodic servicing of bag houses (e.g., inspection, rebagging, and cleaning), cleaning up spills (e.g., beryllium hydroxide), and decontaminating and vacuum cleaning work areas. During the evaluation, NIOSH investigators obtained two full-shift PBZ samples with results of 29.5 µg/m^3 and 31 µg/m^3 for maintenance workers dumping LEV cyclone collectors and inspecting and cleaning floor vacuums.[115] The air sampling rate was 1.5 lpm and the samples were analyzed using both atomic absorption spectrophotometry (NIOSH Method P & CAM 121, LOD 1.0 µg per sample) and the graphite furnace technique (LOD 0.1 µg per sample).

- In addition, NIOSH investigators obtained the results of the facility's quarterly OSHA abatement reports on beryllium exposures for several activities including melting and casting and ventilation system maintenance. In all, 50 positive full-shift PBZ sample results for five quarters (first quarter 1977 through first quarter 1978) were provided to NIOSH. These exposure results reflected ongoing abatement activities associated with OSHA citations.

- A 1971 NIOSH air sampling survey conducted at a Hazelton, Pennsylvania, facility that converted beryl ore to beryllium metal, alloys, and compounds (NIOSH IWS-37-13; Bureau of Mines, 1971). Copper-beryllium master alloy was prepared by calcining beryllium hydroxide into beryllium oxide and then melting the beryllium oxide with copper and carbon powder in an electric arc furnace. The resulting copper-beryllium master alloy was cast into ingots containing about 4 percent beryllium. Copper-beryllium alloy containing about 2 percent beryllium was formed by melting the master alloy with copper in an induction furnace (EPA APTD-1508). During this survey, NIOSH investigators obtained 118 PBZ total beryllium samples throughout the facility. All samples were positive for beryllium and presumed to be full-shift.[116] Most of the sample results are not applicable to the facility's foundry operations. Two relevant job categories for which PBZ data were obtained include furnace repair worker (1.90 µg/m^3, 3.76 µg/m^3, and 3.80 µg/m^3) and maintenance mechanic (4.45 µg/m^3, 5.71 µg/m^3, 17.49 µg/m^3, and 35.97 µg/m^3). These samples could reflect maintenance activities associated with the foundry operations. However, OSHA cannot be certain because the NIOSH report does not elaborate further and the facility's operations included other activities involving furnaces such as beryllium extraction from beryl ore.

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[115] NIOSH presented the morning and afternoon sampling results separately in the report. OSHA estimated the full-shift exposures by combining the morning and afternoon sampling results and time-weighting the concentrations for 8 hours.

[116] Sampling durations for lapel samples were not specifically noted in the written report. However, a NIOSH representative from the Division of Surveillance, Hazard Evaluations and Field Studies, indicated that investigators attempted to collect at least 6-hour samples (Estill, 2004).

Surrogate Data

OSHA obtained exposure data for melting and casting operations from a primary beryllium producer that operates copper-beryllium foundry facilities (Kent et al., 2001). Air sampling results and production process information was provided for alloy furnace operations. Primary beryllium alloy operations occur in two different buildings and include master alloy production and beryllium alloy melting and casting. A Whiting four-electrode arc furnace is used for master alloy production and produces 4 percent copper-beryllium ingots. Feed material for the master alloy consists of copper and beryllium oxide pellets. Beryllium oxide is produced onsite by drying and rotary calcining beryllium hydroxide. The pellets are prepared by combining the resulting beryllium oxide with carbon and ventilation fines. Copper-beryllium alloys with a beryllium content of 2 percent or less are produced by coreless induction furnaces. Products include alloy ingots, rounds, and slabs (Kent et al., 2001).

Air sampling results from a 1999 baseline exposure assessment were provided for tasks associated with its master alloy and beryllium alloy melting and casting operations. These results are presented in Section 3—Beryllium Production of this report (subsections on Exposure Profiles and Technological Feasibility Analysis) and are used in this analysis as supporting information when appropriate. Samples were analyzed by NIOSH Methods 7102 or 7300 and the analytical limit of detection was reported to be 0.1 µg per sample. For results less than the limit of detection, a value of one-half the limit of detection was used to calculate the sampling limit of detection (Kent, 2005).

IMIS

IMIS entries for the years 1978 to 2008 also contain beryllium personal air sampling results associated with aluminum and copper foundries (SICs 3363 [NAICS331521], 3364 [NAICS 331522], 3365 [NAICS 331524], and 3366 [NAICS 331525]). These results are summarized by industry in Table IV-28 and include a total of 891 PBZ samples of which 183 (21 percent) measured detectable levels of beryllium. The means, medians, and distribution of positive-value IMIS results aggregated by relevant job categories are also shown in Table IV-28. Only IMIS results above the limit of detection are used to calculate the summary statistics. As noted in Section 2—Methodology of Chapter IV (Technological Feasibility) of the Preliminary Economic Analysis (PEA), IMIS data can be difficult to interpret because the database does not capture information pertaining to worker activities, workplace conditions, engineering controls, use of personal protective equipment (PPE), sampling time, and sampling limits of detection. Thus, when evaluating job descriptions in the IMIS database with potential beryllium exposure, it is not possible to determine whether beryllium was included in the sample analysis because there was potential workplace exposure to beryllium, or because it was analyzed as part of a routine metal screening. IMIS data are therefore used in this analysis in a supporting role to provide additional insight into the exposure profile of each affected job category.

Table IV-28—Summary of OSHA IMIS PBZ Beryllium Air Sampling Results for Aluminum and Copper Foundries (SICs 3363, 3364, 3365, and 3366)[a]

SIC Code	SIC Description	No. PBZ Samples with Positive Results/Total No. PBZ Samples[b]	Job Descriptions[c] (Positive Results Only)	Range[d] (μg/m^3)	Mean[d] (μg/m^3)	Median[d] (μg/m^3)
3363	*Aluminum die-casting foundries*	*3/38 (8%)*	*Laborer*	*0.17 to 0.2*	*0.19*	*0.2*
3364	*Non-ferrous die casting foundries (except aluminum)*	*17/76 (22%)*	*Grinder; furnace operator; furnace tender; spinner operator*	*0.01 to 13*	*1.54*	*0.05*
3365	*Aluminum foundries*	*68/199 (34%)*	*Caster/casting; grinder; floor trimmer; foundry worker; furnace operator; furnace tender; inspection finisher; machine operator/machinist; mold maker/assembler; pourer/pouring operator; sander; sandblaster; sawyer; welder*	*0.031 to 8.8*	*1.22*	*0.51*
3366	*Copper foundries*	*95/578 (16%)*	*Caster/pourer; casting cleaner; castings finisher; foreman; furnace tender; grinder; grinding finisher; melter/caster; melter/pourer; metal chaser/chasing; molder/mold maker; patina; permanent mold; pourer/pouring; pouring supervisor; production worker; sandblaster, sanding; saw operator; shakeout operator; shifter/shakeout; smelter; welder, wheelabrator operator*	*0.016 to 19*	*0.2*	*0.17*
Total	*All aluminum and copper foundries*	*183/891 (21%)*		*0.01 to 19*	*0.11*	*0.2*

[a] *Information regarding worker activities, engineering controls in place, personal protective equipment worn, sampling duration, and sampling limits of detection is not available in the database reviewed by OSHA.*

[b] *Includes all positive PBZ samples by SIC code regardless of the job description. Note that, for each SIC code, other types of samples (in addition to PBZ samples) may have been obtained such as area, screening, bulk, or wipe samples.*

[c] *Not inclusive. Includes major job descriptions associated with positive PBZ results.*

[d] *The range, mean, and median results are based on positive sample results only. All positive results are included.*

PBZ: personal breathing zone

Source: OSHA, 2009 (OSHA IMIS database, June 1978 to September 2008).

Exposure Profiles for Affected Job Categories

The exposure profile for copper and aluminum foundries is summarized in Tables IV-29 and IV-30. For each job category, OSHA reviewed the available exposure information, as discussed above, and selected the best available data for the foundry exposure profile. For one job category, maintenance operators, OSHA was not able to identify exposure information specific to the foundry industry. For this group of workers, OSHA has relied on PBZ results from a primary beryllium producer, which uses some of the same processes encountered in foundries. The exposure profile for each job category is discussed below.

Table IV-29—Personal Exposure Profile by Job Category for Workers in Aluminum and Copper Foundries (NAICS 331521, 331522, 331524, 331525)

Job Categories	Total Number Samples*	Range (μg/m^3)	Mean (μg/m^3)	Median (μg/m^3)
Molder	*8*	*0.24 to 2.29*	*0.67*	*0.45*
Material handler (crane/forklift operator)	*1*	*0.93*	*0.93*	*0.93*
Furnace operator (melt/heating operator and assistants)	*11*	*0.2 to 19.76*	*4.41*	*1.14*
Pouring operator	*5*	*0.2 to 2.2*	*1.21*	*1.4*
Shakeout operator	*1*	*1.3*	*1.3*	*1.3*
Abrasive blasting operator	*5*	*0.05 to 0.15*	*0.11*	*0.12*
Grinding/finishing operator	*56*	*0.01 to 4.79*	*0.31*	*0.05*
Maintenance operator (furnace/ventilation, housekeeping)	*78*	*0.05 to 22.71*	*0.87*	*0.21*
All Job Categories	*165*	*0.01 to 22.71*	*0.9*	*0.2*

* *The exposure profile includes one or more non-detectable (ND) results as follows: furnace operator, two ND results; pouring operator, two ND results; and grinding/finishing operator, three ND results. Non-detectable results are reported as sampling limit of detection concentrations: in each case these were 0.2 μg/m^3 or less.*

Source: CCMA, 2000; ERG Beryllium Site 7, 2003; NIOSH HHE 75-87-280; NIOSH EPHB 326-11a; NIOSH EPHB 326-16a; Brush Wellman Elmore, 2004; MC Pkg I-D, 2010.

Table IV-30—Distribution of PBZ Exposure Results for Total Beryllium in Aluminum and Copper Foundries (NAICS 331521, 331522, 331524, 331525)

Job Categories*	Number of Results in Range (μg/m^3)						Total
	< 0.1	≥ 0.1 to ≤ 0.2	> 0.2 to ≤ 0.5	> 0.5 to ≤ 1.0	> 1.0 to ≤ 2.0	> 2.0	
Molder	*0 (0%)*	*0 (0%)*	*5 (62.5%)*	*2 (25%)*	*0 (0%)*	*1 (12.5%)*	*8 (100%)*
Material handler (crane/forklift operator)	*0 (0%)*	*0 (0%)*	*0 (0%)*	*1 (100%)*	*0 (0%)*	*0 (0%)*	*1 (100%)*
Furnace operator (melt/heating operator and assistants)	*0 (0%)*	*2 (18.2%)*	*1 (9.1%)*	*2 (18.2%)*	*2 (18.2%)*	*4 (36.4%)*	*11 (100%)*
Pouring operator	*0 (0%)*	*2 (40%)*	*0 (0%)*	*0 (0%)*	*1 (20%)*	*2 (40%)*	*5 (100%)*
Shakeout operator	*0*	*0*	*0*	*0*	*1*	*0*	*1*

Table IV-30—Distribution of PBZ Exposure Results for Total Beryllium in Aluminum and Copper Foundries (NAICS 331521, 331522, 331524, 331525)							
	Number of Results in Range (μg/m³)						
Job Categories*	**< 0.1**	**≥ 0.1 to ≤ 0.2**	**> 0.2 to ≤ 0.5**	**> 0.5 to ≤ 1.0**	**> 1.0 to ≤ 2.0**	**> 2.0**	**Total**
	(0%)	*(0%)*	*(0%)*	*(0%)*	*(100%)*	*(0%)*	*(100%)*
Abrasive blasting operator	*2 (40%)*	*3 (60%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*5 (100%)*
Grinding/finishing operator	*33 (58.9%)*	*8 (14.3%)*	*8 (14.3%)*	*3 (5.4%)*	*1 (1.8%)*	*3 (5.4%)*	*56 (100%)*
Maintenance operator (furnace/ventilation, housekeeping)	*12 (15.4%)*	*27 (34.6%)*	*18 (23.1%)*	*11 (14.1%)*	*7 (9%)*	*3 (3.8%)*	*78 (100%)*
All Job Categories	*47 (28.5%)*	*42 (25.5%)*	*32 (19.4%)*	*19 (11.5%)*	*12 (7.3%)*	*13 (7.9%)*	*165 (100%)*

* *The exposure profile includes one or more non-detectable (ND) results as follows: furnace operator, two non-detectable results; pouring operator, two ND results; and grinding/finishing operator, three ND results. Non-detectable results are reported as sampling limit of detection concentrations: in each case these were 0.2 μg/m³ or less.*

Source: See Table IV-29.

Molder—Exposure Profile

The molder exposure profile is summarized in Tables IV-29 and IV-30. All eight samples included in the profile had detectable levels of beryllium, ranging range from 0.24 μg/m³ to 2.29 μg/m³, with a mean of 0.67 μg/m³ and median of 0.45 μg/m³. Five of the eight results are between 0.2 μg/m³ and 0.5 μg/m³, while two additional values are greater than 0.5 μg/m³ and less than or equal to 1.0 μg/m³. A single exposure level for a molder is notably higher, at 2.29 μg/m³.

This exposure profile relies on full-shift PBZ samples obtained by NIOSH during an industrial hygiene evaluation at a copper-beryllium foundry in 2007 (NIOSH EPHB 326-11a). These samples represent the best available information for the molder job category because they were collected on the sand molding line at a foundry that performed both sand casting and permanent mold casting.[117] Additionally, the samples were obtained relatively recently and are well characterized, in that information regarding sampling duration and work conditions and controls is available.[118] OSHA acknowledges that these data were obtained from a single facility; however, information from other sources support this profile.[119]

[117] Although the foundry included both sand casting and permanent mold lines at this facility, NIOSH only sampled molders involved in sand mold production. NIOSH stated in the report that workers in the melting and casting areas of the facility had the greatest potential for exposure (NIOSH EPHB 326-11a).

[118] The foundry is located in the Midwest and employs approximately 45 employees casting standard beryllium alloys. Foundries of this size are typical, representing about 33 percent of nonferrous die-casting foundries (See ERG's Economic Feasibility Report's industry profile for foundries).

[119] The molding operations at this copper-beryllium foundry include the production of sand molds with associated cores as well as a permanent mold system. NIOSH conducted sampling in the mold and core making operations because sand from the shakeout was reused in the production of molds. When sand is reused, metals from previous castings can contaminate it and expose molders to beryllium. All of the samples used in the molder exposure profile represent sand mold and core making activities.

The highest value in the molder exposure profile (2.29 μg/m^3) is associated with "mold cleanout" in the sand casting portion of the facility (NIOSH EPHB 326-11a).[120] Information contained in the report is insufficient to explain why this result was markedly higher than the other molder results, but worker exposures of this magnitude were not uncommon at this foundry. During NIOSH's visit, exposures exceeding the current OSHA PEL of 2.0 mg/m^3 were widespread.[121]

It is possible that lack of a dedicated ventilation system, work practices, and/or co-location exposures contributed to these results. Although the survey report does not specifically discuss work practices, NIOSH investigators made a general recommendation that HEPA-filtered vacuums should be used in beryllium work areas to remove dust from floors and work surfaces and that dry sweeping should be discontinued. After the completion of the survey, the facility initiated a comprehensive upgrade of the entire ventilation system in the foundry areas. Molders might also have used compressed air to clean mold and core surfaces as this practice is common in some foundries (NIOSH HETA 91-0093-2126; NIOSH HETA 92-092-2333; NIOSH HETA 92-157-2304). High dust exposure can occur when brooms (dry sweeping) or compressed air are used for cleaning, and these practices must be prohibited as part of an effective beryllium control program (Materion SF 201, 2011).

An additional molder result (below the analytical limit of detection and reported as "ND") was obtained when NIOSH investigators conducted a health hazard evaluation at a beryllium alloy (copper and aluminum) casting facility in 1975 (NIOSH HHE 75-87-280). The full-shift PBZ sample was collected on a molder in the facility's alloy foundry area. However, OSHA did not include the result in the molder exposure profile because the beryllium analytical limit of detection was significantly higher in the 1970s than in more recent years.[122]

OSHA also examined the IMIS results for molders in aluminum and copper foundries (SICs 3363, 3364, 3365, and 3366). As with all IMIS sample results, no information is available regarding the working conditions associated with these measurements. The IMIS database contains 88 PBZ results with mold and core making job descriptions (e.g., molder, mold maker, core maker, mold assembler, sand molder, automatic molder, permanent mold operator). Of these, 13 samples (15 percent) are positive for beryllium with a range from 0.02 μg/m^3 to 5 μg/m^3, a mean of 1.48 μg/m^3 and a median of 0.9 μg/m^3. The 13 positive results came from three

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[120] NIOSH investigators obtained two samples on workers cleaning molds: the sample resulting in the full-shift value of 2.29 μg/m^3 and a second shorter sample obtained on a different day. The second result was not included in the exposure profile because the 296-minute sampling period did not represent a full-shift sample. This sample resulted in a PBZ concentration of 0.81 μg/m^3 (NIOSH EPHB 326-11a).

[121] Other exposure levels at this foundry included furnace operators (4.72 μg/m^3 and 5.52 μg/m^3), pouring operator (2.04 μg/m^3), saw operator (2.54 μg/m^3), grinder (4.79 μg/m^3), and machine shop supervisor (2.17 μg/m^3). Twenty-four PBZ samples obtained throughout the facility ranged from 0.13 μg/m^3 to 5.52 μg/m^3, with a mean of 1.53 μg/m^3 and median of 1.15 μg/m^3 (NIOSH EPHB 326-11a).

[122] OSHA estimated the sampling limit of detection as 1.68 μg/m^3 by using the limit of detection (1 μg) reported for the analytical methodology (NIOSH Method P & CAM 121), the reported sampling duration (398 minutes) and the air sampling rate (approximately 1.5 lpm). The sampling limit of detection is greater than all but one of the sample results for molders in the exposure profile. To put the higher analytical limit of detection into perspective, if the sample is nondetectable and OSHA Method 125G was used for the analysis (0.02 μg LOD), the sampling limit of detection would have been significantly less (i.e., less than 0.034 μg/m^3). For a given analytical method, a greater volume of air sampled will result in a lower limit of detection for the sample. Great sample volumes are a function of longer sample durations (in minutes) or higher air sampling pump air flow rates, or both.

different facilities (9 results for mold assemblers at a California establishment; 1 result for a molder in a Pennsylvania facility, and three results for permanent molders at an Ohio facility). The three highest results (1.98 µg/m^3, 4.67 µg/m^3, and 5 µg/m^3) were obtained on permanent molders during a November 2007 inspection at the Ohio facility—a copper-beryllium foundry with approximately 38 employees. This finding provides evidence of recent exposures to elevated levels of beryllium for molders in nonferrous foundries foundries. Eleven other samples are associated with molding and a second activity such as melting, pouring, or finishing. Each of these results is nondetectable for beryllium.

Although the range of NIOSH values (0.24 µg/m^3 to 2.29 µg/m^3) used in the molder exposure profile is within the range of positive IMIS data (0.02 µg/m^3 to 5 µg/m^3), the IMIS range is wider than the range of NIOSH values, and the mean and median values are approximately two times greater than the corresponding values in the exposure profile. While this difference between the two sets of samples indicates that the molder exposure profile may be underestimating the median exposure for this group of workers, additional information for the alloy melting and casting operations at a primary beryllium producer signals otherwise. Fifteen full-shift PBZ samples obtained for workers maintaining permanent molds in the beryllium producer's copper-beryllium (containing 2 percent beryllium) melting and casting operations ranged from 0.09 µg/m^3 to 2.88 µg/m^3, with a mean of 0.36 µg/m^3 and a median of 0.16 µg/m^3 (Brush Wellman Elmore, 2004). This range of values is similar to the NIOSH results used in the exposure profile and suggests that exposures for molders in nonferrous foundries may be similar regardless of whether they prepare sand molds and cores or maintain permanent molds. The mean and median values for the molders at the primary beryllium producer's facility are slightly lower than the corresponding values in the exposure profile. This difference in exposure could be attributable to the controls used by the molders at the beryllium producer's facility which include HEPA-filtered vacuum cleaners, down-draft tables and hoods and exhaust ventilated hose drops. Thus, based on the available information, OSHA assumes that the molder exposure profile is representative of the nonferrous foundry industry.

Material Handler—Exposure Profile

Results for material handlers in beryllium alloy casting foundries are extremely limited. NIOSH reported a single positive full-shift (424 minutes) PBZ result of 0.93 µg/m^3 for a crane operator at the beryllium alloy (copper and aluminum) casting facility visited in 1975 (NIOSH HHE 75-87-280). At this site, alloys were cast into billets and sold as is or used to cast other alloys. This facility processed master alloy containing 4 percent beryllium, in addition to other forms containing 2 percent or less beryllium (NIOSH HHE 75-87-280; NIOSH HHE 78-17-567; Kriebel et al., 1988).

An additional less-than-full-shift sample result is also available, but not included in the exposure profile because in addition to typical material handler duties, the worker performed several tasks that are addressed under the furnace operator and grinding/finishing operator job categories (ERG Beryllium Site 7, 2003).[123]

[123] ERG obtained a recent less-than-full-shift (252 minutes) positive result of 2.38 µg/m^3 for a forklift operator at a facility casting copper-beryllium (ERG Beryllium Site 7, 2003). The sample time was less than 6 hours due to an abbreviated work shift (typical at that facility) and represents the employee's total exposure for the day, resulting in an 8-hour time-weighted average (TWA) exposure of 1.25 µg/m^3. However, a worker performing equivalent

OSHA also reviewed the IMIS database for results applicable to material handling. For the years 1978 to 2008, the database contains only three results for material handlers in this industry. Each result was obtained at a different establishment (one result is for a forklift operator in Mississippi, one result is for a crane operator in Illinois, and one result is for a material handler in New York) and all three results are non-detectable for beryllium. Without knowledge of the limit of detection for these samples, of each facility's operations, and of whether beryllium alloy castings are produced, the non-detectable IMIS results do not provide additional insight into material handler exposure in aluminum and copper foundries.

In the absence of other results, OSHA has relied upon the single full-shift PBZ result of 0.93 µg/m^3 for the material handler exposure profile. OSHA acknowledges that a single data point may not be representative of furnace operator exposure in this industry. However, it is the only well characterized full-shift sample result available for this job category. Additional information is needed to increase the accuracy and reliability of the profile, particularly since there is some evidence that the single value might underestimate exposure for this job category.[124] OSHA requests additional information to determine whether the material handler exposure profile is representative of the nonferrous foundry industry.[125]

Furnace Operator—Exposure Profile

Workers in the furnace operator job category have the highest potential and most consistently elevated beryllium exposure of any job category in foundries. The elevated exposure is primarily related to handling of beryllium-containing dross, work practices that place the furnace operator's breathing zone in the path of fumes rising off the furnace, and inadequate design, operation, and maintenance of ventilation systems.

The exposure profile for furnace operators is summarized in Tables IV-29 and IV-30 and is based on 11 full-shift results obtained from five different beryllium alloy foundry operations (CCMA, 2000; ERG Beryllium Site 7, 2003; NIOSH HHE 75-87-280; NIOSH EPHB 326-11a; NIOSH EPHB 326-16a). These results are well characterized and represent the best available

activities for a full 8-hour shift would likely have experienced a full-shift exposure similar to the 252-minute result of 2.38 µg/m^3. In this small foundry, the material handler operated an open cab forklift to deliver raw materials to the furnace (loaded into the furnace by hand), moved the tundish (pour lines) into position in the pouring area, and removed large castings from direct chill casting molds. The same worker also set up the furnace sparging (introduction of gas into the furnace to stir the melt and ensure complete mixing), assisted with casting, and used a low-speed saw (wet process) for a brief period (less than 20 minutes) to cut castings to customer specifications. Less-than-full-shift results for other workers in this foundry (furnace workers) included 1.92 µg/m^3 (267 minutes) and 4.18 µg/m^3 (265 minutes). (ERG Beryllium Site 7, 2003)

[124] Air sampling results for hexavalent chromium (chromium VI) also suggest that material handler exposure results for metal fumes can be similar to or exceed those of other foundry workers. Consultants to OSHA obtained full shift chromium VI results (presented as 8-hour TWAs) of 0.52 µg/m^3 and 1.0 µg/m^3 for crane operators at an iron and steel foundry. A less-than-full-shift result (269 minutes) of 1.7 µg/m^3 was also reported for a crane operator at this facility (OSHA-H054A-2006-0064-0965). The crane operators worked in an unventilated, open cab attached to the crane bridge and were "routinely exposed to fumes from the furnace and pouring operations." For comparison, it is interesting to note that 8-hour TWA chromium results for the floor-level workers at these operations (including furnace and pouring operators) were consistently lower (in the range of 0.2 µg/m^3).

[125] The more recent less-than-full-shift result (2.38 µg/m^3 for 252 minutes; 1.25 µg/m^3 8-hour TWA) suggests that material handler exposures continue to occur in this industry. Furthermore, the exposure profile based on a single NIOSH value may underestimate material handler exposures. Clearly additional information is needed to increase the accuracy and reliability of the profile.

exposure data for furnace operators in nonferrous foundries (e.g., information on the sampling time, general working conditions and the nature of the operations at each foundry is available). Nine of the furnace operator results are positive for beryllium and two are non-detectable (both less than 0.2 μg/m^3).[126]

As shown in Tables IV-29 and IV-30, the 11 results range from 0.2 μg/m^3 to 19.76 μg/m^3, with a mean of 4.41 μg/m^3 and a median of 1.14 μg/m^3. More than one-third of the 11 results (four values, or 37 percent) are above the current PEL of 2.0 μg/m^3 and nearly three-quarters of the results (8 values, or 73 percent) exceed 0.5 μg/m^3. Two of the sample results are less than 0.2 μg/m^3.[127] Among the results for which control information is available, OSHA notes a trend toward higher exposure levels in cases where ventilation systems were deemed inadequate or poorly designed for worker protection. The highest exposure (19.76 μg/m^3) is associated with a furnace operator in a facility where LEV was provided at all operations where dust and fumes were generated; however, NIOSH investigators deemed most engineering controls inadequate and in need of re-evaluation (NIOSH HHE 75-87-280). The second highest result (14.08 μg/m^3) is based on a sample obtained on a furnace operator in a facility that produces copper-, nickel-, and aluminum-beryllium casting and master alloy ingot. The elevated exposure may have been due to the design of the furnace canopy hood, which captured fumes from the melt but also covered the work area for the furnace operator, such that the furnace operator stood in the exhaust stream of contaminants from the furnace (ERG Beryllium Site 7, 2003). Other elevated exposures (such as 1.14 μg/m^3, 1.16 μg/m^3, 4.72 μg/m^3, and 5.52 μg/m^3) were obtained relatively recently on furnace operators in a die casting foundry (NIOSH EPHB 326-11a). Although LEV systems were in place in the furnace areas, NIOSH investigators noted that the existing systems were either not always adequate to capture the emissions or were used incorrectly.

OSHA also reviewed the available IMIS data for information pertaining to furnace operators. OSHA identified 171 samples with job descriptions representative of furnace operators (such as furnace operator, furnace tender, furnace helper, melter, and others). Twenty-two of the job descriptions include a second work activity, primarily pouring (i.e., melting and pouring). Thirty-one (18 percent) of the 171 samples are positive for beryllium and were obtained from 12 establishments in 10 states. These results range from 0.01 μg/m^3 to 45.7 μg/m^3, with a mean of 5.15 μg/m^3 and a median of 0.77 μg/m^3. Forty eight percent of the samples are less than or equal to 0.2 μg/m^3 and 45 percent are greater than 2 μg/m^3. The bimodal distribution of the positive

[126] The non-detectable results are reported as less than the sampling limit of detection concentrations by the data source and analyzed here as sampling limit of detection concentrations (0.2 μg/m^3 for both samples) (CCMA, 2000). This is a conservative approach that will provide a mean estimate that is greater than the true mean (i.e., when beryllium is not detected in a sample, the actual amount of beryllium in the sample is somewhere between zero and the method detection limit).

[127] In addition to the 11 full-shift results used in the furnace operator exposure profile, six partial-shift samples (265 minutes to 350 minutes) were obtained for furnace operators in four beryllium alloy foundries (CCMA, 2000; ERG Beryllium Site 7, 2003; NIOSH HHE 75-87-280; NIOSH EPHB 326-16a). These results range from 0.2 μg/m^3 (non-detectable) to 25.06 μg/m^3 and include one non-detectable result (0.2 μg/m^3). If the partial-shift results are time-weighted for 8 hours, the resulting values range from 0.14 μg/m^3 (non-detectable) to 15.98 μg/m^3, with a mean of 3.66 μg/m^3 and a median of 1.61 μg/m^3. The partial-shift samples were obtained at four of the five facilities represented by the exposure profile, and the 8-hour TWA results are similar to the full-shift values available for furnace operators.

IMIS results suggests substantial differences in work practices and engineering controls within the inspected facilities.

The IMIS results support the range of the data that make up the furnace operator exposure profile. However, the profile could be underestimating the exposure of this group of workers because the range of positive IMIS results (0.01 µg/m^3 to 45.7 µg/m^3) is significantly wider than the full-shift values used in the furnace operator exposure profile (0.2 µg/m^3 to 19.76 µg/m^3). The positive IMIS results also capture a larger segment of the nonferrous foundry industry (i.e., 12 facilities). Four of the highest IMIS results (6.2 µg/m^3, 14.3 µg/m^3, 39.2 µg/m^3, and 45.7 µg/m^3) were obtained in 2007 at a copper-beryllium foundry in the Midwest. This demonstrates recent high beryllium exposures in aluminum and copper foundries, despite the increasing awareness over the past decade of the hazards of beryllium.

The full-shift PBZ results from the alloy furnace operations at a primary beryllium production facility (summarized in Section 3—Beryllium Production Exposure Profile and Technological Feasibility Analysis) also support the trend described by the positive IMIS results for foundry furnace operators. The beryllium producer reported 97 results for beryllium alloy operations involving induction furnaces, which range from 0.06 µg/m^3 to 48.07 µg/m^3 (median 0.50 µg/m^3; mean 1.46 µg/m^3). At the same company, alloy melting using another type of furnace follows the same general trend; 38 results for workers involved with arc furnace operations ranged from 0.15 µg/m^3 to 9.37 µg/m^3 (median 0.95 µg/m^3; mean 1.95 µg/m^3). These data, together with the positive IMIS results, suggest that the exposure profile may be underestimating the maximum exposure for furnace operators in aluminum and copper foundries. The exposure profile is based on the best available data, however, and therefore OSHA assumes these data provide a reasonable representation of the distribution of exposures for this job category in the nonferrous foundry industry.

Pouring Operator—Exposure Profile

The exposure profile for pouring operators includes five results from two sources of information: a NIOSH exposure assessment of mold pourers and other workers in a copper-beryllium foundry and a California Cast Metals Association case study that reports individual beryllium results for foundry workers in the pouring area (CCMA, 2000; NIOSH EPHB 326-11a).[128] These are the only well-characterized exposure data available for pouring operators in the nonferrous foundry industry.

As shown in Tables IV-29 and IV-30, the five pouring operator results range from 0.2 µg/m^3 to 2.2 µg/m^3, with a mean of 1.21 µg/m^3 and a median of 1.4 µg/m^3. Three of the results, which include two values less than the sampling limit of detection (0.2 µg/m^3) and a single value of 2.2 µg/m^3, were obtained on the same date during CCMA's site visit to a centrifugal casting foundry (CCMA, 2000). These results are associated with pouring/casting-area workers performing various tasks, including pouring metal. The pouring area was fitted with engineering controls

[128] No results specifically for pouring tasks are available from the copper-beryllium foundry visited by ERG (ERG Beryllium Site 7, 2003). There, the pouring activities were performed during the last hour of the shift by the same workers involved in furnace operations and investigators judged that the furnace operations (such as dross skimming) made the largest contribution to beryllium exposure results. In the casting area, canopy hoods collected air from casting stations and from conveyers that carried castings out of the pouring area. These ventilation systems were connected to a primary dust collection bag house, with secondary HEPA filtration (Corbett, 2005).

such as mobile ladle exhaust hoods, fixed exhaust at the centrifugal mold pour spout, and a tight-fitting furnace-mounted exhaust hood on the adjacent furnace.[129] The available supporting information does not indicate why this sample result is 10 times higher than the other two also obtained in the pouring area at the same foundry.

The two remaining individual full-shift PBZ samples include results of 1.4 µg/m^3 and 2.04 µg/m^3 (NIOSH EPHB 326-11a). NIOSH investigators obtained these samples on two workers who used a permanent mold system to produce copper-beryllium parts. The trough that funneled molten metal to the mold was equipped with a slotted hood attached to a LEV system. However, workers usually placed a cover over the mold and ventilation duct, a practice that reduced exhaust air flow and hampered emissions capture. NIOSH noted that process thermodynamics might also have been a factor in significant emissions.

OSHA also reviewed the IMIS database and identified 153 results applicable to pouring operators. The job descriptions associated with these samples include caster, casting, caster/pourer, cast helper, casting deck operator, cast machine operator, furnace deck pourer, ladle leader, pourer, pouring molds, pouring supervisor, and other related terms. Forty-five (29 percent) of the 153 IMIS samples are positive for beryllium and were obtained from 17 facilities in eight states. The positive IMIS values range from 0.016 µg/m^3 to 8.8 µg/m^3, with a mean of 0.97 µg/m^3 and a median of 0.13 µg/m^3. This median is one-tenth of the exposure profile median for this job category, suggesting that the exposure profile might overestimate pouring operator exposure levels. In addition to representing more facilities (17 compared to two), the larger IMIS dataset also is distributed more widely across all the ranges of interest,[130] with a markedly larger percent exhibiting low exposure levels: 16 IMIS results (35.5 percent) are less than 0.1 µg/m^3, and 62 percent are less than or equal to 0.2 µg/m^3. Both IMIS and the exposure profile include a substantial percent (in the case of IMIS, 16 percent) that exceed the current PEL of 2.0 µg/m^3. OSHA also identified 33 IMIS results for workers performing metal pouring in conjunction with a second activity, such as melting, molding, grinding, mixing, or shakeout. Six of these results are positive for beryllium and range from 0.02 µg/m^3 to 6.1 µg/m^3 (OSHA, 2009).

An additional sample result of 0.2 µg/m^3, reported for a metal pourer at the aluminum-magnesium foundry visited by NIOSH (NIOSH HETA 83-015-1809), was not used in the pouring operator exposure profile because no information is available about the sampling duration. This value does, however, further suggest that the exposure profile overestimates actual pouring operator exposures.

Based on the available information, OSHA finds that the beryllium exposure profile for pouring operators is representative of the nonferrous foundry industry, but acknowledges that the profile might overestimate the exposure experienced by these workers.

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[129] Although one of the three results (2.2 µg/m^3) exceeds OSHA's current PEL for beryllium, other metal exposure levels (arsenic, cadmium, chromium, lead, nickel, and selenium) at this facility were substantially lower than in other foundries presented as case studies by this source (CCMA, 2000). This shows that the engineering controls at this facility were reducing airborne toxic particles, more so than the other facilities compared in this case study.

[130] The values are distributed widely across the ranges of interest, with 21 results (47 percent) less than or equal to 0.1 µg/m^3, 17 results (38 percent) exceeding 0.2 µg/m^3, 14 results (31 percent) exceeding 0.5 µg/m^3, and seven IMIS results (16 percent) greater than the current PEL of 2.0 µg/m^3 (OSHA, 2009).

Shakeout Operator—Exposure Profile

OSHA based the exposure profile for shakeout operators on one full-shift PBZ result from a recent NIOSH exposure assessment at a copper-beryllium die-casting foundry (NIOSH EPHB 326-11a). This is the only result available for the shakeout operator job category. The 587-minute PBZ sample was obtained on a “mold remover” in the foundry’s shakeout operation and resulted in a concentration of 1.3 µg/m^3. The greater than 8-hour sampling duration was due to the facility’s 10-hour work shift. No specific information is provided to account for the shakeout operator’s exposure. NIOSH investigators did note that the foundry shakeout area was equipped with in-wall fans, but that air flow was less than 50 feet per minute (fpm) at distances 15 feet to 20 feet from the fans. Although most of this foundry’s operations were equipped with some type of LEV (not necessarily functioning optimally), NIOSH provided no details about LEV for the shakeout operation. Beryllium exposure was widespread at this facility, and the shakeout area was not the greatest source of exposure: overall, two-thirds of the samples collected at this facility exceeded 0.5 µg/m^3, and nearly one-third exceeded the current PEL of 2 µg/m^3 (the highest was 5.52 µg/m^3) (NIOSH EPHB 326-11a).

OSHA also reviewed the IMIS database for supporting information. For the years 1978 to 2008, OSHA identified 27 results for shakeout operators. Job descriptions associated with this activity include mold breaker, power shakeout, shakeout operator, shake-up operator, and others. Two of the IMIS sample results are associated with multiple activities, e.g., shakeout and pouring, and shakeout and sand mixing . Six of the 27 results are positive for beryllium and were obtained from two different foundries. The positive results range from 0.05 µg/m^3 to 0.5 µg/m^3, with a mean of 0.22 µg/m^3 and a median of 0.11 µg/m^3. In this case, the positive IMIS results are all lower than the single value used for the shakeout operator exposure profile and suggest that shakeout operator exposures can be substantially lower than suggested by the exposure profile summarized in Tables IV-29 and IV-30. Like the NIOSH data, these concentrations indicate that the highest beryllium exposures for shakeout operators tend to be lower than the highest exposures reported for other job categories in this industry (please refer to Table IV-30). This is in contrast to another air contaminant often released by shakeout operations: crystalline silica (“silica”). Worker silica levels for shakeout operators are routinely among the most elevated for foundry workers (ERG Silica_GenInd1v.2, 2008).

OSHA acknowledges that a single data point may not be representative of shakeout operator exposure in this industry. However, it is the only well-characterized sample result available for this job category. Additional information is needed to increase the accuracy and reliability of the profile. Pending such information, OSHA is assuming that the shakeout operator exposure profile is representative of the nonferrous foundry industry.

Abrasive Blasting Operator—Exposure Profile

OSHA based the exposure profile for abrasive blasting operators on five sample results obtained during a series of industrial hygiene surveys conducted by the primary beryllium producer. The four employees used ventilated blasting cabinets (glove box type) to conduct abrasive blasting of beryllium alloy objects (previously cast in a foundry) at a facility where the castings are periodically abrasively blasted with aluminum oxide or steel shot during repair (MC Pkg I-D, 2010).[131] Two of the exposure results (0.09 µg/m^3 and 0.14 µg/m^3) are associated with a ventilation system that averaged 75 cubic feet per minute (CFM) per blast cabinet.[132] Another two results (0.12 µg/m^3 and 0.15 µg/m^3) were obtained at the same facility after system modifications to improve transport velocity, minimize unnecessary ductwork, and modestly increase air flow (114 CFM). A fifth result from the same (post modifications) time period in this series (0.05 µg/m^3, the lowest in this exposure profile) was also included in this group because a brief period of abrasive blasting and associated work cleaning out the blasting cabinet were this employee's primary potential sources of exposure for the day (MC Pkg I-D, 2010; OSHA, 2009).[133] The investigator recommended additional changes intended to further decrease employee exposure (the report does not indicate whether those were implemented or provide follow-up monitoring). Together, these five full-shift samples for abrasive blasting operators in the exposure profile range from 0.05 µg/m^3 to 0.15 µg/m^3, with a mean of 0.11 µg/m^3 and a median of 0.12 µg/m^3.

OSHA also identified a single short-duration (112 minutes) sample result with a sampling limit of detection of 0.7 µg/m^3 (i.e., the sample result was reported as less than 0.7 µg/m^3) for an abrasive blasting booth worker (CCMA, 2000). The worker used a "blast booth" in a ferrous/non-ferrous foundry where exposure levels for several metals were all well below the respective PELs and usually below the limits of detection (CCMA, 2000). Assuming no additional exposure for the day, OSHA converted the sampling limit of detection to an 8-hour TWA (less than 0.16 µg/m^3), which appears to support the sample results used in the exposure profile.[134]

The IMIS data for this industry include 13 results for abrasive blasting. Job titles associated with the results include abrasive blasting, sandblaster, sandblast operator, wheelabrator operator, and others. Six of the results are associated with tasks in addition to abrasive blasting, such as cutting, cutting and grinding, and grinding and machining. Three of the abrasive blasting results are positive for beryllium and include the minimum value of 0.02 µg/m^3 and two results of 0.101 µg/m^3. The positive results are associated with abrasive blasting (exclusive of any other tasks) and were obtained from three different establishments (OSHA, 2009).

Although limited, OSHA assumes that this abrasive blasting operator exposure profile is representative of this job category in the nonferrous foundry industry.

Grinding/Finishing Operator—Exposure Profile

The exposure profile for grinding and finishing operators is based on 56 full-shift PBZ samples reported by Materion, CCMA, and NIOSH (MC Pkg I-D, 2010; CCMA, 2000; NIOSH HHE 75-87-280; NIOSH EPHB 326-11a; NIOSH EPHB 326-16a). These data, obtained from at least five

[131] Abrasive material composition and size ranged from 36-80 grit size for aluminum oxide and 40-60 grit size for steel shot (MC Pkg I-D, 2010).
[132] Later in the report, the initial air flow is described as 57 CFM. OSHA was not able to determine which is accurate.
[133] This employee normally worked in the grinding/finishing area.
[134] OSHA calculated the 8-hour TWA using the standard equation presented in 29 CFR 1910.1000(d)(1)(i):

$$E = (C_a\ T_a + C_b\ T_b + \ldots C_n\ T_n) \div 480.$$

In this equation E is the 8-hour TWA exposure level, while C_n is the beryllium concentration measured over time T_n (in this case as minutes). E = [(0.7 µg/m^3)(112 minutes) + (0 µg/m^3)(368 minutes)] ÷ 480 minutes = 0.16 µg/m^3.

different establishments, represent the best available exposure information for this job category and are based on well characterized results (e.g., information on sampling time, job description/work location, and facility conditions is available).[135] Three of the 56 results are non-detectable for beryllium, each reported as less than the sampling limit of detection (0.2 µg/m^3). CCMA obtained the non-detectable results on workers grinding and machining castings at a ferrous/non-ferrous foundry.

As shown in Tables IV-29 and IV-30, the exposure profile for grinding and finishing operators ranges from 0.1 µg/m^3 to 4.79 µg/m^3, with a mean of 0.31 µg/m^3 and median of 0.05 µg/m^3. Thirty-three sample results (nearly 60 percent) are less than 0.1 µg/m^3, another eight results (14.3 percent) range from 0.1 µg/m^3 to 0.2 µg/m^3, and another eight exceed 0.2 µg/m^3 but are less than or equal to 0.5 µg/m^3. Three results (slightly over 5 percent) exceed the current PEL of 2.0 µg/m^3.

Forty of the results summarized in the exposure profile were obtained by Materion at one or more of its customer facilities where castings (produced elsewhere) are refurbished. During a series of industrial hygiene visits conditions were documented before and after workstation and ventilation system modifications. Seventeen of these results, ranging from 0.01 µg/m^3 to 0.9 µg/m^3, are associated with the pre-existing work stations, which included flexible ducts and hoods that the employees could position near their work. Five of these 17 results exceed 0.2 µg/m^3. Another 23 sample results, ranging from 0.1 µg/m^3 to 0.06 µg/m^3, were obtained after the work stations had been modeled to include bench-top backdraft-downdraft booths in which the employees reached to work on the piece inside.

One additional less-than-full-shift (321-minute) result was reported by NIOSH for a worker operating a swing frame grinder in the foundry area of a beryllium alloy (copper and aluminum) casting facility in 1975 (NIOSH HHE 75-87-280). The result (15.56 µg/m^3) is reported as an 8-hour TWA and is more than three times greater than the maximum value in the exposure profile. No details were provided about the partial-shift result other than the operator wore NIOSH-certified respiratory protection. Although this sample was obtained in a facility where LEV was supplied at all operations where dust and fumes are generated, NIOSH concluded that engineering controls within the facility were inadequate and recommended that all LEV systems be re-evaluated to determine if they are operating at maximum efficiency, and that a periodic maintenance program be established for these systems.[136]

In addition to the data described above, OSHA also examined the alloy billet sawing operations at Materion Brush's Elmore, Ohio, facility (see Section 3—Beryllium Production Exposure Profile and Technological Feasibility Analysis). In this company's alloying operation, a master alloy (containing 4 percent beryllium in copper) is used to produce a range of continuously cast copper-beryllium alloy billets (simple, rough castings). The billets are subsequently machined to smooth the surface of the casting and remove imperfections prior to use in the production of rolled strip and extruded rod and tube products. Ninety full-shift PBZ samples were obtained for workers cutting, sawing, and drilling alloy billets during the facility's 1999 baseline exposure

[135] The report from Materion implies that more than one facility is covered by the report; however, the number of facilities is not clear in the available redacted version (MC Pkg I-D, 2010).
[136] OSHA contacted NIOSH in April 2004 and confirmed that all of the beryllium air concentrations in Table 1 in NIOSH HHE 75-87-280 are 8-hour TWA concentrations (Hartle, 2004).

assessment. These results range from 0.05 μg/m^3 to 18.97 μg/m^3; however, the maximum exposure result (18.97 μg/m^3) appears to be an outlier, with the next highest sample result less than 20 percent of this level.[137] When this value is removed, the 89 remaining results range from 0.05 μg/m^3 to 3.37 μg/m^3, with a mean of 0.25 μg/m^3 and median of 0.13 μg/m^3. Minus the outlier, the range of values for Materion Brush workers finishing alloy billets is similar to the range of values used in the exposure profile for grinding and finishing operators, thus lending support to the profile for this group of workers. Because grinding/finishing operator sampling results are available for this industry, the data from this Materion Brush beryllium production facility is considered supplemental and not incorporated in the industry profile.

OSHA also reviewed the applicable IMIS data for supporting information. The IMIS database contains 243 samples with job descriptions associated with grinding and finishing operations (OSHA, 2009).[138] Of these, 43 are positive for beryllium and range from 0.03 μg/m^3 to 3.7 μg/m^3, with a mean of 0.47 μg/m^3 and median of 0.2 μg/m^3. The range of positive IMIS values (0.03 μg/m^3 to 3.7 μg/m^3) is similar to the range of values used in the exposure profile (0.1 μg/m^3 to 4.79 μg/m^3) as well as the range of results for workers finishing rough alloy castings at a primary beryllium producer (0.05 μg/m^3 to 3.37 μg/m^3). Based on this available information, OSHA finds that the beryllium exposure profile for grinding and finishing workers is representative of the nonferrous foundry industry.

Maintenance Operator—Exposure Profile

As of the date of this report, OSHA has not been able to identify exposure data, including through IMIS, to describe the beryllium exposure of foundry maintenance operators who perform work that brings them into contact with beryllium in aluminum and copper foundries. As described in the process description for this job category, this work could include servicing production equipment and ventilation systems, repairing refractory ceramic linings, and performing housekeeping tasks.

PBZ beryllium results for maintenance tasks are available, however, for workers in another similar industry (a primary beryllium production facility) that also melts and casts beryllium alloys. Although this casting facility works with alloys of a higher beryllium content (up to 4 percent beryllium) than is typical in other foundries (i.e., copper and aluminum foundries, which rarely cast alloys exceeding 2 percent beryllium) the steps in the casting process are similar. For both types of facilities, major operations involve preparing the furnace charge, melting alloy, adjusting the metal content of the alloy if necessary, inoculating and sparging the molten metal, pouring the alloy into molds, maintaining refractory materials that have been in contact with the molten alloy, and processing the castings. In both types of facilities, industrial exhaust ventilation systems are typically present where fumes and dust are generated in the greatest quantities. Maintenance operators at both types of facilities maintain production equipment, keep ventilation systems running, renovate refractory materials, and perform housekeeping

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[137] With the maximum result of 18.97 μg/m^3 included, these data have a mean of 0.46 μg/m^3 and median of 0.13 μg/m^3.

[138] Examples of IMIS job titles associated with grinding and finishing operations include buffer, casting cleaner, castings finisher, cleaner, cut-off saw operator, finisher, finishing, grinder, grinder/sander, machine operator, polisher, sander, and many other variations. Also among the 243 IMIS results are another 10 (all non-detectable for beryllium) associated with workers doing both molding and finishing tasks (OSHA, 2009).

activities.[139] Therefore, in the absence of information specific to copper and aluminum foundries, OSHA has relied on maintenance worker beryllium exposure data obtained during a 1999 baseline exposure assessment at Materion Brush's alloy operations in Elmore, Ohio, a primary beryllium production facility.

OSHA acknowledges that all systems are not necessarily equivalent between this facility and typical copper and aluminum foundries. For example, the primary beryllium producer might have focused more attention on beryllium exposure controls associated with dross removal from the furnace. OSHA believes this potential is balanced by the higher maximum beryllium content of the alloy cast in the primary beryllium producer's facilities, which to some extent counteracts the reductions in exposure level due to any special controls the primary beryllium producer might have had in place at the time of the baseline assessment.

Regardless of the controls in place and the beryllium content of the materials, routine maintenance operator duties remain the same. For this reason, and in the absence of other data specific to foundries, OSHA has elected to use for the exposure profile the dataset that is available for maintenance operators at the primary beryllium production facility until such time as additional information becomes available. This dataset contains 78 full-shift PBZ samples obtained during a 1999 baseline exposure assessment (see Section 3—Beryllium Production Exposure Profile and Technological Feasibility Analysis) for workers who maintain and service equipment associated with the facility's alloy melting and casting operations (including the alloy furnaces and ventilation system air cleaning devices). These results are summarized in Tables IV-29 and IV-30 and range from 0.05 µg/m^3 to 22.71 µg/m^3, with a mean of 0.87 µg/m^3 and median of 0.21 µg/m^3. These tables also show that 15.4 percent of the sample results (12 of the 78 results) are less than 0.1 µg/m^3. An additional 27 results (34.6 percent) exceed 0.1 µg/m^3 but are less than or equal to 0.2 µg/m^3, and another 18 (23 percent) exceed 0.2 µg/m^3 but are less than or equal to 0.5 µg/m^3. Overall, 57 results (73 percent) are 0.5 µg/m^3 or less. Seven results (9 percent) are greater than 1.0 µg/m^3 but less than or equal to 2.0 µg/m^3, and three results (4 percent) exceed the current PEL of 2.0 µg/m^3. Just one of the 78 sample results (<2 percent) exceeds 20 µg/m^3.

Other sources of information for maintenance operators in primary beryllium production facilities include two NIOSH evaluations conducted in 1975 and 1978 at a Reading, Pennsylvania, beryllium extraction and manufacturing facility that melted, cast, and otherwise processed beryllium alloys into products such as tools, wire, rods, and strip (NIOSH HHE 75-87-280; NIOSH HHE 78-17-567; Kriebel et al., 1988) and a 1971 NIOSH air sampling survey at a Hazelton, Pennsylvania, facility that converted beryl ore to beryllium metal, alloys (melted and cast into ingots), and other beryllium compounds (NIOSH IWS-37-13).

At the Reading facility, one full-shift PBZ result reported as nondetectable for beryllium was obtained in 1975 for a furnace repairman in the facility's alloy melting and casting area (NIOSH HHE 75-87-280). OSHA estimated the sampling limit of detection as 1.56 µg/m^3 using the sampling duration (426 minutes) and flow rate (1.5 lpm) reported in the source document and the beryllium limit of detection reported for the analytical method (1 µg per sample, NIOSH Method

[139] References are Corbett, 2005; NIOSH EPHB-16a; Refractory Services Provider A, 2003; NIOSH HHE 75-87-280; and NIOSH HHE 78-17-567.

P & CAM 121) (see NIOSH HHE 78-17-567).[140] No details were provided about the sample result or the furnace repair job at this facility. In 1978, NIOSH investigators returned to the Reading facility and obtained two full-shift PBZ results of 29.5 μg/m^3 and 31 μg/m^3 for maintenance workers inspecting the vacuum cleaners and emptying ventilation system cyclone collectors (NIOSH HHE 78-17-567).[141] Workers wore half-face air-purifying respirators with high-efficiency cartridges (considered by NIOSH as inadequate protection) and company-provided work clothing (laundered daily). To service the cyclone collectors, workers opened the collectors, dislodged and emptied the accumulated waste through a chute directly into a hand-held plastic trash bag, then double-bagged and sealed the waste. Sometimes workers had to dislodge the waste by reaching arm's-length into the collector and dislodging the waste with their hands or a stick. NIOSH investigators observed this particular work practice during the site visit.

NIOSH also had the opportunity to obtain some additional PBZ exposure data for maintenance workers servicing the facility's ultra dust collectors, one of which supported the alloy melting and casting area (NIOSH HHE 78-17-567). The sampling took place from the first quarter of 1977 through the first quarter of 1978; the resulting data (provided by the Reading facility and associated with ongoing OSHA abatement activities) included 22 full-shift PBZ results ranging from 2.35 μg/m^3 to 53 μg/m^3, with a mean of 16.4 μg/m^3 and median of 11.1 μg/m^3. A major cause of exposure for maintenance workers, associated with the highest sample result of 53 μg/m^3, was identified as accumulated waste overflowing the ventilation system dust collection drums during waste drumming operations. To address this problem, the facility installed automatic valve cut-offs activated by a drum level sensor to control the amount of waste released into the drums. This modification reportedly succeeded in reducing exposures. An examination of the maintenance worker exposure data over time shows that three sampling results (2.76 μg/m^3, 3.48 μg/m^3, and 4.62 μg/m^3) obtained during the first quarter of 1978 were substantially lower than the single result (53 μg/m^3) reported for these workers during the first quarter of 1977. Using this information, OSHA estimated that PBZ exposures were reduced about 93 percent for this activity over one year, although exposures remained above the current PEL of 2.0 μg/m^3 (NIOSH HHE 78-17-567).[142]

During the 1971 air sampling survey at the Hazelton facility (NIOSH IWS-37-13), NIOSH investigators obtained three full-shift PBZ results for furnace repair workers (1.90 μg/m^3, 3.76 μg/m^3, and 3.8 μg/m^3) and four full-shift PBZ results for maintenance mechanics (4.45 μg/m^3, 5.71 μg/m^3, 17.49 μg/m^3, and 35.97 μg/m^3). However, no information was provided about the work practices and procedures used by these workers or the workplace conditions associated with their activities. Additionally, it is not possible to determine if these results are associated with the facility's alloy operations. In addition to beryllium alloy products, the facility's

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[140] OSHA calculated the sampling limit of detection as follows:

$$1 \text{ μg} \times 1{,}000 \text{ liters/m}^3 \div (426 \text{ minutes} \times 1.5 \text{ liters/minute}) = 1.56 \text{ μg/m}^3$$

[141] PBZ samples for beryllium were collected during the morning and afternoon activities of two workers assigned waste collection tasks. NIOSH reported the morning and afternoon results separately. OSHA combined the results and calculated the full-shift TWA concentrations representing the morning and afternoon activities of each worker (6.5 hours total). OSHA assumed zero exposure for the unsampled portion of the work shift.

[142] OSHA estimated the exposure reduction by averaging the three exposure results reported for the first quarter of 1978 and comparing this value to the single result reported for maintenance workers in the first quarter of 1977:

$$(2.76 \text{ μg/m}^3 + 3.48 \text{ μg/m}^3 + 4.62 \text{ μg/m}^3) \div 3 = 3.62 \text{ μg/m}^3$$

$$[(53 \text{ μg/m}^3 – 3.62 \text{ μg/m}^3) \div 53 \text{ μg/m}^3] \times 100 = \text{approximately 93 percent}$$

operations included beryl ore extraction, the production of primary beryllium metal, beryllium powdering operations, and other activities not associated with a typical foundry.

The maintenance operator exposure profile is based on 78 full-shift PBZ results from the alloy operations of a primary beryllium producer because exposure data, including IMIS inspection results, are not available for maintenance tasks in aluminum and copper foundries. OSHA acknowledges that alloy exposure data from a primary beryllium producer may not be representative of the nonferrous foundry industry; however, it is the best available information at the present time. The sampling duration and analytical methodology for these results are known, as well as the workers' job descriptions and basic information on workplace conditions and controls.

The supporting information obtained by NIOSH represents maintenance operator exposure levels at two facilities in the 1970s in Reading and Hazelton, Pennsylvania, that had alloy foundry areas, but for which beryllium operations also included processes not typical of foundries (and routinely involving high-beryllium materials). The primary product of the Reading facility was copper-beryllium alloys, but both facilities also converted beryl ore to beryllium metal, alloys, and compounds. The PBZ results obtained at these facilities for various maintenance tasks (discussed above) are notably higher than the values reported in the exposure profile; OSHA does not consider the Reading and Hazelton results to represent the levels of results currently found in nonferrous foundries.

Based on the available information, OSHA finds that the beryllium exposure profile for maintenance operators is representative of the nonferrous foundry industry.

TECHNOLOGICAL FEASIBILITY

Foundry workers have historically encountered numerous contaminants in their workplaces. Toxic metals, such as beryllium, present a serious challenge in foundries because particulates from fumes, dross, and other sources are difficult to control using traditional methods. Control of beryllium is complicated by this metal's tendency to concentrate as an oxide when it is heated. For alloys of aluminum, both in dross during melting and on the surface of newly cast objects, the beryllium concentration of the oxide is typically five times greater than in the alloy (deYoung and Peace, 2009).[143] Thus, even small amounts of beryllium in an alloy can contribute disproportionally to airborne beryllium exposure levels in foundries. In the absence of information to the contrary, OSHA presumes that the same concentrating effect occurs in copper alloys.

Occupational hazards, such as silica, lead, cadmium, and hexavalent chromium are prevalent in foundries, and most foundries have some controls in place to address these workplace hazards. In particular, silica is common in foundries that use sand casting methods. For silica, OSHA has

[143] The range of beryllium concentration in oxides of aluminum alloys is 2 to 50 times the concentration in the parent alloy. The lower value is associated with higher beryllium content in the alloy (i.e., the concentration factor decreases as the beryllium concentration in the metal increases) (deYoung and Peace, 2009). Assuming the typical concentration factor of 5 and an 8-hour TWA exposure of 10 $\mu g/m^3$ in dust from dross, these authors estimated that workers could experience uncontrolled 8-hour TWA beryllium exposures in excess of 0.2 $\mu g/m^3$ if the parent metal contained as little as 2 parts per million beryllium (0.0002 percent of the total alloy).

conducted an analysis of exposure levels and control methods similar to this analysis for beryllium. Most of the affected job categories can experience exposure to both beryllium and silica. See Section 2—Methodology of Chapter IV (Technological Feasibility) of the Preliminary Economic Analysis (PEA) for detailed discussions on how some of the same controls methods available for one of these contaminants will also help control the other.

Materion Corporation has also evaluated the applicability of beryllium controls across jobs. This manufacturer, as part of its product stewardship efforts, determined that a general set of rigorously applied control measures can consistently maintain beryllium worker exposure at 0.2 $\mu g/m^3$ or less. ((Deubner and Kent, 2007; Knudson and Kolanz, 2009; Materion Interactive Guide, 2012))

Materion Corporation has developed a model for protecting beryllium workers from chronic beryllium disease and other adverse effects associated with the inhalation of beryllium-containing particles (Deubner and Kent, 2007; Knudson and Kolanz, 2009; Materion Interactive Guide, 2012). This producer's experience has shown that worker protection is best provided by a comprehensive exposure control program applied to specific tasks and operations (Materion Interactive Guide, 2012). The Worker Protection Model, summarized in Section 2—Methodology of Chapter IV (Technological Feasibility) of the Preliminary Economic Analysis (PEA) incorporates eight program elements:

- Avoid exceeding an 8-hour TWA exposure level of 0.2 $\mu g/m^3$.
- Keep work areas visibly clean and take steps to ensure they stay that way.
- Keep beryllium off the skin, using long sleeves and hand/wrist protection.
- Keep beryllium off clothing by keeping work clothes visibly clean.
- Keep beryllium at the source and in the work process by taking steps to avoid spreading it.
- Keep beryllium in the work area by eliminating causes of migration.
- Keep beryllium on the plant site by improving cleanliness standards.
- Prepare beryllium workers for safe work with standard operating procedures and appropriate training.

To gain a general understanding of baseline conditions for workers in this industry sector, OSHA used information from both ferrous and nonferrous foundries including four nonferrous foundries that melt and cast beryllium alloys (CCMA, 2000; ERG Beryllium Site 7, 2003; NIOSH EPHB 326-11a; NIOSH EPHB 326-16a). All foundries use similar basic processes; they all melt metal, form or otherwise prepare molds, pour molten metal into the prepared molds to produce a casting, and remove excess metal and blemishes from the castings (NIOSH 85-116). For purposes of this analysis, the major differences in foundry processes occur with the types of molds and cores used. Aside from these differences, foundry operations and worker job tasks are similar regardless of whether the casting metal contains beryllium or not.

Molders

Molder—Baseline Controls

Based on the available information, OSHA finds that baseline conditions for molders in sand-casting foundries typically include the use of reclaimed sand (NIOSH 85-116; NIOSH EPHB 326-11a; NIOSH EPHB 326-16a) which may be contaminated with beryllium alloy and oxide from previous castings. Molders operate sand molding and mixing machines, perform dry brushing and sweeping of molds and work surfaces, and may use compressed air for cleaning molds. Some, but not all sand molding and mixing machines have exhaust ventilation (CCMA, 2000; NIOSH HETA 91-0092-2190; NIOSH HETA 92-157-2304; NIOSH HETA 86-284-1914). Depending on the size of the foundry, molders might also monitor the return sand systems in which sand is returned from the shakeout operations via a conveyor to the mold making area for reuse. Ventilation is usually available for sand reclamation equipment, although historically the systems have been poorly designed or ineffectively maintained, a trend that continues today.[144] Molders can be exposed when sand handling equipment is not adequately enclosed and ventilated and releases contaminated sand and dust into the workplace. For example, sand transfer points may not be enclosed and ventilated; hinged openings (lids) on sand transport equipment may not be gasketed or securely fastened shut to help reduce emissions; and sand chutes and ductwork or seals in sand reclaim machinery may leak (NIOSH HETA 92-044-2265; NIOSH HETA 92-092-2333; NIOSH HETA 86-038-1807; NIOSH HETA 85-482-1730 / 86-116-1730).

Molders who handle and maintain reusable molds usually perform basic cleaning and conditioning (dry sweeping, applying surface preparations) in the pouring area, using ventilation available at that location. This ventilation would typically not be specifically designed for the purpose of mold maintenance (CCMA, 2000; Corbett, 2005). Molders sometimes transport the molds to a special work area for additional care such as grinding and refurbishing. Limited evidence indicates that work areas for permanent mold maintenance contain ventilated work stations (CCMA, 2000).

For both sand and permanent mold casting, general ventilation is typically available in the mold-preparation and pouring areas where molders are most likely to encounter beryllium. However general plant-wide ventilation might not be sufficiently balanced to prevent contaminants from migrating between different areas of the foundry (CCMA, 2000; ERG Beryllium Site 7, 2007; NIOSH HETA 88-244-1951; NIOSH HETA 86-284-1914). In one beryllium alloy foundry visited by NIOSH, investigators observed significant air movement but noted that general exhaust ventilation was not uniform throughout the facility (NIOSH EPHB 326-11a). “Doors and windows were open to promote cross ventilation” and “pedestal and wall-mounted fans were used throughout the facility” for worker comfort. Additionally, in some areas, NIOSH found that in-wall fans were ineffective in promoting general air movement due to the distances between the fans and the foundry activities. These conditions likely defeated any attempted design for supply and exhaust air balancing to prevent contaminant migration.

[144] Sources: ERG Silica_GenInd1v.2, 2008; NIOSH HETA 92-044-2265; NIOSH HETA 92-090-2296; NIOSH HETA 92-092-2333; NIOSH HETA 91-0092-2190; NIOSH HETA 85-482-1730 / HETA 86-116-1730; NIOSH HETA 86-038-1807; NIOSH HETA 88-244-1951.

Molder—Additional Controls

All of the values for molders in the exposure profile exceed the proposed PEL, thus additional controls will be required to further reduce the exposures of all molders. Molders may be exposed to beryllium when preparing non-permanent molds with reclaimed sand or when removing beryllium-containing residue from permanent molds. In addition, molders may be exposed to beryllium from adjacent operations due to cross-contamination (contaminant migration). Additional controls for this job category include one or more of the following:

- Eliminating the use of dry sweeping and compressed air for cleaning.
- Dedicated work areas with improved local exhaust ventilation.
- Enclosing and maintaining sandmixing equipment under exhaust ventilation.
- Using a combination of engineering controls, housekeeping, and improved work practices.
- Balancing ventilation systems

Eliminating the Use of Dry Sweeping and Compressed Air for Cleaning

Dry sweeping and compressed air can disperse beryllium-containing particulate matter into the air. As part of its product stewardship outreach, Materion Corporation reports that the use of compressed air or dry sweeping (brooms) for cleaning parts, equipment, work surfaces or clothing can result in airborne exposure to beryllium and must be prohibited in the workplace (Materion Interactive Guide, 2012). Effective alternative methods for cleaning contaminated surfaces include HEPA vacuuming and wet cleaning.

Researchers from the National Jewish Health Division of Environmental and Occupational Health Sciences have evaluated a number of methods for controlling beryllium aerosols in the workplace (OSHA-H005C-2006-0870-0155). Key among their findings is the need to prohibit dry sweeping of beryllium-containing dust and eliminate compressed air lines from beryllium work areas. Only HEPA-vacuuming or wet cleaning should be used in beryllium work areas. Although no quantitative findings were provided, National Jewish researchers reported that both dry sweeping and the use of compressed air can result in significant worker exposure. In some cases, a worker's primary exposure to beryllium has been associated with the use of compressed air (e.g., cleaning a worker's clothes by blowing them off with compressed air), another practice prohibited by the Materion Corporation Worker Protection Model (OSHA-H005C-2006-0870-0155).

NIOSH recommends the use of HEPA-filtered vacuums or wet methods for cleaning work surfaces and floors in beryllium work areas. During industrial hygiene evaluations at three nonferrous foundries (two of which produce beryllium alloys), NIOSH investigators provided recommendations for reducing airborne beryllium concentrations and controlling worker exposures that included prohibiting dry sweeping and the use of compressed air for cleaning in beryllium-containing work areas (NIOSH EPHB 326-11a; NIOSH EPHB 326-16a; NIOSH HETA 90-0249-2381). At a copper alloy foundry that manufactures bronze bushings and bearings, NIOSH advised that compressed air should not be used to clean molds (NIOSH HETA 91-0093-2126). At this foundry, the use of compressed air for cleaning molds aerosolized silica-containing particulates because a crystalline silica-containing mold wash was used in the permanent centrifugal molds. At the time of NIOSH's visit, the alloy used contained 0.5 to 1.5 percent lead and all employees monitored (including molders) were also overexposed to lead. At another copper alloy foundry (CCMA, 2000), a partial-shift sample (224 minutes) on a grinder operator during floor sweeping showed that he would have been overexposed to lead, had he swept for the entire work shift. These examples demonstrate that dry sweeping generates excessive exposure to airborne casting metal dusts in foundries. As outlined in Section 2—Methodology, of Chapter IV (Technological Feasibility) of the Preliminary Economic Analysis (PEA), lead fumes and lead dust are generated in the same ways that beryllium fumes and dust are formed: uncontrolled fumes and oxides from molten metals, cast metals, and recycled materials such as foundry returns (scrap metal) and contaminated foundry sand. Although lead's greater mass makes it heavier than beryllium, lead and beryllium particles with similar aerodynamic properties will respond similarly when they become airborne.[145] Therefore, beryllium and lead exposures will be reduced to a similar extent when foundries take steps to prevent them from becoming airborne, such as by reducing reliance on compressed air and dry brushing. By effectively capturing these particles before they become airborne, HEPA vacuums can eliminate loose dust as a source of exposure. Employers will need to provide extra control measures for employees while they empty or change filters on vacuums used to capture beryllium dust. These tasks need to be performed in a ventilated enclosure or using bag-in-bag-out procedures to prevent dust from escaping the vacuum.

Finally, OSHA's Hazard Information Bulletin on beryllium lists safe work practices to reduce employees' beryllium exposure (OSHA HIB, 1999). These work practices include never using compressed air for cleaning parts or working surfaces. Dry sweeping is not discussed. Employers are encouraged to use HEPA vacuums for cleaning equipment and work surfaces.

A critical component of the Materion Corporation Worker Protection Model is systematic cleaning of all work surfaces, including molds. Materion Corporation reports that repair or maintenance of equipment associated with copper-beryllium processes can generate airborne beryllium; it lists HEPA-filter vacuuming and wet cleaning as effective procedures for safely maintaining process equipment (Materion Interactive Guide, 2012). The reduction in exposures resulting from use of HEPA filter vacuuming and wet cleaning reusable molds before handling them has not been precisely quantified, capturing these particles before they become airborne will reduce this source of exposure.

Dedicated Work Areas with Improved Local Exhaust Ventilation
Molders can achieve reductions in beryllium exposure by improving exhaust ventilation at dedicated work areas (or installing such work stations if not available). For example, use of backdraft-downdraft workstations would increase the consistency of the dust control above the benefit provided by operator-positioned hoods alone.

Studies have demonstrated that exposures can be reduced by improving LEV and reducing dependence on workers to correctly position exhaust systems. For example, the results of a case study of workers maintaining molds containing copper-beryllium alloy (1.8 to 2 percent

[145] Additional discussion of aerodynamic diameter and particle properties is presented in Section 2—Methodology, of Chapter IV of the PEA.

beryllium) showed significant exposure reductions when work stations were redesigned to accommodate both backdraft and downdraft exhaust ventilation inside an enclosure.[146] The enclosure included a front opening and rear exhaust, as is available for abrasive cut-off saws (Figure VS-80-17 in ACGIH, 2010), and the downdraft table ventilation of a hand-grinding bench (Figure VS-80-18 in ACGIH, 2010). An adaptation provides a rear-slot exhaust (rather than plain rear takeoff), which is preferable for hand grinding that might not occur at a single fixed spot inside the booth. For employers to receive similar results, the booth exhaust should provide 250 fpm across the opening and be fitted with a HEPA air filter, and special precautions must be used when servicing the booth or blower and changing the filter (respiratory protection needed for these tasks). Alarms will indicate when filter performance falls outside an effective range. For cases in which this booth design does not sufficiently control exposures, Materion Corporation has achieved lower exposure levels by increasing the ventilation rate to provide 400 fpm across openings, a strategy that has proven successful for a variety of hood designs at Materion Corporation's plants and those of their customers (Materion Information Meeting, 2012).

Materion Corporation advocates grinding booths of this general backdraft-plus-downdraft design, paired with work practices and careful housekeeping methods, as an effective method for reducing exposure levels for workers performing manual grinding and related tasks using powered or rotary tools, such as polishing and buffing to concentrations of 0.2 μg/m^3 or less (Materion Information Meeting, 2012). The control measures (i.e., engineering controls, work practices, and housekeeping) must be used together to ensure that exposure levels are reliably maintained below 0.2 μg/m^3 for the vast majority of workers nearly all the time. In this standard group of controls, the grinding bench will control the exposures of grinding/finishing operators while they manually grind beryllium alloy castings, but work practice and administrative controls are necessary to ensure that the bench ventilation is maintained in working order, kept clean, and that beryllium particles are not released when the ventilation system is serviced and the filter is changed. In addition to improving LEV, training should be conducted to ensure that all employees use engineering controls properly. Housekeeping in facilities that use beryllium alloys should be performed routinely to prevent the accumulation of dust that can be spread to other work areas or become airborne if disturbed. Cleaning should be performed with HEPA vacuums or wet methods instead of traditional vacuums, and the use of compressed air and dry sweeping should be prohibited.

Materion Corporation's exposure reduction guidelines are generic and applicable to any industry where beryllium-containing particles are generated using powered or rotary hand tools. Thus, these guidelines pertain equally to foundries as they do to other types of facilities. Although no study demonstrates the effectiveness of these controls specifically in foundries, the value of well-designed ventilation controls in combination with work practices that enhance the effectiveness of the ventilation systems has been demonstrated by a series of industrial hygiene surveys conducted in plants that work with beryllium alloy objects (including foundry-cast dies designed for casting other products such as plastics) (MC Pkg I-D, 2010). These surveys and findings are described in greater detail in the discussion of additional controls (LEV and enclosures) for

[146] These workers use a variety of hand tools and supplies to perform their tasks including Scotch-Brite pads, hand stones, pneumatic grinders and sanders, high-speed electric sanders, and lubricants. Wheel surface speeds can achieve a maximum of 20,000 revolutions per minute (Materion PCSC 105, 2011).

grinding/finishing operators. Briefly, upgrading workstations used with hand-held pneumatic grinding tools reduced the maximum exposure level by 94 percent. The upgrade changed equipment from an employee-positioned flexible duct or downdraft table, to a benchtop booth (enclosing the top, back and sides of the work area, with an open front through which the worker reached) installed over a downdraft-backdraft table (MC Pkg I-D, 2010).

Although the case study did not take place in a foundry, workers used similar equipment and procedures to perform the same task that foundry molders perform while maintaining reusable molds. In both cases the source of beryllium was a beryllium copper alloy. However, one significant difference bears discussion: this case study involved no molten metal and a minimal amount of surface oxides. Instead, existing beryllium alloy molds were being resurfaced. In a foundry setting, the presence of beryllium oxides (which tend to concentrate beryllium) on the mold surface could increase the baseline exposure levels (deYoung and Peace, 2009).

This case study of workers maintaining copper-beryllium injection molds in a non-foundry work environment is the best available information on beryllium exposure reductions for molders working with permanent molds in the nonferrous foundry industry. These findings suggest that even molders already using flexible duct or downdraft ventilation systems can achieve significant exposure reductions when provided with dedicated workstations including booths and enhanced LEV. As shown in Table IV-30, most molders in nonferrous foundries have exposures between 0.2 μg/m^3 and 0.5 μg/m^3, but this case study has shown that exposures to molders can be reduced to concentrations of 0.01 μg/m^3 to 0.06 μg/m^{3,} well below the proposed PEL. As mentioned in the subsection on Grinding/Finishing Operations—Additional Controls, this reduced range was obtained after improvements were made to engineering controls. Note that this range of exposures was obtained directly from sampling, with the range sampled prior to improvements to engineering controls being 0.01 μg/m^3 to 0.9 μg/m^3. This represents a 94 percent reduction in exposures due to upgrades to the engineering controls.

Enclosing and Maintaining Sandmixing Equipment Under Exhaust Ventilation

Exposures can be reduced by installing covered or enclosed systems for transporting sand through or near the molding area. NIOSH and OSHA evaluated pneumatic and enclosed systems to isolate the storage and transport of dry sand in two facilities. The four molder PBZ silica results from these foundries ranged from 13 to 23 μg/m^3 , with a median of 17 μg/m^3 (NIOSH ECTB 233-107c, 2000; OSHA SEP Inspection Report 122122534). At another facility, OSHA reported a 65 percent to 70 percent reduction in silica exposures (from 140 μg/m^3 to 50 μg/m^3 and 42 μg/m^3) after the facility made improvements to sand delivery systems and exhaust ventilation systems throughout the facility (OSHA SEP Inspection Report 100494079). If the sand was contaminated with beryllium, these reductions in silica dust exposure would also translate into reduced beryllium dust exposure (see Section 2—Methodology, of Chapter IV (Technological Feasibility) of the Preliminary Economic Analysis (PEA)). By controlling sand dust emissions to achieve median silica results of 17 μg/m^3, the employers have also potentially reduced the beryllium exposure of molders to 0.20 μg/m^3.[147]

[147] The value 0.20 μg/m^3 was calculated using the estimated silica-to-beryllium ratio in the sand (85 times more silica) as calculated in the example case in Section 2—Methodology of Chapter IV (Technological Feasibility) of the Preliminary Economic Analysis (PEA) (0.2 μg/m^3 beryllium = 17 μg/m^3 silica ÷ 85). The controlled median exposure level of 17 μg/m^3 is the median for the four molder exposures (13 μg/m^3 (LOD), 13 μg/m^3 (LOD), 20

Using a Combination of Engineering Controls, Housekeeping, and Improved Work Practices
Because work activities can vary throughout the day, a combination of engineering controls, housekeeping, and improved work practices are often required to reliably reduce beryllium exposures below 0.2 µg/m^3. As previously discussed, Materion Corporation advocates this strategy in its Worker Protection Model (described at the beginning of the subsection on Aluminum and Copper Foundries—Technological Feasibility). Materion Corporation indicates that the target PEL of 0.2 µg/m^3 can be achieve where worker protections include the combination of well-designed engineering controls, rigorous housekeeping, and workers who fully understand and follow the control processes.

Irwin (2003) reported on a foundry that used a combination of LEV (enclosing and ventilating the mold dumping and sand return areas) and adding a rotary media tumbler to substantially reduce worker silica exposure levels. In addition, the foundry changed work practices and performed aggressive housekeeping. Altogether, these controls reduced the silica exposure levels by more than 80 percent. Similar results were obtained on multiple sampling dates. The 80 percent reduction in silica exposure would likely extend to any contaminant present in the silica dust, including beryllium (see Section 2—Methodology, of Chapter IV (Technological Feasibility) of the Preliminary Economic Analysis (PEA). An 80% reduction would reduce to 0.2 µg/m^3 or less the exposures of all molders included in the exposure profile—except the single most highly exposed molder, whose exposure would be reduced from 2.29 µg/m^3 to 0.46 µg/m^3.

Balancing Ventilation Systems
Molders are also exposed to airborne metals when poorly balanced ventilation systems allow contaminated air from other parts of the foundry to enter the molding area. Lead and cadmium evaluations demonstrate how metal fumes (including beryllium fumes) can be spread to the molding area. For example, air monitoring conducted by the foundry industry showed that molders in sand casting foundries are exposed to metals, such as lead and cadmium, in foundries that cast copper-based alloys containing these metals (CCMA, 2000). Results for molders obtained between 1994 and 1999 in two copper alloy and bronze foundries (CCMA Case Histories A and B) indicated PBZ lead exposures ranging from 4 percent to 90 percent of the 50 µg/m^3 PEL for lead (2.11 µg/m^3 to 44.4 µg/m^3). In one of the foundries (CCMA Case History A), the ventilation was predominately exhaust-driven (i.e., no mechanically supplied makeup air). This condition created negative air pressure within the foundry, which in turn induced supply air into the casting department through openings behind the furnaces. The induced supply air moved fugitive emissions from the melting and ladle filling operations toward the shakeout, pouring, and molding activities. The cross-contamination created by the induced airflow likely was responsible for the shakeout and molder operators' exposures to lead (31 µg/m^3 to 130.53 µg/m^3 for shakeout operators and 2.9 µg/m^3 to 39 µg/m^3 for molders and core makers). The shakeout operators and molders were also exposed to crystalline silica. Silica exposure at the shakeout was likely due to a lack of LEV above the shakeout pit; most molder exposures were probably caused by the same patterns of air movement that swept the lead dust and fumes there. The molders were located downstream from the melting and casting operations in a part of the facility with little to no air movement.

µg/m^3, and 23 µg/m^3) obtained by NIOSH and OSHA (NIOSH ECTB 233-107c, 2000; OSHA SEP Inspection Report 122122534).

At a beryllium alloy casting facility visited in 2003, the furnace room and offices were not separated by any air supply system and the doors between them were usually open (ERG Beryllium Site 7, 2003). Investigators noted that evidence of cross-contamination was visible because graphite (used in the casting process to coat the permanent molds for quick release of the ingots) was covering many surfaces in the offices with a dark film.

To combat cross-contamination caused by improper balance in facility ventilation, CCMA advocates an integrated "whole foundry" approach to ventilation system design, testing, monitoring, and maintenance. The CCMA system maximizes local capture of air contaminants at the points where they are generated and balances all (local and general) air exhaust and supply systems in each work area to minimize cross-contamination. This approach does not require physical barriers to achieve balanced ventilation; it only requires that the amount of exhausted air equal the amount of mechanically supplied air. Initial and routine system testing and air monitoring are used to point to areas where improvements or maintenance are needed. CCMA consultants note that "cross-contamination can be virtually eliminated by establishing zones of balanced ventilation" (Scholz and Liello, 2000). Elimination of cross-contamination should also virtually eliminate airborne contamination from other foundry areas as a source of beryllium exposure for workers in the molding area.

Molder—Conclusion

Based on the available information presented in Tables IV-29 and IV-30, all exposure levels experienced by molders at nonferrous foundries that produce beryllium exceed 0.2 $\mu g/m^3$. Additional controls will be needed to reduce the exposure levels of all workers in this job category to 0.2 $\mu g/m^3$ or less. Materion Corporation Worker Protection Model indicates that 0.2 $\mu g/m^3$ can be achieved for most workers where control methods include the combination of well-designed engineering controls, rigorous housekeeping, and workers who fully understand and follow the control processes. For molders particularly, important elements of that model include eliminating the use of dry sweeping and compressed air for cleaning.

In addressing molders' exposures in sand casting foundries, exposure to beryllium is associated with sand spillage and dust exposures from reclaimed sand systems. Irwin (2003) reported on a foundry that used a combination of LEV, work practices, and aggressive housekeeping to reduce silica exposure levels by at least 80 percent. When the source of beryllium is as a contaminant in the sand, a reduction of this magnitude would reduce of seven of the eight molder beryllium sample results included in the exposure profile to 0.2 $\mu g/m^3$ or less.[148] The one exception (the highest result for this job category) would be reduced from 2.29 $\mu g/m^3$ to 0.46 $\mu g/m^3$.

Molders who clean and maintain permanent molds will also experience lower beryllium exposures when equipped to consistently use HEPA filter vacuums, wet-cleaning methods, and enhanced LEV in dedicated work areas when maintaining the molds. A study of workers maintaining copper-beryllium injection molds showed that when mold workers were provided with dedicated workstations including booths and enhanced LEV, significant exposure reductions occurred, from a maximum of 0.9 $\mu g/m^3$ to maximum of 0.06 $\mu g/m^3$ for 28 full-shift

[148] This determination is based on general principles governing airborne particles. Please refer to Section 2—Methodology, of Chapter IV of the PEA, for a more detailed discussion on particles and relevance in exposure reductions.

samples (Materion PSCS 105, 2011; MC Pkg I-D, 2010). Since approximately 88 percent of all molders currently have beryllium exposure levels between 0.2 μg/m^3 and 1.0 μg/m^3 (only slightly higher than the maximum exposure of 0.9 μg/m^3 in the above study), OSHA preliminarily concludes that exposure levels of 0.1 μg/m^3 or less can be achieved for the majority of these workers.

Where molder exposure levels are influenced by beryllium emissions from the activities of workers in other job categories, foundries can further improve molders' exposures by balancing facility ventilation systems to eliminate cross-contamination of the molding area from other foundry spaces, provided that the exposure levels of workers in other job categories in those spaces are also controlled to 0.2 μg/m^3. For example, poorly balanced ventilation can cause contaminated air from nearby operations, such as furnace operations, to be delivered to other areas of the facility, such as the casting department that includes molders' activities (CCMA Case History A).

Based on the available information, OSHA preliminarily concludes that an exposure level of 0.2 μg/m^3 can be achieved most of the time for most molders by implementing one or more of the additional controls mentioned above. The available information also suggests that an alternative PEL of 0.1 μg/m^3 can be achieved by most workers in this group most of the time.

Material Handler

Material Handler—Baseline Conditions

Material handlers typically operate open cab cranes and forklifts (ERG Beryllium Site 7, 2003; OSHA-H054A-2006-0064-0965). Poor housekeeping on the material handling equipment and in the facility contribute to their exposure, as do inefficient process ventilation and poorly balanced general facility ventilation systems that allow airborne contaminants to spread throughout the facility (CCMA, 2000; ERG Beryllium Site 7, 2003; OSHA-H054A-2006-0064-0965).

Material handlers also assist with manual work in foundry departments where process ventilation exists to some extent, but the ventilation is not necessarily specific to the operation performed by the material handler. For example, material handlers (and other workers) who deliver charge to the furnace operator can manually load charge into buckets (ERG Beryllium Site 7, 2003). This work would be conducted in the vicinity of the furnace hood, but with no ventilation specifically applied to the charge transfer operation (see furnace operator job category).

The single full-shift result for this job category is for a material handler who operated a crane from a presumably open[149] cab in a beryllium alloy casting facility and experienced exposure of 0.93 μg/m^3 (NIOSH HHE 75-87-280). OSHA lacks information that would confirm the validity of this value as the baseline level for the job category. The only other value available to OSHA is a sample result of 2.38 μg/m^3 from a less-than-full-shift sample taken on a forklift operator

[149] OSHA presumes that the cab was open due to indications from baseline conditions that the vehicles used for material handling in foundries are usually not equipped with a properly sealed cab so as to prevent significant exposures to workers.

who spent considerable time assisting with other tasks not related to material handling (casting and cutting the cast billets with a saw). (ERG Beryllium Site 7, 2003).[150]

Material Handler—Additional Controls

Baseline conditions for material handlers are associated with one full-shift PBZ result of 0.93 µg/m^3, indicating additional controls will be required to reduce exposures to 0.2 µg/m^3 or less. OSHA notes that the beryllium exposure levels of material handlers will decrease substantially when housekeeping is improved sufficiently to reduce the presence of beryllium dust that material handling can disturb (e.g., by driving a forklift over settled dust) and when control measures are implemented to reduce the exposures of workers in other job categories. Airborne beryllium emitted from processes or present at elevated background levels contribute to the total beryllium exposure of material handlers who work in or pass through those spaces. Another control option includes operator cabs that are fully enclosed and ventilated. Modified work practices and administrative controls that coordinate plant activities so material handlers are not present during processes that generate airborne beryllium are also available control options.

Housekeeping

Plant-wide diligent housekeeping and migration control efforts will help decrease material handler exposures. In particular, vehicular traffic can re-entrain/resuspend settled dust in foundries and contribute to airborne contaminant concentrations (CCMA, 2000). Settled dust and spilled debris containing beryllium can be disturbed by passing vehicles, including forklifts, trucks, and in-plant tractors and rail transport equipment. Additionally, when these materials are crushed under passing traffic, particle sizes are further reduced and the particles can become resuspended more easily than in their original form.

In a separate analysis of respirable dust and respirable crystalline silica, ERG identified numerous instances in several industries where poor housekeeping contributed to the crystalline silica exposure of material handlers driving on surfaces where silica had settled or been spilled (ERG Silica_GenInd1v.2, 2008). Although not a metal like beryllium, crystalline silica is a solid mineral that is prevalent in sand-casting foundries and a prominent air contaminant in these facilities. Silica and beryllium particles of a given aerodynamic diameter will behave similarly in air, regardless of the source material (see Section 2—Methodology for additional information on particle behavior).

Similarly, OSHA evaluated a ferrous sand casting foundry and found that respirable dust levels were 60 percent to 80 percent lower after foundry-wide dust control efforts, including a thorough cleaning (OSHA SEP Inspection Report 303207518). Because Kent et al. (2001), Martyny et al. (2000), and NIOSH EPHB 326-11a, (2008) found that much of the mass of airborne dust in foundries that cast beryllium consists of respirable and near respirable size particles, OSHA reasonably finds that the respirable dust control results reported for the foundry visited by OSHA are also relevant to beryllium dust control in beryllium casting foundries where settled or spilled materials are a potential source of exposure.[151] Dust control efforts, including a thorough

[150] For the purposes of this technological feasibility analysis those additional tasks are addressed under the discussion of the furnace operator and grinding/finishing operator job categories.
[151] For example, NIOSH reported beryllium concentrations and particle size results in the furnace area and machine shop (near cutting equipment) at a copper-beryllium foundry that manufactures products (0.45 to 2.15 percent beryllium) for the metal die casting industry (NIOSH EPHB 326-11a, 2008). The cutting equipment was used with

cleaning, that are effective for respirable dust in foundries can have a similar effect in reducing airborne beryllium exposure (i.e., a 60 to 80 percent reduction) in foundries that cast this metal. Industry experience has also shown that housekeeping and migration control are important to controlling beryllium exposure in any facility handling beryllium materials. These control measures are listed as critical elements in the Materion Worker Protection Model (Materion Interactive Guide, 2012).

Effective housekeeping methods typically involve the use of vacuums fitted with HEPA filters, a routine cleaning schedule that ensures a thorough daily cleaning, elimination of compressed air for cleaning, and policies for cleaning up spills immediately before they can spread.

Process Enclosures
Material handlers can benefit from process enclosures, which can be as simple as covering beryllium alloys to be transported by the material handler so oxide dust is not released into workplace air. As an option to control beryllium particles while the material handler opens the containers (e.g., bin or barrel), employers can provide a ventilated booth into which the container fits, such as the ventilated mixing station enclosure described by NIOSH for use in handling butter flavorings containing diacetyl (another toxic substance sometimes occurring in a powdered form) (NIOSH-CAL/OSHA-ltr, 2007). A large ventilated booth into which forklift drivers can insert bins to be emptied can be used to reduce dust levels. Contaminant capture may further be improved by reducing the effective opening using flexible strips and by maintaining an air flow rate to 400 fpm across the opening. (Materion meeting, 2012).

Until other job categories are controlled to a similar level, material handlers typically will not be able to avoid *all* work near dust- or fume-emitting processes (e.g., delivering and loading charge into the furnace or assisting with casting and de-molding operations). In facilities where material handlers must work near processes that have not yet been fully controlled, enclosures and modified work practices can help decrease material handler exposures. For example, until a close-fitting ventilation hood can be installed on a furnace, a physical barrier around the furnace to reduce spread of fumes might help minimize the beryllium exposure of material handlers delivering raw materials to the furnace area during melting.

Operator Enclosures
Enclosed operator cabs on equipment such as forklifts and cranes can help reduce beryllium exposure for material handlers. Information from the lead smelting and agriculture industries demonstrates this point. Lead, like beryllium, is released as a metal fume from furnace operations, as an oxide from heated processes, and as a dust from abrasive action on the metal or oxide. Although the concentration of lead in leaded metals tends to be markedly higher (up to 100 percent) than the amount of beryllium in beryllium alloys, the forms of particulates and principles of contamination migration are generally the same for both lead and beryllium in

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coolants. In addition to machining, the shop was used for grinding, polishing, and buffing, with most of the equipment fitted with local exhaust ventilation (e.g., canopy hood, side draft, slot). The six samples indicated that 59 to 77 percent of the sample mass concentration was associated with particles less than 18 µm (NIOSH EPHB 326-11a, 2008). Another study of aerosols generated during beryllium machining under typical working conditions also showed that more than 50 percent of the beryllium machining particles in the workers' breathing zones were less than 10 µm aerodynamic diameter (Martyny et al., 2000). See Section 2 (Methodology) of this technological feasibility analysis for a more detailed discussion of particle sizes and particle behavior.

metal casting activities such as that discussed in the first example below. The second example involves control of pesticides, which also occur as fine mists or particulates and can be very toxic (low acceptable human exposure limits).

Example: Cabs Used in Lead Smelting
A 1996 NIOSH report on a lead smelting facility demonstrated that lead concentrations were 80 percent lower inside a front-end loader's HEPA-filtered, air-conditioned cab than outside it (NIOSH ECTB 202-15b). At the time the worker was using the loader to move lead-bearing materials between buildings. When, on another day, the worker performed raw material storage operations within one indoor work area the cab protected the operator even better, reducing lead exposure by 95 percent.[152] NIOSH obtained these values at a time when visible dust was noted in the cab and another related data collection effort indicated that the dust in the cab contained lead. Exposure reduction levels would likely have been lower if the cab had been cleaned; NIOSH recommended that cabs receive a thorough cleaning (using wet methods) after each shift.

Example: Cabs Used in Agricultural Spraying
More recent studies have demonstrated that even greater reductions are possible when the cab is properly sealed, fitted with air conditioning and pressurizing equipment, and consistently maintained. Haney (2000) showed that enclosing cabs on heavy equipment in an agricultural setting can reduce the operator's exposure to respirable dust by 90 to 95 percent (inside the cab compared to outside the cab). These measurements were made simultaneously and represent absolute change, regardless of the starting concentration.[153] In another study evaluating exposure controls for pesticides, aerosol monitoring was performed on a factory-installed cab (original equipment) and a retrofit cab (aftermarket addition to a tractor that was not originally enclosed). The authors compared air inside and outside the cab and concluded that both cabs provided *at least* a factor of 5 reduction (80 percent reduction) for 0.3 micrometer (µm) particles (Hall et al., 2002). Actual measurements of particles less than 1 µm showed protection factors (as reported by the author) of 16 and 43 for the two cabs, with corresponding exposure reductions in the range of 94 percent to 97 percent are possible for these fine particles.[154] Greater protection factors were also reported for particles larger than 3 µm. The authors also noted that the evaluation method used in this study "can be applied to various cabs used in different industries including agriculture, construction, and manufacturing."

To put these findings into perspective, airborne beryllium in foundries is present as both dust and fumes. The size of dust particles can vary widely, from visible to submicroscopic; fume particles

[152] The investigator did not provide reasons for these difference in measured cab dust control efficiency, however, OSHA notes that a number of conditions can contribute to such variations, including wind direction relative to the dusty work operation and the sample collection point (e.g., right or left side) on the exterior of a cab operated outdoors, cab cleanliness, and the frequency with which the operator opened the cab door or dismounted from the cab (allowing air contaminants to enter through the door, bypassing the cab filtration system). These details were not reported in this study (NIOSH ECTB 202-15b).

[153] This means that if a lower concentration (e.g., fractions of a µg/m^3) of beryllium dust had been present instead of a higher concentration of nontoxic respirable dust, the percent exposure reduction would remain the same.

[154] The relationship between protective factor and exposure reduction can be described by the following example: if the concentration outside of the cab is 100 µg/m^3 and the protection factor is 16, the inside concentration will be reduced to a level 1/16 of the outside (100*1/16=6.25), or approximately 6 µg/m^3, which is an exposure reduction of 94 percent; if the protection factor is 43, the outside concentration will be reduced by 1/43 inside, to a level of 2.3 µg/m^3, a reduction of at least 97 percent.

are very small, usually less than 1 µm in diameter. The particle size range of smelter dust and fumes is reported to range from 0.1 µm to 100 µm (Alpaugh, 1988). During visits to two beryllium alloy foundries, NIOSH investigators used a real time instrument to collect particle size and number concentrations at various locations (melting and casting, cutting and grinding, office) throughout the foundries (NIOSH EPHB 326-11a; NIOSH EPHB 326-16 a). The instrument was capable of measuring particles ranging from 0.5 µm to 20 µm in diameter.[155] Particles in this size range were detected at both foundries, and the particle number concentrations were greatest for particles below 1 µm (around 0.5 µm to 0.8 µm).

In another report on cab enclosures, Cecala et al. (2005) measured an average reduction in exposure of 93 percent for respirable dust as measured simultaneously inside and outside the cab during active operating conditions at an earth-drilling site. Effective operator enclosures are fully sealed (around doors and windows and utility gaps as for electrical wiring). These cabs are pressurized to provide fresh, filtered air to the operator. In hot environments, cooling the air encourages workers to keep windows and doors closed consistently. Providing heating and cooling at the ceiling—rather than floor—level minimizes disturbance of dust from the operator's boots. Enclosed cabs are currently in use at some foundries: NIOSH describes a gray iron foundry where crane operators worked in enclosed, pressurized cabs (NIOSH ECTB 233-107c).

Although these studies do not describe the benefits of enclosed cabs as they pertain to material handlers' beryllium exposures in foundries, they are relevant. Properly enclosed and ventilated operator cabs will reduce material handler exposures to beryllium as well as other airborne contaminants because the material handlers will be isolated from the sources of beryllium particles when they remain inside the cab. To determine the benefit such a cab would offer foundry material handlers, OSHA calculated that a 90 percent reduction (rounding down from the exposure reductions reported by most authors) in the 0.93 $\mu g/m^3$ value offered as the baseline exposure level for this job category would result in an exposure level of 0.093 $\mu g/m^3$ (or less than 0.1 $\mu g/m^3$) when material handlers remain inside the cab.

Automation

Many manual processes with which material handlers assist other foundry departments can be automated. For example, the material handler at the foundry visited by ERG assists other workers in loading the furnace charge manually (ERG Beryllium Site 7, 2003). This process can be performed automatically using a fully enclosed conveyer (CCMA, 2000). Such a system would all but eliminate the involvement of the material handler in the process. For optimal exposure control the conveyer enclosures would need to be connected to an exhaust ventilation system, such as shown in VS-50-20/22 of ACGIH's Industrial Ventilation (ACGIH, 2010).

Work Practices

Modified work practices can affect material handlers' exposure. For example, raw material/charge deliveries might be timed so that material handlers or overhead crane operators approach the furnace between periods of degassing, sparging, and dross skimming, thus avoiding those periods when airborne contaminant levels in that area are highest. Forklift operators who

[155] The equipment range encompasses the full range of "respirable-size" particles (1 µm to 10 µm, centered on 4 µm), plus particles 50 percent larger or smaller than that range. These studies did not evaluate the relative presence particles larger than 22 µm (NIOSH EPHB 326-11a; NIOSH EPHB 326-16 a).

deliver large castings to shakeout areas should move out of the area before vibrating equipment is activated. Material handlers should not linger in areas where exposure is incompletely controlled.

Material Handler—Conclusion

The exposure profile for material handlers is based on one full-shift PBZ result of 0.93 µg/m^3, which is above the proposed PEL of 0.2 µg/m^3. Although limited, this is the best available exposure information for this job category. OSHA has determined that for most workers in this job category, the primary sources of exposure are beryllium emissions from work performed by individuals in other job categories, combined with ineffective housekeeping. Therefore, OSHA preliminarily concludes that exposure levels of 0.1 µg/m^3 or less will be achieved for most material handlers when 1) the exposure levels of other job categories are reduced to an equivalent level and 2) housekeeping is concurrently improved to minimize the presence of beryllium dust that could become airborne if disturbed.

Where exposures continue to exceed this level (including in facilities where other job categories continue to reach or exceed 0.1 µg/m^3), OSHA estimates that this level can still be achieved for material handlers who can consistently use fully enclosed, sealed, pressurized, and air-conditioned operator cabs. Such cabs routinely provide the operator with a better than 90 percent reduction in dust exposure levels (Cecala et al., 2005; Hall et al., 2002; Haney, 2000). A 90 percent reduction would bring the beryllium exposure level of material handlers below the proposed action level of 0.1 µg/m^3 (0.093 µg/m^3). OSHA recognizes, however, that many material handlers' duties preclude them spending the entire shift in an enclosed cab and respiratory protection might be necessary for material handlers working in the vicinity of the uncontrolled processes until such time as the processes can be controlled.

In some facilities, material handlers' own activities generate airborne beryllium in excess of the proposed PEL. In these cases, employers can reduce the exposure level of this job category through automation and ventilation. For example, employers can eliminate entries by material handlers into furnace and shakeout areas by using automated, ventilated material handling equipment, such as an enclosed conveyer belt equipped with an exhaust ventilation system (see VS-50-20 through VS-50-22 in ACGIH, 2010). Another promising option is coating the beryllium scrap or castings to prevent release of surface oxide while material handlers transport them (Materion meeting, 2012).

Based on the availability of these control options, OSHA preliminarily concludes that the exposure levels of most material handlers can be reduced to 0.2 µg/m^3 (the proposed PEL), and an alternative PEL of 0.1 µg/m^3, although some material handlers might require respiratory protection as an interim measure until the emissions associated with other job categories can be controlled to the same level.

Furnace Operator

Furnace Operator—Baseline Controls

Furnace operators typically work with exhaust ventilation at the furnace; however, the ventilation system is likely to have been designed to capture heat and control foundry emissions for environmental purposes, not to prevent exposure to workers. As a result, these systems may not function optimally or be suitably designed to minimize worker exposure to beryllium. Few of the furnace ventilation systems viewed by NIOSH, ERG, and CCMA were fully effective for worker protection (NIOSH HHE 75-87-280; ERG Beryllium Site 7, 2003; CCMA 2000). Also, most foundries make little effort to control exposure from collected dross and/or charge preparation activities (e.g., Beryllium Alloy Casting Facility A, 2005). Housekeeping is typically not adequate to manage the quantity of dust and debris generated. Although some facilities have central vacuum systems in the furnace area, surface wipe samples indicate that these are not used often or efficiently enough to eliminate accumulations of beryllium-containing dust (e.g., ERG Beryllium Site 7, 2003).

Therefore, OSHA considers baseline controls to include some form of LEV (such as a slotted plenum), which provides improved worker protection over traditional canopy hoods, but provides limited performance. Other baseline controls include an industrial vacuum system, which is used inconsistently as part of a modest housekeeping program. Furnace operators typically use some form of dross collection receptacle, but without dedicated or efficient exhaust ventilation. Exhaust ventilation is also typically not available for furnace charge preparation or charge bucket heating activities. Because all of the sample results included in the exposure profile were obtained under these general baseline conditions, OSHA preliminarily concludes that the median for these baseline conditions is represented by the exposure profile median level of 1.14 $\mu g/m^3$.

Furnace Operator—Additional Controls

Baseline conditions for furnace operators are described by a median exposure level of 1.14 $\mu g/m^3$, although, as noted under Exposure Profiles for Affected Job Categories in the Aluminum and Copper Foundries section, the exposure profile for furnace operators could be underestimating exposures for this job category. Table IV-30 indicates that just 18 percent of furnace operator exposures are currently 0.2 $\mu g/m^3$ or less. Additional controls will be needed to reduce the exposures of most furnace operators (the remaining 73 percent) to this level. OSHA observes that exposure levels are spread over a wide range, including a substantial number of furnace operators (37 percent) who currently experience exposures well in excess of the current beryllium PEL of 2.0 $\mu g/m^3$. Poorly designed furnace ventilation systems, the challenges of working with dross (which tends to concentrate beryllium as a dusty oxide), and the extremely high temperature of molten metal all contribute to the elevated exposures.[156, 157]

To reduce exposures associated with this job category, it will be necessary to take a multi-faceted approach, combining a number of control options. The following paragraphs describe a foundry

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[156] Although the supporting information is limited for many of the sample results for this job category, some trends are evident: the highest exposures in this job category are associated with ventilation systems that were deemed inadequate or poorly designed for worker protection. For example, one of the highest results (14.08 $\mu g/m^3$) is associated with a furnace operator who performed extensive dross skimming and other furnace tending activities under a canopy exhaust that pulled fume and dust from dross skimming through the worker's breathing zone. The operator also conducted pouring tasks, which can contribute to elevated peak exposures.

[157] Two particular challenges associated with reducing the exposure of these workers include the high molten metal temperatures and the delicate nature of the furnace lining relative to cooling water coils. These challenges often render impractical the designs for automating high-exposure furnace area tasks, such as rubbing down furnace lining walls and skimming dross (Corbett, 2005).

that reduced furnace operator exposures to 0.55 μg/m^3 or less. As discussed later in this section, additional controls beyond those implemented by this foundry may reduce the exposure levels of many additional furnace operators to the level of the proposed PEL of 0.2 μg/m^3. Such controls may include furnace-mounted exhaust hoods, additional preventative maintenance on furnace and ventilation systems, use of enhanced work practices, disciplined housekeeping, and automated dross skimming. Some of these controls may require the development of new technology.

A NIOSH workplace evaluation at a beryllium alloy foundry (NIOSH EPHB 326-16a, 2008) suggests that most foundry workers, including most furnace operators, can achieve exposures of 0.5 μg/m^3 or less with currently available technology. The facility in this evaluation has two foundry areas: 1) a green sand foundry where workers use sand molds and cores for casting copper alloys of 1 percent to 4 percent beryllium (including on the sampling day) and 2) an ingot foundry using a permanent mold system to cast alloys up to 5 percent beryllium (during the sampling, workers cast aluminum alloy containing 2.5 percent beryllium). In both foundries, LEV systems are in place to remove fumes and dust associated with the furnaces, crucible transport (green sand foundry), pouring activities, and the dross barrels. In addition, the foundries (and cutting and grinding shop) are designated beryllium work areas with controlled access, PPE requirements, and processes in place to minimize beryllium migration to other facility areas.[158] Housekeeping practices include the use of HEPA vacuums, and workers are responsible for cleaning and maintaining their work areas during the day and at the end of their work shift. Over two consecutive sampling dates, NIOSH collected a total of 17 PBZ full-shift beryllium samples at this facility.

NIOSH's sampling of the melting and casting operation in the green sand foundry included six workers: one furnace operator, three molders, and two pouring operators. NIOSH investigators collected 12 samples from these workers that ranged from 0.03 μg/m^3 to 0.58 μg/m^3 (including two nondetectable samples at 0.03 μg/m^3 and 0.04 μg/m^3), with a mean of 0.17 μg/m^3 and a median of 0.11 μg/m^3 (NIOSH EPHB 326-16a, 2008). The supporting information available for the green sand foundry portion of this investigation does not link individual job categories or activities with these samples.[159] NIOSH did, however, note that the workers with greatest potential for overexposure in the foundry were associated with the melting and casting processes.

In the ingot foundry, four workers were involved with the process: two furnace operators who monitored the pouring of aluminum-beryllium alloy into the ingot molds, one worker who removed dross, and one worker who monitored the cooling process and conveyor to ensure that ingots were released from the molds and dropped into the ingot shoot. NIOSH collected five PBZ samples on workers in the ingot foundry. The results of these samples ranged from 0.03 μg/m^3 to 0.55 μg/m^3, with a mean of 0.17 μg/m^3 and a median of 0.03 μg/m^3. The two highest results (0.21 μg/m^3 and 0.55 μg/m^3) were obtained on furnace operators. The remaining three results (each with a value of 0.03 μg/m^3) were listed only as samples for workers in the ingot

[158] To minimize beryllium migration, the facility employees change into clean work clothing in a change area with clean side and dirty side change rooms and enter/exit designated beryllium work areas through one of two air showers. At the end of the work shift, employees must leave their work clothing to be laundered by the company and shower before entering the clean side change room (NIOSH EPHB 326-16a, 2008).

[159] NIOSH does note that two samples associated with a supervisor were 0.1 μg/m^3 and 0.58 μg/m^3 (NIOSH EPHB 326-16a, 2008). The remaining, non-supervisor results ranged from 0.03 μg/m^3 to 0.42 μg/m^3).

room, with no specific job category or activity linked to the individual samples (NIOSH EPHB 326-16a, 2008).

Although limited, these findings represent the best available information on well-controlled[160] conditions during foundry operations involving alloys containing percentages of beryllium that are at the top end of the typical range used in foundries. These results show that all foundry workers in a melting and casting area, including the furnace operators, can achieve beryllium exposures of 0.55 $\mu g/m^3$ or less in foundries with effective engineering controls, even when the alloy beryllium content is at the highest typical percentage. Because beryllium tends to concentrate in dross and oxides from molten metal, use of lower beryllium alloys does not directly translate to an equivalently lower exposure level; however, where the beryllium content is considerably lower than 2 percent, exposures could be somewhat lower than measured at this facility. For example, since the highest exposure for a foundry operator at a facility using higher beryllium alloys (at 2.5 percent) is 0.55 $\mu g/m^3$, the comparable worker in a foundry handling alloy with beryllium less than 2 percent could experience a modestly lower exposure level of, for example, 0.5 $\mu g/m^3$ most of the time.

By contrast, exposure levels were markedly higher at a second beryllium alloy foundry visited by NIOSH, where NIOSH concluded that a comprehensive upgrade of the entire ventilation system in the foundry areas was required. Like the well-controlled facility described above, this second facility also operated both green sand and permanent mold foundries. The facility cast copper-beryllium alloy, but of a lower beryllium content (0.45 percent to 2.15 percent) than the well-controlled facility (NIOSH EPHB 326-11a). Although melting and casting operations were ventilated at the second facility, the existing systems were inadequate or not used properly. Three full-shift PBZ samples for furnace operators are associated with results of 1.16 $\mu g/m^3$, 4.72 $\mu g/m^3$, and 5.52 $\mu g/m^3$. These results are two to 10 times greater than the highest value for a furnace operator in the well-controlled foundry (0.55 $\mu g/m^3$).

To reduce most furnace operators' exposures to the levels that NIOSH measured at the well-controlled facility (0.55 $\mu g/m^3$ or less), several control measures will need to be implemented:

- Installing LEV for dross receptacles and furnace tools.
- Improving LEV on furnaces.
- HEPA filter vacuuming or otherwise cleaning clothing when exiting the furnace area.

Additional controls, beyond those reported in the well-controlled foundry visited by NIOSH, would be needed to reach the proposed PEL of .2 $\mu g/m^3$.These controls include pressurized booths, furnace-mounted exhaust hoods, additional preventative maintenance on furnace and ventilation systems, use of enhanced work practices, disciplined housekeeping, and possibly the development of new technology. It may not be feasible for most furnace operators to reach the PEL based on currently available technology.

[160] For the purposes of this analysis, this foundry is described as "well-controlled" in order to compare working conditions to other foundries described. OSHA notes that additional controls, beyond those described by NIOSH in this well-controlled foundry, can be implemented.

Local Exhaust Ventilation for Dross Receptacles and Furnace Tools

Dross receptacles can be fitted with exhaust ventilation. A beryllium producer designed and installed a ventilated dross collection tray that integrates fume control with furnace-mounted slot hood exhaust ventilation. The tray extends down to the edge of the furnace slot hood opening; using a skimming tool, the operator places several scoops of dross from the furnace onto the tray. Dross fumes are collected by both the furnace slot hood and the dross hood. When the tray is full, the operator activates a control that retracts the dross tray into a ventilated enclosure and dumps the tray contents into a barrel (also under exhaust ventilation) (Corbett, 2005).

Another source of exposure is furnace tools that have come into contact with the molten metal. Dross skimming rakes, furnace lining rub bars, thermal couples, and degassing wands that have contacted molten metal release fumes as they are removed from the furnace after the task. At Materion Corporation's beryllium production facility, furnace operators place the furnace tools in ventilated tool holders after use to capture residual beryllium fumes. This control method should work equally well for capturing beryllium fumes from furnace tools at beryllium alloy foundries.

Improved Local Exhaust Ventilation for Furnaces

Foundries will also need to upgrade LEV on furnaces to improve fume and dust capture and to reduce the influence of cross-drafts (CCMA, 2000). A foundry casting copper-based alloy (CCMA Case History Foundry C) used a horseshoe-shaped slotted hood at the top of the furnace (CCMA, 2000). This design allows ready access to the molten metal for treatment and dross skimming. An auxiliary ventilation system would be required to ensure that skimmed dross and the associated scoop would be continually held under exhaust ventilation as they passed between the furnace mouth, the dross receptacle, and the scoop storage area. At a beryllium alloy foundry where NIOSH (NIOSH EPHB 326-16a) found beryllium exposures for nearly all foundry workers to be below 0.5 $\mu g/m^3$, the employer had installed a slotted hood above the furnace in the green sand foundry and a slotted hood with flexible hoses connected to a Hawley Trav-L-Vent system over the crucible to remove fumes during pouring and transport. In the ingot foundry, the furnace was equipped with both a slotted hood over the furnace pot and a canopy hood with canvas side extensions. Visual observations indicated that dust and smoke from the melting and casting operations were effectively captured at the LEV openings.

In the nonferrous foundry industry, three types of metal melting furnaces are typically used, including induction furnaces, crucible furnaces, and reverberatory furnaces (EPA 310-R-97-004, 1998). The ACGIH Industrial Ventilation Manual offers several designs for furnace ventilation systems, including tilting induction furnaces, non-tilt crucible furnaces, and others (See Group 13.55, in ACGIH, 2010). The beryllium production industry uses slotted ventilation hoods around induction furnace openings.

Personal Hygiene

For most furnace operators to achieve levels of 0.5 $\mu g/m^3$ or less, workers exiting the melting and casting area must also clean their clothing (e.g., with a HEPA filter vacuum or a HEPA-filtered air shower). This step reduces the extent to which clothing continues to contribute to worker exposure as workers move to other, possibly cleaner areas. Additionally, the step will reduce the spread of beryllium to other facility areas.

Control Booths
Employers can reduce furnace operators' exposure by providing control booths equipped with air conditioning and HEPA filters (99.97 percent effective against particles of 0.3 µm in size). The same principles described for operator cabs (in the material handler job category) will be effective for furnace operator booths.

Furnace-Mounted Exhaust Hoods
Ventilation exhaust hoods located at any distance above the furnace (e.g., canopy hoods) are subject to air disturbances and cross-currents that render them less effective. These furnace hoods also make it possible for workers to lean over the furnace, placing their breathing zone between the source of fumes and the exhaust hood.

Several alternative hood designs are readily available, although some require modifying the furnace or even replacing it. The centrifugal casting foundry visited by CCMA, which casts both ferrous and non-ferrous alloys, uses furnace-mounted exhaust hoods (CCMA, 2000). This type of hood reduces the influence of cross-drafts and also prevents operators from working between the fume source and the exhaust hood. Both of the full-shift beryllium furnace operator exposure results associated with this control were less than the sampling limit of detection (in this case 0.2 $\mu g/m^3$). ACGIH offers a design for an enclosing induction melting furnace hood (see Figure VS-55-07, "Induction Melting Furnace—Tilting") (ACGIH-Ch-13, 2010). Foundries that do not perform extensive dross removal might also achieve this level (0.2 $\mu g/m^3$).

While OSHA anticipates that this type of hood would present a challenge to facilities casting high-beryllium-content alloys, it appears that the development of alternate exhaust systems for these facilities is feasible. Dross must be removed from the metal to produce quality castings (Air Products, 2005). A fully enclosing hood would hamper the process. For example, the reduced access to the furnace top means workers would not be able to remove dross without displacing the hood. To minimize this problem, foundries would need to design the hoods with trap doors to access the melt. Even so, OSHA understands that purity specifications for certain castings will require more rigorous dross removal and greater access to the furnace interior. In these facilities it will be necessary to remove the enclosing exhaust hood and replace it with an auxiliary ventilation system, which will capture fumes and dust while providing access to the furnace. At the same time, to better capture fumes and dust from dross as the dross is transferred out of the furnace, foundries will need to incorporate a ventilation system extension or mobile arm that covers the entire path of the dross scoop from the furnace to the ventilated receptacle. OSHA is not aware of a commercial source for such a ventilation system; however, experts agree that to fully control fumes from toxic metals it is necessary to keep the entire process under LEV (CCMA, 2000; Corbett, 2005). Because retrofit foundry ventilation systems are often custom-designed, the lack of a commercial source is a less compelling concern than it might otherwise be. Recent advances in computer modeling offer advanced methods for designing exhaust ventilation and for predicting the benefits of various configurations (NIOSH EPHB 233-133c; Huang et al., 2004; Heinonen et al., 1996).

Preventive Maintenance
Regular preventive maintenance on the furnace and ventilation system is a critical component of worker protection. A continuous maintenance program, including frequent inspections, is necessary. For example, at a foundry visited by NIOSH (Case History 11), employees checked

the furnace cover seal seat after each charging to ensure that it was in good condition. On a daily basis, the facility also monitored dust collector differential pressure and motor amperage, augers and fans, and hoppers (for overfilling). Ventilation system drive components, pneumatic systems, and hoods were checked once per week, as were bag house filtration units. The fan impellers were cleaned monthly (NIOSH 79-114, 1978). A program of routine air monitoring would also help identify problems with exposure controls so they could be investigated and corrected (CCMA, 2000).

Enhanced Work Practices

Consistently applied, enhanced work practices could help minimize furnace operator exposure levels. For example, current exposure levels at a beryllium production furnace operation are associated with deviations from optimal work practices, such as overfilling the specially designed dross tray, thus overwhelming the LEV system (Corbett, 2005).

Exposures caused by overfilling the dross collection barrel in the ventilated enclosure before changing the barrel present another work practice challenge. To prevent overfilling, a mechanical level indicator could be installed to help workers determine barrel fullness. Deviations from optimal work practices can be further minimized by establishing clearly defined written procedures, providing task-specific operator training, and making work practice observations to ensure procedures are understood and followed. As part of a comprehensive approach to controlling inhalation exposure to beryllium, Materion Corporation recommends that employers develop and implement written procedures and work instructions (Materion Interactive Guide, 2012).

This beryllium producer also suggests that beryllium exposures can typically be reduced by about 20 percent to 50 percent through improved work practices (Kent, 2005). While individual quantitative exposure information on beryllium is not available to support this professional judgment, an equipment manufacturer's study and a second study by The Center to Protect Workers' Rights do quantify the benefit of enhanced work practices in two different industries. The first study assesses the particulate containment performance of the equipment manufacturer's ventilated hood and suggests that work practice improvements can provide significant exposure reductions (Mento et al., no date).[161] In this investigation, PBZ samples were collected on three operators performing three different traditionally dusty powder-handling tasks with a surrogate test powder (lactose) in a ventilated enclosure. Two PBZ samples were collected simultaneously on each operator (at the left and right sides of the operator's breathing zone) while each task was performed. Sampling durations ranged from 24 minutes to 48 minutes. One of the operators was considered moderately skilled and trained at these tasks. The other two operators were considered unskilled at these tasks. The average results for each operator by task are summarized in Table IV-31.

Table IV-31—Work Practice Variability and Operator Exposure to a Surrogate Powder (Lactose) During an Equipment Manufacturer's Performance Testing of a Ventilated Enclosure

Task (Performed in the Ventilated Enclosure)	PBZ Results (μg/m^3)

[161] This hood is a portable, ventilated cabinet providing a partial enclosure with an open front, under which a drum can be placed and raised up into the hood—so workers can manipulate the drum opening inside the cabinet (Mento et al., no date).

	Operator 1 (Skilled)	Operator 2 (Unskilled)	Operator 3 (Unskilled)
Bulk powder weighing	*0.088*	*1.622*	*0.491*
Powder sieving and weighing	*0.174*	*0.521*	*0.116*
Powder drying (fluid bed) and weighing	*0.095*	*0.662*	*0.114*
Operator exposures represent the average of two personal breathing zones samples collected simultaneously during each task. Sampling durations ranged from 24 minutes to 48 minutes. Operator 1 was considered moderately skilled and trained at these tasks. Operators 2 and 3 were considered unskilled. *Source: Mento et al., no date*			

The results in Table IV-31 show that when the task and the controls are the same, operator work technique can influence exposures. Operator 1 was the most skilled and had the lowest exposures for two out of the three tasks. Although Operators 2 and 3 were both considered unskilled, Operator 2 consistently had the highest exposure for all three tasks, suggesting that there was something different about this operator's work technique. For bulk powder weighing, Operator 2's exposure was 18.5 times greater than the lowest result; for sieving and drying, this operator's exposure was 4.5 times greater than the lowest result; and for fluid bed drying and weighing, Operator 2's exposure was about seven times greater than the lowest result. Although not specific to beryllium, these findings show that there can be significant differences in exposure to airborne contaminants due to work practices and suggest that exposure reductions ranging from 78 percent to 95 percent might be possible when work practice improvements are implemented.

The second example regarding exposure to chromium IV during welding operations provides similar results. At a training center for pipefitters and plumbers, investigators sampled PBZ chromium VI fumes for welders before and 6 months after they received instruction in using LEV to minimize their exposure. The results were dramatic. For welders using LEV while working on carbon steel, the mean chromium VI sample result dropped by 99.6 percent from 40.6 $\mu g/m^3$ before instruction to 0.16 $\mu g/m^3$ after the students were instructed on using LEV (exposure levels ranged from less than 0.04 $\mu g/m^3$ to 0.38 $\mu g/m^3$). The difference was less extreme, but still considerable with an 85.7 percent reduction when welders worked on stainless steel (Susi and Meeker, 2008; TAPS Grant U54 OH008307-05 Year3, 2007). The investigators suggested that differences in the welding material gauge and percent time spent welding might account for the differences in results for welders working on different base metals.

Materion Corporation's suggested exposure reductions of 20 percent to 50 percent, the equipment manufacturer's findings of possible reductions of 78 percent to 95 percent, and the Susi and Meeker (2008) study (85.7 percent to 99.6 percent) represent the best available information on the exposure reductions that might be associated with work practice improvements. OSHA acknowledges that exposure reduction results will vary depending on the task, equipment, and work force; however, the value of work practice improvements in the use of controls is evident across these industries. To develop a preliminary estimate of the general effect on exposure levels that might be expected across a variety of settings, OSHA took the midpoint point (35 percent) of the primary beryllium producer's suggested exposure reduction range (20 percent to 50 percent), attributed to enhanced work practices (Kent, 2005). Although the two more quantitative studies showed real potential for considerably greater exposure reduction, OSHA judges the Kent (2005) assessment to be most relevant to beryllium alloy product manufacturing operations, including foundry furnace operations.[162] A 35 percent reduction in the 0.5 μg/m^3 exposure level would result in an exposure level for furnace operators of 0.33 μg/m^3.

To further reduce furnace operator exposures, it might be necessary to eliminate manual dross skimming and dross barrel changing by automating these processes. Dross barrel changing might be automated using existing materials handling technology. For example, remote-controlled manipulators could allow a worker in a control booth to seal the barrel and clean its exterior before removing it from the ventilated enclosure.

Automated Dross Skimming
Automating the dross skimming process presents a challenge, and the feasibility of this technology needs to be investigated. However, two induction furnace manufacturers contacted by OSHA suggest that mechanical dross skimming is possible. This process has been developed only to a limited extent and is not widely marketed because furnace manufacturers have not received customer requests for this feature. Customers may be reluctant to embrace such technology because of the potential for damaging the furnace lining and associated safety hazards. If automated dross skimming is not performed correctly, molten metal could become superheated and/or water could be trapped by molten metal and cause a furnace explosion. Given the potential safety issues, furnace manufacturers suggest, employers are reluctant to automate the dross removal process (Pillar Induction Company, 2005). However, at least one manufacturer does offer equipment to partially automate the dross skimming task. The substantial expense associated with automation is offset where the foundry can use the same piece of equipment for several furnaces of similar size (ABB, 2005). By completely eliminating both manual dross barrel changing and manual dross skimming as a source of furnace operator exposure, OSHA estimates that furnace operators could achieve exposure levels of 0.1 or less μg/m^3 with this practice since the majority of exposures for these workers occur during this activity; however, at present it is not clear that the safety risks of automated dross skimming justify the health risks, and other control methods may prove more feasible to reduce the health risks of beryllium exposures. OSHA could not obtain exposure information for this combination of processes because these methods are not currently in use.

Prevention of Dross Formation
Another option for reducing (but not eliminating) manual dross skimming involves minimizing dross formation. Dross is formed by impurities in the metals melted in the furnace and by oxygen coming into contact with the hot metal surface. Increasing the cleanliness of the molten metal helps minimize dross formation.

Another means of reducing dross/oxide formation is using a vacuum environment or an inert gas at the melt surface. Inert gas prevents beryllium metal in the molten alloy from contacting oxygen in air and forming oxide. An inert atmosphere is achieved either by using an evacuated chamber with oxygen sucked out, creating a vacuum, or creating a chamber or blanket of an inert gas, such as argon or nitrogen, which displaces air at the molten metal surface. The oxygen level

[162] An alternate, less cautious interpretation, involves averaging the midpoints of the three ranges. This method suggests that enhanced work practices might reduce exposures by approximately 71 percent. The midpoint of 20 percent and 50 percent is 35 percent, the midpoint of 78 percent and 95 percent is 86.5 percent, and the midpoint of 85 percent and 99 percent is 92 percent. The average of the three midpoints 35, 86.5, and 92 is 71 percent.

can be reduced from the usual 21 percent in air to 1 percent in the inert gas, reducing employee exposures (Beryllium Casting Facility A, 2005; Air Products, 2005).

Several foundry operations have attempted to use an inert gas layer at the surface of the molten metal. The advantages of this technology are great: by reducing dross production by 50 percent (or more for metals that are strongly attracted to oxygen), foundries can reduce the amount of time workers spend removing dross (Beryllium Casting Facility A, 2005; Air Products, 2005). Use of the oxygen-displacing blankets also results in a more pure metal for casting (Beryllium Casting Facility A, 2005; Air Products, 2005).

Other attempts at inert gas layering have had mixed success and have not yet resulted in a marked decrease in employee exposure levels. In principle, this method could reduce beryllium exposure levels for the furnace operator and others who work in the area (e.g., material handlers, maintenance workers—including those repairing refractory linings that become contaminated with dross residue). In practice, inert blanketing presents a challenge due to the extensive LEV system requirements associated with beryllium melting and casting operations. For example, the more exhaust air moved through a LEV hood the more inert gas is needed to provide adequate surface protection. Facilities that use this method may need to spend time modifying the ventilation system and balancing exhaust rate/exhaust point to minimize exposure while minimizing disruption of the inert gas layer (Corbett, 2004). Even with oxygen displacement technologies, fumes continue to be generated at a rate dependent on the physical properties of the metal and the temperature (Air Products, 2005).

Industrial gas supply companies offer services that help foundries achieve the optimal equipment configuration for excluding oxygen while conserving inert gas supplies (Air Products, 2005). Currently, however, these services do not evaluate employee exposure in determining whether a design is satisfactory.

Local Exhaust Ventilation for Furnace Charge Loading and Charge Bucket Heating
Furnace charge loading and charge bucket heating can contribute to furnace operator exposures to metal dusts, including those that contain beryllium (CCMA, 2000). Furnace operators may need to conduct both processes under LEV. Although not widely used, such systems have been in limited use for many years. A gray iron foundry visited by NIOSH in 1978 used a 10,000 cfm exhaust system to provide LEV first at the point where the charge bucket was filled, and later at the charge pre-heater hood. Dampers were used to divert the entire air flow to the first hood used in this sequential process, and then to the second hood (NIOSH 79-114, 1978). Much of the process was automated at this foundry, but the principles of ventilating the bucket loading and heating steps hold for all methods. In OSHA’s professional judgment a downdraft table or backdraft plenum hood at the charge bucket filling station could substantially reduce furnace operator exposure levels. Charge bucket pre-heaters, fitted with exhaust ventilation in the form of caps covering the bucket mouths and each connected to an exhaust duct, were installed at an iron and aluminum casting foundry visited by CCMA (2000). As mentioned previously in the discussion of material handlers, CCMA also visited a gray iron foundry that used an enclosed charge feed conveyer to transfer the charge to the furnace. In Figure VS-50-21, ACGIH recommends an airflow rate of 250 cfm per square foot of open area on the hood when covered conveyers carry toxic materials (such as beryllium) (see VS-50-21, in ACGIH, 2010).

Disciplined Housekeeping

In addition to engineering and work practice improvements, diligent and frequent housekeeping is important in furnace areas and all other areas of the facility. Enhanced housekeeping would be helpful for reducing exposures at most facilities and must be a component of any overall exposure control plan. The primary beryllium producer in the United States reports that good housekeeping is an essential component of its beryllium Worker Protection Model (Materion Interactive Guide, 2012). Incremental housekeeping is likely to reduce exposures in facilities where they remain elevated.

Although beryllium exposure reductions specifically associated with enhanced housekeeping practices in foundries are not available, information on other common foundry dusts demonstrates the point. An OSHA inspection report describes crystalline silica and respirable dust reductions in a ferrous sand casting foundry after the facility vacuumed and washed walls and dust accumulation points in the casting cleaning department (OSHA SEP Inspection Report 303207518). Initially, general area samples indicated that the background respirable silica level in the casting cleaning department was 63 $\mu g/m^3$. After the foundry-wide cleaning, no respirable silica was detected in the casting cleaning department air (estimated as less than 12 $\mu g/m^3$ or an exposure reduction of at least 81 percent). Additionally, total respirable (which contains respirable silica and other particles) dust levels were 60 percent to 80 percent lower than the original level of 1.4 mg/m^3.

This example demonstrates the extent to which worker exposures can be influenced by accumulated dust from poor housekeeping practices and suggests that significant improvements in the level of housekeeping through more effective and/or more frequent cleaning might result in similar exposure reductions for beryllium. Although this example is not specific to beryllium dust, it does pertain to another toxic air contaminant associated with foundry dust and represents the best available information on the benefits of good housekeeping. Using the findings from the foundry cleaning example, OSHA estimates that exposures might be reduced on average as much as 70 percent (60 percent to 80 percent). If housekeeping and inconsistent work practices both contributed to worker exposures at the foundry described at the beginning of this section on additional controls for furnace operators, those furnace operator exposures might be reduced to 0.099 mg/m^3 by implementing improved work practices and disciplined housekeeping.[163] Well defined housekeeping programs that are closely followed and performed each shift should reduce exposures in any facility.

Furnace Operator—Conclusion

OSHA preliminarily concludes that exposure levels of 0.5 $\mu g/m^3$ or less have been achieved for 27 percent of furnace operators in the aluminum and copper foundry industry, and based on current results for a well-controlled foundry (NIOSH EPHB 326-16a), OSHA preliminarily concludes that exposure levels of 0.5 $\mu g/m^3$ or less can be achieved for most furnace operators most of the time by installing LEV on the dross receptacle; improving LEV on furnaces; and using HEPA filter vacuuming or otherwise cleaning clothing when exiting the furnace area. For

[163] The value of 0.099 $\mu g/m^3$ for furnace operators who originally had exposure levels in the range of 0.5 $\mu g/m^3$ is derived as follows: Improving work practices reduces exposures by 35 percent from 0.5 $\mu g/m^3$ to 0.33 $\mu g/m^3$. Improved housekeeping further reduces exposures by 70 percent from 0.33 $\mu g/m^3$ to 0.099 $\mu g/m^3$.

all foundry employers to achieve an exposure level of 0.5 μg/m^3, all components of this strategy must be used together.

In most facilities where either work practices or housekeeping (or both) have room for improvement, the exposure levels of most furnace operators can be further reduced to at least the 0.5 μg/m^3 level at the well-controlled foundry. As discussed in the section on additional controls for furnace operators, enhanced work practices could result in a 35 percent decrease in exposure, to 0.33 μg/m^3 (Kent, 2005). Furthermore, because even a modest amount of disturbed dust can be a significant source of exposure relative to the proposed PEL of 0.2 μg/m^3, OSHA preliminarily concludes that most furnace operators could experience measurably lower exposure levels through disciplined housekeeping. This has been shown to be true for two other foundry dusts (airborne crystalline silica and respirable dust), which were reduced by an average of 70 percent and 81 percent, respectively, through rigorous housekeeping in a foundry visited by OSHA (OSHA SEP Inspection Report 303207518). OSHA acknowledges that the effect of improved housekeeping can vary depending on the current quality of housekeeping in a facility. However, even if beryllium exposures were reduced by just half this amount (35 percent) through disciplined housekeeping, in addition to the 35 percent related to enhanced work practices, the exposure levels of most furnace operators (for example the 63 percent whose current exposure levels are already 2 μg/m^3 or less), could be reduced to 0.23 μg/m^3 or less. With improved housekeeping, many furnace operators who currently have exposure levels below 1.0 μg/m^3 could have exposures reduced to below the proposed PEL of 0.2 μg/m^3.

To reliably reduce most furnace operator exposure levels to the proposed PEL (0.2 μg/m^3) or less, additional exposure controls such as fully enclosed furnace hoods, the control or elimination of manual dross skimming and exposure control for fumes from adjacent pouring processes may be necessary. Specific information is not available on the extent of exposure reduction from these controls. However, Materion Corporation and other sources repeatedly describe dross removal and handling, and fumes from the furnace as major sources of exposure for this job category (Materion Information Meeting, 2012; Be Casting Facility A, 2005; Corbett, 2005; CCMA, 2000).

To the extent that manual dross skimming and open dross barrel handling can be eliminated from foundry operations, OSHA estimates that the exposure level of nearly all furnace operators would be reduced to 0.2 μg/m^3 or less. However, OSHA recognizes that with current technology it is unclear whether automated dross-skimming equipment can be effective. If such equipment were to frequently damage the refractory lining, the frequency of complete replacement would increase, thus increasing the furnace downtime (a few days up to a week per replacement cycle) and the extent to which workers are potentially exposed to crystalline silica—a hazard workers encounter while both removing and replacing refractory furnace liners.

Although a number of additional controls are available to furnace operators, and each could reduce one source of beryllium exposure by some percent, OSHA judges that even when all methods are combined, it may not be possible for most furnace operators to achieve levels of 0.2 μg/m^3. Additionally, based on the available information presented in this section, OSHA preliminarily concludes that an alternative PEL of 0.1 μg/m^3 is unlikely to be achieved reliably for workers in this job category. In foundries where the exposures of furnace operators cannot feasibly be reduced to the proposed PEL, respiratory protection with a maximum use concentration (MUC) of at least 10 (e.g., a minimum of an elastomeric half-mask respirator with P-100 filters) and PPE in the form of gloves and freshly laundered work clothes or Tyvek suits must be used.

Pouring Operator

Pouring Operator—Baseline Controls

The median exposure level for pouring operators is 1.4 μg/m^3. This value is based on five exposure results from two foundries. The evidence presented in the available literature suggests that baseline controls for pouring operators include mobile ladle or crucible hoods and some form of ventilation on pouring lines (CCMA, 2000; ERG Silica_GenInd1v.2, 2008; NIOSH EPHB 326-11a; NIOSH EPHB 326-16a; Corbett, 2005). Due to the greater toxicity of the alloy components in non-ferrous casting facilities, pouring area ventilation in these foundries is typically designed to provide better exposure control than the pouring area ventilation systems in ferrous casting facilities. For example, CCMA reported that four of the non-ferrous casting foundries it visited contained some form of LEV in the pouring area, as did the ERG and NIOSH foundry site visits (CCMA, 2000; ERG Silica_GenInd1v.2, 2008; NIOSH EPHB 326-11a; NIOSH EPHB 326-16a; Corbett, 2005). Although two of these systems were described as "state-of-the-art," none functioned optimally due to work practice problems, inadequate exhaust rates, cross-currents and lack of makeup air, or system design.

Pouring Operator—Additional Controls

Foundry experts agree that LEV is the primary control measure for pouring operations involving toxic metals, including beryllium and lead (Corbett, 2005; CCMA, 2000). Ventilation systems are common in foundries that cast beryllium alloys both to reduce worker exposure levels and because the U.S. EPA's Clean Air Act lists beryllium as a hazardous air pollutant and restricts most releases of beryllium fumes into the atmosphere.

A number of ventilation system designs for pouring operator tasks are available in the AFS *Foundry Ventilation Manual*, the ACGIH Industrial Ventilation Manual for Design, and a report by CCMA (AFS, 1985, CCMA, 2000 and VS-55-21 and VS-65-01in ACGIH, 2010). These documents describe special mobile ventilation hoods that pouring operators can attach to ladles or crucibles. The hoods connect to flexible ducts extending from overhead trunks (ACGIH Group 13.65, 2010). When the ladle or crucible is transported by crane, the duct moves with the crane to remove fumes during transport and pouring. Similar designs are available for ladles pushed on wheeled carts or on tracks. When appropriately designed, ventilated, and fitted to the ladle or crucible, these hoods continuously exhaust the ladle or crucible as it carries metal from the furnace to the molds. With their enclosing design, they can collect virtually all fumes and other contaminants rising from molten metal in the ladle or crucible.

The data sources, described in this report (see Data Sources subsection in the Aluminum and Copper Foundries section) indicate that those beryllium results included in the exposure profile for pouring operators exceeding the proposed PEL of 0.20 μg/m^3 are associated with either a ventilation system that is not state-of-the-art, or one that could designed to be state-of-the-art but is not operated efficiently. The decrease in efficiency might be due to inadequate exhaust rates and/or work practices (such as speed of ladle movement).

For example, two of the three elevated full-shift PBZ samples for pouring operators in the exposure profile had results of 1.40 μg/m^3 and 2.04 μg/m^3 (NIOSH EPHB 326-11a). At this facility, the pouring stations in both foundry areas (green sand and permanent mold casting) were equipped with LEV hoods, and the crucible transfer mechanism in the green sand foundry was ventilated. However, NIOSH reported that the existing ventilation systems were inadequate or used improperly. NIOSH found that pouring operators in the permanent mold casting area placed a cover over the mold and ventilation duct, which reduced air flow and capture of process emissions. The facility subsequently conducted a comprehensive upgrade of the entire ventilation system in the foundry areas (no exposure data from after the upgrade are available).

At another beryllium alloy foundry (NIOSH EPHB 326-16a) with well-controlled conditions and effective engineering controls, exposures are significantly lower, despite the higher beryllium content (2.5 percent, the upper end of the range used by foundries). Twelve PBZ samples collected in the facility's green sand foundry ranged from 0.03 μg/m^3 (the sampling limit of detection) to 0.58 μg/m^3, with a mean of 0.17 μg/m^3 and a median of 0.11 μg/m^3. These results reflected all major foundry jobs including pouring operators. Although the specific values for pouring operators were not identified, the source document indicated that the highest result (0.58 μg/m^3) was obtained on the green sand foundry supervisor. In this facility's ingot foundry, NIOSH investigators collected 5 PBZ samples that ranged from 0.03 μg/m^{3}to 0.55 μg/m^3. The two highest results (0.21 μg/m^3 and 0.55 μg/m^3) were obtained on furnace operators that performed both melting and casting, suggesting that casting exposures alone would be less.[164]

Thus, based on the available information, OSHA finds that where pouring operators frequently experience exposure levels exceeding 0.2 μg/m^3, foundries can reduce exposures to that level by installing well-designed ventilation systems in the pouring area and ensuring that exhaust rates are adequate to capture contaminants released by pouring area processes. This assumes that exposure levels associated with other job categories in the foundry are similarly controlled and that the foundry ventilation system is balanced to minimize cross-contamination if a release occurs in another area.

Another option for controlling pouring operator exposures would be to augment these controls with ventilated ladle heaters, as recommended by CCMA (2000). A ladle heater can further reduce pouring operators' exposure levels by eliminating the fumes created when workers inadvertently apply heat inconsistently to the ladle using a torch, overheating residual alloy.

Improved work practices and increased ventilation system maintenance are also options to help reduce the exposure level of this group. As discussed above for furnace operators, improvements in work practices might reduce exposures by approximately 35 percent (Kent, 2005).

Pouring Operator—Conclusion

Based on the limited data described by the exposure profile in Tables IV-29 and IV-30, pouring operators have a median exposure level of 1.4 μg/m^3, and exposure levels of 0.2 μg/m^3 or less have already been achieved for 40 percent of the workers in this job category, largely through the use of exhaust ventilation. Exposures tend to be notably higher when ventilation systems do not

[164] The furnace operator tasks associated with managing dross are among the activities that generate the highest and most frequent potential beryllium exposures in foundries (Corbett, 2004).

work as intended. In fact, two of the three pouring operator sample results that exceed 0.2 μg/m^3 in the industry profile (those with results of 1.4 μg/m^3 and 2.04 μg/m^3) are associated with a pouring process with an ineffective ventilation system (NIOSH EPHB 326-11a).

OSHA preliminarily concludes that the exposure levels of most of the remaining 60 percent of the pouring operators (those whose exposures currently exceed 0.2 μg/m^3) can be reduced to a level of 0.2 μg/m^3 or less most of the time by improving existing ventilation systems or installing new exhaust ventilation systems that effectively capture fumes. OSHA based its conclusion upon the following four considerations: 1) the evidence in the previous paragraph that elevated beryllium exposures can be directly attributed to ineffective ventilation systems, 2) the extent to which foundry pouring operation ventilation system designs (some completely enclosed) are readily available through ACGIH (2010), 3) the evidence in Tables IV-29 and IV-30 (exposure profile) that 40 percent of pouring operators already have exposures at or below 0.2 μg/m^3, and 4) as discussed in the pouring operator exposure profile section, the exposure profile might overestimate the actual exposure of pouring operators.[165] This conclusion assumes that exposure levels associated with other job categories in the foundry are controlled to a similar extent and that the foundry ventilation system is balanced to minimize cross-contamination if a release occurs in another area or during another activity (particularly during adjacent furnace operations, shakeout activities, and permanent mold preparation work performed by molders in the pouring area). However, if adjacent operations are not controlled to this same level (e.g., for an interim period while furnace operator exposures are at 0.5 μg/m^3), pouring operators might experience exposures approaching 0.5 μg/m^3 as well, and so will require respiratory protection (offering an MUC of at least 10) and protective gloves and clothing.[166] Based on available information, OSHA believes that achieving an alternative PEL of 0.1 μg/m^3 for this job category most of the time with the use of engineering and work practice controls is challenging. Therefore, the Agency requests additional information (including exposure data and information on the effectiveness of controls) to make a determination about the feasibility of an alternative PEL of 0.1 μg/m^3.

Shakeout Operator

Shakeout Operator—Baseline Controls

The exposure profile presented in Tables IV-29 and IV-30 for shakeout operators is based on a single full-shift PBZ result of 1.3 μg/m^3. Data from IMIS suggest the exposures of shakeout operators occur over a wider range, generally well below this sample result, which might overestimate exposure for this group of workers (OSHA, 2009). Little information is available to describe the working conditions of shakeout operators in foundries that cast beryllium alloys; however, there is clear evidence that these foundries do use sand-casting methods or sand cores that require a shakeout process (Corbett, 2004; NIOSH EPHB 326-11a; NIOSH EPHB 326-16a).[167]

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[165] Among the 45 positive IMIS results for pouring operators in 17 foundries, the median exposure level is 0.13 μg/m^3, with 62 percent of these samples 0.2 μg/m^3 or less (OSHA, 2009).
[166] An elastomeric half-mask respirator fitted with P-100 filters will provide an MUC of 10.
[167] The foundry that ERG visited did not use a shakeout process (ERG Beryllium Site 7, 2003). Rather, the direct-chill mold casting passed directly to the finishing area on a conveyer fitted with exhaust ventilation.

According to the *AFS Foundry Ventilation Manual* (AFS, 1985), the shakeout operation is typically one of the dirtiest operations in foundries. Beryllium exposures result when dust is released as hot, dry sand molds are dumped, agitated, and broken to release castings. Through contact with molten metal, the sand can become contaminated with alloy fragments and oxides of beryllium. Shakeout area dust can also contain other hazards, such as crystalline silica if the mold or core sands are silica-based sands, and metals from other alloys cast at the facility (e.g., lead). Shakeout conditions can vary dramatically, from manually dumping molds (by hand or using powered material handling equipment) to fully automated systems. A common feature is a vibrating grate that will “shake out” the sand from castings and convey it to another part of the foundry for reuse in molding. The vibrating shakeout equipment typically generates substantial airborne dust.

During investigations of one of the two beryllium alloy foundries with green sand casting operations from which OSHA has incorporated data into the exposure profile (see Data Sources, within this Aluminum and Copper Foundries section), NIOSH reported on the LEV controls for the melting and casting operations (NIOSH 326-11a, 2008). Although NIOSH did not describe any LEV specifically associated with the shakeout operations, the report states that “... in-wall fans, primarily in the shake-out area, were operating to induce general air flow through the plant, but typical of this type of fan air flow dropped to less than 50 feet per minute (fpm) at distances of 15 to 20 feet from the fan” (NIOSH 326-11a, 2008). Since other foundry ventilation systems were described in at least as much detail, this description of only in-wall fans for this area implies that additional LEV was not associated with shakeout equipment at this facility. However, this facility is unusual in that most foundries shakeout areas *are* equipped with some LEV: ERG’s analysis of crystalline silica exposure in other types of foundries (e.g., ferrous sand-casting foundries) found that the majority of foundries, including copper and aluminum alloy foundries, have installed some form of LEV in the shakeout area, although the ventilation might not be functioning optimally (ERG Silica_GenInd1v.2, 2008). Thus, OSHA concludes that the baseline condition in beryllium alloy casting foundries typically involves a shakeout operator positioning castings on ventilated equipment that may not function optimally for dust control. Additionally, OSHA notes that some foundries have installed enclosures around the shakeout operation.

The exposure profile sample result was obtained at a facility in which the shakeout equipment was not equipped with even the baseline ventilation equipment, which further supports OSHA’s earlier note that the industry single-sample profile likely overestimates the beryllium exposure level for most shakeout operators working under typical conditions in foundries casting beryllium alloys (NIOSH 326-11a, 2008).

Shakeout Operator—Additional Controls

Based on the exposure profile, all shakeout operators will require additional controls to reduce their exposures. At the beryllium alloy foundry where the single result (1.3 $\mu g/m^3$) in the exposure profile was obtained, NIOSH investigators reported that LEV systems within the facility were inadequate or not being used correctly and that general exhaust ventilation appeared non-uniform (NIOSH EPHB 326-11a). Additionally, the shakeout room appeared to have inadequate general dilution ventilation.

NIOSH also visited a second similar foundry and found that operations were better controlled there than at the first foundry. In the better controlled foundry, LEV systems were in place to remove fumes and dust associated with the furnaces, crucible transport, pouring activities, and the dross barrels. In addition, the foundry designated beryllium work areas with controlled access, PPE requirements, and processes in place to minimize beryllium migration to other facility areas. Housekeeping practices include the use of HEPA vacuums, and workers are responsible for cleaning and maintaining their work areas during the day and at the end of their work shift. Although NIOSH indicated that the shakeout operation at the second foundry was monitored for beryllium exposure, the report does not identify the specific PBZ results associated with this activity. However, the 12 full-shift PBZ samples obtained in this green sand foundry had results ranging from 0.03 µg/m^3 (sampling limit of detection) to 0.42 µg/m^3 for foundry workers, plus a value of 0.58 µg/m^3 for the foundry supervisor (NIOSH EPHB 326-16a). Although OSHA cannot be certain which of the results reflect shakeout activities, it likely was not the foundry supervisor, suggesting that the shakeout operator experienced an exposure level no greater than 0.42 µg/m^3 and possibly less. This point suggests that a level of 0.42 µg/m^3 or less can be achieved for shakeout operators in foundries casting beryllium alloys with the controls described in this paragraph.

In some foundries, beryllium exposure for shakeout operators could be nearly eliminated by reducing the need for the dusty, high-energy shakeout process. This would involve switching to sand-free cores and non-sand-casting methods, particularly methods that reduce surface beryllium oxide formation (die casting, direct chill casting, and rapid temperature-controlled cooling methods for castings) (Schleg and Kanicki, 2000). Use of foam or other expendable material for cores (rather than sand) is increasingly popular among foundries. Die casting is also feasible for many beryllium alloys; for example, two plants visited by NIOSH used both green sand and die casting methods for beryllium alloys (NIOSH EPHB 326-11a; NIOSH EPHB 326-16a). However, OSHA acknowledges that most casting processes are not interchangeable, so this control option is not available to all foundries with shakeout operations.

When sand is used in the casting process, beryllium exposure levels can be controlled if the sand is collected and processed under enclosed and ventilated conditions. ERG's analysis of crystalline silica in foundries showed that there are several opportunities to reduce the dust exposure of shakeout operators by installing or upgrading ventilation (ERG Silica_GenInd1v.2, 2008). Foundries that currently use enclosed equipment to separate sand from castings can reduce shakeout operator exposures by improving the enclosures, fixing leaks, and ensuring ventilation provides at least 200 fpm air velocity across all openings (AFS, 1985; and Group 13.20 in ACGIH, 2010). Foundries can further minimize shakeout operators' exposure to beryllium released from other processes by ensuring that LEV systems are coordinated with general ventilation, thus preventing the flow of contaminated air between the furnace, pouring and shakeout areas. To achieve the lowest exposure levels, shakeout operations should be automated and fully enclosed, where feasible.

Based on the tendency of dusts with aerodynamic properties to be similarly affected by local exhaust ventilation, and the tendency of the larger particles to settle out of the air more quickly compared to smaller respirable-size particles, OSHA has determined that dusts containing beryllium will be controlled to an equivalent extent by the methods used to control respirable silica dusts in foundries. When contaminated sand is the source of beryllium exposure, a corresponding reduction in beryllium levels might also be assumed for this control method. The tendencies of these dusts to behave similarly is further discussed in Section 2—Methodology, of Chapter IV (Technological Feasibility) in this Preliminary Economic Analysis (PEA).

Shakeout enclosures are available as standard equipment or may be constructed by the foundry. The ACGIH Industrial Ventilation Manual for Design (see Group 13.20 in ACGIH, 2010) provides four ventilation designs for open and enclosed styles of shakeout equipment. As an option on all their machines, at least one shakeout equipment manufacturer offers standard covers specifically to help control dust. This company sells shakeout equipment to handle molds of various sizes, including those for large castings that can be awkward to handle (Kinergy, 2000).[168] Although the benefits of enclosure have not been specifically quantified for this task, process enclosure (with an effective level of suction through any openings and an appropriate air cleaning device to capture the dust) is a proven technique for managing dusts of all types in any settings where the process can be enclosed (see details for enclosing hoods in Sections 6.2 and 6.3 of ACGIH, 2010).

Although data are not available to quantify the benefit for reducing beryllium exposure levels, OSHA did quantify the benefit of a flexible foundry-made shakeout enclosure for reducing crystalline silica results. A “pickoff” worker who removed castings from a vibrating conveyor in the shakeout area had full-shift TWA respirable quartz exposure levels of 95 $\mu g/m^3$ in 1997 and 126 $\mu g/m^3$ in 1998. Following the installation of a flexible fireproof curtain adjacent to the mold dump area to direct the dust to the ceiling-mounted exhaust ducts, as well as installation of equipment to remove more sand from the casting prior to its arrival at the pickoff area, the worker’s respirable quartz exposure was reduced to 74 $\mu g/m^3$ (a 33 percent reduction below the mean of the prior results) in 1999 (OSHA SEP Inspection Report 300530029). Because this reduction was obtained using a rudimentary enclosure adapted to existing ventilation equipment, results could be markedly improved by designing purpose-built enclosures and ventilation specific to the setting.[169]

Rotary sand/castings separators or rotary media drums are an alternative to vibrating shakeout equipment for many small to medium-size casting applications, including much production using beryllium alloys (South Cast Equipment, 2000; Didion, 2003). For example, sand casting systems (particularly flaskless casting systems) often include a rotary media drum to separate sand and clean the casting as the next step after pouring and cooling. This equipment tumbles the casting along with shaped “media” (e.g., 1-inch to 2-inch metal stars, or other media appropriate for use with the casting metal) that remove and separate sand from both castings and scrap. Only sand in small internal spaces of the casting is not completely removed. Although the effectiveness of this equipment for reducing worker exposure has not been quantified, the double concentric barrel design (an inner perforated barrel rotating within an outer ventilated barrel) is reportedly “significantly less dusty than a vibratory shakeout” (South Cast Equipment, 2000). At the same time, castings are cleaner and require less shot blasting time and less labor during subsequent phases of casting production according to one manufacturer (Didion, 2003).

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[168] For example, the Kinergy company advertises shakeout equipment to handle molds for castings ranging from “0 to 40 tons” (Kinergy, 2000).

[169] NIOSH also supports the use of ventilated enclosures. At one foundry with a dusty shakeout process, NIOSH recommended that the shaker table be enclosed on three sides and ventilated, and that molds be dropped onto the semi-enclosed shaker table rather than directly onto the floor (NIOSH HETA 92-044-2265).

"Four-in-one" shot blast machines are another alternative to the vibratory shakeout process for small and medium-size castings (O'Brien, 2000). This enclosed, ventilated equipment serves multiple functions including separating casting from sand, blasting off sticking sand, and sifting sand for reuse. Again, the effectiveness of this equipment has not been quantified. However, NIOSH noted that locating multiple automated processes in one continuous enclosure may reduce the chance of worker exposure during manual handling or from dust escaping at transfer points (O'Brien, 2000).

A combination of methods offers the most effective control option. Respirable silica dust was dramatically reduced by enclosing and ventilating the sand handling and mold dumping areas, and a rotary media tumbler at a foundry evaluated by OSHA (Irwin, 2003). As a result, shakeout operator silica exposure levels were substantially reduced. At this facility, shakeout operators dumped molds onto a shaker conveyer, operated a rotary media drum that removed additional sand from the casting, and then hung the castings on an overhead conveyer. Initially, this process was associated with an operator total dust (respirable fraction) exposure level of 2,930 µg/m^3. The employer then "designed and built an enclosure that ran the length of the shakeout conveyer from the mold dump position to the [media tumbler]" and also increased exhaust ventilation to the area (Irwin, 2003). Once these changes were in place and the facility had been vacuumed and power washed, shakeout operator silica exposure levels decreased to a post-abatement level of 550 µg/m^3 of total dust (respirable fraction) (Irwin, 2003). This represents an 81 percent reduction in dust exposure. Considering that any beryllium dust contaminating the dust would be contained and captured to an equal extent, then the enclosure, ventilation system, media tumbler, and housekeeping measures would also reduce the beryllium exposure level of the shakeout operator by a comparable 81 percent. An 81 percent reduction in the exposure profile exposure level of 1.3 µg/m^3 would result in shakeout operator exposures of 0.25 µg/m^3, while the same 81 percent reduction in the maximum exposure level for a group of workers including a shakeout operator evaluated by NIOSH (0.42 µg/m^3) would result in an exposure level of 0.08 µg/m^3.

Computer modeling suggests that similar results might be obtained using custom-designed local exhaust ventilation, even for very large castings that can be less compatible with automated systems. A NIOSH study used computer modeling to test 18 different combinations of ventilation system modifications that might be used to improve dust control at the shakeout stations of a gray iron foundry producing bathtubs using large castings (NIOSH EPHB 233-133c). The model predicted how effectively each design would reduce the concentration of airborne respirable dust and also considered energy usage factors. The simulation design results suggested the following:

- Side barriers and fresh air supplied from the side were effective for limiting the spread of dust and for providing clean air to the workers.
- The addition of floor exhaust (suction) near the shakeout table would effectively capture dust.
- The existing overhead exhaust ducts acted as a ceiling that helped direct and improve the effectiveness of the fresh air supply jet.

- The overhead exhaust in use at this foundry did not offer a clear benefit to worker exposure.

Furthermore, the results suggested several ventilation system designs that might reduce respirable dust by a substantial amount based on the points noted above. The computer model predicted the five best designs that might reduce exposure by 98 percent or more compared to a process with no ventilation. The model also predicted that these designs would reduce exposures more than 86 percent over the existing ineffective ventilation system (if the existing system were operated at twice the actual air exhaust rate). As an added benefit, this computer model also helped engineers evaluate the best-performing proposed designs to determine which offered beneficial exposure reduction for the least amount of air exhausted. Recognizing that the prediction of 98 percent reduction might not be achieved under real-world conditions, OSHA preliminarily concludes that large reductions are possible with appropriately designed ventilation systems, but that more realistic values might be somewhat lower than those reported. For example, OSHA estimates that a more realistic exposure reduction might be derived by rounding down by approximately 10 percent, from an exposure reduction of 98 percent to 90 percent (compared to no ventilation), or from 86 percent to 75 percent reduction (compared to the existing ineffective overhead ventilation system). This NIOSH report shows that even relatively modern, or recently renovated exhaust ventilation systems do not necessarily perform effectively; however, opportunities for substantial improvement are available to facilities that consider a full range of realistic design options.

Where exposures remain elevated, increasing the air flow rate through openings in the ventilated enclosures from 250 fpm to 400 fpm will offer an additional benefit. Even partially ventilated enclosures with ventilation of 400 fpm routinely reduce exposure levels to 0.2 μg/m^3 or less for workers using a wide range of equipment in various industries (Materion Corp-meeting, 2012). Other ventilation-related changes are also options for reducing shakeout operator exposures under special circumstances. A foundry visited by NIOSH found that reducing cross-currents caused by man-cooling fans and using a foundry ventilation system as designed reduced the dust exposure levels of shakeout operators by 50 percent. Computer models predicted that a substantial additional reduction (over 75 percent) could be achieved by renovating the existing shakeout area ventilation system in a foundry producing very large castings (NIOSH EPHB 233-133c).

Shakeout Operator—Conclusion

The exposure profile for shake out operators contains only one sample of 1.3 μg/m^3, which indicates that shakeout operators will require additional controls. NIOSH reported measuring a maximum concentration of 0.42 μg/m^3 for a group of workers that included a shakeout operator, however, the sample directly associated with the shakeout operator was not identified (NIOSH EPHB 326-16a). Additionally, the six samples in the IMIS data from two different foundries range from 0.05 μg/m^3 to 0.5 μg/m^3, with a mean of 0.22 μg/m^3 and a median of 0.11 μg/m^3. The result of 0.42 μg/m^3 reported by NIOSH is consistent with the IMIS sample results for shakeout operators, and therefore more likely to be representative for this job category.[170]

[170] An exposure of 0.42 μg/m^3 can be considered more typical of this job category because it is within the range of IMIS sample results for shakeout operators , for which the maximum level is 0.5 μg/m^3 (the median for IMIS data for this job category is 0.11 μg/m^3).

Recommendations for control measures provided in the NIOSH report suggest that the exposure level of shakeout operators can be held to a level of 0.42 μg/m^3 or less by rudimentary improvements in the function and maintenance of existing shakeout area ventilation (NIOSH EPHB 326-11a). When comparing this value of 0.42 μg/m^3 obtained by NIOSH in a facility with rudimentary controls to the baseline value of 1.3 μg/m^3, OHSA notes that exposures for shakeout operators can be significantly reduced when compared to the exposure associated with baseline conditions (ERG Silica_GenInd1v.2, 2008).

Irwin (2003) reported that enclosure, significant ventilation system improvements, addition of a media tumbler, and housekeeping measures reduced the respirable dust exposure levels of a shakeout operator by 81 percent. If beryllium contained in the dust is captured to an equal extent, then additional controls to reduce dust levels in the shakeout operation could reduce the beryllium levels for the most highly exposed shakeout operators by as much as 80 percent. A reduction of 80% to the industry profile value of 1.3 μg/m^3 would result in a value of 0.25 μg/m^3, and the estimate from the supplemental data of 0.42 μg/m^3 would be reduced to 0.08 μg/m^3.

OSHA preliminarily concludes that the proposed PEL of 0.2 μg/m^3 can be achieved for some shakeout operators, but additional information on the range of current exposures and the effectiveness of existing dust controls for shakeout operations is needed to determine whether the proposed PEL can be achieved in most operations most of the time.

Abrasive Blasting Operator

Abrasive Blasting Operator—Baseline Controls

The exposure profile for abrasive blasting operators is based on five PBZ results for workers abrasively blasting on foundry castings during repair work performed on the castings (at a facility that routinely refurbished the cast shapes). The exposure levels measured range from 0.05 μg/m^3 to 0.15 μg/m^3. Although the employees associated with the results in the exposure profile used enclosed and ventilated equipment that was only minimally automated (the employees had to transfer abrasive media back into the system hopper manually after use), abrasive blasting operators in foundries typically use enclosed and ventilated blasting units or other surface preparation machines that are partially or fully automated, which could potentially result in lower exposures than those summarized in the exposure profile if the abrasive blasting equipment is well maintained. However, ERG's analysis of crystalline silica in foundries suggested that blasting machines are typically poorly maintained, incompletely sealed, and associated with inefficient ventilation systems (ERG Silica_GenInd1v.2, 2008). And as described above for molders, cross-contamination can be an additional source of exposure. Abrasive blasting operations are often located near the pouring and shakeout areas. Air contaminants in any adjacent areas (whether originating in or migrating through the spaces) can also spread through the abrasive blasting operator work area, contributing to the exposure of workers in this job category.

Abrasive Blasting Operator—Additional Controls

The somewhat limited exposure profile (five values from one facility with a median of 0.11 μg/m^3) indicates that abrasive blasting operators are typically exposed to levels below 0.2 μg/m^3.

Additional data from IMIS suggest that sample results exceed 0.1 by a modest amount (e.g., two of three positive IMIS results were 0.101 μg/m^3). Cross-contamination between foundry areas can contribute to workers' exposure levels. Elimination of cross-contamination (by balancing all supply and exhaust air systems) should also reduce airborne contamination from other foundry areas as a source of beryllium exposure for workers in the abrasive blasting area, allowing these workers to achieve exposure results of 0.1 μg/m^3 or less.

Although they do not appear to be necessary in most foundries that cast beryllium alloys, a number of additional control methods are available for abrasive blasting operators.

Improve Existing Blasting and Surface Preparation Machines
A primary control for abrasive blasting operators involves repairing or improving the machines that they control to seal leaks, and augmenting ventilation systems to achieve 500 fpm air flow through all openings (see VS-80-02 in ACGIH, 2010; Pangborn, 2003).

A wide range of abrasive media are available for use in surface preparation machines. Some media can themselves be a source of additional beryllium exposure (due to their own beryllium content) or can contain other toxic substances (e.g., crystalline silica, other metals) (KTA-Tater-Phase-I, 1998). Employers must evaluate any surface preparation media prior to use and ensure workers are adequately protected from all associated hazards (OSH Act, 1970).

Sealed Blasting and Surface Preparation Machines
To minimize beryllium exposure levels, foundries can select airtight, batch-style blasting and surface preparation machines, with a door that seals closed. The modest leakage that might occur from continuous blasting machines (parts constantly conveyed in and out of the machine though openings in the machine) might prevent abrasive blasting operators from achieving the lowest levels (e.g., exposure levels less than 0.1 μg/m^3). However, a well-functioning, completely sealed blasting machine could be expected to reduce exposures to that value or lower. An important feature of a fully enclosed and ventilated blasting or other surface preparation machine (or blast cabinet) is an interlock that prevents the machine door from being opened until the ventilation system has had a chance to remove dusty air from the unit.

To achieve the lowest exposure levels, OSHA believes that it will also be necessary to control dust release during transport of castings to and away from blasting or surface preparation machines. To this end, conveyers, containers, and other equipment used to transport castings to the machines should be enclosed and any openings exhausted with LEV. After blasting with abrasive media, castings and the interior of the machine should be wiped to remove dust from surfaces (similar techniques are used to minimize dust from machining operations; see Section 3—Beryllium Production Exposure Profile and Technological Feasibility Analysis and Section 7— Precision Turned Products).

Additionally, employers should be aware that beryllium dust can become a source of beryllium exposure for abrasive blasting operators when they use a leaking blasting machine. And in addition to maintaining blasting machines so they function as intended, machines that clean the abrasive media between cycles, and operating procedures that promote the standard practice of replacing all or part of the media on a routine basis, will both help minimize the buildup of beryllium dust in the abrasive blasting media.[171]

In the series of industrial hygiene surveys during which the exposure profile data were obtained, Materion Corporation evaluated abrasive blasting of the castings in glove-box-type ventilated blasting cabinets at a facility where the castings are periodically abrasively blasted with aluminum oxide or steel shot during repair (MC Pkg I-D, 2010). Five full-shift samples for abrasive blasting operators ranged from 0.05 $\mu g/m^3$ to 0.15 $\mu g/m^3$, with no improvement (in the already modest exposure levels) recorded after the blast cabinets were centralized and ducts redesigned. After this period of system modification, the investigator reported on the characteristics for the abrasive blasting cabinets as follows:

- Average inlet area air velocity 482 fpm to 1,194 fpm.
- Five to 10 air changes per minute in the cabinet interior.
- 80 cfm to 131 cfm air flow.
- Duct transport velocity 4,000 fpm.
- Connected to a centralized dust collection system.
- Service and maintain abrasive blasting cabinets on an ongoing basis.

Additional recommendations suggested there was still some room for improvement in the system and work practices. The recommendations noted that:

- Dust should not fall from the doors when they are opened.
- Gloves of the abrasive blasting cabinets need to be replaced when they get worn, are torn, or have holes in them.
- Install interlocks to require at least air changes of the enclosed volume before the operator is permitted to open the cabinet after abrasive blasting tasks.
- Use a HEPA filter vacuum on the floor if it becomes dusty.
- Evaluate worker exposure with air sampling to confirm that the cabinet is working properly and protecting workers from excessive exposure.
- During abrasive blasting, until air monitoring confirms that the abrasive blasting cabinet controls worker exposure to the accepted level, use NIOSH-approved respiratory protection covered by a fully implemented respiratory protection program in accordance with OSHA's Respiratory Protection standard (29 CFR 1910.134).

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[171] Most steel shot, grit, and related abrasive blasting media can be air cleaned (as part of the normal function of some standard abrasive blasting machine designs) or, in some cases washed. Many mineral media types fracture with each cycle of use and are already replaced on a regular basis to maintain effective performance.

Numerous models of sealed, ventilated blast cabinets and related surface preparation machines are commercially available. One manufacturer of blast cabinets and related equipment recommends 150 cfm of air suction for a 12-inch (diameter) cylindrical tumble blast cabinet and up to 1,800 cfm air suction for a 48-inch unit (Clemco-tumble, 2007). The same manufacturer provides air suction and filtration equipment for blasting and surface preparation equipment, each fitted with primary filters and optional secondary HEPA filters (Clemco, 2011).[172] For toxic dust applications in facilities that handle beryllium, these units can be fitted with pressure and airflow sensors to confirm continuous effective function, and bag-in-bag-out systems that help protect workers changing the filters (Clemco, 2011).

Isolating Booths

Isolating booths that separate the worker from the casting are a control option for manual abrasive blasting of small and large castings. For small castings, a well-enclosed, ventilated glove-box-style blasting cabinet would serve the purpose. For long castings, available options include linking glove boxes or glove-style pressure blasting cabinets. For example, at least two manufacturers produce ventilated cabinets with internal working compartment dimensions at least 5 feet wide and 40 inches deep (Pauli RAM 31, 2001; Pauli SSPC, 2001; Clemco, 2007). These boxes can be interlocked to prevent operation unless the unit is sealed. In addition, a time delay feature can also prevent operators from opening doors for a pre-set number of seconds, until the vacuum suction has had a chance to remove dust from the cabinet interior (at a ventilation rate of 840 cfm to 900 cfm, depending on the model). Finally, the boxes can be fitted with HEPA dust collectors and completely enclosed, ventilated media reclamation systems. A larger ventilation system is needed when two or more of these double-wide cabinets are linked together to provide a larger internal workspace (Pauli SSPC, 2001).

Castings that are larger in more than one dimension would require a larger, less effective alternative. Abrasive blast booths that include an incompletely sealed partition to separate the operator from the blasting activity, such as roll-up doors with an access slot and window, will provide an additional level of protection if negative pressure is maintained in the blasting enclosure. This type of equipment is commercially available and used by two granite-working facilities in which NIOSH conducted control technology assessments (NIOSH ECTB 233-106c; NIOSH EPHB 233-131c). However, NIOSH reported mixed results in these booths' ability to control silica exposures. Air pressure and turbulence introduced during blasting may limit the reliability of this control option.

Wet Abrasive Blasting and Surface Preparation

Wet abrasive blasting or water-jetting methods (adding water to the blasting solution or blasting with high-pressure water) offer additional control options for both small and large non-ferrous castings. Use of wet methods can significantly reduce airborne dust during surface cleaning (SSPC, 2001). A report prepared for the U.S. Army National Guard (presenting U.S. Naval Yard Study results) compares various wet and dry abrasive blasting methods and the frequency with which heavy metal PELs were exceeded (Industrial Hygiene West, 2000). Air sampling suggested that workers had a 33 to 44 percent risk of exceeding the PELs for lead (50 µg/m^3) or cadmium (5 µg/m^3) when using dry blasting methods (open abrasive blasting and blasting inside

[172] The standard filter has an efficiency rating of 99.7 percent when tested with particles that are 0.5 µm in size. A HEPA filter has an efficiency rating of 99.97 percent for 0.3 µm particles (Clemco, 2007).

a blasting enclosure). In contrast, limited sample results for workers using low-volume water slurry blasting (steel shot with water added) and high-pressure water jetting without abrasive added indicated the risk of exceeding the lead or cadmium PEL was between 0 percent and 3 percent.[173]

Reduce Beryllium Oxide on Castings

Reducing beryllium oxide formation on casting surfaces is an additional option for reducing the beryllium exposure of abrasive blasting operators. Foundry efficiency is increased by casting methods that reduce blemishes and imperfections, such as oxides, which must later be removed from castings. Additionally, because most oxide on the casting will be removed during blasting, and because alloy oxide often has greater beryllium content than the base metal, reducing oxide formation might have a notable effect on blasting operator exposure.

Casting methods to minimize oxide formation include those that minimize the contact of oxygen in the air with the hot metal surface, such as permanent mold or die casting. Methods such as direct chill casting that cool the casting rapidly to reduce surface temperatures to a level at which oxide does not form as quickly are particularly effective. One casting facility visited by NIOSH, a secondary smelter that also cast copper anodes, sprayed and submerged red-hot castings in water to cool them as quickly as possible (NIOSH HETA 82-024-1428).

The benefit of reducing surface oxide as a method for reducing abrasive blasting operator exposure levels has not been quantified for beryllium; however, reducing the amount of friable contaminant-bearing coatings will reduce the extent to which these materials are dislodged during abrasive blasting. In the case of beryllium alloy castings, the base metal would continue to be a source of exposure for blasting operators; however, the highly friable and higher-beryllium-content oxide would be eliminated as a source of airborne exposure if removed by pre-cleaning.

Abrasive Blasting Operator—Conclusion

Based on five sample results ranging from 0.05 $\mu g/m^3$ to 0.15 $\mu g/m^3$, supported by IMIS results of 0.02 $\mu g/m^3$ to 0.101 $\mu g/m^3$, OSHA finds that exposure levels of 0.2 $\mu g/m^3$ have already been achieved for most abrasive blasting operators through use of well-sealed, completely enclosed, ventilated abrasive blasting cabinets. As a result, OSHA preliminarily concludes that the proposed PEL of 0.2 $\mu g/m^3$ can be achieved for most abrasive blasting operators most of the time through this control.

Additionally, any excessive beryllium exposure due to cross-contamination or secondary exposure from activities of workers in other job categories will be reduced when the other workers' exposures are reduced to 0.2 $\mu g/m^3$, or alternatively, when cross-contamination by air currents is eliminated by balancing all supply and exhaust air systems. Exposures will also be reduced if employers use wet methods, or reduce beryllium oxide on castings. OSHA estimates

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[173] The total number of results reported for each method and contaminant (cadmium [Cd] or lead [Pb]) are as follows: *open abrasive blasting* (Cd, 21 results; Pb, 12 results), *containment with recycled metal media* (Cd, 207 results; Pb, 338 results), *low-volume water slurry blasting* (Cd, 22 results; Pb, 38 results), *high-pressure water jetting* (Cd, 25 results; Pb, 25 results) (Industrial Hygiene West, 2000). Neither individual results nor information on the metals content of the material being removed are available.

that these additional controls will be adequate to further reduce the exposure of most abrasive blasting operators to an alternative PEL of 0.1 μg/m^3.

Grinding/Finishing Operator

Grinding/Finishing Operator—Baseline Controls

Grinding, sanding, cutting, and polishing of aluminum and copper castings are commonly performed in enclosures as a wet process or with LEV. Enclosures with wet methods or LEV were generally used with the finishing operations at the copper-beryllium casting facilities visited by NIOSH (NIOSH EPHB 326-11a; NIOSH EPHB 326-16a). Housekeeping in and around the grinding/finishing workstation, however, is not always thorough or performed consistently.

Wet methods were used frequently at the foundry that ERG visited (ERG Beryllium Site 7, 2003). The material handler, who worked in all areas of the foundry over the abbreviated work shift, used a band saw briefly to trim larger castings prior to shipment. No corresponding exposure results were collected because no worker was dedicated to this task at that small foundry. Although no use of LEV was reported for this task, ERG noted that the band saw was designed with an option for wet cutting using a lubricant stream and that the investigator recommended that the area around the saw should be covered with absorbent mats. This suggests that the floor was wet and that at least some, if not all, of the cutting that day was performed as a wet process.

At one of the beryllium alloy foundries visited by NIOSH, the employer reportedly conducted all cutting and grinding operations in partially enclosed booths equipped with LEV (NIOSH EPHB 326-16a). However, a photograph of the cutting and grinding shop shows that in addition to the two partially enclosed booths with LEV, the shop also contained two finishing work stations where only LEV is used for control, with no partially enclosed booths around the equipment. Six full-shift PBZ samples were obtained in the cutting and grinding shop with the following results: 0.10 μg/m^3, 0.23 μg/m^3, 0.27 μg/m^3, 0.29 μg/m^3, 0.44 μg/m^3, and 1.07 μg/m^3. No information was provided describing the circumstances associated with these results. LEV was also available to all employees conducting grinding and finishing operations at the castings refurbishing facility (highest exposure 0.9 μg/m^3). After initial exposure measurements were made with user-positioned duct/hood combinations, the workstations were redesigned with more reliable benchtop backdraft-downdraft booths (highest exposure 0.06 μg/m^3) (MC Pkg I-D, 2010).

At the other alloy foundry that NIOSH visited, grinding/finishing operators used a combination of automation, enclosures, and wet methods (NIOSH EPHB 326-11a). There, castings were sent to the machine shop for "machining, grinding, polishing, and buffing." NIOSH reported that workers placed parts into enclosed automated lathes and used cutting fluids to control and contain the release of metal particles.

Grinding/Finishing Operator—Additional Controls

The exposure profile for grinding/finishing operators is described by a median exposure level of 0.05 μg/m^3. Based on the profile presented in Tables IV-29 and IV-30, 58.9 percent of grinding/finishing operators currently have exposures less than 0.1 and another 14.3 percent of sample results range from 0.1 μg/m^3 to 0.2 μg/m^3. The exposure profile indicates that most grinding/finishing operators already experience exposures of 0.2 or less; however, additional controls will be required to reduce the exposures for the remaining 26.8 percent to this level. Additional control options for grinding/finishing operators include LEV, full or partial enclosures, wet methods, and eliminating or minimizing work practices that increase exposure. In some cases, existing ventilated enclosures may need to be more fully enclosed to improve the efficiency of the LEV.

LEV and Enclosures
For manual grinding tasks, regardless of the nature of the industry, Materion Corporation suggests a booth designed with both backdraft and downdraft exhaust ventilation inside the partial enclosure (Materion Information Meeting, 2012). For example, such a booth would include a front opening and rear exhaust as is available for abrasive cut-off saws (Figure VS-80-17 in ACGIH, 2010), and the downdraft table ventilation of a hand-grinding bench (Figure VS-80-18 in ACGIH-Ch13, 2010). An adaptation to provide a rear-slot exhaust (rather than plain rear takeoff) is preferable for hand grinding, which might not occur at a single fixed spot inside the booth. The booth exhaust should provide 250 fpm across the opening and be fitted with a HEPA air filter; special precautions such as respiratory protection must be used when servicing the booth or blower and changing the filter. The booth should also be equipped with alarms to indicate when filter performance falls outside an effective range. According to Materion Corporation, if this booth design does not sufficiently control exposures, the booth can be redesigned to achieve lower exposure levels by increasing the ventilation rate to provide 400 fpm across openings, a strategy that has proven successful for a variety of hood designs at Materion Corporation's plants and those of its customers (Materion Information Meeting, 2012).

Materion Corporation advocates grinding booths of this general backdraft-plus-downdraft design, paired with work practice controls and careful housekeeping methods, as an effective method for reducing exposure levels for workers performing manual grinding (and related tasks using powered or rotary tools, such as polishing and buffing) to concentrations of 0.2 μg/m^3 or less (Materion Information Meeting, 2012). The control measures (i.e., engineering controls, work practice controls, and housekeeping) must be used together to ensure that exposure levels are reliably maintained at or below 0.2 μg/m^3 most of the time for grinding and finishing operations. Materion Corporation's exposure reduction guidelines are generic and applicable to any industry where beryllium-containing particles are generated using powered or rotary hand tools. Thus, these guidelines apply to foundries and machining facilities in the same manner as they apply to other types of facilities.

In addition to improving LEV, employee training should be augmented to ensure that all employees use engineering controls properly and routinely. Housekeeping in facilities that use beryllium alloys should be performed routinely and thoroughly to prevent the accumulation of dust that can be spread to other work areas or become airborne if disturbed. Cleaning should be performed with HEPA vacuums instead of traditional vacuums, and the use of compressed air and dry sweeping should be prohibited. With this standard group of controls, the grinding bench will control the exposures of grinding/finishing operators while they manually grind beryllium alloy castings, and work practice and administrative controls are necessary to ensure that the bench ventilation is maintained in working order and kept clean, and that beryllium particles are not released when the ventilation system is serviced and the filter is changed.

Although no study demonstrates the effectiveness of these controls in foundries, several studies provide evidence that ventilation systems in combination with work practices that enhance the effectiveness of the ventilation systems can reduce worker exposure levels substantially in establishments where the grinding/finishing work is substantially similar to work that otherwise could be performed in a foundry. This information was obtained from Materion Corporation's exposure reduction guidelines, and they are generic and applicable to any industry where beryllium-containing particles are generated using powered or rotary hand tools. Thus, these guidelines pertain equally to foundries as they do to other types of facilities.

The value of well-designed ventilation controls and associated work practices is demonstrated particularly well by a series of industrial hygiene surveys conducted by Materion Corporation in plants that work with beryllium alloy objects (including foundry-cast dies designed for casting other products such as plastics) (MC Pkg I-D, 2010; also summarized in Materion PSCS 105, 2011). In the industrial hygiene surveys, the investigator measured full-shift PBZ exposure levels before and after interventions for workers performing grinding at a bench (called "benching") using hand-held pneumatic grinding tools. Although the grinding operations did not take place in foundries, they are typical of grinding activities that are performed in foundries; both activities involve the same beryllium alloy castings, the same grinding tools, and the same objective of removing defects and excess metal as part of a finishing process (MC Pkg I-D, 2010).

As presented in Table IV-32, 17 grinder operators initially experienced exposure levels ranging from 0.01 $\mu g/m^3$ to 0.9 $\mu g/m^3$ while using downdraft or user-positioned exhaust trunk ventilation. After additional controls were implemented, results from 23 samples indicated that exposures were reduced to a range of 0.01 $\mu g/m^3$ to 0.06 $\mu g/m^3$, representing a 94 percent reduction in the maximum exposure level compared to exposure levels measured while workers used the less effective ventilation systems originally in place (MC Pkg I-D, 2010).[174] The additional controls used to achieve this reduction included a benchtop booth (enclosing the top, back, and sides of the work area, with an open front through which the worker reached) installed over a downdraft-backdraft table. Other improvements included improved lighting, a work practice "to allow the worker to see well, reducing the need to be in close proximity to the part," duct transport velocities of 4,000 fpm to prevent particles from settling in the ducts, and "a single power switch, turning on lighting, all pneumatic and electric power, and opening the hood blast gate." The tools would not operate if the blast gate was not open . Additionally, due to its variable-drive fan motor, the dust collection system was able to increase air flow when more hoods were in use—maintaining a more consistent air flow rate for all workstations, regardless of the number of workstations operating at one time. Removable plates made it easier to clean the downdraft plenum and the entire hood tilted to improve access to the part being worked (MC Pkg I-D, 2010). Ventilated bench top grinders could be placed within a similar hood to offer an added level of worker protection.

[174] The reported geometric mean was reduced by 68 percent from 0.087 $\mu g/m^3$ to 0.028 $\mu g/m^3$ (MC Pkg I-D, 2010). The report includes in the geometric means four sample results that were not included in the OSHA's exposure profile (one result with the original controls the concentration value of which was illegible, and so void, and three less-than-full-shift samples [174 minutes to 276 minutes duration] obtained after controls were upgraded, for which results are 0.01 $\mu g/m^3$, 0.02 $\mu g/m^3$ and 0.03 $\mu g/m^3$) (MC Pkg I-D, 2010).

Table IV-32—Summary of Personal Exposure for Grinding/Finishing Operators Working on Beryllium Alloy Under Various Conditions				
Job Category	**Total Number Samples**	**Range ($\mu g/m^3$)**	**Mean ($\mu g/m^3$)**	**Median ($\mu g/m^3$)**
*Grinding/finishing—user-positioned duct**	*17*	*0.01 to 0.9*	*0.18*	*0.05*
*Grinding/finishing—backdraft/downdraft hood**	*23*	*0.01 to 0.06*	*0.03*	*0.02*
Grinding/finishing—Other	*16*	*0.1 to 4.79*	*0.86*	*0.27*
Grinding/finishing operator—Total	**56**	**0.01 to 4.79**	**0.31**	**0.05**

No samples for workers using backdraft/downdraft hoods exceeded 0.2 $\mu g/m^3$ and all were also less than 0.1 $\mu g/m^3$. Among the group using user-positioned ducts: 5 of 17 samples (29 percent) exceed 0.2 $\mu g/m^3$. Within the group working under other (undefined) conditions, 10 of 16 samples (63 percent) exceeded 0.2 $\mu g/m^3$.

* *Originally, the exposure profile consisted of 16 samples. Materion provided OSHA with these additional samples that have been incorporated into the exposure profile.*

*Source: CCMA, 2000; NIOSH HHE 75-87-280; NIOSH EPHB 326-11a; NIOSH EPHB 326-16a; *Materion Pkg –D, 2010.*

At a beryllium machine shop ERG visited (ERG Beryllium Site 1, 2002), all machining operations are fully enclosed and ventilated. Six full-shift PBZ samples obtained on machinists ranged from 0.02 $\mu g/m^3$ to 0.11 $\mu g/m^3$, with a mean of 0.035 $\mu g/m^3$ and median of 0.02 $\mu g/m^3$. At another machine shop ERG visited, some of the enclosures and/or LEV systems were in need of upgrade. During a site visit in 2004 (ERG Beryllium Site 9, 2004), six full-shift PBZ results ranged from 0.1 $\mu g/m^3$ to 2.3 $\mu g/m^3$, with a mean of 0.68 $\mu g/m^3$ and a median of 0.25 $\mu g/m^3$. The highest exposure (2.3 $\mu g/m^3$) was associated with surface grinding operations that had partially enclosed LEV systems and used a flood coolant. However, visible airborne coolant contaminated with beryllium particles was generated at high speeds and observed escaping the existing control system. ERG investigators made recommendations for fully enclosing the surface grinder at the time of the visit. The facility subsequently designed and installed fully enclosed LEV systems on the surface grinder operations and reported that operator exposure was reduced from an average of 1.6 $\mu g/m^3$ to 0.08 $\mu g/m^3$, based on the results of their air monitoring program (ERG Beryllium Site 9, 2004). Both of these facilities (ERG Sites 1 and 9) machine pure beryllium and/or high-beryllium alloys; however, the benefits of using ventilated enclosures are evident and would be applicable to any machining operation regardless of the beryllium content of the materials handled.

Wet Methods

In the series of industrial hygiene surveys conducted by Materion Corporation, the investigator measured full-shift PBZ exposure levels before and after interventions for machine shop workers performing semi-automated lapping while refurbishing cast beryllium alloy shapes (MC Pkg I-D, 2010). "Dry [lapping] work practices were observed during baseline sampling that resulted in a 0.51 $\mu g/m^3$ exposure to the operator."[175] Plant managers confirmed that the work should have

[175] "Lapping" is a machining process that involves physically rubbing a material surface against the surface of second, harder or more abrasive surface (usually flat, but not necessarily so) to flatten (or contour) the first surface. Alternatively, an abrasive grit (such as aluminum oxide or jewelers rouge) may be introduced between the surfaces to provide the microscopic abrasive action. Because lapping achieves material surface attrition by abrasive action, its action is related to grinding (in that it generates fine particles), but lapping is often performed at lower speeds, without the grinding wheels or burrs typical of modern grinding processes.

been done wet with flood coolant. Follow-up samples were collected after "work practice controls prohibited dry [lapping]; [14 results] ranged from 0.007 µg/m^3 to 0.2 µg/m^3 with an average of 0.062 µg/m^3" (MC Pkg I-D, 2010). These sample results demonstrate the value of wet methods in controlling fine particles released by abrasive action of semi-automated surface shaping tasks on material surfaces. .

Work Practice Improvements
Other control methods for grinding/finishing operators include minimizing work practices that increase exposure. For example, at one facility where pure beryllium and high-beryllium alloys are machined, an exposure level of 6.6 µg/m^3 was obtained on a machinist operating a fully enclosed and ventilated double-sided lapper (ERG Beryllium Site 4, 2003). During the machining cycle, investigators noted that the worker opened the machine enclosure four or five times to check on the progress of the parts. It is likely that this work practice increased the operator's exposure to beryllium. This judgment is supported by the findings of a NIOSH study that identified peak metalworking fluid exposures to machine operators in the course of their work (NIOSH ECTB 218-12a). Using video exposure monitoring and an aerosol photometer, NIOSH investigators observed that both full and partial entry into a machining center led to higher operator exposures. One worker had his highest metalworking fluid exposure when he was cleaning inside a machining center. Another worker experienced his highest exposures at the open door of partially enclosed machining centers, at times with his arm inside the enclosure.

Eliminating or minimizing poor work practices will help reduce exposures for workers machining beryllium-containing materials. Although the double-sided lapper example may not pertain to all foundry finishing operations (e.g., many finishing operations require the operator to manually hold the part or the finishing tool and may not be able to use full enclosures), it illustrates the impact of worker technique on exposures. As mentioned in the subsection on Furnace Operator –Additional Controls, Enhanced Work Practices, according to the primary beryllium producer's suggested exposure reduction range, work practice improvements might reduce exposures by approximately 35 percent on average.

Other Control Methods
Some of the available methods for reducing the beryllium exposure of grinding/finishing operators are specific to the casting process (e.g., decreasing casting defects). The grinding/finishing operators in foundries typically work on the castings produced by other workers in the same facility. This gives foundries an added opportunity to reduce the exposure of their own grinding/finishing operators by producing the cleanest possible castings. To do this, they can reduce the amount of oxide on the surface of castings as well as the quantity of casting defects that require grinding and/or finishing.

<u>Pre-cleaning Castings</u>
Most castings can be pre-cleaned using enclosed, automated, and ventilated processes, such as vibrating abrasive media, rotary media drums, or enclosed shot blasting (Huston, 1981; South Cast Equipment, 2000; Pangborn, 2000). Pre-cleaning is typically performed after shakeout, but in some cases these pre-cleaning methods can replace the shakeout process entirely (South Cast Equipment, 2000). Pre-cleaning produces cleaner castings and thus reduces labor associated with grinding and other finishing tasks (Huston, 1981; Didion, 2011). This means that

grinding/finishing operators would need to spend less time working on beryllium alloy castings and therefore reduce the overall beryllium exposure associated with these tasks.

Reducing Casting Defects

Sand inclusions, surface imperfections, and other defects incorporated into casting surfaces are chipped or ground out by grinding/finishing operators. According to a report in *Modern Casting* magazine, nine different process-related problems can leave sand tightly adhered to the casting surface (burn-in), and 11 process problems can result in sand embedded as projections into the casting (sand inclusions) (Spada, 2000). Causes include low or high mold moisture, or the wrong sand mixture, and equipment problems. Once identified, each cause can be eliminated by modifying and improving process quality control (Spada, 2000). Use of refractory mold and core coatings can also minimize burn-in (Coelho and Bharati, 1999). Another option is substitution of one granular medium for another that reduces the incidence of burn-in. For example, five gray and ductile iron foundries testing a ceramic alternative to silica sand for casting reported reduction of burn-in/burn-on during green sand, core, shell, and lost foam casting applications (Carbo, 2000). One of these foundries (Number 6) reported an estimated 90 percent reduction in burn-in when it switched to the alternate ceramic media for cores.

Reducing Surface Oxide

Some casting methods reduce formation of surface oxide by preventing the molten metal from contacting oxygen in air. These casting methods include die-casting and other reusable solid molds into which metal is poured. The solid metal walls of the mold stay in contact with the molten metal and exclude air. Methods that cool the metal quickly, such as direct chill casting, reportedly offer an added benefit. These rapid cooling methods reduce the time that high-temperature metal surfaces are in contact with oxygen in the air and thus reduce surface oxide formation (Corbett, 2004). Direct chill casting, involving a chilled water jacket circulating around the mold, is the method used by the copper-beryllium casting facility ERG visited (ERG Beryllium Site 7, 2003). The castings at this site were described as “clean” and generally free of loose surface oxides (Corbett, 2005). Other casting facilities use water baths on molds and water spray on hot castings for the same purpose—to rapidly cool the casting surface and minimize the opportunity for oxides to form. A smelting facility visited by NIOSH used this technique to cool cast anodes (NIOSH HETA 82-024-1428).

Grinding/Finishing Operator—Conclusion

Based on the exposure profile presented in Tables IV-29 and IV-30, an exposure level of 0.2 $\mu g/m^3$ or less has already been achieved for slightly greater than 73 percent of grinding/finishing operators. Additional controls will be required to reduce the beryllium exposure of the remaining 26.8 percent of grinding/finishing operators to 0.2 $\mu g/m^3$ or less. Based on information contained in this section, OSHA preliminarily concludes that by using either tabletop booth enclosures (250 fpm across the booth face) that are associated with downdraft-backdraft workbenches, or wet dust control methods, and by simultaneously implementing Materion Corporation’s Worker Protection Model, the exposure for all workers in this job category can be reduced to 0.2 $\mu g/m^3$ or less. As previously discussed, Materion Corporation’s Worker Protection Model involves specific steps to maintain cleanliness of clothing, skin and work areas; avoid spreading beryllium particles; and prepare workers for safe work with standard operating procedures and appropriate training. After downdraft-backdraft booths and Worker Protection Model controls were implemented in a facility where workers resurfaced foundry-cast beryllium alloy dies using hand-held pneumatic and electric grinding tools, results from 23 full-shift personal samples had a mean of 0.03 μg/m^3 and all results were 0.06 μg/m^3 or less. This maximum value represents a 94 percent reduction compared to the maximum value of 0.9 μg/m^3 associated with the less effective ventilation control originally in use (MC Pkg I-D, 2010). The same series of industrial hygiene studies showed that during wet lapping 14 exposure levels ranged from 0.007 μg/m^3 to 0.2 μg/m^3 with a mean of 0.062 μg/m^3 (MC Pkg I-D, 2010). In contrast, a sample result of 0.51 μg/m^3 had been obtained when a worker performed the same lapping task using dry methods.

Based on this information, OSHA preliminarily concludes that an exposure level of 0.2 μg/m^3 or less can be achieved for all grinding/finishing operators. To the extent that grinding equipment such as ventilated bench grinders and lapping machines can be enclosed in booths that draw 250 fpm across the opening (and that are designed to eliminate dead space inside the booth), OSHA preliminarily concludes that most grinding and finishing operator exposure levels can be reduced to an alternative PEL of 0.1 μg/m^3.

Maintenance Operators

Maintenance Operators—Baseline Controls

Maintenance operators are exposed to beryllium when they disturb beryllium contamination that may present equipment and work surfaces. Based on information from the ERG, NIOSH, and CCMA reports, OSHA believes that maintenance operators most typically work with general dilution ventilation only, unless work is performed on equipment that is fitted with exhaust ventilation (CCMA, 2000; NIOSH HHE 78-17-567; ERG Beryllium Site 7, 2003). When working on ventilated equipment, such as furnaces, the process exhaust ventilation system might offer some degree of exposure control for the maintenance operator, but is unlikely to be designed to provide optimal control of maintenance activities. As an example, furnace ventilation hoods are designed to capture fumes released from the top of the furnace, rather than from the furnace interior where a maintenance operator might chip and patch the refractory lining. Some foundries may have LEV systems available for maintenance activities. Other baseline conditions include dry sweeping and the use of compressed air; however, central or portable HEPA vacuums are available in some nonferrous foundries for cleaning equipment and removing dirt and dust from work surfaces.

Maintenance Operators—Additional Controls

The exposure profile for maintenance operators shows a range of exposures from 0.05l μg/m^3 to 22.71 μg/m^3, with a median exposure level of 0.21μg/m^3. Based on the exposure profile presented in Tables IV-29 and IV-30, 50 percent of maintenance operators have exposures that exceed 0.2 μg/m^3 and will require additional controls to reduce exposures to 0.2 μg/m^3 or less. Available control options include process equipment changes, wet methods, HEPA filter vacuums, LEV (including the use of ventilated tools), and work practice improvements.

Process-related engineering controls can reduce exposures. This control option is particularly beneficial if exposure levels routinely exceed the current PEL of 2.0 μg/m^3. For example, as noted in the subsection on Exposure Profiles for Affected Job Categories in this Aluminum and Copper Foundries section, to reduce maintenance operator exposures when emptying the facility’s dust collectors, a beryllium production facility installed automatic valve cut-offs activated by drum level sensors to control the amount of waste released into drums (NIOSH HHE 78-17-567). Using exposure data collected by the facility, OSHA estimated that PBZ exposures were reduced about 93 percent over one year, from 53 μg/m^3 (one result) in the first quarter of 1977 to 3.62 μg/m^3 (average of three results) in the first quarter of 1978. Applying this reduction to the highest exposures (16.51 μg/m^3 and 22.71 μg/m^3) brings these extremely high levels to values ranging from 1.2 μg/m^3 to 1.6 μg/m^3.

Materion Corporation reports that the repair or maintenance of equipment, including process ventilation equipment, can generate airborne beryllium particles (Materion SF 102, 2011; Materion SF 201, 2011). Protecting workers may require specific work practices or procedures involving the combined use of decontamination, wet and vacuum cleaning methods, ventilation, PPE including respiratory protection, and possibly restricted work zones. To implement these controls, foundries will need to develop detailed procedures for safely maintaining process equipment and ventilation systems. These procedures should thoroughly describe the use of wet methods or vacuuming, ventilation, and appropriate PPE to prevent maintenance operator exposure to airborne beryllium. In addition, all maintenance operators need to be trained in the proper procedures before performing any maintenance or service activities. Appropriate combinations of these methods must be used (by the maintenance operator or another worker assigned this part of maintenance operator duties) to pre-clean process equipment to remove residual beryllium before the maintenance operator begins maintenance or repair work.

HEPA Filter Vacuums

Process equipment and associated support systems (e.g., dust collectors) should be cleaned regularly to prevent the accumulation of beryllium-containing materials and before any service or maintenance. HEPA filter vacuuming and wet cleaning are effective methods for cleaning contaminated work surfaces; only these methods should be used to clean beryllium work areas (Materion SF 201, 2011; OSHA-H005C-2006-0870-0155). Dry sweeping and the use of compressed air for cleaning should be prohibited. As noted during the discussion of additional controls for molders, in some cases a worker’s primary exposure to beryllium has been due to the use of compressed air.

During the emptying or maintenance of HEPA vacuums, beryllium-containing particles may be released into the workplace. To minimize the potential for exposure, employers will need to develop and implement proper procedures for emptying and maintaining HEPA vacuums. These procedures include all of the following provisions (Materion Interactive Guide, 2012):

- Conduct all service and maintenance on HEPA vacuums in accordance with the manufacturer’s instructions.
- Wear appropriate PPE (such as disposable coveralls, gloves, and respirators) during the entire process, including cleanup.
- Use a designated, contained area for servicing HEPA vacuums.
- Place plastic sheeting or another suitable material on the floor to contain any material that may be released and to facilitate cleanup afterwards.

- Use ventilation or other engineering controls, where feasible, to control the release of airborne particles.
- Place the material removed from the vacuum (dust, debris, prefilters, etc.) in a heavy-duty plastic bag and seal the bag with tape or by some other means. Then place this bag inside a second bag and seal, label, and dispose of appropriately.
- Use another HEPA vacuum or wet cleaning methods to clean the area (after completing the maintenance), including the vacuum that was serviced.

Local Exhaust Ventilation
For most maintenance operators, the primary control might include portable LEV systems or stationary systems that can be adapted to benefit the maintenance operator. As was previously noted, maintenance operators’ work positions may limit the benefit of process ventilation systems on the equipment they service. For example, tundish repair can occur on the pouring line floor near exhaust ventilation intended for the hot molds. A slotted hood or duct trunk at the pouring station might provide some exposure control when the tundish is between the worker and the hood; however the control is not typically constant. Eventually as work progresses around the tundish, the worker’s back will be to the ventilation hood and contaminated air from the tundish cleaning might be pulled past the worker’s breathing zone.

This challenge can be resolved by an enclosure or booth placed around the work (or work placed inside an enclosure that the operator reaches into). Materion Corporation has installed a large ventilated booth in which movable refractory equipment is placed for refractory replacement or repair work (Materion Meeting, 2012). For stationary equipment with refractory lining, a company that provides refractory overhaul services developed a method for installing temporary LEV. This method is used for complete lining removal, but is also applicable to smaller (patching) jobs in gas-fired furnaces. It involves company-built exhaust fans fitted with air filters (three filters of increasing efficiency in series) (Refractory Services Provider A, 2003). The fans create an air flow pattern in the furnace that pulls fresh air from outside the furnace past the worker’s face and removes dusty air from near the chipping point. Workers stretch plastic sheeting as necessary to ensure that the fresh air enters the furnace only from the most advantageous point (for the purpose of providing clean air to the worker), while they set one or more fan/filter boxes into the opposite and lower end of the furnace to exhaust contaminated air. Existing openings, such as access hatches and gas vents, are used as needed to maintain favorable circulation (Refractory Services Provider A, 2003). The sheeting and boxes might need to be moved to other sections of the furnace as the work progresses. Although the fan/filter boxes are specially built for this purpose, they are made of materials readily available at hardware stores and cost relatively little to construct (Refractory Services Provider A, 2003).

Providing exhaust ventilation throughout a process, from start to finish, will help maximize control of metal dust and fumes (CCMA, 2000). The ventilation system will be equally effective for particles with similar aerodynamic properties, regardless of whether the airborne dust or fumes are cadmium, lead, or beryllium (see Section 2—Methodology for additional information on the behavior of particles in air). Maintenance operators who repair refractory linings benefit from enclosed, exhausted waste receptacles to hold debris generated during the repair process.

Beryllium-contaminated waste (such as spent refractory materials) generated during maintenance activities should be transferred under LEV from the furnace or tundish to the receptacle.

Downdraft/backdraft enclosures at workbenches have also proven effective for work with hand tools in facilities working on beryllium alloy castings. As described in detail in the section discussing additional controls for the molder job category (elsewhere in this chapter on copper and beryllium foundries), three grinder operators initially experienced exposure levels ranging from 0.012 µg/m^3 to 0.900 µg/m^3 while using downdraft or exhaust trunk ventilation. After additional controls were implemented, results from 28 samples indicated that exposures were reduced to a range of 0.0084 µg/m^3 to 0.0577 µg/m^3, representing a 94 percent reduction in the maximum exposure level compared to exposure levels measured while workers used the less effective ventilation systems originally in place (MC Pkg I-D, 2010).[176] The additional controls used to achieve this reduction included a benchtop booth (enclosing the top, back, and sides of the work area, with an open front through which the worker reached) installed over a downdraft-backdraft table.

Ventilated Hand Tools

The benefits of tool-mounted exhaust systems for controlling beryllium have been demonstrated in the control of hazardous dusts (such as crystalline silica) in other industries, including construction and ready-mix concrete. For example, the chipping of refractory materials is similar to chipping concrete, another silica-containing material. To evaluate chipping equipment, NIOSH tested two tool-mounted LEV shrouds for hand-held pneumatic chipping equipment (impact drills): one custom built, the other a commercially available model. Comparing multiple short-term samples, NIOSH found that the shrouds reduced PBZ respirable dust by 48 percent to 60 percent (NIOSH EPHB 282-11a).

Independently, Shepherd et al. (2009) studied hand-held drills and found that, compared with uncontrolled hole drilling, using dust collection cowls connected to portable vacuums reduced respirable dust exposure by 83 to 88 percent and inhalable dust 80 to 94 percent. This study shows that a well-designed dust capture device can be similarly effective for respirable and total (inhalable) dust.[177] Although dust extraction devices such as these are sometimes only evaluated for ability to capture one specific type of dust (e.g., respirable dust), many will perform similarly well for capturing all airborne dust, including total dust containing beryllium. An increasing number of ventilated (i.e., fitted with vacuum suction for dust extraction) power hand tools and after-market shrouds for power hand tools are available from commercial sources (Bosch Tools, 2013; Dustless Tools-Shrouds, 2012; Milwaukee Tools, 2013).

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[176] The reported geometric mean was reduced by 68 percent from 0.087 µg/m^3 to 0.028 µg/m^3 (MC Pkg I-D, 2010).

[177] OSHA measures crystalline silica as respirable dust (less than 10 µg in aerodynamic diameter), while measuring beryllium as total dust, which in this study is called by the contemporary term: inhalable dust (Shepherd et al., 2009). Inhalable dust is generally less than 100 µg in size; larger particles fall and do not remain airborne and so are not inhaled) (ACGIH-TLV-Appendix C, 2011). Although a large body of dust extraction research focused on controlling crystalline silica (a respirable dust) Shepherd et al. (2009) show that it is possible for an effective dust collection device that performs well in capturing respirable dust to perform similarly well for inhalable/total airborne dust. This finding holds true for facility-based industrial ventilation systems as well. A well-designed ventilation system reduces not only the respirable fraction of particles, but also those of airborne particles of greater size. The ability of ventilation systems to reduce total dust is shown by this technological feasibility analysis (see section on beryllium production as an example), previous PELs dealing with total dust concentration such as hexavalent chromium, and every day industrial hygiene practice.

Work Practices

Maintenance operators can reduce their beryllium exposures by cleaning production equipment and associated support systems (such as dust collectors) prior to service or maintenance to remove as much beryllium contamination as possible. HEPA filter vacuums should be used to remove gross surface contamination followed by wet wiping. To control airborne dust generated by their activities, maintenance operators should also use portable ventilation units with HEPA filtration. Because the operator controls and adjusts these tools, operator work practices could be a factor in the higher exposures reported for some maintenance operators. Workers not only need to use these controls consistently and diligently, they also need to use them correctly, such as properly positioning portable LEV units for maximum effect and using appropriate procedures for emptying and maintaining HEPA vacuums as described above.

Foundries can also reduce maintenance operators' beryllium exposure by using administrative controls such as scheduling routine maintenance to avoid times when an incompletely controlled process is being conducted in the area. Work practices such as limiting the number or location of operators working in a furnace at one time could reduce maintenance operator exposures during chipping activities. During an evaluation of respirable crystalline silica, OSHA obtained a notably higher result for a worker reportedly using a jackhammer in the "lower part of a [furnace]" than was reported for the second operator who also used a jackhammer during the same evaluation (OSHA SEP Inspection Report 116201997). Sweeney and Gilgrist (1998) also reported a higher respirable silica exposure level for an operator working in a lower position within a 1,100-pound holding furnace for molten aluminum:

> *Of the two workers involved in performing this project, the higher exposure occurred to employee 1, who did less of the jackhammering but more of the grabbing and tossing of the pieces and chunks of old refractory material. This apparently was because his head was down closer to the jackhammer's point of operation and dust generated than the head of operator 2, who was standing up and operated the jackhammer. However, both employees were overexposed to the respirable dust containing crystalline silica* (Sweeney and Gilgrist (1998)).

Reducing Dross and Oxide Production

Any success in reducing dross formation at the surface of the molten metal (as discussed for the furnace operator job category) is also likely to reduce deposition of dross onto furnace walls. However, because of the limited experience with these controls and problematic results in applications, the benefit of this control has not been quantified. Even if a method such as inert gas layering were to be successfully implemented at the furnace, some oxide is likely to occur at the ladle and tundish, although the quantity might be limited because metal poured from the furnace would be cleaner.

Maintenance Operators—Conclusion

As indicated in the exposure profile (Tables IV-29 and IV-30), a median exposure level of 0.21 $\mu g/m^3$ (and a range of 0.05 $\mu g/m^3$ to 22.71 $\mu g/m^3$) describes the best available exposure data for maintenance workers. Based on these data, OSHA preliminarily concludes that foundries have achieved exposure levels of 0.2 or less for half of all maintenance operators, primarily by providing work areas with little active beryllium emission and low dust contamination. However, it is also the case that 50 percent of the workers in this job category have exposures greater than

0.2 µg/m^3 and require additional controls to further reduce exposures to 0.2 µg/m^3 or less. These controls primarily include a combination of LEV, HEPA filter vacuums, wet methods (e.g., for cleaning and dust suppression during manual demolition) and enhanced work practices (e.g., consistently and diligently decontaminating work surfaces and equipment prior to service or maintenance, and correctly and consistently using LEV). In some cases, process modifications might be necessary. Beryllium exposure reductions specific to these additional controls, either individually or in combination, are not available for maintenance operators in nonferrous foundries. However, Materion Corporation has stated that HEPA filter vacuuming and wet cleaning are effective methods for cleaning contaminated work surfaces and only these methods should be used in beryllium work areas (Materion Info Meeting, 2012; Materion SF 201, 2011; OSHA-H005C-2006-0870-0155). Materion Corporation strives for exposure levels below 0.2 µg/m^3 and typically achieves this level for most workers most of the time, including maintenance operators.

Based on the information described in this section, OSHA preliminarily concludes that the proposed PEL of 0.2 µg/m^3 can be achieved for most maintenance workers most of the time. Based on available information, OSHA believes that achieving an alternative PEL of 0.1 µg/m^3 for this job category most of the time with the use of engineering and work practice controls is challenging. Therefore, the Agency requests additional information (including exposure data and effectiveness of controls) to make a determination about the feasibility of an alternative PEL of 0.1 µg/m^3.

In some circumstances, however, engineering controls will not be feasible due to the nature or infrequency of the job (e.g., during upset conditions). In other cases, maintenance operators may require supplemental protection while performing pre-cleaning to reduce exposure levels during the maintenance or repair task. In both of these cases, supplemental use of respiratory protection may be necessary. The level of protection will vary with the circumstances, but in all cases the respirator must have an assigned protection factor (APF) that offers a MUC of at least the anticipated exposure level. For example, a tight-fitting powered air-purifying respirator will provide an APF of 1,000. For the proposed PEL of 0.2 µg/m^3, this will permit the maintenance operators to work in environments containing airborne beryllium concentrations up to 200 µg/m^3. With an APF of 50, a tight-fitting air-purifying respirator (non-powered) will be suitable for use up to a beryllium concentration of 10 µg/m^3. Although the most elevated exposure levels in the exposure profile for this job category exceed 10 µg/m^3, process equipment modifications are likely to reduce even the highest exposure level to the point where an APF of 50 would be suitable; for example, process equipment modifications reduced extremely elevated maintenance operator exposures by 95 percent (from 53 µg/m^3 to 3.62 µg/m^3) (NIOSH HHE 78-17-567). However, in a few foundries, as indicated by maintenance operators that currently experience results exceeding 20 µg/m^3, a respirator with an APF of 1,000 (e.g., full-facepiece powered air purifying respirator) might be necessary until process changes can be made.

Summary of the Technological Feasibility for Aluminum and Copper Foundries

OSHA identified eight job groups in aluminum and copper foundries with routine beryllium exposure: molding, material handling, furnace operation, pouring, shakeout operation, abrasive blasting, grinding/finishing, and maintenance. The Agency developed exposure profiles based on an industrial hygiene evaluation conducted by NIOSH in 2007 and a Health Hazard Evaluation (HHE) conducted in 1975, an ERG site visit in 2003, a site visit report from 1999 by the California Cast Metals Association (CCMA); and data air sampling surveys conducted in 1999 and from 2007 to 2009, obtained from Materion in 2004 and 2010, respectively.

The exposure profile indicates that in foundries processing beryllium alloys, six of the eight job groups identified have median exposures that exceed the proposed PEL of 0.2 μg/m^3 with baseline working conditions. One exception is grinding/finishing operations, where the median value is 0.12 μg/m^3 and 73% of exposure samples are below 0.2 μg/m^3. The profile for abrasive blasting, which was conducted using an enclosed cabinet, also showed low beryllium exposures (i.e., 5 samples below 0.2 μg/m^3). Exposures for other job groups ranged from just below to well above the proposed PEL, including molder (all samples above 0.2 μg/m^3), material handler (1 sample, above 0.2 μg/m^3), furnace operator (81.8% of samples above 0.2 μg/m^3), pouring operator (60% of samples above 0.2 μg/m^3), shakeout operator (1 sample, above 0.2 μg/m^3), and maintenance worker (50% of samples above 0.2 μg/m^3).

In some of the foundries where the air samples included in the exposure profile were collected, there are indications that the ventilation systems were not properly used or maintained, and dry sweeping/brushing and compressed air systems may have contributed to high dust levels. OSHA preliminarily concludes that beryllium exposures in foundries can be substantially reduced by improving and properly using and maintaining the ventilation systems; switching from dry brushing, sweeping and compressed air to wet methods and HEPA-filtered vacuums for cleaning molds and work areas; enclosing processes; automation of high-exposure tasks; and modification of processes (e.g., switching from sand-based to alternative casting methods), and improved work practices. Therefore, OSHA preliminarily concludes that additional engineering controls and modified work practices can be implemented to achieve the proposed PEL most of the time for molding, material handling, maintenance, abrasive blasting, grinding/finishing, and pouring operations at foundries that produce aluminum and copper beryllium alloys.

The Agency is less confident that exposure can be reliably reduced to the proposed PEL for furnace and shakeout operators. Beryllium concentrations in the proximity of the furnaces are typically higher than in other areas due to the fumes generated and the difficulty of controlling emissions during furnace operations. The exposure profile for furnace operations shows a median beryllium exposure level of 1.14 μg/m^3. OSHA preliminarily concludes that furnace operators’ exposures can be reduced using local exhaust ventilation and other controls to reduce overall beryllium levels in foundries, but it is not clear that they can be reduced to the proposed PEL with currently available technology. In foundries that use sand molds, the shakeout operation typically involves removing the freshly cast parts from the sand mold using a vibrating grate that shakes the sand from castings. The shakeout equipment generates substantial amounts of airborne dust that can be difficult to contain, and therefore shakeout operators are typically exposed to high dust levels. When casting beryllium alloys, the dust may contain beryllium and beryllium oxide residues dislodged from the casting during the shakeout process. The exposure profile for the shakeout operations contains only one result, of 1.3 μg/m^3. This suggests that a substantial reduction would be necessary to achieve compliance with a proposed PEL of 0.2 μg/m^3. OSHA requests additional information on employee exposure levels and the effectiveness of dust controls for shakeout operations for copper and aluminum alloy foundries.

Additionally, OSHA preliminarily concludes that an alternative PEL of 0.1 μg/m^3 would be feasible for molders, material handlers, abrasive blasting operators, and grinding and finishing operators. For the other four job categories, OSHA believes that achieving levels at or below an alternative PEL of 0.1 μg/m^3 would be challenging with the engineering and work practice controls identified in this analysis. OSHA is requesting additional information that the Agency can consider to make its final feasibility findings.

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SECTION 6—SECONDARY SMELTING, REFINING, AND ALLOYING, INCLUDING HANDLING OF SCRAP AND RECYCLED MATERIALS

INDUSTRY PROFILE

Workers employed in establishments performing secondary smelting, refining, and alloying of copper, aluminum, and other nonferrous materials may be exposed to beryllium. Secondary refining, smelting, and alloying establishments produce metals from scrap.[178] These scrap materials include machine shop turnings, punchings, and borings, as well as defective or surplus metal goods (EPA 310-R-95-010). Firms also recover metals from lower grades of nonferrous scrap, including slags, ashes, residues, and mixed scrap comprised of electronic scrap, printed circuit boards and other clad materials, and metal-laden liquors. Beryllium can be present in these types of scrap material.

Exposures to beryllium can occur both during the processing of scrap and during the smelting and alloying[179] process. Direct handling and processing of beryllium-alloy scrap and processing of unalloyed nonferrous metals that contain trace amounts of beryllium can result in beryllium exposures (NIOSH HETA 83-162-1746, 1986).[180] Based on the information presented in this section, OSHA has reached the preliminary conclusion that the primary potential exposure source for workers in these facilities is processing of beryllium-alloy scrap derived from electronics and computer parts and from metals recycled from defense, aerospace, and other similar applications. For the purposes of this analysis, the processing of beryllium-alloy scrap is characterized by two operations: mechanical processing and furnace operations.

The Industry Profile subsection provides an overview of the types of establishments included in this application group, while the subsections on Producers of Copper-Beryllium and Aluminum-Beryllium Alloys and Precious Metal Recovery provide, respectively, estimates of the number of establishments that produce beryllium alloys or are engaged in precious metal recovery where beryllium exposures might occur.

Industry Overview

Table IV-33 presents the 2010 County Business Patterns data on establishments in three six-digit NAICS industries: Secondary Smelting, Refining, and Alloying of Copper (331423); Secondary Smelting and Alloying of Aluminum (331314); and Secondary Smelting, Refining, and Alloying

[178] "Scrap" consists of a) discarded materials that contain recoverable metals of interest and b) metal-bearing byproducts or waste generated by secondary metal processing operations.
[179] Alloying is the addition of specific materials (typically other metals or minerals) to molten metal in the refining furnace to produce the desired properties of the metal. Examples of properties that can be enhanced by alloying include resistance to corrosion, strength, and ductility (EPA EIIP, 2001). Alloying materials vary depending on the type of metal processing and can include beryllium, boron, bronze, cadmium, chromium, cobalt, iron, magnesium, manganese, molybdenum, silicon, strontium, titanium, zirconium, and others (Belmont Metals, 2005; KB Alloys, 2005; Specialloy, 2005; Freedom Alloys, 2005).
[180] See Cunningham (2004) for an overview of beryllium recycling in the United States.

of Nonferrous Metal, Except Copper and Aluminum (331492). In 2010, 394 establishments in the United States performed secondary smelting, refining, and alloying of copper, aluminum, and other nonferrous metals. These establishments employed 15,331 workers. Nevertheless, relatively few of these firms actually handle beryllium-alloy scrap materials.

Three types of establishments in these industries—smelters, refiners, and alloyers—use copper, aluminum, and other scrap to produce nonferrous metal products. Low-grade copper and other nonferrous scrap require a smelting process to produce higher grades of refined metal. In smelting, the scrap is melted in a blast or rotary furnace, resulting in slag and impure copper. In the next step, refining (also known as fire refining), additional impurities are removed and the metal is cast into billets or anodes. Better grades of nonferrous metal scrap, such as copper and aluminum, can be refined through fire refining alone, without smelting. Alloy ingot makers re-melt high-grade copper or aluminum scrap in a melting furnace along with other materials (such as metals or minerals) to produce a variety of copper and aluminum alloys.

Table IV-33—Secondary Smelting, Refining, and Alloying of Copper, Aluminum, and Nonferrous Metal—2010

	331423, Secondary Smelting, Refining, and Alloying of Copper	331314, Secondary Smelting and Alloying of Aluminum	331492, Secondary Smelting, Refining, and Alloying of Nonferrous Metal (Except Copper and Aluminum)	331421, Copper Rolling, Drawing, and Extruding
No. of Establishments	*24*	*122*	*248*	*96*
Total Employees	*789*	*4,846*	*9,696*	*9,849*
Source: U.S. Census Bureau, 2010; U.S. Census Bureau, 2007.				

Due to environmental issues and adverse copper market conditions, many secondary copper smelters and refiners ceased operations in the early 1990s. According to published industry information, the companies currently operating in NAICS 331423 (Secondary Smelting, Refining, and Alloying of Copper) include no secondary smelters, six fire refiners (mostly tube or wire mills), and 23 copper alloyers (CDA, 2003). [181] While both the refiners and alloyers utilize copper scrap, only the alloyers actively seek out copper-beryllium scrap and produce copper-beryllium alloys. All three copper refiners that ERG contacted stated that they do not handle copper-beryllium scrap (Warrenton Copper, 2001; Cerro Copper, 2001; Southwire, 2001). These refiners may, however, receive and process copper scrap with trace amounts of beryllium contamination, which may be identified when the scrap is sampled. Thus, the only companies in NAICS 331423 that deliberately handle copper-beryllium scrap materials are the alloyers.

Establishments producing aluminum-beryllium alloys from aluminum alloy scrap do generate beryllium exposures. ERG's industry contacts indicate that, among establishments in NAICS 331314 (Secondary Smelting and Alloying of Aluminum), only a few secondary aluminum smelters and alloyers handle aluminum-beryllium scrap alloys and produce aluminum-beryllium

[181] The 2010 Census data used in Table IV-33 are more recent than those provided by the industry source, but do not provide the same level of disaggregation. Also, the Census information refers to facilities rather than to the firm-level information available from the industry source.

alloys. Such aluminum alloyers produce master aluminum-beryllium alloys, primarily for use as stabilizers (deoxidizers), hardeners, and grain refiners in the production of aluminum and aluminum alloys. American producers offer aluminum-beryllium master alloys that are 1.0 percent, 2.5 percent, or 5.0 percent beryllium (Diroccho; 2002; Milward, 2011). [182]

Establishments that recover precious metals, classified in the 331492 NAICS code, may also generate beryllium exposures. However, OSHA has no exposure data to characterize the nature of beryllium exposures in this industry. Since precious metals are rarely found with beryllium, OSHA does not believe exposures in this industry may be as common as in the recovery of copper (and aluminum to a smaller extent) as copper-beryllium alloys are widely used. It is possible that some precious metal scrap may contain beryllium, such as nickel, since nickel-beryllium alloys have some industrial applications. In case exposures exist in this industry, engineering controls described in this section will be equally applicable to this industry as well as the other two industries. This is because the recovery of precious metals requires the same operations as the recovery of copper or aluminum, i.e., smelting, refining, and alloying (ingot making).

Producers of Copper-Beryllium and Aluminum-Beryllium Alloys

Based on industry contacts, a review of The Thomas Register, and Internet searches, OSHA identified six companies that currently produce copper-beryllium or aluminum-beryllium alloys.

One of these is Materion Corporation[183] (classified in NAICS 331419, Primary Smelting and Refining of Nonferrous Metals), and another is NGK Metals (classified in NAICS 331421, Copper Rolling, Drawing, and Extruding), with a single establishment in Sweetwater, Tennessee. All of the activities performed by Materion Corporation are covered in Sections 3, Beryllium Production, and 4, Beryllium Oxide Ceramics and Composites, of Chapter IV, Technological Feasibility, of the Preliminary Economic Analysis (PEA), and are therefore not included in this section. NGK Metals also produces rolled and extruded copper-beryllium products. The activities performed by NGK Metals are covered in Section 8—Copper Rolling, Drawing, and Extruding, of Chapter IV of the PEA.

Three additional companies are classified in NAICS 331423, Secondary Smelting, Refining, and Alloying of Copper. One of these companies processes beryllium scrap and produces copper-beryllium alloys for specialty applications. This company has one location and 90 employees (Belmont Metals, 2001). Another company specializes in beryllium alloys and produces nickel-beryllium and aluminum-beryllium in addition to copper-beryllium (Freedom Alloys, 2005). Details about the size of this single-establishment firm were not available. The third company produces copper-beryllium alloys in the form of billets and slabs, using both scrap and purchased

[182] Small quantities of the master alloy are added to the aluminum melt during the production process to reduce magnesium losses (Diroccho, 2002; KB Alloys, 2005; Lefgren, 2002). Beryllium oxidizes more readily than magnesium, thereby limiting oxidation of magnesium in the melt (Lefgren, 2002). Small beryllium additions to the melt also improve the surface quality of the die-cast billets and impart improved mechanical properties for premium quality aluminum castings (KB Alloys, 2005).
[183] Materion Corporation used to be called Brush Wellman. In 2011, however, subsequent to the collection of the information presented in this chapter, the name changed. “Brush Wellman” is used whenever the data being discussed pre-date the name change.

master ingots (90 percent copper, 10 percent beryllium) as inputs, and reports that the alloying process requires three workers on each of three daily shifts (Specialloy, 2000). The remaining company specializes in aluminum alloys and is classified in NAICS 331314, Secondary Smelting and Alloying of Aluminum. This firm reports that 10 to 15 percent of its employees are occasionally involved in aluminum-beryllium master alloy production (Mulcahy, 2002).

Although detailed employment data are not available for the four establishments specializing in beryllium alloy production (i.e., excluding Materion Corporation and NGK), Census-based industry statistics for NAICS 331423 and 331314 show an average of 40.2 and 50.4 employees per establishment, respectively (U.S. Census Bureau, 2010). NGK's employment is not known, but the average employment for NAICS 331421 (Copper Rolling, Drawing, and Extruding), where it is classified, is 103 workers. Table IV-34 summarizes employment estimates for these establishments, based on industry averages.

Precious Metal Recovery

Establishments engaged in precious metal recovery from scrap are classified in NAICS 331492, Secondary Smelting, Refining, and Alloying of Nonferrous Metal (Except Copper and Aluminum). These establishments recover precious metals from copper scrap extracted from electronics equipment and other wastes. Recovery establishments may also perform recycling and demanufacturing, and thus, may also undertake sorting, testing, and shredding processes. Recovery establishments use several methods to separate the precious metals from the copper scrap, including chemical and electrolytic separation, thermal reduction and burning, melting and pyro-metallurgic separation, and milling. The 2007 Economic Census reports 29 firms in NAICS 331492 with sales greater than $100,000 that produce "secondary precious metals and precious metal alloys." Although the exact number is unknown, OSHA estimates that about 30 establishments nationwide recover precious metals from electronic scrap and therefore, could encounter copper-beryllium alloys . Based on the average employment per establishment in this industry, OSHA estimates that these 30 establishments employ 1,173 total workers. These estimates are also shown in Table IV-34.

Table IV-34—Refiners and Alloyers Producing Beryllium Alloys and Precious Metals and Alloys

NAICS Industry	Affected Establishments	Affected Employees
331421, (Copper Rolling, Drawing, and Extruding): Producers of Cu-Be alloys	*1*	*103*
331314, Secondary Smelting and Alloying of Aluminum: Producers of Al-Be alloys	*1*	*40*
331423, Secondary Smelting, Refining, and Alloying of Copper	*3*	*99*
331492, Secondary Smelting, Refining, and Alloying of Nonferrous Metal (Except Copper and Aluminum): Producers of secondary metals and precious metal recovery	*30*	*1173*
Total	*35*	*1,414*
Sources: U.S. Census Bureau, 2007; U.S. Census Bureau, 2010; OSHA estimates. See text.		

Table IV-34—Refiners and Alloyers Producing Beryllium Alloys and Precious Metals and Alloys

NAICS Industry	Affected Establishments	Affected Employees
Note: Excludes Materion Corporation's Elmore, Ohio, plant, and NGK Metals.		

While beryllium could be encountered in other types of secondary metal recovery, OSHA found no evidence of such exposures outside of those handling copper scrap and other beryllium-containing alloys or recovering precious metals (CDA, 2003; OSHA, 2009; U.S. Census Bureau, 2007; U.S. Census Bureau, 2010). A review of beryllium samples contained in OSHA's Integrated Management Information System (IMIS) database, covering the period 1994 through 2002, shows few detectible samples for establishments not engaged in secondary copper smelting (all of which are now closed), copper refining and alloying, or precious metal recovery (OSHA, 2009). In OSHA's judgment, the establishments shown in Table IV-34 represent those in this application group affected by OSHA's proposed beryllium standard. Among the NAICS associated with this application group, the vast majority of affected establishments (and workers) are engaged in precious metal recovery (NAICS 331492—Secondary Smelting, Refining, and Alloying of Nonferrous Metal (Except Copper and Aluminum)).

PROCESS DESCRIPTION

Secondary metal processing and recovery is the processing of metal-containing materials to recover and reuse the metal(s). The workers who process and recover metals may be broadly grouped into two major categories: mechanical process operators who handle and treat source material (i.e., break down scrap materials) and furnace operations workers who run the various heating processes for refining, melting, and casting refined metal alloy. Both groups of workers are responsible for performing housekeeping in their work areas and are also called upon to sample the scrap and intermediary materials to determine recoverable metal content. The scale of the operation and the specifics of the recovery process vary depending on the industry as well as the facility, and not all metal processing industries or facilities have the same mix of worker activities. For example, some facilities engaged primarily in alloying may not utilize recovered, recycled, or purchased scrap in their operations (i.e., these alloy ingot makers use only purchased raw materials). Table IV-35 summarizes key operations associated with secondary metal processing.

Table IV-35—Summary of Secondary Metal Processing Operations*

Job Category	Key Operations
Mechanical process operators	• *Mechanical separation* • *Solvent, hydrometallurgical, and other cleaning* • *Collecting samples of starting and intermediary materials to determine recoverable metals* • *Cleaning work areas*
Furnace operations workers	• *Furnace charging; melting/smelting, reducing, and oxidizing processed scrap material (including pyrometallurgical cleaning)* • *Alloying and refining*

Table IV-35—Summary of Secondary Metal Processing Operations*	
Job Category	**Key Operations**
	• *Pouring/casting and finishing metal alloys (e.g., as ingots)* • *Collecting samples of intermediary and finished materials to determine metals content* • *Cleaning work area*
* *Not all industries or facilities use all of the processes or operations.* *Sources: Kent et al., 2007; ERG Site Visit, 2005; NIOSH EPHB 326-12a, 2008; ERG Beryllium Site 2, 2003; ERG Beryllium Site 7, 2003; EPA EIIP, 2001.*	

Mechanical Processing Operators

Mechanical process operators prepare scrap for melting by sorting and processing the scrap to separate the metal of interest from other metals (potentially also of interest) and from unwanted materials such as plastics, paint, oil, and dirt. The most commonly used techniques include mechanical separation using crushing and grinding machinery, centrifugation, pyrometallurgical cleaning (burning by furnace operations workers), solvent and hydrometallurgical cleaning, and heavy media separation. One or more of these techniques are used by all secondary metal processing facilities (EPA EIIP, 2001).

Mechanical separation includes sorting, shredding, crushing, pulverizing, and other mechanical methods to reduce the scrap to smaller pieces. Reducing the scrap to smaller pieces helps remove unwanted materials and concentrate the metal for additional processing. Methods used to concentrate metals include screening, magnetic removal, eddy currents, and pneumatic classification (EPA EIIP, 2001). Sometimes feed scrap is briquetted in a hydraulic press (EPA 310-R-95-010). Metal dusts, including beryllium dust, might be generated during mechanical processes.

Workers also use other methods to separate scrap from recoverable metals; however these processes are primarily wet processes. Examples include solvent cleaning used to remove oils and grease from scrap; hydrometallurgical cleaning (leaching)—a washing step to remove water-soluble contaminants from crushed scrap; and centrifugation (rare), also to remove oils and grease from scrap. In some cases, workers use heavy-media separators containing a viscous water medium to separate high-density metal from low-density metal.[184] No evidence exists that workers are exposed to beryllium while performing these wet processes.

Mechanical process operators are also responsible for housekeeping in their work areas and for sampling process materials before or after processing (NIOSH 326-12a, 2008; ERG Beryllium Site 2, 2003; Kent et al., 2007). The samples are analyzed to quantify the recoverable metals at key stages in the process; the preparation of such samples can involve mechanical processing activities (e.g., a sample may be taken after material is ground in a ball mill). Samples can be collected indoors or outdoors, and manually or with the use of material handling equipment, such

[184] During heavy-media separation, metal-containing scrap is added to water amended with chemicals to create a high-density liquid. Under pressure from a compressed air source, low-density metal rises to the surface of the liquid medium and forms a layer of valuable solids that is subsequently removed (EPA EIIP, 2001).

as a fork lift truck (Corbett, 2005). In the past, sampling tasks were sometimes performed by dedicated workers (NIOSH HETA 83-162-1746).

FURNACE OPERATIONS WORKERS

Melting separates the metals of interest from their metallic compounds and removes contaminants remaining after mechanical processing. Melting is used to make alloys and allows castings to be made from the liquid metal. Furnaces or heated crucibles are used for melting, and heat sources include fuels or electricity (EPA EIIP, 2001).

Furnace operations workers charge (load) furnaces with a mixture of pretreated scrap, flux materials, fuels, and other materials as required. The flux materials used depend on the type of metal being processed and can chemically break metallic oxide bonds to produce pure metal (chemical reduction). Flux materials may also further purify the metal by oxidizing impurities in the scrap (EPA EIIP, 2001).

Furnace operations workers can use a series of furnaces for these processes. For example, pyrometallurgical cleaning and separating is performed in furnaces intended for sweating (taking advantage of differences in melting temperature to melt specific metals out of mixed scrap) or roasting (burning other wastes out of scrap metal).[185] As another example, copper recovery facilities use two different furnaces to produce high-purity copper. [186] As a third example, the zinc industry may use distillation furnaces to recover zinc and other metals.[187]

After the metal is refined, furnace operations workers pour the molten metal from the furnace into molds that form bars, ingots, or a final product. The workers allow the metal shape to cool and then remove it from the mold. If the formed metal is a final product, the furnace operator may perform some type of finishing work, such as abrasive blasting, to remove mold sand or scale, or grinding or sanding to smooth rough edges (EPA EIIP, 2001). In some facilities, bars and ingots are sent to another facility for further alloying or to make a final product. Furnace operations workers are responsible for housekeeping duties in their work areas (Kent et al.,

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[185] During pyrometallurgical cleaning (technically a form of scrap cleaning, grouped here functionally because it is a furnace operation), the furnace operator uses heat to separate the metal of interest from other metals and contaminants and is accomplished by sweating and roasting processes. During sweating, furnace operations workers heat scrap to temperatures above the melting point of the metal of interest but below that of the other metals. Workers can be exposed to metal fumes in the process. For example, sweating is used to recover aluminum from high-iron-content scrap by heating the scrap to temperatures above the melting point of aluminum but below the melting point of iron. In contrast, the lower temperature roasting process involves heating metal scrap that contains organic contaminants to temperatures high enough to vaporize or carbonize the organic contaminants but not high enough to melt the metal of interest (thereby minimizing release of metal fumes). Burning insulation from copper wire is an example of roasting (EPA EIIP, 2001).

[186] A blast furnace is used initially to melt copper scrap into impure copper and slag (nonmetallic impurities), and then a reverberatory furnace is used to produce higher purity copper from the impure (blast furnace) copper (EPA EIIP, 2001).

[187] Another method of metal refining is distillation. When processing metal by distillation, workers vaporize the molten metal in a furnace, condense the vapor, and recover the metal in different forms. In the zinc industry, zinc is recovered in several forms depending on the equipment used, recovery time, temperature, and presence or absence of oxygen (EPA EIIP, 2001). The industries that recover zinc may be found in NAICS 331492.

2007). Depending on the size of the establishment, one worker might perform all these furnace-related operations, or some of the tasks might be assigned to specialized workers.

EXPOSURE PROFILE

To determine the exposure profile of secondary smelting, refining, and alloying workers, OSHA reviewed exposure data from two ERG site visits; one to a precious/base metals recovery facility and one to a facility that melts and casts beryllium-containing alloys (ERG Beryllium Site 2, 2003; ERG Beryllium Site 7, 2003). ERG also visited an electronic scrap recycling facility, although no exposure monitoring was performed (ERG Site Visit, 2005). Additionally, OSHA considered a robust dataset from a 1983 NIOSH Health Hazard Evaluation (HHE) at a precious metals refinery but determined that, due to changes in exposure controls within this industry, exposures at facilities *currently* engaged in precious metals recovery are not well represented by the sample results from that study (NIOSH HETA 83-162-1746). Each of these reports is summarized briefly below. Finally ERG reviewed results from three NIOSH visits to electronic recycling operations (disassembly/deconstruction facilities) conducted at federal penal institutions in 2007 and 2008, and a study of industries that handle beryllium-containing materials in France, but determined that these reports did not represent the potentially exposed populations in the United States; therefore, sample results from these sources are not included in the exposure profile (ERG Site Visit, 2005; NIOSH EPHB 326-12a; EPHB 326-15a; EPHB 326-17a; Vincent et al., 2009).[188]

Exposure data from secondary smelters were not incorporated into the exposure profile because currently no secondary copper smelters are operating in the United States, and OSHA has no exposure data for workers at aluminum smelters or other nonferrous metal smelters. The markedly smaller share of aluminum-beryllium alloys produced in comparison to copper beryllium alloys suggests that the beryllium scrap from aluminum-beryllium alloys in the likely input stream of all smelters would be minimal. However, OSHA is not able to verify this due to the lack of exposure data from aluminum smelters.

Data Sources

ERG Beryllium Site 2—Precious and Base Metals Recovery Facility

ERG Beryllium Site 2 is a precious and base metals recovery facility, and is classified under NAICS code 331492. ERG investigators visited this facility in 2003 to characterize worker exposure to airborne and surface levels of beryllium (ERG Beryllium Site 2, 2003). ERG Beryllium Site 2 buys scrap materials containing precious metals (e.g., silver, gold, platinum, palladium, iridium, rhodium, ruthenium) from electronic, automotive, jewelry, metal-coating, and fabrication industries; processes the materials; and then sells the recovered metals. Lower grade materials containing precious metals are assayed (sampled and analyzed) and then shipped

[188] The circumstances surrounding worker exposures in foreign work places can differ from those in the United States for many reasons, including (but not limited to) differences in regulations and occupational exposure limits, enforcement policies, safety culture and related resources, employee work culture, number of hours in the standard work day or week, labor organization initiatives, concentrations of hazardous substances in materials, process equipment used, level of worker awareness and communications, control technology available, industry classifications, and typical facility size.

to an offsite smelter. ERG Beryllium Site 2 has no direct knowledge about the beryllium content of the scrap metals it processes and does not impose any beryllium limits on incoming materials. The facility process operations include material receipt and handling, mechanical preparation, granulation/shredding, thermal reduction, ball milling, screening, blending, melting, drying/grinding, and electrowinning (ERG Beryllium Site 2, 2003).

Generally, ERG Beryllium Site 2 operates one 8-hour shift per day, five days per week, 50 weeks per year. However, the thermal reduction process runs 24 hours per day (3 shifts), 5 days per week. The work force at the site consists of 75 employees (110 companywide), including approximately 18 full-time workers with potential beryllium exposure. The facility processes approximately 15 million pounds (lbs) of electronic scrap per year and was reportedly at 50 percent capacity at the time of the visit. ERG investigators reported four operations at the site with potential beryllium exposure, including shredding, thermal reduction, milling/blending, and melting. ERG conducted personal air monitoring of workers in these processes. Although some of the samples were not full-shift (4 hours rather than at least 6 hours), OSHA has nonetheless included them in the exposure profile because these samples represent part of the best available information to OSHA.

The following descriptions indicate the activities performed by workers at this site. OSHA has grouped the shredding mill and mill blend operators into the mechanical processing job category, and the thermal reduction and melting operators into the furnace operations job category.

The ***shredding mill operator*** receives cardboard containers of scrap electronic components, including printed circuit boards, crucibles, electronic modules, and telephones. Scrap material is loaded onto a shaker table with a forklift, pulled from the shaker table onto a conveyor, and passed through a hammer mill/shaker screen and ring mill/shaker screen combination that reduces the scrap to ⅝-inch pieces. A collection box at the end of the process fills in approximately 7 to 10 minutes, is moved to storage, and then the process is repeated. Samples are collected during shredding by an automated sampling feature integrated within the process. Shredded samples undergo additional processing to determine the precious metals value of the scrap lot. Miscellaneous tasks completed by the shredding mill operator during the shift include changing the shaker screen drum, changing the baghouse drum (filtration system), housekeeping, and administrative duties (ERG Beryllium Site 2, 2003).

The ***thermal reduction operator*** loads dry components and precious metal-containing scrap, both of which may contain organic materials, into gas-fired convection furnaces that operate at 1,400°F. The furnaces drive off the organics into an emissions collection system, leaving behind the precious metals for recovery. The work tasks associated with this process include loading and unloading the furnace, material transport and handling, housekeeping, and administrative duties. The process operates for three 8-hour shifts, five days per week (ERG Beryllium Site 2, 2003).

The ***mill/blend operator*** receives prepared metallic, precious metal-containing scrap in 55-gallon drums. The prepared scrap input material is received from shredding, thermal reduction, or grinding (the grinding department was not operating during the ERG visit). Scrap and intermediate powder-like products are poured, vacuum-conveyed, or at times, manually transferred from input drums or intermediate product containers through a series of processes that include ball milling, blending, and screening. After screening, two samples (about 30 to 40 ounces each) are collected from each batch of processed scrap for laboratory analysis. ERG investigators identified the screening task as a good candidate for task-specific sampling because the operator leans into the drum, and fine powder was observed escaping the local exhaust ventilation (LEV) system (ERG Beryllium Site 2, 2003).

The ***melting operator*** processes precious-metal-bearing scrap in one of three induction furnaces (250 lb, 500 lb, or 750 lb). The scrap input material is predominately metallic and relatively free of organic contaminants. The work tasks associated with this process include furnace charging, melting, sampling, mold preparation, pouring, rubbing slag from the furnace lining, ingot removal from molds, mold quenching, and mold slag removal with a compressed air needle gun. ERG investigators identified the pouring task as a good candidate for task specific sampling because metal fumes were observed escaping the LEV system (ERG Beryllium Site 2, 2003).

Controls in Place
During the site visit, ERG investigators noted the use of the following exposure controls (Corbett, 2005; ERG Beryllium Site 2, 2003), as discussed herein. Workers are required to change into company-provided work clothes/shoes and don respiratory protection before entry into restricted areas. Respiratory protection includes half-mask air-purifying respirators with HEPA filters (for all workers not in the melt shop) and loose-fitting, powered air-purifying respirators with HEPA filters (for melt shop workers, including the melting operators). Gloves (cotton/leather) are worn as necessary for abrasion/cut protection. Showers are required at the end of the work shift. Worker clean/dirty change rooms, lunch/break rooms, hygiene facilities, and personal protective equipment storage are provided by the employer. Work uniforms are laundered off site by an outside vendor. Written housekeeping procedures have been established for each department, and a central vacuum system is provided in the mill/blend department to assist with housekeeping.

LEV systems are provided to control aerosols generated by the processes. In the shredding department, LEV is provided through either partial or full enclosures on the hammer mill, ring mill, transfer conveyors, and screening stations. The thermal reduction unit is an enclosed furnace that is ducted to an afterburner and baghouse filtration system. The mill/blend processes are operated under negative pressure, with isolated product transfer and milling ducted to the central vacuum and baghouse filtration systems. The melt shop has canopy hoods installed over the furnaces to capture metal fumes during melting and pouring.

Although LEV is provided, ERG investigators observed visible emissions escaping the hoods (especially in the melting shop and milling/blending departments) and recommended that a ventilation engineering firm be used to redesign the current layout of the system (ERG Beryllium Site 2, 2003). The LEV was deemed to be less than optimal due to inappropriate hood design and lack of adequate capture. Investigators also observed open handling and transfer of powder-like materials to and from 55-gallon drums and suggested a need for work practice controls and improved particulate capture via ventilated process hoods and enclosures (Corbett, 2005).

ERG Beryllium Site 7—Melting and Casting Beryllium-Containing Alloys
ERG investigators visited this alloyer in 2003 to characterize worker exposure to airborne and surface levels of beryllium (ERG Beryllium Site 7, 2003). ERG Beryllium Site 7, classified under NAICS code 331421, manufacturers over 1 million lbs. of beryllium-containing casting

and master alloys annually. The company manufactures copper-beryllium, aluminum-beryllium, and nickel-beryllium alloy products with beryllium content ranging from 0.35 percent to 10.5 percent. All beryllium alloys are manufactured using high-purity metallic beryllium or certified master alloys.

Casting at ERG Beryllium Site 7 is done by three workers during the night shift, with only one casting done on an average night. One or more induction furnaces are loaded with pure metal ingots and beryllium master alloy ingots (primarily by hand) from crates hoisted into place above the melting pot. All three workers are involved in removing ingots from the crates and filling up the furnace. Once the furnace is loaded, heat is applied and the melt begins. Inert gas cover and degassing technology, along with automatic furnace controls and ingot mold conveyors, are utilized for melting and casting operations. During melting, dross (metal oxides in or on the surface of molten metal) is skimmed off the surface, and the melt is sparged to ensure complete mixing (i.e., gas is introduced into the furnace to stir the melt). The majority of the shift, however, is spent in the office waiting for the melting to be completed (ERG Beryllium Site 7, 2003).

When the melt is complete, the pour begins. The furnace is tilted in place to pour the molten metal into molds. The type of mold selected depends on customer specifications and can change from pour to pour. The cast materials are allowed to cool and then are placed either by hand or with a lift truck into containers for shipment. Larger molds may be trimmed using a band saw with lubricant stream before being shipped (ERG Beryllium Site 7, 2003).

ERG investigators monitored all three workers involved with the melting and casting operations. Worker job descriptions include furnace operator, furnace helper, and forklift operator. The furnace operator oversees the melt and subsequent pour from the furnace. During the melt, the furnace operator works from a 1-meter high platform surrounding the furnace. Work tasks include rubbing, skimming, and sparging. Dross is skimmed using a ladle and thrown into a bucket underneath a hood on the work platform. (Investigators noted that the method used to transfer dross causes contamination to be spread outside the ventilated buckets.) Much of the time involves waiting for the loaded furnace to melt the ingots placed in it at the start of the shift. During that time, all the workers generally are in the office, as noted previously. From time to time, the furnace operator leaves the office and returns to the work platform to check the temperature of the melt and may collect samples for analysis before the pour begins. During the pour, the furnace operator controls the pour into the mold or tundish (ERG Beryllium Site 7, 2003). The furnace helper assists the furnace operator and is usually nearby (ERG Beryllium Site 7, 2003). However, the furnace helper does not participate in and is not close by during the pour (ERG Beryllium Site 7, 2003). During the ERG visit, the pour lasted 15 to 20 minutes (ERG Beryllium Site 7, 2003).

The forklift operator moves the crates containing the furnace charge material (ingots) using an open-cab forklift. The ingots are primarily unloaded by hand into the furnace. The forklift operator moves the tundish into position, may remove billets from the mold if a larger single piece is being cast, and cuts the billets on the band saw, if necessary, depending on customer specifications (ERG Beryllium Site 7, 2003).

ERG investigators collected a total of four personal breathing zone (PBZ) total beryllium samples for the three workers described above, which were analyzed by OSHA Method ID-125G (Metal and Metalloid Particulates in Workplace Atmospheres) using inductively coupled argon plasma-atomic emission spectroscopy (ICAP-AES). The laboratory analytical reporting limit was 0.02 micrograms per filter. As with ERG Beryllium Site 2 (2003), three of the samples are less-than-full-shift duration (two for furnace helper and one for forklift operator). Nevertheless, OSHA has determined that in the absence of other recent exposure data for comparable facilities, these sample results offer the best available information on this portion of the industry, although, for reasons explained below, they might overestimate exposures somewhat.

Controls in Place
The primary exposure control in the facility is a canopy hood located over the furnace to capture fumes from the melt. LEV includes canopy hoods over casting stations, ingot conveyors, and dross buckets (Corbett, 2005). The main hood covers the charge platform for the furnace such that workers stand in the path of the exhaust ventilation over the furnace. The transfer of rubbing and skimming tools from the furnace is not ventilated (i.e., rubbing and skimming tools are fuming when they are removed from the furnace), and a significant number of 90-degree transitions in the exhaust ducts were noted (Corbett, 2005).

Workers wear company-provided work clothes, and a washer and dryer are available on the premises for cleaning these clothes. During the pour, aluminized/heat-reflective suits and gloves are required for thermal protection. All three workers wear respiratory protection during the pour; at other times some workers don respirators whenever fume is visible. The furnace room and the offices are not separated by different air supply systems, and the doors between them are usually open. Evidence of cross-contamination is visible, as the graphite used to coat the molds for quick release of the ingots can be seen covering numerous surfaces in the offices (ERG Beryllium Site 7, 2003).

Additional Sources of Information

The following sources also contributed information to this analysis. Exposure data from these sources are not included in the exposure profile but were considered in OSHA's analysis.[189]

ERG Walk-through Visit at an Electronic Recycling and Sampling Facility[190]

ERG staff visited a facility that receives and samples regular-grade electronic scrap (including circuit boards, integrated circuits, trim from circuit board manufacturing, connectors, and other electronic parts) prior to shipment to the company's smelter (at a different location) (ERG Site Visit, 2005). The firm also receives some metallic inputs, such as scrap from a copper punching operation. The non-electronic scrap represents only about 15 percent of its inputs. Circuit boards comprise about 80 percent of the electronic scrap. The sample results determine the payment customers will receive for the precious metal content recovered from the shipments. The samples

[189] For example, exposure data are excluded from the exposure profile when all of the following occur for data in consideration: (1) the sample duration is less than full shift, (2) the source includes only grouped data (rather than individual sample results), and (3) supporting information (e.g., sample duration, job category) is insufficient for the purposes of this analysis.
[190] See Appendix A for more detailed information on this site visit.

also identify hazardous constituents in the samples and are used to determine whether the facility is willing to process the materials. Beryllium is typically not a major constituent of this scrap. In fact, the facility will not accept scrap with beryllium levels exceeding 200 parts per million.[191]

No personal or area sampling was conducted during the ERG visit, but facility representatives informed ERG interviewers that employees are monitored for beryllium exposure on a monthly basis. The company uses an 8-hour time-weighted average (TWA) action level of 0.1 μg/m^3 for PBZ samples but typically maintains exposure levels of 0.03 μg/m^3.

NIOSH Visits to Federal Penitentiary Electronic Recycling Operations

Between August 2008 and January 2009, NIOSH investigators conducted studies of the recycling of electronic components at Federal Prison Industry operations at three federal penitentiaries to assess workers' exposures to metals, including beryllium, and to other occupational hazards associated with these operations (e.g., lead, cadmium) (NIOSH EPHB 326-12a; NIOSH EPHB 326-15a; NIOSH EPHB 326-17a). The processes NIOSH observed included receiving and sorting, disassembly, glass-breaking operations, packaging and shipping, and cleaning and maintenance.

Material received for recycling primarily consisted of computers (both desktops and laptops) and related devices such as printers. Electronic memory devices were removed and degaussed or destroyed, and CPUs, servers, and similar devices were sent for disassembly. Monitors and other devices with CRTs were sent for disassembly and removal of the CRT. Inks and toners were removed from printers, copiers, and other similar equipment prior to being sent to the disassembly area.[192]

During disassembly, the devices were taken apart, and valuable materials such as copper wiring and aluminum framing were removed and sorted by grade. Components such as circuit boards or chips that might have value or otherwise contain precious metals such as gold or silver were also removed and sorted. In the glass-breaking operation, workers used hammers to remove electron guns from CRTs and then break the funnel glass. During the subsequent packing and shipping operations, materials (i.e., those separated during disassembly and glass breaking activities) were moved to the loading dock for shipment. Some items, such as plastic cabinets and metal frames were compacted for easier shipment, while other materials were boxed prior to shipment.

Combined, NIOSH researchers took 112 PBZ samples during the recycling operation visits. Almost all of these samples were less than full shift in duration (i.e., < 360 minutes), and only two showed detectable levels of beryllium. Both of these samples were less than 4 hours in duration and included results of 0.07 µg/m^3 (187 minutes) for a metal bailer and 0.08 µg/m^3 (164 minutes) for a disassembly worker. The remaining sample results all indicated that exposure concentrations were less than the limits of detection (LODs), which ranged from 0.005 µg/m^3 to 0.1 µg/m^3 (most were 0.03 µg/m^3 or less).

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[191] According to Cunningham (2004), the low beryllium content (e.g., 2 percent) of most beryllium alloys used in electronic applications results in most such scrap being reclaimed for its copper and precious metal values. Little beryllium is recovered.
[192] CPU: central processing unit; CRT: cathode-ray tube.

NIOSH reported that engineering controls were used at two of the three locations at which the glass breaking was performed. At one of those locations the controls consisted of an enclosed booth with an LEV system. At the other location, glass breaking was performed beneath a large ventilated walk-in hood. Glass breaking was the only process where LEV was utilized.

The evidence from these studies indicates that workers engaged in recycling operations such as those sampled by NIOSH (demanufacturing and CRT recycling) are not at risk of significant beryllium exposures. However, the operations at these facilities did not include crushing, shredding, sampling, or melting activities (such as observed at ERG Beryllium Site 2), which might be expected to produce significant exposures (see Table IV-37). Because workers at these facilities are not engaged in activities that create risk of exposure to beryllium (even without control measures), the sample results from these evaluations are not included in the exposure profile.

Kent et al.—Air Monitoring of Cellular Telephone Recycling at an Electronic Scrap Processing Facility

Investigators conducted air monitoring for metals, including beryllium, while workers recycled cellular telephones at an electronic scrap processing facility. The sampled operations included shredding, roasting, milling (including screening to separate -20 to +20 mesh fractions of crushed material), and assaying (sampling and analyzing) recycled cellular phones. A sample of five phones contained 52 parts per million (ppm, by weight) beryllium.[193] The summarized results of multiple 8-hour PBZ samples indicated that no worker exposure exceeded 0.2 µg/m^3 (the company's internal occupational exposure limit) during any of the operations. Average beryllium concentrations over a 5-week sampling period were 0.01 µg/m^3 for shredding (16 samples), 0.01 µg/m^3 during roasting (18 samples), 0.02 µg/m^3 during milling (9 samples), and 0.05 µg/m^3 for alloying activities (16 samples). At this plant, several measures had been implemented to manage airborne metal dusts, including partial enclosures and exhaust ventilation on the shredder, material sampling equipment, and conveyor belt drop points, as well as at product transfer points associated with the mill, roasting oven, and furnace, and in the ingot descaling (finishing) area (Kent et al., 2007). Individual exposure results were not provided; therefore, the results of this study are not included in the exposure profile.

Vincent et al.—Air Monitoring in Industries Recycling Metal and Non-Metal Waste and Scrap

Investigators in France evaluated beryllium exposures in several industries, including those recycling metal and non-metal waste and scrap. Twenty-three personal and area air samples obtained during dismantling of electrical waste ranged from 0.004 µg/m^3 to 0.038 µg/m^3, with a median of 0.03 µg/m^3 (Vincent et al., 2009). Air samples were 4 to 6 hours in duration and reportedly represented the activities workers performed for their entire shift. Most samples were analyzed by inductively coupled plasma atomic emission spectroscopy (ICP-AES); however, a few were analyzed by atomic absorption spectrometry (depending on the laboratory). Overall, the median reported limit of quantification (LOQ) was 0.015 µg/m^3 (range 0.001 to 0.2 µg/m^3) for all samples obtained in this study of numerous French industries. The sample LOQ

[193] A small part made of beryllium alloy is a standard component in most (and possibly all) cellular phones (Materion Information Meeting, 2012). During this study, beryllium content was chemically analyzed as 52 ppm (0.0052 percent) in a series of 1-gram samples of materials produced by processing five phones through each step of the recycling operation (Kent et al., 2007).

concentration exceeded 0.05 μg/m^3 14 percent of the time (Vincent et al., 2009). The recommended occupational exposure limit for beryllium in France is the same as the current U.S. permissible exposure level (PEL) of 2 μg/m^3. The study did not provide information about worker activities or exposure controls. Together, the four reports described above suggest that beryllium exposure levels are generally low during electronic waste recycling activities. (ERG Site Visit, 2005; NIOSH EPHB 326-12a; Kent et al., 2007; and Vincent et al., 2009).

NIOSH—Precious Metals Refining (Handy and Harman)

NIOSH conducted an HHE at Handy and Harman, Inc. in Fairfield, Connecticut, in July and November 1983 (NIOSH HETA 83-162-1746). Operations at the Handy and Harman facility included refining precious metals from industrial scrap and fabricating silver and gold alloys in various mill forms. NIOSH described operations at Handy and Harman as primarily involving recoverable scrap, including precious metal-bearing scrap from the computer, electronics, chemical, photographic, and decorative industries. The report offers considerable detail on the processes used in this establishment. At the time of the 1983 evaluation, the processes and ventilation systems had remained essentially the same for decades. NIOSH noted numerous areas in which control measures could be improved (i.e., repairing leaking ventilation systems, adding baffles and enclosures, reducing the extent to which materials were intentionally or inadvertently dumped on the floor and later swept or shoveled, and reducing reliance on compressed air for cleaning).

NIOSH investigators collected a total of 160 full-shift (7 to 8 hours) PBZ samples while workers at Handy and Harman were engaged in the following activities: mechanical processing (e.g., crushing, screening, and ball milling), sampling, housekeeping, and furnace and casting operations. NIOSH indicated that sampling was well-distributed across job categories and work shifts. The samples were analyzed by NIOSH for beryllium and various other metals using ICP-AES. The volume-adjusted lower LOQ for beryllium was reported to be 0.5 μg/filter (NIOSH HETA 83-162-1746). By comparison, NIOSH's current LOD for beryllium is 0.005 μg/filter using the NIOSH Method 7300. During NIOSH's 1983 evaluation, a large portion of the sample concentrations (55 percent) were below the LOD, which for that NIOSH evaluation ranged from 0.21 μg/m^3 to 0.6 μg/m^3 (above OSHA's current range of interest for this analysis) (NIOSH HETA 83-162-1746).

OSHA compared the findings from the 1983 NIOSH Handy and Harman HHE to those from more recent studies of precious metal refining operations and determined that many of the same general steps are still in use today; however, concerns about environmental and workplace health and safety have led to increased attention to exposure management (Kent, 2007). As a result, in similar facilities, improved engineering controls and work practices are in place and, thus, current worker beryllium exposure levels are considerably lower than were measured by NIOSH 30 years ago (Kent et al., 2007; Vincent, 2009). Based on the high LOD; the large number of nondetectable samples; and current evidence that in precious metal recovery facilities, exposure levels today are considerably lower than reported in 1983 by NIOSH, OSHA has eliminated this otherwise robust dataset from the exposure profile. The Handy and Harman report remains a source of general information about processes, equipment, and historic exposure levels in the precious metal refining industry and furnace operations in general.

IMIS

ERG reviewed unpublished exposure data from IMIS for beryllium (OSHA, 2009). These data, however, can be difficult to interpret because the database is not designed to capture information pertaining to worker activities, workplace conditions, engineering controls, personal protective equipment, and nondetectable sample concentrations and durations. Furthermore, job categories may not be systematically sampled for possible beryllium exposures. For these reasons, sample results from IMIS are not included in the exposure profile.

The IMIS database for the secondary smelting, refining, and alloying industry contains a total of 655 PBZ samples collected on workers from June 1978 to September 2008 in the matching SIC classifications: 3341 (Secondary Smelting and Refining of Nonferrous Metals); 3399 (Primary Metal Products, Not Elsewhere Classified); and 4953 (Refuse Systems). Detectable levels of beryllium were found for 334 (51 percent) of these samples. Table IV-36 summarizes the IMIS findings. Only positive IMIS results have been included in the analysis because the volume-adjusted reporting limit concentrations for nondetectable samples are not available to ERG. For the SIC groups combined, the median value is 0.6 $\mu g/m^3$, the mean is 1.85 $\mu g/m^3$, and the range is 0.006 $\mu g/m^3$ to 19.0 $\mu g/m^3$. Given that 50 percent of the IMIS entries are nondetectable, the true median for these SIC groups might be less than 0.6 $\mu g/m^3$.[194] It should be noted that all the positive samples reported for SIC 3399 were apparently taken at Materion Corporation's Elmore, Ohio, plant.[195] The results from 1997 and 1999 inspections of that facility were classified under this SIC code. Since Materion Corporation operates a vertically integrated operation, including the production of alloys from beryllium scrap, these sampling results are relevant to the application group under consideration here.

[194] These tables do not include an outlier maximum exposure value of 3,671 $\mu g/m^3$ reported for a worker with the job description of caster. This PBZ sample was collected in 1990 at a beryllium alloyer of 19 $\mu g/m^3$. No information is available to account for such a substantial difference in exposure for this job category.

[195] Based on IMIS sample result information available at http://osha.gov/opengov/healthsamples.html, accessed October 24, 2010.

Table IV-36—IMIS PBZ Total Beryllium Air Sampling Results for Establishments Engaged in Secondary Smelting/Refining, Alloying, and Recycling: SIC Groups 3341, 3399 and 4953[a]

SIC Code	Total Number of Establishments	SIC Description	Total PBZ Samples/ Number PBZ Samples with Positive Results[b]	Job Descriptions (Positive Results Only) (as listed in the IMIS database)	Range[c] (μg/m³)	Mean[c] (μg/m³)	Median[c] (μg/m³)
3341	*79*	*Secondary Smelting and Refining of Nonferrous Metals*	*552/299 (54.2% positive)*	*Arc room arc furnace; assistant operator slab mill; baghouse operator; bail mill 2,3,4; ball mill operator; briquetter operator; caster; charge shed operator #1; crusher; electrician; foundry laborer; furnace operator; furnace helper; incinerator operator; kiln operator; laborer; lead man mill blend; lift truck driver; mold maker; pan man; ring mill operator; saw man; sorter; tool assembly[d]*	*0.006 to 19.0a*	*1.8*	*0.5*
3399	*14*	*Primary Metal Products, Not Elsewhere Classified*	*52/28 (53.8% positive)*	*Furnace operator; helper coiler; laundry operator; lead operator; mill operator; mix make-up operator; trainee*	*0.1 to 9.3*	*2.3*	*1.1*
4953	*22*	*Refuse Systems*	*61/7 (11.5% positive)*	*Bull dozer operator; mechanic/welder; welder*	*0.01 to 12.0*	*1.8*	*0.01*
Total	**115**		**665/334 (50% positive)**		**0.006 to 19.0**	**1.85**	**0.6**

[a] *This table does not include an outlier maximum exposure value of 3,671 μg/m³ reported for a worker with the job description of caster. This PBZ sample was collected in 1990 at a beryllium alloyer covered by this application group. However, a second sample collected on a caster at this facility on the same date had a result of 19.0 μg/m³. No information is available to account for such a substantial difference in exposure for this job category.*

[b] *Includes all PBZ samples by SIC code.*

[c] *The range, mean, and median results are based on positive sample results only. All positive results are included regardless of the total sample time.*

[d] *Summarized job descriptions. The complete listing of job descriptions for SIC 3341 with positive results includes 80 different descriptions as entered into the IMIS database.*

Source: OSHA, 2009 (OSHA Integrated Management Information System). Information regarding worker activities, the engineering controls in place, personal protective equipment worn during sampling, and nondetectable sample concentrations and durations is not available through the IMIS database.

Exposure Profile by Job Category

To determine the exposure profile of refining, smelting, and alloying workers, OSHA used data from the ERG site visits to a precious/base metals recovery facility and a facility that melts and casts beryllium-containing alloys (ERG Beryllium Site 2, 2003; ERG Beryllium Site 7, 2003). Together, these sources cover all the work activities in secondary refining, smelting, and alloying facilities discussed in this section. The sample results contained in these reports represent the best exposure data available to OSHA to characterize beryllium exposure in the refining, smelting, and alloying application group. Although recent exposure data for this application group are extremely limited, OSHA finds that these limited data are well supported by summary information in other recent reports that could not be included in the exposure profile because of insufficient detail.

Tables IV-37 and IV-38 represent the exposure profile for refining and alloying establishments. These tables summarize all of the available full-shift PBZ total beryllium exposure data. Nondetectable sample results are included in the exposure profile (all less than 0.1 µg/m^3). Results reported as less than the analytical LOD or LOQ are incorporated into the exposure profile as volume-adjusted LOD or LOQ (reporting limit) concentrations. This is a conservative approach that may overestimate the exposure results.

Table IV-37—Personal Exposure Profile in the Refining, Smelting and Alloying Application Group (NAICS 331314, 331423, 331492)[a,b]

Job Category	No. of PBZ Samples	Range (µg/m^3)	Mean (µg/m^3)	Median (µg/m^3)
Mechanical processing operator	*3*	*0.03 to 0.2*	*0.14*	*0.20*
Furnace operations worker	*6*	*0.03 to 14.08*	*3.85*	*2.15*
Beryllium recovery and alloying	*4*	*1.92 to 14.08*	*5.64*	*3.28*
Other recycling and precious metal recovery	*2*	*0.03 to 0.5*	*0.26*	*0.26*
TOTAL	**9**	**0.03 to 14.08**	**2.61**	**0.5**

[a] Sample results are used as presented by the source investigators. Sample duration is greater than or equal to 6 hours for all results, except the furnace operations worker job category, which includes three samples of 265 to 314 minutes duration.

[b] Nondetectable sample results are included in the exposure profile. Results reported as less than the analytical limit of detection (LOD) or quantitation (LOQ) are incorporated into the exposure profile as volume-adjusted LOD or LOQ concentrations. This is a conservative approach that may overestimate the exposure results. All such results are less than 0.1 µg/m^3.

Sources: ERG Beryllium Site 2, 2003; ERG Beryllium Site 7, 2003

Table IV-38—Distribution of Full-Shift PBZ Exposure Results for Total Beryllium in the Refining, Smelting and Alloying Application Group (NAICS 331314, 331423, 331492)[a,b]

Job Category	Number of Results in Range (µg/m^3)						Total
	< 0.1	≤ 0.1 to ≤ 0.2	> 0.2 to ≤ 0.5	> 0.5 to ≤ 1.0	> 1.0 to ≤ 2.0	> 2.0	
Mechanical processing operator	*1 (33.3%)*	*2 (66.7%)*	*0 (0.0%)*	*0 (0.0%)*	*0 (0.0%)*	*0 (0.0%)*	*3 (100.0%)*
Furnace operations workers (total)	*1 (16.7%)*	*0 (0.0%)*	*1 (16.7%)*	*0 (0.0%)*	*1 (16.7%)*	*3 (50.0%)*	*6 (100.0%)*

Table IV-38—Distribution of Full-Shift PBZ Exposure Results for Total Beryllium in the Refining, Smelting and Alloying Application Group (NAICS 331314, 331423, 331492)[a,b]

Job Category	Number of Results in Range (µg/m^3)						Total
	< 0.1	≤ 0.1 to ≤ 0.2	> 0.2 to ≤ 0.5	> 0.5 to ≤ 1.0	> 1.0 to ≤ 2.0	> 2.0	
Furnace operations workers in beryllium recovery and alloying	*0 (0.0%)*	*0 (0.0%)*	*0 (0.0%)*	*0 (0.0%)*	*1 (25.0%)*	*3 (75.0%)*	*4 (100.0%)*
Furnace operations workers in other recycling and precious metal recovery	*1 (50.0%)*	*0 (0.0%)*	*1 (50.0%)*	*0 (0.0%)*	*0 (0.0%)*	*(0.0%)*	*2 (100.0%)*
TOTAL	**2 (22.2%)**	**2 (22.2%)**	**1 (11.1%)**	**0 (0.0%)**	**1 (11.1%)**	**3 (33.3%)**	**9 (100.0%)**

[a] Sample results are used as presented by the source investigators. NIOSH (HETA 83-162-1746) results are 8-hour TWAs. Sample duration is greater than or equal to 6 hours for all results except the furnace operations workers job category, which includes three samples of 265 to 314 minutes duration.

[b] A nondetectable sample result (less than 0.1 µg/m^3) is included in the exposure profile. Results reported as less than the analytical LOD or LOQ are incorporated into the exposure profile as volume-adjusted LOD or LOQ concentrations. This is a conservative approach that may overestimate the exposure results.

Sources: ERG Beryllium Site 2, 2003; ERG Beryllium Site 7, 2003

Mechanical Processing Operator

The exposure profile for mechanical processing operators is presented in Tables IV-37 and IV-38. This profile represents the best available exposure data. As shown in Table IV-37, the exposure profile is based on three sample results and is described by a median of 0.2 µg/m^3, a mean of 0.14 µg/m^3, and a range from 0.03 µg/m^3 to 0.2 µg/m^3. Table IV-38 indicates all (100 percent) of sample results for this job category are 0.2 µg/m^3 or less.

Working conditions are well documented for the three mechanical processing operator samples in the exposure profile obtained at ERG Beryllium Site 2. The screening, blending, and ball milling processes are operated under negative pressure, with isolated product transfer and milling ducted to the central vacuum and baghouse filtration systems. Despite these controls, investigators observed visible emissions escaping the exhaust hoods and noted that major changes need to be made to bring the system into compliance with recognized design standards for ventilation systems (ERG Beryllium Site 2, 2003).

Although this exposure profile is based on samples collected at just one facility, it is supported by equally low results obtained at similar facilities where mixed or electronic waste are refined (Kent et al., 2007; Vincent et al., 2009; ERG Site Visit, 2005). Kent et al. obtained multiple 8-hour PBZ samples over several weeks at a facility where workers performed mechanical processing of cell phones, confirmed to contain beryllium alloy parts (total beryllium content in the processed material was measured as 52 ppm by weight). The investigators found that mechanical process operator exposures averaged 0.01 µg/m^3 during shredding (16 samples) and

0.02 μg/m^3 during milling and screening (i.e., sieving) (9 samples).[196] Workers involved in shredding and milling tasks also performed sampling and housekeeping as part of their normal duties. Although these sample results were presented as summary information and so were not included in the exposure profile, they fully support the exposure profile shown in Tables IV-37 and IV-38.

Vincent et al. (2009) reported similar exposure levels during electronics waste dismantling activities in France, for which 23 partial-shift sample results indicated that worker beryllium exposures ranged from 0.004 μg/m^3 to 0.038 μg/m^3, with a median of 0.03 μg/m^3 (Vincent et al., 2009). Additional information is not available regarding worker activities or exposure controls, so this summary information from France is not included in the exposure profile.

Low exposures (typically 0.03 μg/m^3) were also reported by a facility visited by ERG in 2005, where small parts of previously disassembled electronic devices are mechanically processed (by shredding, roasting, milling, screening, sampling, and housekeeping) to recover metal that is then shipped to the company's smelter for alloying (ERG Site Visit, 2005). All workstations are ventilated at this facility. Although exposure information from this facility is not included in the exposure profile, the summary information provided by ERG (2005), as well as Vincent (2009), fully supports OSHA's exposure profile for mechanical processing operators.

Furnace Operations Worker

The exposure profile for furnace operations workers is presented in Tables IV-37 and IV-38. This profile represents the best available exposure data. Furnace operations include roasting, sweating, melting, and casting activities performed by workers (and their helpers) that operate furnaces and incinerators. As shown in Table IV-37, the exposure profile is described by an overall median of 2.15 μg/m^3, a mean of 3.85 μg/m^3, and a range from 0.03 μg/m^3 to 14.08 μg/m^3. The exposure profile includes two full shift samples from furnace operations workers in other (than beryllium) recycling and precious metal recovery. One result is less than 0.1 μg/m^3 and one result is greater than 0.2 μg/m^3 but less than or equal to 0.5 μg/m^3. Due to the extremely limited number of full-shift samples for this job category (two) and the availability of several additional well-documented samples from the same facilities, OSHA has included in Tables IV-37 and IV-38 the results of four samples (listed below with sample durations) that are less than full shift. These samples were obtained from workers in the beryllium recovery and alloying application group. All are presented as TWAs for the period sampled, which exceeds 4 hours in each case.

Furnace Operations Workers Performing Beryllium Recovery and Alloying

Not surprisingly, furnace operations worker exposures are notably higher in the portion of the industry that specifically produces beryllium alloy than in the facilities where work with beryllium-containing materials is incidental to the primary activity (e.g., precious metal refining). OSHA's exposure profile in Table IV-37 illustrates this difference. During beryllium alloying operations (0.35 to 10.5 percent beryllium), four sample results for furnace operations workers ranged from 1.92 μg/m^3 to 14.08 μg/m^3 (mean 5.64 μg/m^3, median 3.28 μg/m^3) (ERG

[196] Using statistical methods, Kent et al. (2007) estimated exceedance fraction upper confidence limits (at 95 percent confidence), which predicted that during shredding activities, less than 1 sample per 100 samples would exceed 0.2 μg/m^3, and during milling activities, 2.5 samples per 100 samples might exceed 0.2μg/m^3.

Beryllium Site 7, 2003). Only one of the four sample results (25 percent) is (very slightly) less than OSHA's current PEL of 2 μg/m^3.

Considerable information is available on the working conditions associated with the samples in the exposure profile. For the workers alloying beryllium at ERG Beryllium Site 7 (2003), represented by three partial-shift sample results of 1.92 μg/m^3, 2.38 μg/m^3, and 4.18 μg/m^3 (all of durations of 252 minutes to 267 minutes) and one full-shift sample of 14.08 μg/m^3 (532 minutes), the primary exposure control in the facility is a canopy hood located over the furnace to capture fumes from the melt. Other sources of LEV include canopy hoods over casting stations, ingot conveyors, and dross buckets. The main hood covers the charge platform for the furnace and likely accounts for the high PBZ results for these workers; a closer examination of these data show that three of the sample results (1.92 μg/m^3, 4.18 μg/m^3, and 14.1 μg/m^3) are associated with workers standing on the platform and directly in the path of the exhaust ventilation over the furnace (ERG Beryllium Site 7, 2003). Because of this design, these exposure results might not be representative of typical operating conditions in this industry. However, another source of exposure also existed, which might be more typical of the industry. The transfer of rubbing and skimming tools from the furnace is not ventilated (i.e., rubbing and skimming tools were fuming when they were removed from the furnace), and a significant number of 90-degree transitions were noted in the exhaust ducts (Corbett, 2005).[197]

Furnace Operations Workers Engaged in Recycling and Precious Metal Recovery
The exposure profile shown in Tables IV-37 and IV-38 also lists two sample results (less than 0.03 μg/m^3 and 0.5 μg/m^3, with mean and median of 0.26 μg/m^3) representing worker exposure during furnace operations in other recycling and precious metal recovery facilities (ERG Beryllium Site 2, 2003). At the facility where these samples were obtained, the thermal reduction unit is an enclosed gas-fired convection furnace that is ducted to an afterburner and baghouse filtration system. In the melting shop, canopy hoods are used to collect metal fumes generated during melting and casting operations. However, investigators observed visible emissions escaping the hoods (especially during pouring) and noted that major changes need to be made to bring the system into compliance with recognized standards for ventilation systems. A recommendation was made to utilize the services of an engineering firm to redesign the current layout of the LEV system to ensure that sufficient ventilation is always available (ERG Beryllium Site 2, 2003).[198]

Summary information from other similar facilities also suggests that the sample results in OSHA's exposure profile are at the upper range of typical exposures for furnace operations workers and that this exposure profile might overestimate typical exposure levels in both the beryllium alloying and precious metals refining industries. A facility that mechanically processes electronic scrap for precious metals recovery operates a small furnace to produce sample batches of test alloy (100 pounds) for analytical purposes. This company reports that exposure levels for all employees throughout the facility are typically 0.03 μg/m^3 (ERG Site Visit, 2005). Kent at al. (2007) performed extensive air sampling in a precious metal recovery and refining facility that processes cellular telephones. These investigators found that, over 4 weeks of sampling, 18 PBZ

[197] All three workers wear respiratory protection during the pour; at other times, some workers don respirators whenever fume is visible (Corbett, 2005; ERG Beryllium Site 7, 2003).
[198] In addition to LEV, furnace operations workers at this facility are required to wear loose-fitting, powered air-purifying respirators in the melt shop (ERG Beryllium Site 2, 2003).

full-shift sample results for furnace operations workers averaged 0.01 μg/m^3 during roasting and 0.05 μg/m^3 during alloying activities.[199]

ERG also reviewed sampling results reported in OSHA's IMIS database to gain additional insight into the exposure profile of this job category (OSHA, 2009). The IMIS database (SIC groups 3341, 3399, and 4953) contains 219 PBZ samples (sample dates August 1979 to February 2001) for workers with job descriptions most consistent (i.e., not ambiguous) with furnace/incinerator operations (e.g., furnace operator, furnace helper, melter, incinerator operator, kiln operator, caster, stationary engineer, fireman, assistant and auxiliary operators, power attendant). Of these samples, 123 were positive for beryllium, with a mean of 32.5 μg/m^3, a median of 1.0 μg/m^3, and a range from 0.02 μg/m^3 to 3,671 μg/m^3.[200] However, 44 percent (97 samples) of these results are nondetectable, suggesting that the real median is significantly lower.

Together, both the background information available on the sample results used in the exposure profile and the additional sources of supporting exposure information (i.e., summary information not included in the exposure profile) suggest that the exposure profile might overestimate current exposure levels for furnace operations workers in the refining and alloying industry (ERG Beryllium Site 2, 2003; ERG Beryllium Site 7, 2003; ERG Site Visit, 2005; Kent et al., 2007; OSHA, 2009).

TECHNOLOGICAL FEASIBILITY

Mechanical Processing Operator

Mechanical Processing Operator—Baseline Controls

Based on the available data, ERG finds that mechanical processing operations typically are conducted with some level of automation, LEV, and partial or full enclosures, although the effectiveness of these controls can be less than optimal.

Mechanical Processing Operator—Additional Controls

The preliminary median baseline exposure level for mechanical processing workers is 0.20 μg/m^3, and sample results for this job category range from less than 0.03 μg/m^3 to 0.2 μg/m^3 (see Table IV-37). An exposure level of 0.2 μg/m^3 or less has already been achieved for all workers in this job category through engineering controls (LEV) and work practices and administrative controls that keep processed scrap materials in enclosed equipment or areas served by LEV. To reach a level less than 0.1 μg/m^3, however, mechanical processing operators will require additional controls.

Effective Local Exhaust Ventilation and Process Enclosures

Manual processing operations can be conducted with minimal exposure to beryllium when the operations are equipped with effective engineering controls. For example, at ERG Beryllium Site

[199] Using statistical methods, Kent et al. (2007) estimated exceedance fraction upper confidence limits (at 95 percent confidence), which predicted that during roasting activities, less than 1 sample per 100 samples would exceed 0.2μg/m^3, and during alloying tasks, 3.86 samples per 100 samples might exceed 0.2 μg/m^3.

[200] If the maximum value is disregarded these data are described by a median of 0.95 μg/m^3, a mean of 2.7 μg/m^3, and a range from 0.02 μg/m^3 to 19 μg/m^3.

2, a 423-minute PBZ sample collected on the shredding process operator indicated a nondetectable beryllium concentration (less than 0.03 μg/m^3). The shredding process operator loads cardboard containers of scrap electronic components (e.g., circuit boards, cell phone parts) onto a shaker table with a lift truck. Scrap is pulled from the shaker table onto a conveyor and transported through a sequence of steps that reduce the size of the scrap to ⅝-inch pieces. The sequence includes a hammer mill, a shaker screen, a covered conveyor, a ring mill, a second shaker screen, and then a conveyor that transports the processed scrap to a collection box. The collection box fills every 7 to 10 minutes and is moved to a storage area once full. Other tasks completed by the shredding process operator include changing the shaker screen drum, changing the baghouse drum, housekeeping, and administrative duties. Engineering controls in the shredding department include partial or full exhausted enclosures on the hammer mill, ring mill, transfer conveyors, and screening stations. Investigators observed no visible emissions escaping the LEV systems in the shredding department.

Properly enclosing, sealing, and ventilating mechanical processing activities can be expected to significantly reduce worker exposures associated with these operations. Kent et al. (2007) reported on a facility where, to achieve average 8-hour TWA PBZ results of 0.01 μg/m^3 to 0.02 μg/m^3, ventilation was applied to the shredder, milling equipment, semi-automated product sampling equipment, and conveyer system drop/transfer points. They describe these ventilation systems as follows:

> *A 2,000 cubic feet per minute (CFM) dust collector ventilated the shredder. Partial enclosure and canopy style hoods were used on the shredder, product sampler and for elevation changes between conveyance systems. Capture velocities for these hoods ranged from 45-150 fpm. …In milling, the ball mill charging hood, the sampler, and sampling drums were ventilated by a 3,000 CFM portable dust collector. Capture velocities for the partial enclosure style hood ranged from 180-200 fpm. … [W]orkpractices used to reduce airborne dust levels included: cleaning of process equipment, floor cleaning with a sweeper/scrubber…* (Kent et al., 2007).

Additionally, Kent et al. (2007) indicated that the facility reduced airborne dust levels through work practices such as routine cleaning of process equipment and cleaning floors with a power sweeper or scrubber. Using these controls, the investigators characterized beryllium exposure levels as “well-controlled” compared to the company’s internal occupational exposure limit of 0.2 μg/m^3.

In the event that additional controls are still needed for mechanical processing tasks involving finely divided particles (i.e., high beryllium concentrations in the scrap, such as beryllium alloying dross), or the beryllium exposures are otherwise attributable to the handling or generation of powder-like materials, pharmaceutical quality powder handling systems may be able to reduce exposures to 0.1 μg/m^3. These systems typically include: hood design and capture consistent with ACGIH design criteria; no open handling; glove boxes; totally enclosed processes; and material transport systems meeting zero leakage criteria (Naumann et al., 1996). For example, pharmaceutical-quality packing head systems are used for filling/weighing operations involving high-hazard powders. Packing head systems provide a sealed connection between the filling device and the container for dust-free transfer of product. Vented and extraction-type sealing heads are available for applications where container pressure must be avoided. Packing heads used in conjunction with laminar flow containment booths (containment isolator) further ensure operator safety during container filling. Or, as an alternative, containment booths can be used as secondary containment between two vessels during make-break operations. Typical applications for powder containment booths include large-scale dispensing, weighing, and product sampling (Absolute Control Systems, Inc., 2004; Hosokawa Micron Group, 2005). Additionally, customized double butterfly valves can be fabricated for applications where gas and dust-tight discharging of bulk materials is required in addition to stringent emission and leakage limits. According to one equipment manufacturer, pharmaceutical-quality high-containment powder and granule handling systems can achieve total dust control levels of 0.1 $\mu g/m^3$ or less (Hosokawa Micron Group, 2005).

Beryllium Content of Scrap

At a secondary copper smelting and refining operation (now closed), NIOSH investigators collected 50 PBZ samples (NIOSH HETA 82-024-1428). This facility performed the same type of refining and smelting operations represented in the exposure profile. Only five of the samples (10 percent) had detectable levels of beryllium, with concentrations ranging from 0.2 $\mu g/m^3$ to 0.5 $\mu g/m^3$. These exposure concentrations were lower than those previously measured by the company. In the year immediately preceding NIOSH's visit, the company collected 127 airborne beryllium samples, with results that ranged from less than 0.1 $\mu g/m^3$ to 2.0 $\mu g/m^3$. Seventeen percent (21 of 127) of the samples exceeded the NIOSH recommended standard of 0.5 $\mu g/m^3$. NIOSH researchers attributed this variability in exposure primarily to the beryllium content of the furnace charge (with no additional discussion included in the report) and recommended that the company establish a policy to refuse all scrap that might be potentially contaminated with beryllium if adequate controls cannot be implemented to reduce beryllium exposures. Worker exposure to beryllium in smelting and refining operations can be eliminated or further reduced if the use of beryllium-containing scrap is eliminated or limited to scrap containing a low percentage of beryllium.[201] For example, Noranda Recycling, Inc. has established a 200 ppm solid material limit and a 50 ppm dusty material limit for beryllium-containing scrap (Noranda, 2005). Noranda assays incoming scrap for its beryllium content and also requires suppliers to provide laboratory analysis reports. To deal with scrap that breaches Noranda's beryllium limits, the company has established a protocol that can include refusing to accept the scrap and suspending business with suppliers. These limits do not appear to eliminate the need for engineering controls and personal protective equipment but may limit the extent of exposures. Other control measures reportedly established and implemented by Noranda include but are not limited to: 1) a stringent code of practice for management of beryllium-containing materials; 2) employee training on standard operating procedures, with an emphasis on proper handling and processing; 3) employee education on the nature of beryllium exposure through seminars on beryllium awareness and surveillance; 4) an extensive industrial hygiene air sampling program; and 5) ventilation improvements at all affected smelting and recycling facilities (Noranda, 2000, 2003, and 2005).

Mechanical Processing Operator—Conclusion

Based on the information contained in this analysis, OSHA preliminarily concludes that exposure levels of 0.2 $\mu g/m^3$ or less have already been achieved for the majority of mechanical processing operations most of the time through process enclosure, LEV, and semi-automated

[201] For alloyers that intentionally melt and cast beryllium alloys, this option is not feasible.

sampling equipment. This level has been achieved despite less-than-optimal LEV and process containment (investigators observed visible dust emissions from process equipment) (ERG Beryllium Site 2, 2003).

In the event that additional exposure reductions are necessary, these can be achieved by fully enclosing, sealing, and ventilating mechanical processing operations and ensuring that all LEV meets established design criteria (See Chapter 13 of ACGIH, 2010). Kent et al. (2007) reported on a facility that performs extensive mechanical processing of beryllium-containing electronic waste (confirmed to be 52 ppm beryllium by laboratory analysis). There, average exposure levels for mechanical processing operators were 0.01 $\mu g/m^3$ to 0.02 $\mu g/m^3$, suggesting that the vast majority of samples were well below 0.1 $\mu g/m^3$.

OSHA preliminarily concludes that both the proposed PEL of 0.2 $\mu g/m^3$ and an alternative PEL of 0.1 $\mu g/m^3$ can be achieved for the vast majority of mechanical processing operations most of the time.

<u>Furnace Operations Worker</u>

Furnace Operations Worker—Baseline Controls

OSHA finds that baseline engineering controls for melting and casting workers at refining and alloying establishments typically include some level of automation, process enclosures (full or partial), graphite and inert gas blankets to minimize the formation of metal oxides, and LEV systems with baghouse filtration (Kent et al., 2007; ERG Site Visit, 2005). Furnaces, casting areas, and conveyors are typically ventilated. However, LEV systems frequently are less than optimal and in need of significant enhancement (e.g., increased exhaust flow and/or improved hood and ductwork design) (Kent et al., 2007; ERG Site Visit, 2005). Furthermore, certain processes are not fitted with LEV hoods and remain uncontrolled (e.g., furnace charging, slagging, tapping).

Other exposure controls typically available for melting and casting workers include company-provided work clothing and respiratory protection (Kent et al., 2007). Some facilities may have additional controls, including downdraft booths (air showers) to remove surface dust, change rooms, showers, and dedicated lunch/break room and hygiene facilities (Kent et al., 2007).

Furnace Operations Worker—Additional Controls

The overall exposure profile median exposure level for furnace operations workers is 2.15 $\mu g/m^3$. The atypical ventilation system conditions observed by ERG at Site 7 (workers standing directly in the furnace exhaust air stream) and other sources of information for similar operations suggest, however, that worker exposure may be overestimated for this job category (ERG Beryllium Site 7, 2003; Kent et al., 2007; ERG Site Visit, 2005). Thus, the overall median baseline exposure level is estimated to be less than 2.15 $\mu g/m^3$. Furthermore, OSHA notes that the conditions of exposure differ for furnace operations workers at beryllium recovery and alloying facilities and those at facilities refining waste with a substantially lower beryllium content (e.g., electronic scrap). Therefore, OSHA has divided this job category into two subgroups representing furnace operations workers in these two portions of the industry.

Furnace Operations Workers Performing Beryllium Recovery and Alloying

The exposure profile for the subcategory of furnace operations workers in beryllium recovery and alloying facilities, provided in Tables IV-37 and IV-38, indicates that four sample results from one facility ranged from 1.92 μg/m^3 to 14.08 μg/m^3 (ERG Beryllium Site 7, 2003). As described in the exposure profile discussion for this subgroup, however, due to the configuration of the furnace deck, at least three of the four samples were associated with workers standing within the path of the furnace exhaust air. Additionally, the method used to remove dross from the furnace resulted in some spillage outside the dross receptacle.

To reduce exposures associated with this job category, it will be necessary to take a multifaceted approach, combining a number of control options. Section 5—Nonferrous Foundries, of Chapter IV, Technological Feasibility, of the PEA—describes how the foundry industry is able to reduce most furnace operator exposures to 0.5 μg/m^3 or less. In the foundry industry, workers also melt and cast metals, including alloys, ingots of special alloy blends, and metals with both high (in this case up to 5 percent) and lower (down to 1 percent) beryllium content. For the purposes of this analysis, OSHA finds great similarity between the equipment and alloying processes (and other melting and casting tasks) used in the foundry industry and those used in the smelting, refining, and alloying industry. Section 5 discusses additional controls for furnace operations workers, including a NIOSH workplace evaluation at a beryllium alloy foundry (NIOSH EPHB 326-16a, 2008) suggesting that exposure levels of 0.5 or less can be achieved for most foundry workers, including most furnace operations workers. The facility described in this NIOSH report has two foundry areas: 1) a green sand foundry, where workers use sand molds and cores for casting copper alloys of 1 percent to 4 percent beryllium; and 2) an ingot foundry using a permanent mold system to cast alloys up to 5 percent beryllium (during the sampling, workers cast aluminum alloy containing 2.5 percent beryllium). The ingot foundry process is essentially an alloying operation (in this case, performed in a foundry industry facility). Both of the foundries, however, offer control strategies useful to the smelting, refining, and alloying industry.

In both foundries, LEV systems are in place to remove fumes and dust associated with the furnaces, crucible transport (green sand foundry), pouring activities, and the dross barrels (all exposure sources in smelting, refining, and alloying facilities). In addition, the foundries (and cutting and grinding shop) are designated beryllium work areas with controlled access, personal protective equipment requirements, and processes in place to minimize beryllium migration to other facility areas. Housekeeping practices include the use of HEPA vacuums, and workers are responsible for cleaning and maintaining their work areas during the day and at the end of their work shift. Over two consecutive sampling dates, NIOSH collected a total of 17 PBZ full-shift beryllium samples at this facility.

NIOSH indicated that the melting and casting operation in the green sand foundry included six workers: one furnace operator, three molders, and two pouring operators. For workers in the green sand foundry, NIOSH investigators collected 12 samples that ranged from 0.03 μg/m^3 to 0.58 μg/m^3 (including two nondetectable samples at 0.03 μg/m^3 and 0.04 μg/m^3), with a mean of 0.17 μg/m^3 and a median of 0.11 μg/m^3 (NIOSH EPHB 326-16a, 2008). The supporting information available for the green sand foundry portion of this investigation does not link individual job categories or activities with these samples. NIOSH did, however, note that the workers with greatest potential for overexposure in the foundry were associated with the melting and casting processes.

In the permanent mold casting foundry (referred to as ingot foundry above), four workers were involved with the process: two furnace operations workers who monitored the pouring of aluminum-beryllium alloy into the ingot molds, one worker who removed dross, and a worker who monitored the cooling process and conveyor to ensure that ingots were released from the molds and dropped into the ingot shoot. NIOSH collected five PBZ samples on workers in the ingot foundry. The results of these samples ranged from 0.03 µg/m^3 to 0.55 µg/m^3, with a mean of 0.17 µg/m^3 and a median of 0.03 µg/m^3. The two highest results (0.21 µg/m^3 and 0.55 µg/m^3) were obtained on furnace operations workers. The remaining three results (each with a value of 0.03 µg/m^3) were listed only as samples for workers in the ingot room, with no specific job category or activity linked to the individual samples (NIOSH EPHB 326-16a, 2008).

Although limited, these findings in both green sand and permanent mold casting foundries represent the best available information on well-controlled conditions during furnace operations involving alloys containing percentages of beryllium (in this case, 2.5 percent beryllium). Note that exposures to beryllium in sand and permanent mold casting foundries are similar since the operations are the same, except that sand molds are destroyed (to retrieve the cast) once a product is cast whereas a permanent mold is reused. See Section 5—Nonferrous Foundries, of Chapter IV of the PEA for a detailed discussion of foundries. These results show that all foundry workers in a melting and casting area, including the furnace operations workers, can achieve beryllium exposures of 0.55 µg/m^3 or less in foundries with effective engineering controls. Due to the similarities in equipment and processes between the foundry and alloying industry furnaces, OSHA believes that these findings apply equally to the furnace operations workers in the smelting, refining, and alloying industry.

Because beryllium tends to concentrate in dross from molten metal, use of lower beryllium alloys (e.g., less than 2 percent) does not directly translate to an equivalently lower exposure level; however, where the beryllium content is considerably lower than 2 percent, exposures could be somewhat lower than measured at this facility. For example, since the highest exposure for a foundry operator at a facility using higher beryllium alloys (at 2.5 percent) is 0.55 µg/m^3, the comparable worker in a foundry handling alloy with beryllium less than 2 percent could experience a modestly lower exposure level of, for example, 0.5 µg/m^3 most of the time.

Dross must be removed from the metal to improve alloy purity and therefore, the quality of the ultimate castings (Air Products, 2005). The Section 5 discussion of additional controls for foundry furnace operations workers also describes ventilation options for dross handling. Fully enclosing hoods provide the best fume capture. To minimize the challenges of maintaining adequate, consistent ventilation while workers access the furnace interior to remove dross, facilities that melt beryllium alloys need to design the fully enclosing hoods with trap doors to access the melt.

OSHA understands that purity specifications for certain alloys will require more rigorous dross removal and greater access to the furnace interior, which in turn could require different furnace control options. In these facilities, the primary option available to reduce exposures from this source is to remove the enclosing exhaust hood and replace it with an auxiliary ventilation system that can capture fumes and dust while providing access to the furnace. At the same time, to better capture fumes and dust from dross as the dross is transferred out of the furnace, foundries can incorporate a ventilation system extension or mobile arm that covers the entire path of the dross scoop, from the furnace to the ventilated receptacle. OSHA is not aware of a commercial source for a pre-constructed ventilation system with these characteristics; however, Materion Corporation has installed such a ventilation system over a furnace dross transfer point as part of a series of measures to control worker exposures to furnace emissions to levels of 0.5 $\mu g/m^3$ or less, and most exposures in the facility to 0.2 $\mu g/m^3$ or less (Materion Information Meeting, 2012). Experts agree that to fully control fumes from toxic metals, it is necessary to keep the entire process under LEV (CCMA, 2000; Corbett, 2005). Because retrofit foundry (including furnace) ventilation systems are often custom-designed, the lack of a commercial source is a less compelling concern than it might otherwise be. Recent advances in computer modeling offer enhanced methods for designing exhaust ventilation and for predicting the benefits of various configurations (NIOSH EPHB 233-133c; Huang et al., 2004; Heinonen et al., 1996).

Kent et al. (2007) measured 8-hour TWA PBZ beryllium levels during alloying operations for other metals (precious metals), where beryllium was also present as a low percentage (0.0052 percent, or 52 ppm) of the total metal. Because beryllium can be concentrated in the dross, however, the effective amount to which workers could be exposed might have been substantially greater (i.e., 2 to 50 times greater) but still perhaps not present in the concentrations encountered at a facility specifically producing beryllium alloys (DeYoung and Peace, 2009). Over multiple (three to five) charge/fluxing cycles and slag pours, beryllium exposure averaged 0.05 $\mu g/m^3$. This metals recovery facility had installed a 16,000 cubic feet per meter (CFM) dust collector to ventilate five 24-inch diameter furnaces. Fumes from the furnace were captured close to the point of emission using side-draft slot-ring hoods (350 feet per minute [fpm] to 400 fpm) (Kent et al., 2007). Although the amount of beryllium in the recovered metal alloy was certainly considerably less than would be encountered in a smelting establishment working with common beryllium alloys, this example demonstrates that the industry also uses furnace ventilation systems that eliminate the opportunity possibility for workers to stand within the path of the exhaust air.

Furnace Operations Workers Engaged in Recycling and Precious Metal Recovery

As indicated in Table IV-37, OSHA obtained two results (less than the LOD of 0.03 $\mu g/m^3$ and 0.5 $\mu g/m^3$) for furnace operations workers involved in recycling and precious metal recovery. One of the sample results exceeds 0. 2 $\mu g/m^3$, and additional controls will be required to reduce the remaining exposure levels to this level. The results were obtained in a facility where investigators noted visible dust emissions from process equipment (ERG Beryllium Site 7, 2003), meaning that ventilation was insufficient.

The primary control option to lower exposure levels involves upgrading or replacing existing ventilation systems to improve particulate capture. Lower full-shift PBZ exposure levels (averaging 0.01 $\mu g/m^3$ to 0.02 $\mu g/m^3$, and reliably 0.2 $\mu g/m^3$ or less) were obtained by Kent et al. (2007) in a facility where workers performed similar roasting, alloying, sampling, and housekeeping activities. At that facility, control technology included LEV at three points: at the roasting tray dumping station, in the alloying area on the melting furnace, in the dross/ingot pouring operation, and for the ingot de-scaling operation. Kent et al. (2007) described the engineering controls as follows:

> *A 125 CFM High Efficiency Particulate Air (HEPA) filtered vacuum ventilated an enclosure style hood used for the roast produce transfer. Face velocities for the hood ranged from 80-100 feet per minute (fpm)…. A 16,000 CFM dust collector and ventilated five 24-inch diameter furnaces using closed capture side draft slot ring hoods. Centerline capture velocities for the exhaust hoods ranged from 350-400 fpm* (Kent et al., 2007).

Additionally, a precious metal refining facility visited by ERG in 2005 reported achieving typical exposure levels of 0.03 $\mu g/m^3$ for all operations (including mechanical processing and furnace operations such as roasting, plus melting and casting samples of the processed material [batched in 100 lbs. of copper]). That facility had upgraded ventilation on the induction furnace in response to concerns about possible beryllium exposure (ERG Site Visit, 2005).

The ACGIH Industrial Ventilation Manual for Design provides examples of LEV hood designs for numerous metal melting furnace operations, including tilt and non-tilt furnaces, dross pots, pouring stations, fixed and mobile casting hoods, and others (see Group 13.55 in ACGIH, 2010). Hood design and capture consistent with ACGIH design criteria would be expected to significantly reduce exposures associated with melting and casting. Exhaust ventilation typically is required during metal melting furnace operations for metal oxide/fume control. For some applications, a single hood can be used for charging, melting, and pouring. Other applications may require a separate hood for furnace charging due to the type of charge or furnace. The skimming of dross prior to pouring is a potentially significant source of metal oxide/fume exposure and may require a separate exhaust system for metal oxide and/or dross control. Additionally, design specifications for LEV systems (i.e., hood design and exhaust flow) must take into consideration the increase in air temperature and the rapidly generated exhaust plume associated with metal purification (ACGIH, 2010 [see Group 13.55]).

Although no secondary copper smelters currently exist in the United States, and OSHA has no exposure information about secondary aluminum smelters or other nonferrous metal smelters that may operate in the United States, resources for controlling exposures in this portion of the industry are readily available. In addition to the information described above, which is relevant to a wide variety of furnace operations involving beryllium alloys, and the ACGIH Industrial Ventilation Manual for Design, OSHA offers an eTool for secondary lead smelters (OSHA Lead eTool, 2006). The eTool provides extensive guidelines (including LEV design criteria) for controlling metal dust and fume exposures associated with secondary smelting, including melting and casting operations. Although this eTool is specific to secondary lead smelters, it provides useful information applicable to this industry sector as a whole.

Beryllium Content of Scrap

As previously discussed, for some establishments, worker exposures might be eliminated or reduced if the use of beryllium-containing scrap is eliminated or limited to scrap containing a low percentage of beryllium. ERG visited a precious metal recovery facility that will not accept scrap with a beryllium content that exceeds 200 ppm (ERG Site Visit, 2005). At this facility, the raw materials are electronic waste (primarily circuit boards) and metals (such as copper scrap from manufacturing establishments. The company melts a portion of each batch of processed scrap for testing purposes (alloyed with 100 pounds of copper) and reports that monthly PBZ beryllium sampling shows that exposures throughout the facility are typically maintained at 0.03 μg/m^3.

Furnace Operations Worker—Conclusion

The exposure profile, presented in Tables IV-37 and IV-38, shows that the median exposure level for all furnace operations workers is 2.15 μg/m^3. OSHA has identified two distinct types of furnace operations:; those that conduct precious metal recovery and refining, and those that perform beryllium recovery and alloying. Two separate feasibility determinations are given below.

Furnace Operations Workers Engaged in Recycling and Precious Metal Recovery

OSHA preliminarily concludes that exposure levels of 0.5 μg/m^3 or less have already been achieved for those furnace operations workers engaged in recycling and precious metal recovery/refining (operations that tend to involve materials with low beryllium content). Though based on an extremely small sample, exposure levels of 0.2 μg/m^3 or less have already been achieved for half (50 percent) of those precious metal recovery/refining operations, and improvements to existing controls (e.g., repairing LEV systems, upgrading housekeeping) will likely reduce the exposure level of all furnace operations workers in this part of the industry to levels of 0.2 μg/m^3 or less. This conclusion is supported by observations in other facilities. A precious metal refining facility visited by ERG in 2005 reported PBZ beryllium exposure levels of 0.03 μg/m^3 for all workers in the facility. At another facility, over a 5-week period, Kent et al. (2007) collected 16 samples averaging 0.01 μg/m^3 for furnace operations workers performing roasting, and another 16 samples for furnace operations workers involved in precious metal alloying activities that averaged 0.05 μg/m^3 (with a statistical estimate that fewer than four samples per 100 samples might exceed the proposed PEL of 0.2 μg/m^3). These results were achieved by installing a ventilation hood in the roasting tray dumping area and providing a 16,000 CFM dust collector for the five 24-inch diameter furnaces used for alloying (e.g., side-draft slot ring hoods with centerline capture velocities of 350 to 400 fpm) (Kent et al., 2007). OSHA preliminarily concludes that by using these methods, the proposed PEL of 0.2 μg/m^3 can be achieved for all of the furnace operations workers involved in precious metals recovery from mixed waste (e.g., electronic parts and components). Furthermore, an alternative PEL of 0.1 μg/m^3 can be achieved for most mixed waste recovery operations most of the time.

Furnace Operations Workers Performing Beryllium Recovery and Alloying

OSHA also preliminarily concludes that sample results of 0.5 μg/m^3 or less can be achieved for furnace operations workers performing beryllium recovery and alloying; however, these workers might continue to be exposed to levels above the proposed PEL of 0.2 μg/m^3 some of the time, and particularly when handling materials with elevated beryllium content (e.g., greater than 2.5 percent).

Based on current results for a well-controlled foundry with effective engineering controls (NIOSH EPHB 326-16a), OSHA preliminarily concludes that exposure levels of 0.5 μg/m^3 or less can be achieved for most furnace operations workers most of the time by installing LEV on the dross receptacle, improving (or rebuilding) LEV on furnaces if not yet installed, installing operator booths pressurized with filtered air, using HEPA filter vacuuming, and implementing beryllium migration policies such as having workers pass through air showers when exiting the furnace area to remove beryllium contamination on clothing. Exposures were below 0.5 µg/m^3 for nearly all workers engaged in these furnace operations (including furnace operations workers, whose duties and equipment were similar to those in a smelting facility) at a beryllium alloy foundry visited by NIOSH (NIOSH EPHB 326-16a) where such controls were implemented. In that foundry, which has two casting areas, furnace controls for one furnace include a slotted hood above the furnace and a slotted hood with flexible hoses installed over the crucible. The second furnace (in another area of the same establishment) was equipped with both a slotted hood over the furnace pot and a canopy hood with canvas side extensions. OSHA preliminarily concludes that employers can achieve an exposure level of 0.5 µg/m^3 for all furnace operations workers engaged in refining and alloying beryllium by implementing the same set of controls (all components of this strategy must be used together). Even so, OSHA further preliminarily concludes that exposure levels of 0.2 µg/m^3 might not reliably be achieved for furnace operations workers refining and alloying beryllium, and therefore respiratory protection would be required.

The level of respirator required for furnace operators will be depend on the effectiveness of the controls. Half facepiece respirators with an APF of 10 would provide sufficient protection for furnace operations workers for whom exposure levels have been reduced to a level of 2.0 µg/m^3 or less. A powered air-purifying respirator with a loose fitting facepiece provides an APF of 25, which offers adequate protection for beryllium exposures up to 5.0 µg/m^3. A powered air-purifying respirator or a supplied air respirator with a tight fitting full facepiece with an APF of 1000 would provide sufficient protection for exposure to levels as high as 200 µg/m^3.

<u>Summary of the Technological Feasibility Findings for Secondary Smelting, Alloying, and Refining</u>

OSHA identified two job groups in this application group with exposure to beryllium: mechanical process operators and furnace operations workers. The exposure profile for the mechanical processing operator indicates low exposures (3 samples less than 0.2 µg/m^3), even though these samples were collected at a facility where the ventilation system was allowing visible emissions to escape exhaust hoods. Summary data from studies and reports published in 2005-2009 showed that mechanical process operator exposures averaged between 0.01 and 0.04 µg/m^3 at facilities where mixed or electronic waste including beryllium alloy parts were refined. Based on these results, OSHA preliminarily concludes that the proposed PEL is already achieved for most mechanical processing operations most of the time, and exposures could be further reduced through improved ventilation system design and other measures, such as process enclosures.

As with furnace operations examined in other industries, the exposure profile showed considerably higher worker exposures for the furnace operator job category (six samples with a median of 2.15 µg/m^3, and 83.3% above 0.2 µg/m^3). The two lowest samples in this job's exposure profile (0.03 and 0.5 µg/m^3) were collected at a facility engaged in recycling and recovery of precious metals where work with beryllium-containing material is incidental. At this facility, the furnace is enclosed and fumes are ducted into a filtration system. The four higher samples, ranging from 1.92 to 14.08 µg/m^3, were collected at a facility engaged primarily in beryllium alloying operations, where beryllium content is significantly higher than in recycling and precious metal recovery activities and the furnace is not enclosed and workers are positioned directly in the path of the exhaust ventilation over the furnace. OSHA preliminarily concludes that these exposures could be reduced by enclosing the furnace and repositioning the worker, but is not certain whether the reduction achieved would be enough to bring exposures down to the proposed PEL. Based on the limited number of samples in the exposure profile and surrogate data from furnace operations, the proposed PEL may not be feasible for furnace work in beryllium recovery and alloying, and respirators may be necessary to protect employees performing these tasks.

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SECTION 6—SECONDARY SMELTING, REFINING, AND ALLOYING, APPENDIX 1−OVERVIEW OF SCRAP HANDLING PROCESSES AT AN ELECTRONICS RECYCLING FACILITY

The following description summarizes ERG's 2005 walk-through visit of an electronic waste recycling facility, addressed previously in this section on Secondary Smelting, Refining and Alloying. No personal or area sampling was conducted during the visit, but facility representatives informed ERG interviewers that employees are monitored for beryllium on a monthly basis. The company uses an 8-hour TWA action level of 0.1 μg/m^3 for PBZ samples but typically maintains exposure levels of 0.03 μg/m^3.

The facility receives and samples regular-grade electronic scrap (including circuit boards, integrated circuits, trim from circuit board manufacturing, connectors, and other electronic parts) prior to shipment to the company's smelter (at a different location) (ERG Site Visit, 2005). The firm also receives some metallic inputs, such as scrap from a copper punching operation. The non-electronic scrap represents only about 15 percent of its inputs. About 80 percent of the electronic scrap consists of circuit boards. The sample results determine the payment customers will receive for the precious metal content recovered from the shipments. The samples also identify hazardous constituents in the scrap and are used to determine whether the facility is willing to process the materials.

The facility will not accept scrap with beryllium that exceeds 200 parts per million.[202, 203] According to facility spokesmen, prospective customers are sometimes rejected if they fail (or are otherwise unable) to follow the facility's beryllium guidelines. Customers also often need to be educated about beryllium or beryllium oxide hazards when handling their scrap. Similarly, regarding all plant operations, the facility executives said that the company has directed them to do whatever is necessary to safeguard workers and that there is essentially no budget constraint on necessary safety and health expenditures.

This facility receives only small electronic components. Other facilities receive larger components and, in some cases, entire pieces of equipment (e.g., computers, printers). Beryllium metal is not generated in sufficient quantity, however, to be economically recoverable from this facility's processes. The company's smelter recovers gold, silver, palladium, platinum, and copper.

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[202] According to Cunningham (2004), the low beryllium content (e.g., 2 percent) of most beryllium alloys used in electronic applications results in most such scrap reclaimed for its copper and precious metal values and little beryllium being recovered.

[203] Recycling of beryllium-containing electronics has grown in recent years with the rise in the use of cell phones, computers, and other electronic devices. Beryllium alloys are used in the manufacture of connectors, and some beryllium ceramics might also be used in electronic equipment. Cell phone components under the keypad routinely contain a small beryllium alloy component (as a result, cell phones on average contain 50-60 parts per million (ppm) beryllium). Copper-beryllium components are often employed for connectors where the electrical circuit is intended to be frequently broken.

The facility employs 15 total production workers (referred to as "operators") divided over 2 shifts per day on 5 days per week or as necessary to meet demand, and 10 managerial and administrative personnel on the same division and schedule as production workers. Most operators can run all the equipment in the facility. The most skilled job is the operation of the induction furnace. Each shift has a shift leader and an assistant shift leader.

Processes employed at this facility include the following:

- ***Receiving:*** All incoming materials must be packaged in Gaylord boxes (large cardboard boxes), 55-gallon steel drums, or 1-ton bags that have been securely strapped onto wooden pallets. During the visit, workers packaged incoming material in Gaylord boxes most of the time. The facility uses barcode lot identifiers and a computerized system to track its lots and schedule production.

- ***Inspection:*** All lots are inspected in their packaging and then again on a conveyor prior to shredding/sampling to verify that the lot does not contain materials that pose a health, fire, or explosion risk. Prohibited materials include lithium batteries, nickel-cadmium batteries, mercury relays, Teflon-coated wire, polyvinyl chloride (PVC)-coated wire, and residual cyanide from gold stripping operations. Worker training covers the identification of prohibited materials, and examples of such materials are posted on a bulletin board along one of the main walkways in the facility. As noted above, the facility limits beryllium content to a maximum of 200 ppm. This level is based on what can safely be handled at the facility and the company's smelter. If a lot slightly exceeds this level, the facility might dilute the shipment's beryllium content rather than reject the lot.[204] Nevertheless, the facility executives suggested that the beryllium limits were strictly enforced. According to a description of the facility's operation, small quantities of prohibited materials will be removed prior to shredding, whereas large quantities can lead to rejection of shipments. The rejected material will then be returned to the customer facility at the company's expense. The executives noted that beryllium-free lots are rare, but about 25 to 30 percent of lots contain less than 10 ppm beryllium. Most lots contain less than 50 ppm beryllium.

- ***Shredding:*** Approximately one half of all input materials are received pre-shredded and others require shredding at the facility. Materials for shredding are emptied onto a shaking table and then conveyed to a 150-horsepower shredder where they are reduced to below 1.25 inches in diameter. Previously shredded materials enter the process flow at the point of the shredder discharge.

- ***Sampling:*** Shredded material is conveyed to the top of the facility's rotary sampling machine where the primary sample is taken. The sample size is normally 2.5 percent to 5.0 percent of the lot, although this can vary for unusual lots or materials. The sample is always over 500 lbs to ensure that sufficient increments are taken to minimize the variance in sample results. The rotary sampler is designed to ensure that

[204] For example the facility would hold a lot that contained more than 200 ppm beryllium for a period of time until another lot was received that contained less than less than 200 ppm beryllium. The facility then would combine both lots such that the combination of both lots equaled a maximum of 200 ppm beryllium. The new lot would then be ready for processing.

a representative sample of material is taken from the lots received. The primary sample is collected in steel drums and weighed. A reserve sample is collected at the same time and is stored in the warehouse. The bulk of the material is collected in Gaylord boxes and shipped to the company smelter. Dusts collected from the baghouse that serves both the shredding and sampling steps are weighed and sampled as well. A proportional dust sample is added to both the primary and reserve shredded material samples.

- ***Roasting:*** The primary sample is then roasted in a tray furnace for 2 hours at 800°F to 1,200°F to remove volatiles, combust plastics, and embrittle circuit boards. The roasting renders the scrap friable and amenable to subsequent size reduction in a ball mill. The roasted material is removed from the oven, cooled, and weighed. The tray furnace has two primary chambers, two afterburner chambers, and one retention chamber to ensure that all volatiles are burned. The hot gases are air-cooled and then directed to the baghouse.

- ***Ball milling:*** The roasted sample is milled for 30 to 45 minutes in a 4x5 ft ball mill. The mill is housed in a soundproof enclosure, and dusts generated from the loading and discharging are recovered and returned to the sample. The company enhanced ventilation for the ball mill when it upgraded the ventilation system in the late 1990s.

- ***Screening:*** The pulverized sample from the ball mill is conveyed to a 5-ft vibrating Sweco screen. Two screens are used to separate the material into three fractions: ¼-inch + metallics, > ¼-inch and > 35 mesh metallics, and < 35 mesh "sweeps." The dusts collected from the ball milling and screening are also added to the "sweeps" fraction.

- ***Sampling of Sweeps:*** The sweeps are blended in a Gemco blender for 20 minutes and discharged and sampled. The sample is split on a rotary splitter to between 400 and 800 grams. The sweeps sample is screened at 120 mesh, and any that is oversized is pulverized to minus 120 mesh in a ring mill. The minus 120-mesh fraction is then split into four portions of approximately 100 grams each.

- ***Sampling of Metallics:*** An assay sample of the metallics is obtained by melting the metallics with copper to produce a uniform melt that gives a reproducible assay result. If the total weight of metallics exceeds 100 lbs, the >35 mesh and +1/4 inch metallics are melted separately. However, if the total weight of metallics is less than 100 lbs, the two fractions are combined for melting. Approximately 300 to 400 lbs of clean copper are melted in one of two induction furnaces, both of which are equipped with a fume ring (hood). The fume rings were custom-designed for the facility. The metallic sample, together with fluxes, is added to the melt, and the charge is heated until a uniform melt is produced. The slag is skimmed off, and pintube samples are taken of the melt.[205] The melt is then cast into ingots and the ingots are weighed. The ingots are semi-spherical pieces that are then sent to the company smelter for further

[205] Slag is a nonmetallic covering that forms on the molten metal from impurities contained in the original charge, some ash from the fuel, and silica and clay eroded from the refractory lining. Slag is skimmed off prior to tapping the heat (NIOSH 85-116F).

processing. For the pintube sampling, a worker uses a long-handled tool that clasps at the end of a set of narrow, glass pintubes. These are lowered into the melt, and the glass at the end of the tube is melted. Because the glass tubes are vacuum-sealed, the melting of the end causes the melt to rise into the tube. These portions can then be sampled.

- ***Ventilation:*** All workstations are ventilated with hoods and/or partial enclosures, and the ventilation system is connected to two separate baghouses. The facility upgraded ventilation at the ball mill and induction furnace when the company became concerned about possible beryllium exposures.

- ***Housekeeping:*** Operators do cleaning between lots and at the end of shifts. The facility has HEPA filter vacuums available for cleaning and performs monthly housekeeping inspections and periodic additional inspections. Housekeeping requires approximately 15 minutes per day. All operators participate. It takes workers approximately 2 minutes to vacuum themselves, and they must do so before leaving the production floor.

As noted earlier in this summary, company representatives indicated that they conduct monthly personal air monitoring for beryllium and find that the procedures described here typically maintain 8-hour TWA exposure levels in the range of 0.03 $\mu g/m^3$.

SECTION 7—PRECISION TURNED PRODUCTS

INDUSTRY PROFILE

An additional profile of the industry is available in Chapter III of this document. The precision turned product manufacturing industry (NAICS 332721) includes companies that produce metal products by a combination of machining processes, including but not limited to turning, milling, tapping, drilling, sawing, and grinding. Beryllium-containing materials that might be used for these products include beryllium metal and beryllium alloyed with other metals, including copper, nickel, aluminum, magnesium, gold, and zinc (Kirk-Othmer, 1992).

Due to differences in the potential for worker exposure and the extent to which controls such as local exhaust ventilation (LEV) have already been implemented, OSHA has divided the industry into two groups: establishments that machine pure beryllium or alloys with a high beryllium content, and establishments that machine metal alloys with a low beryllium content.[206]

Establishments using materials with a high beryllium content typically work with pure beryllium or aluminum-beryllium alloys, typically greater than 30 percent beryllium.[207] Workers machine these materials primarily to produce parts for aerospace and other high-technology applications, including military aircraft, structural parts for missiles and satellites, optical systems, and X-ray windows.

Facilities that machine low-beryllium materials primarily work with copper-beryllium alloys (typically less than or equal to 2 percent beryllium), which are the most widely used forms of beryllium (U.S. Department of the Interior, 2002). Workers machine copper-beryllium alloys to produce resistance welding electrodes and other elements of electrode assemblies, aircraft parts (e.g., hydraulic systems), electronic components, battery posts for the automotive industry, and seals for the oil and gas industry (Affeldt, 2002; Akers, 2002; Capozzi, 2002; F&M, 2010; Parkinson, 2002; Schmidt, 2002). Additionally, copper-beryllium is used to manufacture injection molds for the plastics industry. While tool steel is the traditional material for this application, copper-beryllium is used for certain specialty molds. Copper-beryllium molds decrease warping and improve dimensional accuracy of the molded plastic part and decrease production cycle time (CDA, 1997; Sagar, 2000; Veitch, 2006). Beryllium-free copper molds were introduced as an alternative in the late 1980s, and one industry source reports that the trend is away from copper-beryllium and toward beryllium-free materials (Performance Alloys, 2002).

The number of establishments that machine pure beryllium or aluminum-beryllium alloys is very small due to the limited demand for beryllium parts and the difficulties of working with these

[206] Analysis of the results for machinists shows a substantial difference between the median exposure level for workers machining pure beryllium and/or high-beryllium alloys (between 30 and 100 percent beryllium) compared to workers machining low-beryllium alloys (typically containing 2 percent beryllium)—see the exposure profile in Table IV-41.
[207] The U.S. Geological Survey reports that high-beryllium alloys have a beryllium content equal to or greater than 30 percent (USGS, 1998).

metals; machining damages the surface of beryllium parts, so greater care or use of nontraditional machining techniques is required to limit damage.

Low-beryllium alloys (e.g., copper-beryllium alloys), on the other hand, are more easily machined and can be worked using conventional metalworking processes (Akers, 2002; Brush Wellman Guide, 2002). Nevertheless, based on industry sources, several factors constrain the number of establishments working with copper-beryllium. First, the market for machined copper-beryllium parts is small. Second, due to a combination of health concerns and the high cost of copper-beryllium, manufacturers have increasingly preferred beryllium-free materials (Affeldt, 2002; Performance Alloys, 2002). A number of contacts report they have stopped using copper-beryllium (Delvert, 2002; Plantenberg, 2002) or are using it in small quantities and only occasionally (Gray, 2002; Parkinson, 2002; Randolph, 2002). Most sources, including a contact at the National Machining and Tooling Association, believe that the number of machine shops working with copper-beryllium alloys represents a small percentage of the total number of machine shops, but could not provide a more accurate estimate the percentage (Akers, 2002; Nolan, 2002).

Based on the information discussed above, OSHA estimates that fewer than10 percent, or 312 of the 3,124 establishments in the precision turned products manufacturing industry, work with beryllium or its alloys. Based on discussions with representatives of two of the largest machining facilities of pure beryllium and aluminum-beryllium alloys, OSHA estimates that about 18 (5.9 percent) of these 312 establishments might work with pure beryllium or high-beryllium alloys (Facility A, 2002; Facility B, 2002). The Agency thus estimates that the majority of these 312 total establishments (294) work with low-beryllium alloys.

OSHA assumes that the size distribution of beryllium-using establishments is the same as the size distribution of all industry establishments. Therefore, these 312 establishments would be expected to employ 7,875 workers ((78,749/3,124) x 312 affected establishments). The 5.9 percent of these establishments using high-beryllium alloys yields an estimate of 465 (5.9% x 7,875) workers working with high-beryllium alloys, with the remaining 7,410 workers working with low-beryllium alloys.

Table IV-39 provides profile information for NAICS 332721 based on 2010 County Business Patterns data (U.S. Census Bureau, 2010).

Table IV-39—Number of Affected Establishments and Employees NAICS 332721—Precision Turned Products

	Affected Establishments	Affected Employees
Facilities using high-beryllium content alloys	*18*	*465*
Facilities using low-beryllium content alloys	*294*	*7,410*
Total	*312*	*7,875*

Sources: U.S. Census Bureau, 2010; OSHA Office of Regulatory Analysis

PROCESS DESCRIPTION

Precision turned products manufacturing facilities use a variety of metal forming equipment to machine and fabricate beryllium and beryllium alloy shapes, often for defense or aerospace applications. Machinists operate computer numerically controlled (CNC)[208] mills, lathes, lappers, borers, grinders, and other metalworking equipment to process beryllium-containing material. Much of this equipment is automated and enclosed, but manual machining or electrical discharge machining (EDM)[209] might also be performed.[210] The metal pieces machined can vary in length from a centimeter to several meters (ERG Beryllium Site 1, 2002; ERG Beryllium Site 4, 2003; ERG Beryllium Site 9, 2004). Multiple pieces can be produced hourly or may require months and even years for completion, depending on complexity and size. Some pieces may be produced using a single machine, while others may require several processing steps on multiple machines. Additionally, multiple tool bits may be used during the machining cycle with a single machine, with the process periodically stopped to change bits. Figure IV-2 illustrates the plant layout of a precision machine shop that machines pure beryllium and high-beryllium alloys.

Machine shops working with low-beryllium alloys, such as copper-beryllium, use the same basic machining processes as those that work with other types of metals, and industry contacts report only minor differences in the types of equipment used to machine copper-beryllium and other metals.

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[208] CNC machines are operated by executed programmed commands, and the work process is highly automated.

[209] EDM refers to a machining method that develops a desired object when electrical discharges remove material from the raw object.

[210] Although most machining in the precision turned products industry is automated (precision) machining, workers in the industry do perform some manual processes (e.g., manual deburring), also covered in this section. Similarly, other establishments that work metal might occasionally have modest manual or semi-automated machining capability. For example, in a foundry finishing department, foundry grinding/finishing operators might use a lathe or other machine tool as needed. This job category is addressed in Section 5—Nonferrous Foundries, of Chapter IV of this Preliminary Economic Analysis. This chapter discusses examples of machining exposures and controls regardless of where they occur.

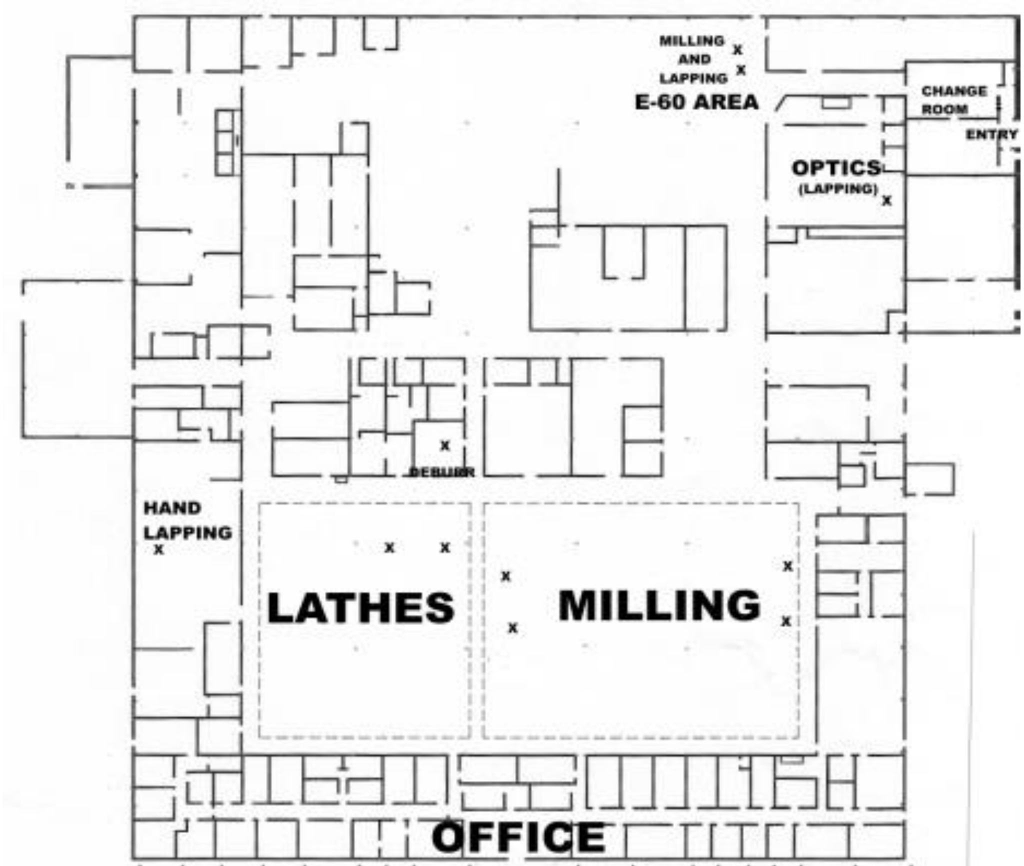

Figure IV-2. Plant layout of a precision machine shop that machines pure beryllium and high-beryllium alloys.

Production precision machining includes turning, boring, milling, planing, and grinding operations. The machinery used may be enclosed, partially enclosed, or not enclosed. Machining may be performed wet using a machining fluid, or dry. Industry experts suggest that most machine shops recognize the importance of ventilating beryllium-machining operations and typically utilize some type of LEV. Production machinery (such as CNC machining centers) may be enclosed, fully sealed, and exhausted. [211] Alternatively, a moveable exhaust duct can be manually positioned by the machinist to exhaust machining operations on partially enclosed or open machinery (ERG Beryllium Site 1, 2002; ERG Beryllium Site 4, 2003; ERG Beryllium Site 9, 2004).

Machinists are generally responsible for cleaning their equipment at the end of a work shift, but may also clean it during a machining cycle, between parts, after several parts have been machined, or midway through a work shift. Cleaning is conducted manually and includes removing metal scraps from the inside of the machine by hand or by using a vacuum or a small hand brush and dust pan, but might also include rinsing or dry wiping the machine inside and out (ERG Beryllium Site 1, 2002; ERG Beryllium Site 4, 2003; ERG Beryllium Site 9, 2004).

Affected Occupations

Machinists and other workers who operate machining equipment and perform related tasks have the greatest potential for beryllium exposure in this industry sector. Machinists working with pure beryllium, high-beryllium materials, and low-beryllium copper alloys all have some potential for beryllium exposure.[212] In facilities that machine low-beryllium alloys, most employees in non-machinist jobs were found to have very low exposures, below 0.1 $\mu g/m^3$. These jobs include maintenance workers (equipment and buildings), janitors, inspectors, shippers/receivers, and supervisors. Likewise, data and information presented in Appendices 7C and 7D indicate that exposures for most non-machinists in facilities machining pure beryllium or high beryllium alloys are also already below the alternative PEL of 0.1 $\mu g/m^3$. Thus, although non-machining employees working with both high and low beryllium materials are potentially exposed to beryllium, because their exposure levels are already below 0.1 $\mu g/m^3$ employers would not be required to change existing protections for these employees, so they are excluded from the exposure profile and the discussion of technological feasibility that follows.

Number of Affected Workers

To estimate the total number of potentially exposed employees in the precision turned product manufacturing industry, OSHA used occupational employment data from the Bureau of Labor Statistics (BLS) 2008 Occupational Employment Statistics Survey (OES) (BLS, 2008). OSHA

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[211] References include Corbett (2006), NIOSH EPHB 326-16a (2008), ERG Beryllium Site 1 (2002), ERG Beryllium Site 4 (2003), ERG Beryllium Site 9 (2004), Materion PSCS 102 (2011), Materion PSCS 103 (2011), and Materion PSCS 104 (2011).

[212] OSHA notes that some machine tool operators in this industry might also perform other tasks (e.g., chemical finishing/acid etching). The available information is not sufficient to individually characterize worker exposure during these tasks in the precision turned products industry; however these activities are addressed elsewhere in this technological feasibility analysis (see Section 8 of this chapter, "Rolling, Drawing and Extruding," and Section 9, "Fabrication of Beryllium Alloy Products").

first matched OES occupational titles in the corresponding four-digit NAICS classification (3327) with at-risk jobs, and then summed the number of workers associated with each job title. OSHA calculated the percentage of total employment represented by each job title, and used these shares to project the number of employees in at-risk jobs, based on the estimated number of workers in facilities working with beryllium or its alloys in Table IV-39. These estimates are shown in Table IV-40.

Table IV-40—Estimates of Workers Potentially Exposed to Beryllium in the Precision Turned Product Manufacturing Industry (NAICS 332721)

Employment by Occupation	Percent of Total Employment	Number of Employees*
Total Estimated Employment	*100.0%*	*7,875*
Total Estimated Production Employment (machining/non-machining)	*77.6%*	*6,112*
Total Machining-Related Occupations:	**47.8%**	**3,764**
Computer-Controlled Machine Tool Operators, Metal and Plastic	*7.5%*	*591*
Numerical Tool and Process Control Programmers	*0.9%*	*71*
Cutting, Punching, and Press Machine Setters, Operators, and Tenders, Metal and Plastic	*2.0%*	*158*
Drilling and Boring Machine Tool Setters, Operators, and Tenders, Metal and Plastic	*1.3%*	*102*
Grinding, Lapping, Polishing, and Buffing Machine Tool Setters, Operators, and Tenders, Metal and Plastic	*2.3%*	*181*
Lathe and Turning Machine Tool Setters, Operators, and Tenders, Metal and Plastic	*4.4%*	*347*
Milling and Planing Machine Setters, Operators, and Tenders, Metal and Plastic	*1.8%*	*142*
Machinists	*26.3%*	*2,071*
Multiple Machine Tool Setters, Operators, and Tenders, Metal and Plastic	*1.3%*	*102*
Total Non-Machining Related Occupations	*29.8%*	*2,347*
Installation, Maintenance, and Repair Occupations	*2.5%*	*197*
Other Production Occupations	*27.3%*	*2,150*
Non-Production Workers	*22.4%*	*1,764*

* *Estimated number of employees may not add up due to rounding.*

Sources: BLS, 2008; Table IV-39

The BLS data suggest that 4,111 workers, or approximately 52.2 percent of employment at precision machining establishments, are associated with non-machinist occupations (197 workers in installation/maintenance/repair occupations plus 2,150 workers in other production operations and 1,764 workers in non-production occupations) (BLS, 2008). Prorated across the 312 affected establishments based on the number of establishments among the two segments of the affected industry, OSHA estimates that 250 non-machinists are employed at establishments that work with pure beryllium or high-beryllium alloys ((4,111 affected workers / 312 total establishments) x 19 establishments working with pure beryllium or high-beryllium alloys = 250 affected workers). Using the same methodology, OSHA estimates that the remaining 3,860 non-machinists are employed at establishments that work with low-beryllium alloys.

EXPOSURE PROFILE

To estimate the beryllium exposure profile in the precision turned product manufacturing industry, OSHA used individual full-shift personal breathing zone (PBZ) lapel sample results for machinists from several sources, including surveys from the National Institute for Occupational Safety and Health (NIOSH), exposure data from the U.S. Navy Environmental Health Center (NEHC), two ERG site visits to precision machining facilities, and case study reports from six facilities machining copper-beryllium alloys.[213,214] These data represent the best available exposure information for this industry analysis.

OSHA also reviewed published studies of precision machinists and other workers for exposure information (Martyny et al., 2000; Kelleher et al., 2001; Madl et al., 2007; and Johnson et al., 2001). However, the authors of these papers present only summary statistics no individual total beryllium PBZ lapel sample results were reported. However, these papers do provide information on average exposure levels associated with various control methods.

Finally, OSHA reviewed exposure data from the Integrated Management Information System (IMIS) for beryllium (OSHA, 2009). As with all data obtained from IMIS, no additional information is available regarding the sampling or working conditions associated with these measurements. OSHA therefore used the IMIS analysis and the summary statistics from published studies only as supporting data in developing the exposure profile for the precision turned product manufacturing industry.

Data Sources

NIOSH Surveys

The NIOSH surveys include individual exposure data obtained for production machinists at four different establishments. All of the full-shift NIOSH data are used in the industry exposure profile. These surveys include the following sites:

A Small, High-Precision Machining Facility That Produces Components for Commercial and Military Applications

In 1976, NIOSH described this facility as a small, well controlled establishment. NIOSH collected one area sample and five PBZ lapel samples (two full-shift and three 15-minute samples) on production machinists manufacturing small pure-beryllium parts (NIOSH HHE 76-103-349, 1976). Machining operations at this facility included turning, drilling, boring, and milling. Each work station was equipped with a low-volume high-velocity LEV system. The capture velocity at the face of the intake hood was greater than 800 feet per minute (fpm), with velocities between 300 fpm to 500 fpm in a 4-inch radius around the cutting tools. No beryllium was detected in any of the samples; however, the per-sample LOD for beryllium was reported as

[213] For the purposes of this analysis, full-shift samples are PBZ samples with a sampling duration equal to or greater than 360 minutes (6 hours).

[214] NIOSH HHE 76-103-349, 1976; NIOSH HETA 84-510-1691, 1986; NIOSH EPHB 326-14a, 2008; NIOSH EPHB 326-16a, 2008; OSHA-H005C-2006-0870-0145; NEHC, 2000; ERG Beryllium Site 1, 2002; ERG Beryllium Site 4, 2003; ERG Beryllium Site 9, 2004; Brush Wellman Machining, 2004; OSHA-H005C-2006-0870-0097; Materion PSCS 102, 2011; Materion PSCS 103, 2011; and Materion PSCS 104, 2011.

0.5 µg (individual sampling limit of detection (LOD) concentrations were not reported). OSHA calculated the estimated sampling LOD concentration of 0.52 µg/m^3 (LOD/sample volume) using the reported LOD and an estimate of the sample air volume (.96 m^3).[215]

Key observations noted by NIOSH investigators regarding this site include the following:

- All beryllium work was conducted in a separate room called the Beryllium Room. The area was well labeled and contained washing facilities. Employees washed their hands before leaving the work area for breaks or to exit the building.
- All employees were provided with clean uniforms on a daily basis. Uniforms and shoes were changed at the end of the day or whenever leaving the building. A shower was also present.
- Work practices and handling of beryllium parts were good. For example, grinding small parts with an emery stick was done using an oil suspension so that beryllium dust did not become airborne.
- General housekeeping in the plant was excellent. Periodic cleaning of the dust collection system was also conducted. The employee doing the cleaning was provided with a respirator approved for beryllium dust.
- Employees appeared to be well informed of the hazards associated with beryllium and the required safety and health practices.
- All employees received a thorough medical examination annually from a physician knowledgeable of their exposures to beryllium and possible health effects.

NIOSH investigators concluded that the facility was a good example of how a small company can provide a safe and healthy work environment for its employees. NIOSH recommendations included: 1) wearing safety glasses on a consistent basis; 2) not eating, drinking, or smoking in the Beryllium Room; and 3) providing a vacuum system for cleaning (NIOSH HHE 76-103-349, 1976).

The Former Rocky Flats Nuclear Weapons Plant in Golden, Colorado

NIOSH documented exposure levels at this facility in 1984, but collected little information on exposure controls. A total of 40 PBZ lapel samples were taken over a total of three shifts on two different sampling dates on production machinists milling beryllium parts presumed to contain pure beryllium and/or high-beryllium alloys (NIOSH HETA 84-510-1691, 1986). Results ranged from 0.08 µg/m^3 to 7.2 µg/m^3, with 14 of the results (35 percent) nondetectable for beryllium. Thirty-nine of the samples were full-shift; one was a partial-shift sample (210 minutes) and was not used in the exposure profile. Samples were collected and analyzed using NIOSH Method 7300, and the laboratory analytical limit of detection was reported to be 0.2 µg per sample.[216] No

[215] To estimate the sample volume in cubic meters, OSHA multiplied the reported sampling duration (480 minutes) times 2 liters per minute, the recommended sampling rate for total beryllium, as follows: 480 minutes x 2 liters/minutes x cubic meter/1,000 liters = 0.960 cubic meters.

[216] Thirteen of the NIOSH samples were below the laboratory analytical reporting limit of 0.2 µg/sample and reported as nondetectable. OSHA estimated the sampling LOD concentrations (µg/m^3) by using the sampling

information was provided about engineering controls or work practices in place during the exposure evaluation; however, NIOSH investigators recommended exhaust ventilation for all beryllium parts that are machined in the facility.

A Copper-Beryllium Machine Shop That Produces Connectors and Test Pins for the Electronics Industry
Exposure controls at this facility were described in a report by NIOSH's following a visit in 2008. Five full-shift PBZ lapel samples were obtained on employees turning, grinding, polishing, and buffing copper-beryllium alloys (containing 2 percent beryllium) in the machine shop over two consecutive sampling dates (NIOSH EPHB 326-14a, 2008). One result was positive, with a value of 0.047 µg/m^3, and four of the results were reported as below the limit of detection, ranging from 0.016 µg/m^3 to 0.017 µg/m^3. In addition to machinists, three PBZ samples were collected on quality control personnel. All three results were nondetectable for beryllium, with sampling LOD concentrations ranging from 0.015 µg/m^3 to 0.021 µg/m^3. Air samples were collected and analyzed according to NIOSH Method 7300 (with modifications), and the estimated analytical reporting limit for this method was 0.005 µg per sample. Machining operations were enclosed and performed wet with metal-cutting fluids to minimize the release of airborne particles. The only source of LEV was a HEPA-filtered[217] downdraft booth (6 feet high by 3 feet wide and 2 feet deep), vented outdoors, which was used on an intermittent basis to grind and buff small-diameter rods.

A Beryllium Alloy Foundry Including an Aluminum-Beryllium Permanent Mold Casting Area, a Separate Green Sand Casting Area for Copper-Beryllium, and a Machine Shop
This foundry produces ingots and a variety of copper-beryllium products (containing a maximum of 4 percent beryllium), including non-sparking hand tools. Six full-shift PBZ lapel samples were obtained in the cutting and grinding shop of the copper-beryllium green sand foundry (NIOSH EPHB 326-16a, 2008). All six samples were positive for beryllium with results ranging from 0.10 µg/m^3 to 1.07 µg/m^3. Samples were collected and analyzed according to NIOSH Method 7300 (with modifications), and the estimated reporting limit for this method was 0.005 µg per sample. In the cutting and grinding shop, workers operated saws and grinders to remove excess metal from the castings produced in the foundry. Cutting and grinding activities were performed in enclosed and ventilated booths, and all workers were equipped with respiratory protection.

U.S. Navy Data

The U.S. Navy data include exposure data submitted by the Naval Environmental Health Center (NEHC) to the OSHA Beryllium Docket (OSHA-H005C-2006-0870-0144; OSHA-H005C-2006-0870-0145) and unpublished data OSHA obtained from the Navy Occupational Exposure Database (NEHC, 2000). These data represent PBZ lapel samples collected on workers machining copper-beryllium bushings and other beryllium-containing or potential beryllium-containing parts from 1987 to 2001. The Navy data include 45 PBZ samples taken during beryllium machining. Only six of the 45 results are based on full-shift sampling and are included in the exposure profile. These results range from 0.03 µg/m^3 to 0.46 µg/m^3 and include two samples nondetectable for beryllium (LOD concentrations reported as 0.08 µg/m^3 and 0.33

durations reported by NIOSH and a sample flow rate of 1.5 liters per minute to estimate the sample air volumes. The resulting air volumes and the laboratory reporting limit of 0.2 µg/sample were used in the following equation to calculate the estimated sampling LOD concentration for each nondetectable sample: Sampling LOD concentration (µg/m^3) = Laboratory analytical LOD (µg) x 1,000 liters/m^3 ÷ Air volume sampled (liters).

[217] A HEPA filter is a high efficiency particulate air filter.

µg/m^3). The samples were analyzed using either NIOSH Method 7102 or Method 7300, and the estimated LOD for both methods was 0.005 µg beryllium per sample. Other than a brief description of the machining task, no information is available about workplace conditions or exposure controls.

ERG Beryllium Site Visits

ERG conducted site visits to two different production machining facilities. One facility is referred to as ERG Beryllium Site 1 (ERG, 2002). This facility is small, with approximately 10 full-time employees, and it manufactures precision machined products from pure beryllium metal, high-beryllium aluminum alloy (primarily 60 percent beryllium), and other metals. The second facility, Beryllium Site Visits 4 and 9, manufactures products from pure beryllium metal, high-beryllium aluminum alloy (primarily 60 percent beryllium), and a beryllium metal/beryllium oxide matrix (also called Beryllium Metal-Matrix Composite, Beryllium-based MMC, or E-Material) (ERG Beryllium Site 4, 2003; ERG Beryllium Site 9, 2004; Materion MSDS M08, 2011; Martyny et al., 2000). The second facility was visited twice and is substantially larger than the first facility, with a high-volume production operation and a workforce in excess of 200 employees.[218]

During its visits to the two facilities, ERG collected a total of 18 full-shift PBZ lapel samples that are included in the exposure profile, with results ranging from 0.02 µg/m^3 to 6.6 µg/m^3. Seven of the 18 results are nondetectable for beryllium, with a sampling LOD of 0.02 µg/m^3. The samples were analyzed by the OSHA Salt Lake Technical Center (SLTC) using OSHA Method 125-G, and the reporting limit for beryllium was 0.02 µg per sample. Although engineering controls varied depending on the task and the facility, the controls primarily included enclosed and ventilated machining centers, moveable operator-positioned LEV ducts, and partial enclosures with LEV.

The highest samples were values of 1.1 µg/m^3, 2.3 µg/m^3, 2.9 µg/m^3, and 6.6 µg/m^3. The 1.1 µg/m^3 result was obtained on a worker machining 60 percent beryllium parts on two high-speed core grinders (ERG Beryllium Site 9, 2004). Two to three parts per shift were completed. The grinders were set to operate automatically, and once they were set in motion, the operator stood away from the grinders. The grinding was done wet, with machining fluid, and the grinders were partially enclosed and had exhaust ventilation. The elevated result suggests that the enclosure and/or exhaust ventilation might have been ineffective (perhaps due to the speed of the grinders) or that the adjacent surface grinding operation might have contributed to the worker's exposure (the adjacent surface grinding worker's exposure was 2.3 µg/m^3 and is discussed below).

The 2.3 µg/m^3 result was obtained on a worker performing single-sided high-speed surface grinding on 60 percent beryllium parts (ERG Beryllium Site 9, 2004). The parts were placed in a lapper (surface grinder) for approximately one hour per cycle[219]. During the hour, the operator stopped the lapper at various times to check on the progress of the parts. The grinding was performed under flood coolant with a partially enclosed LEV system. It is possible that the design of the exhaust ventilation and/or enclosure was insufficient for the speed of the grinder,

[218] ERG surveyed the larger precision machining facility on January 21–23, 2003 (ERG Beryllium Site 4, 2003), and again on February 3–5, 2004 (ERG Beryllium Site 9, 2004).
[219] In this case, a cycle refers to the machine completing the grinding of the entire length of a single side of the part.

because ERG investigators observed visible airborne coolant escaping the existing control system at high speeds. The investigators recommended fully enclosing the lapper.

The 2.9 μg/m^3 exposure result was obtained on a machinist grinding high-beryllium parts on two high-speed core grinders (ERG Beryllium Site 4, 2003). The grinding was done wet, using machining fluid, and the grinders were partially enclosed and had exhaust ventilation. It is possible that the exhaust ventilation on the grinders was inadequate, because ERG investigators noted that the design of some ventilation (especially in the department where the core grinders were located) might not be sufficient to ensure maximum collection efficiency. The investigators recommended redesigning the layout of the ventilation system. Additionally, because the operator stood away from the grinders during the machining cycle, this worker's exposure might have been affected by an adjacent operation.

The 6.6 μg/m^3 exposure result was obtained on a machinist operating an enclosed and ventilated double-sided lapper (ERG Beryllium Site 4, 2003). During the lapping cycle, the operator opened the machine four to five times to check on the progress of the parts. It is likely that this work practice increased the machinist's exposure. This assumption is supported by a NIOSH study that evaluated the ability of air filtering cleaners to control metalworking fluid mist emissions on partially enclosed machining centers used to produce transmission parts (NIOSH ECTB 218-12a, 1997). Through the use of video exposure monitoring with a direct-reading aerosol photometer, NIOSH investigators observed that peak exposures occurred when operators entered or partially entered the machining center enclosures. Other factors that might have contributed to the elevated beryllium exposure include the effectiveness of the machine enclosure and/or LEV as well as any adjacent contaminant-producing operations.

The published literature also contains reports with exposure data obtained from the larger precision machining facility surveyed by ERG (Kelleher et al., 2001; Madl et al., 2007; Martyny et al., 2000). These data (described below in the subsection on Machinists Machining Pure Beryllium and/or High-Beryllium Alloys—Conclusion) were obtained prior to ERG's site visits; they supplement recent information obtained from the facility and make possible comparisons of exposures before and after various control measures were implemented.

Case Studies

OSHA obtained individual PBZ (lapel) total beryllium sample results for three precision machine shops processing copper-beryllium alloys (Brush Wellman Machining, 2004). Summary statistics for these data are available in the OSHA Beryllium Docket (OSHA-H005C-2006-0870-0097). These data include 63 full-shift and nine partial-shift results for machinists, and 30 full-shift results for non-machinists. Only full-shift results from the case studies were used in the beryllium exposure profile. The full-shift results for machinists range from 0.005 μg/m^3 to 24 μg/m^3, and 63 percent of the results (40 of the 63 samples) are nondetectable for beryllium (sampling LOD ranging from 0.005 μg/m^3 to 0.2 μg/m^3). The non-machinist job categories include supervisor (not otherwise specified), shipper and receiver, inspector (machining), maintenance worker (equipment and building maintenance), and janitor. Eighty-seven percent of the PBZ results for the non-machinists (26 of 30 samples) are nondetectable for beryllium, with sampling LOD concentrations ranging from 0.005 μg/m^3 to 0.012 μg/m^3. The four positive results include values of 0.006 μg/m^3, 0.008 μg/m^3, 0.021 μg/m^3, and 0.037 μg/m^3. The analytical methodology was not specified for all the case study data; however, for most of the samples, NIOSH Method 7102 was used and the beryllium reporting limit was 0.005 µg per sample. Other than a job title and the type of beryllium machined, little information regarding workplace conditions and control technology is available for these data.

Three more recent copper-beryllium machining case studies from 2011 were also reviewed (Materion Corporation, 2011). The purpose of the studies was to characterize worker exposure to airborne beryllium and identify work practices and LEV controls necessary to maintain exposures consistently below a recommended exposure guideline of 0.2 µg/m^3. These studies include the aggregated results of a baseline exposure evaluation (no individual sampling results available) and a description of the operating conditions and exposure controls. In one of the studies, the machinists exposure results were consistently below 0.2 µg/m^3, and after LEV improvements were made, additional PBZ samples indicated that all exposures were below 0.1 µg/m^3 (Materion PSCS 102, 2011; Materion PSCS 103, 2011; Materion PSCS 104, 2011). OSHA used the information from these investigations to support the exposure profile and technological feasibility analysis for the precision turned product manufacturing industry. These studies include ram EDM (electrical discharge machining) and machining with CNC lathes and milling machining centers (Materion PSCS 102, 2011; Materion PSCS 103, 2011; Materion PSCS 104, 2011). In all, a total of 34 full-shift PBZ samples were collected, with results ranging from 0.007 µg/m^3 (nondetectable reporting limit) to 0.020 µg/m^3. Because individual sampling results are not available, it is not possible to determine the number of nondetectable results. Nonetheless, all results are below 0.1 µg/m^3. The CNC machining was done in enclosed machining centers with water soluble machining fluids (to lubricate and cool the cut and to flush away the turnings). No LEV was used. By contrast, the ram EDM was equipped with a manufacturer-supplied LEV system. A description of the LEV upgrades and cost information is included with the case study summary.

Other Published Studies

The published studies described below include three reports on the same large precision machining facility visited twice by ERG (Martyny et al., 2000; Kelleher et al., 2001; and Madl et al., 2007). These publications discuss aggregated exposure information for machinists and non-machinists at the respective facilities; no individual PBZ results are included. OSHA used these publications as supporting material to evaluate the effectiveness of engineering controls and supplement the exposure profile discussion with the information contained in these reports wherever possible.[220]

Martyny et al. (2000)

This study reports 64 beryllium PBZ lapel samples (as well as other types of samples) collected on machinists from June 1996 to February 1997 at a well-studied precision machining facility (ERG Beryllium Site 4 and Site 9). The investigators looked at five mechanical processes typically used to machine beryllium, including milling, lathing, deburring, lapping, and grinding (Martyny et al., 2000).[221] The beryllium samples were collected over two shifts and are

[220] OSHA also reviewed one additional report, which discusses the beryllium exposure control program at the Cardiff Atomic Weapons Establishment in the United Kingdom (Johnson et al., 2001). It too presents only aggregate exposure results. A summary of this report appears in Appendix 7A of this technological feasibility analysis.

[221] The 64 samples evaluated total beryllium, but other fractional analyses were also included in this report (Martyny et al., 2000). Sampling dates for Martyny et al. (2000) are included in a companion publication by Kelleher et al. (2001).

characterized by a mean of 1.48 μg/m^3, a median of 0.29 μg/m^3, and a range from 0.03 μg/m^3 to 41.48 μg/m^3. The median exposure concentration by type of machining was as follows: 0.10 μg/m^3 (lapping); 0.20 μg/m^3 (milling); 0.26 μg/m^3 (grinding); 0.40 μg/m^3 (lathing); and 0.57 μg/m^3 (deburring). The number of nondetectable samples was not disclosed. Most samples were analyzed using NIOSH Method 7300, which had a LOD of 0.007 μg per sample and a limit of quantitation (LOQ) of 0.030 μg per sample. A limited number of samples (number unspecified) were analyzed using NIOSH Method 7102. This method had a LOD of 0.0003 μg per sample and a LOQ of 0.005 μg per sample. Results below the LOD were assigned a value of one-half the method LOD for the purposes of statistical analysis. Martyny et al. noted that the machinists adjusted their own ventilation control devices (i.e., LEV) and that these devices may not have been positioned as effectively as possible for each machining process evaluated.

Kelleher et al. (2001)
In a companion publication to the Martyny study, Kelleher et al. (2001) reported on 37 full-shift PBZ lapel samples collected in September 1999 on workers with non-machinist job titles at the beryllium precision machining facility. Exposure results were based on personal cascade impactor samples (as opposed to total beryllium sampling with a filter cassette) collected over a period of two shifts for the major non-machinist job titles, including chemical finisher, assembler, inspector, shipper, specialty cell worker, maintenance worker, engineer, manager, and administrator. Other than the job titles, no information is available about the non-machinist jobs. Major work practice and engineering control changes in the facility from 1995 to 1998 are summarized in the paper and include eliminating compressed air for cleaning; discouraging dry sweeping of beryllium; requiring work uniforms and dedicated work shoes; upgrading LEV for the lap, deburr, grind, and EDM departments; and installing enclosures on some deburring processes.[222]

Madl et al. (2007)
In another investigation of the same precision machining facility, Madl et al. (2007) reconstructed beryllium exposures of workers who were beryllium sensitized (BeS) or diagnosed with chronic beryllium disease (CBD) in an effort to determine whether a threshold for BeS and CBD could be identified. In doing so, the investigators analyzed the historical plant industrial hygiene data (1980–2005) for both machinists and non-machinists to understand the trend in airborne beryllium concentrations over time in comparison to engineering and administrative control improvements. The authors calculated the summary statistics for the plant's PBZ lapel and general area samples for three time periods to summarize the change in exposure levels due to the implementation of various administrative and engineering controls over time. No individual PBZ results were presented in this paper. The median of the PBZ samples on machinists decreased from 0.33 μg/m^3 for samples taken between 1980 and 1995 to 0.16 μg/m^3 for samples taken between 1996 and 1999, to 0.09 μg/m^3 for samples taken between 2000 and 2005. For nonmachinists, the median concentrations decreased from 0.08 μg/m^3 to 0.04 μg/m^3 over the same time period. The authors attribute the reduction to improvements made in the LEV system at this facility, such as installing total suspended particulate mist eliminators on some milling machines, replacing LEV ductwork for milling and lathe operations, and adding additional exhaust systems to some departments.

[222] This information provides useful background on sample results from 1996 to1997 reported by Martyny et al. (2000).

IMIS Data

The IMIS database contains a total of 20 PBZ samples from June 1978 to September 2008 in the matching precision turned product manufacturing Standard Industrial Classification (SIC) codes 3451 (Screw Machine Products [NAICS 332721]) and 3452 (Bolts, Nuts, Screws, Rivets and Washers [NAICS 332722]). These results include 10 samples with job descriptions representative of machining activities (e.g., machinist, Bridgeport operator, Davenport machine operator, lathe operator, slotter operator) and 10 samples with other job descriptions, including part cleaner, plater, press operator, skimmer, and spot welding. Only one of the 20 samples (5 percent) is positive for beryllium, with a result of 0.12 µg/m^3 for the slotter operator. This sample was obtained in 1984 at a fastening systems manufacturer. As with all data in IMIS, no information is available about the nature of the exposures and the working conditions associated with the results. However, although limited, these results suggest that beryllium exposures in the precision turned product manufacturing industry are relatively low and infrequent.

Machinists

To develop the exposure profile for the precision turned product manufacturing industry, OSHA first reviewed all of the full-shift PBZ data described under "Data Sources" within this section on Precision Turned Products. These sources include both data from older reports and more recent sample results from a few facilities that were studied extensively while they made substantial changes in exposure controls. While these more recent reports offer evidence that some facilities have reduced exposure levels dramatically, OSHA notes that other facilities within the industry might not yet have made the same modifications, and therefore elevated exposure levels could still occur in facilities that have not been the subject of published reports. Therefore, OSHA has included both the early data and the more recent, better-controlled sample results in the exposure profile to represent the full range of possible exposures in this industry. OSHA acknowledges that this would result in the exposure profile overestimating the exposure of these workers in this industry if all precision machining facilities have reduced exposures to the levels of the few well-studied establishments.[223]

The exposure profile for machinists is based on 139 samples from nine establishments, with exposures ranging from 0.005 µg/m^3 to 24 µg/m^3.[224] The mean exposure level is 0.56 µg/m^3; however, the median is substantially lower at 0.1 µg/m^3. Eight samples (six percent) exceed the current PEL of 2.0 µg/m^3.

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[223] Some of the available supporting information suggests that older data tend to reflect higher exposures. In addition to the examples of facilities that have implemented additional controls (See the Technological Feasibility subsection of Section 7—Precision Turned Products), a review by Kreiss et al. (1996) of historical industrial hygiene measurements made at a beryllium oxide ceramics plant using high-content beryllium that included machining operations reported that beryllium exposures generally decreased over the 12 years of operation from 1980 to 1992. The earliest machining exposure measurements obtained between 1985 and 1988 were generally higher than subsequent measurements (i.e., average exposures for machinists and other workers over the course of their employment were considerably lower than the historic measurements made in the early time periods). For example, the number of machining results greater than 5 µg/m^3 dropped from 7.7 percent during the October 1985 to March 1988 time period to 2.1 percent during October 1991 to March 1992. Similarly, the number of machining results greater than 25 µg/m^3 dropped from 2.3 percent in the earlier time period to 1.1 percent in the later period.

[224] One establishment was evaluated twice but is only counted once (ERG Beryllium Site 4, 2003; ERG Beryllium Site 9, 2004).

Analysis of the results for machinists shows a substantial difference between the median exposure level for workers machining pure beryllium and/or high-beryllium alloys compared to workers machining low-beryllium alloys. Based on this review, OSHA determined that the available exposure data for machinists can also be described as two separate subcategories: one for workers machining pure beryllium and/or high-beryllium alloys and a second for workers machining low-beryllium alloys. This finding is consistent with the industry profile assessment (see this chapter at Industry Profile), which found that a small number of establishments (estimated at 15) specialize in precision machining of pure beryllium and/or high-beryllium alloys. A larger number of establishments work only with low-beryllium alloys such as copper-beryllium.[225] The exposure profile discusses these two groups of machinists in this chapter at Machinists Machining Low-Beryllium Alloys—Baseline Controls and Machinists Machining Low-Beryllium Alloys—Additional Controls below.

Table IV-41—Personal Exposure Profile in the Precision Turned Product Industry for Workers Machining Beryllium-Containing Materials (NAICS 332721)a

Job Category	Number of Samples	Range (μg/m^3)	Mean (μg/m^3)	Median (μg/m^3)
Machinist—machining pure beryllium and/or high-beryllium alloys[b]	*59*	*0.02 to 7.2*	*0.72*	*0.31*
Machinist—machining low-beryllium alloys (typically ≤ 2% beryllium)[c]	*80*	*0.005 to 24*	*0.45*	*0.01*
TOTAL	*139*	*0.005 to 24*	*0.56*	*0.1*

[a] *The exposure profile is based on full-shift PBZ (lapel) total beryllium sample results. Full-shift sample results represent a sampling duration of 360 minutes or longer and are 8-hour TWA concentrations. Nondetectable sample results are included in the exposure profile as the sampling LOD or LOQ concentrations. This is a conservative approach that may overestimate the exposure results.*

[b] *Twenty-two of the 59 samples (37 percent) are nondetectable for beryllium, with sampling LOD concentrations ranging from 0.02 μg/m^3 to 0.52 μg/m^3.*

[c] *Forty-six of the 80 samples (58 percent) are nondetectable for beryllium, with sampling LOD concentrations ranging from 0.005 μg/m^3 to 0.33 μg/m^3.*

Sources: Brush Wellman Machining, 2004; ERG Beryllium Site 1, 2002; ERG Beryllium Site 4, 2003; ERG Beryllium Site 9, 2004; NEHC, 2000; NIOSH EPHB 326-14a, 2008; NIOSH EPHB 326-16a, 2008; NIOSH HHE 76-103-349, 1976; NIOSH HETA 84-510-1691, 1986; OSHA-H005C-2006-0870-0145

Table IV-42—Distribution of Full-Shift PBZ Total Beryllium Exposure Results in the Precision Turned Product Industry for Workers Machining Beryllium-Containing Materials (NAICS 332721)[a]

Job Category	Number of Results in Range (μg/m^3)						Total
	<0.1	≥ 0.1 to ≤ 0.2	> 0.2 to ≤ 0.5	> 0.5 to ≤ 1.0	> 1.0 to ≤ 2.0	> 2.0	
Machinist—machining pure beryllium and/or high-beryllium alloys[b]	*8 (13%)*	*7 (12%)*	*26 (44%)*	*9 (15%)*	*4 (7%)*	*5 (9%)*	*59 (100%)*

[225] Copper-beryllium alloys and other low-beryllium alloys (primarily nickel-beryllium) typically contain two percent or less beryllium by weight (CDA, 2006). High-beryllium alloys are alloys in which the beryllium percentage is substantially larger. In actual use, such metals are typically aluminum alloys containing as much as 62 percent beryllium (Materion MSDS M13, 2011).

Machinist—machining low-beryllium alloys (typically ≤ 2% beryllium)[c]	*59 (74%)*	*9 (11%)*	*6 (8%)*	*2 (2%)*	*1 (1%)*	*3 (4%)*	*80 (100%)*
TOTAL	*67 (48%)*	*16 (11%)*	*32 (23%)*	*11 (8%)*	*5 (4%)*	*8 (6%)*	*139 (100%)*

[a] The exposure profile is based on full-shift PBZ (lapel) total beryllium sample results. Full-shift sample results represent a sampling duration of 360 minutes or longer and are 8-hour TWA concentrations. Nondetectable sample results are included in the exposure profile as the sampling LOD or LOQ concentrations. This is a conservative approach that may overestimate the exposure results.

[b] Twenty-two of the 59 samples (37 percent) are nondetectable for beryllium, with sampling LOD concentrations ranging from 0.02 µg/m^3 to 0.52 µg/m^3.

[c] Forty-six of the 80 samples (58 percent) are nondetectable for beryllium, with sampling LOD concentrations ranging from 0.005 µg/m^3 to 0.33 µg/m^3.

Sources: Brush Wellman Machining, 2004; ERG Beryllium Site 1, 2002; ERG Beryllium Site 4, 2003; ERG Beryllium Site 9, 2004; NEHC, 2000; NIOSH EPHB 326-14a, 2008; NIOSH EPHB 326-16a, 2008; NIOSH HHE 76-103-349, 1976; NIOSH HETA 84-510-1691, 1986; OSHA-H005C-2006-0870-0145

Machinists Machining Pure Beryllium and/or High-Beryllium Alloys

The exposure profile for workers machining pure beryllium and/or high-beryllium alloys is shown in Tables IV-41 and IV-42. These tables summarize the best available full-shift PBZ exposure data for machinists and report the distribution of the results in relation to the proposed and current PELs for beryllium. As shown in Table IV-41, the exposure profile for this subcategory is characterized by a mean of 0.72 µg/m^3, a median of 0.31 µg/m^3, and a range from 0.02 µg/m^3 to 7.2 µg/m^3. Table IV-42 shows that 13 percent of the results are less than 0.1 µg/m^3, 12 percent are between 0.1 µg/m^3 and 0.2 µg/m^3, 44 percent fall between 0.2 µg/m^3 and 0.5 µg/m^3, another 22 percent range between 0.5 µg/m^3 and 2.0 µg/m^3, and 9 percent exceed the current PEL of 2.0 µg/m^3. These values represent 59 full-shift PBZ total beryllium sample results reported for machinists in two NIOSH investigations (NIOSH HHE 76-103-349, 1976; NIOSH HETA 84-510-1691, 1986) and three ERG site visits to two beryllium machining facilities (one facility was visited twice) (ERG Beryllium Site 1, 2002; ERG Beryllium Site 4, 2003; ERG Beryllium Site 9, 2004). Twenty-two of the 59 samples (37 percent) in the exposure profile are nondetectable for beryllium, with sampling LOD ranging from 0.02 µg/m^3 to 0.52 µg/m^3 (i.e., seven nondetectable results with values of 0.02 µg/m^3 and 15 nondetectable results with values ranging from 0.29 µg/m^3 to 0.52 µg/m^3).

Seventy-one percent of the results (42 of 59 samples) in the exposure profile represent NIOSH data obtained more than 25 years ago when exposures and the analytical reporting limits were likely higher (e.g., 16 of the 42 NIOSH results [38 percent] are nondetectable, with estimated LOD concentrations ranging from 0.29 µg/m^3 to 0.52 µg/m^3). Therefore, it is possible that the exposure profile may be overestimating exposures for machinists working with pure beryllium and/or high-beryllium alloys. However, workers handling materials of pure or high concentrations of beryllium are at risk for experiencing extremely high exposure levels, so it is also possible that the true value approached these LOD concentrations. More recent information supports the conclusion that these higher levels are true values; ERG found exposures ranging from 0.02 µg/m^3 to 6.6 µg/m^3 during three site visits to pure or high-beryllium machining facilities. Four of the 18 sample results (22 percent) from these three site visits exceeded 1.0 µg/m^3, indicating that significant exposures continued to occur through 2004 (ERG Beryllium Site 1, 2002; ERG Beryllium Site 4, 2003; ERG Beryllium Site 9, 2004).

All but two of the full-shift NIOSH results represent exposure data collected on production machinists in the beryllium shop at the Department of Energy's Rocky Flats plant in 1985 (NIOSH HETA 84-510-1691, 1986). The NIOSH report does not describe the workplace conditions and controls at the Rocky Flats plant beryllium shop in 1985, other than a recommendation to provide adequate exhaust ventilation for the machining of all beryllium parts. However, in a retrospective exposure assessment of beryllium exposure at the Rocky Flats plant, Barnard et al. (1996) stated that exposure varied through the years, depending on ventilation and production conditions. The NIOSH investigation took place in 1985 during a period of high production. Ventilation controls in the beryllium shop at that time consisted of a centralized LEV system that had been modified during the exposure period of 1975 to 1982. The effectiveness of the ventilation system was not reported; however, the ventilation system in place at the time of the survey might not have been effective in controlling worker exposure because the facility installed a new low-volume, high-velocity (LVHV) LEV system in September 1986. In 1984 and 1985, the estimated average beryllium exposure was 1.092 μg/m^3 (33 samples) and 1.195 μg/m^3 (51 samples), respectively (Barnard et al., 1996).

Based on the available information, the high-beryllium content involved, and the possibility that some facilities in this industry have not controlled exposures to the same extent as the few well-studied facilities described in this analysis, OSHA preliminarily concludes that the exposure profile for machinists working with pure beryllium and/or high-beryllium alloys represents an accurate portrayal of exposures in this industry. As noted above, to the extent that exposures in this industry vary at all from the values summarized in Tables IV-41 and IV-42, the use of historical data in the exposure profile is more likely to overestimate than underestimate exposure.

Machinists Machining Low-Beryllium Alloys

Tables IV-41 and IV-42 summarize the best available full-shift PBZ exposure data for machinists working with low-beryllium alloys and report the distribution of the results in relation to the proposed and current PELs for beryllium. As shown in Table IV-41, the exposure profile is characterized by a mean of 0.45 μg/m^3, a median of 0.01 μg/m^3, and a range from 0.005 μg/m^3 to 24 μg/m^3. Approximately 74 percent of the exposure results (59 of 80 samples) are less than 0.1 μg/m^3, 11 percent are at least 0.1 μg/m^3 but no greater than 0.2 μg/m^3, 8 percent fall between 0.2 μg/m^3 and 0.5 μg/m^3, 3 percent fall between 0.5 μg/m^{3}and 2.0 μg/m^3, and another 4 percent exceed 2 μg/m^3 (see Table IV-42). These values represent 80 full-shift PBZ total beryllium exposure results reported for machinists in the Brush Wellman case studies (Brush Wellman Machining, 2004), two recent NIOSH studies (NIOSH EPHB 326-14a, 2008; NIOSH EPHB 326-16a, 2008), and sample results supplied by the U.S. Navy (NEHC, 2000; OSHA-H005C-2006-0870-0145). Most of these data were obtained within the last 10 years and reflect low analytical reporting limits (i.e., 0.005 μg beryllium/sample). Forty-six of the 80 results (58 percent) are nondetectable for beryllium, with sampling LOD concentrations ranging from 0.005 μg/m^3 to 0.33 μg/m^3 (i.e., 39 nondetectable results with values less than 0.1 μg/m^3; six nondetectable results with values ranging from 0.11 μg/m^3 to 0.2 μg/m^3; and one nondetectable result of 0.33 μg/m^3).

For a majority of the exposure results (69 of the 80 samples), other than the type of beryllium handled and the nature of the machining task, no information is available about the workplace conditions and controls. The remaining 11 results in the exposure profile were obtained during NIOSH investigations at two copper-beryllium machine shops. At one of the machine shops

(NIOSH EPHB 326-14a, 2008), five full-shift PBZ samples collected on machinists operating Swiss screw machines (automated lathes) ranged from 0.016 $\mu g/m^3$ to 0.047 $\mu g/m^3$; four of the five results were nondetectable for beryllium. The machining operations at this facility were enclosed, and metal cutting fluids were used when operating to control the release of airborne contaminants.

At the second machine shop surveyed (NIOSH EPHB 326-16a, 2008), six full-shift PBZ results for workers cleaning and deburring copper-beryllium castings (with saws and grinders) were all positive for beryllium and included values of 0.1 $\mu g/m^3$, 0.23 $\mu g/m^3$, 0.27 $\mu g/m^3$, 0.29 $\mu g/m^3$, 0.44 $\mu g/m^3$, and 1.07 $\mu g/m^3$. At this machine shop, all cutting and grinding operations were reportedly conducted in partially enclosed booths equipped with LEV. For at least one of the booths (abrasive cutoff saw), however, the estimated booth exhaust air flow rate was half the recommended amount (ACGIH, 2010 (Figure VS-80-17)).[226, 227]

Although the median exposure level for workers machining low-beryllium alloys is less than 0.1 $\mu g/m^3$, the available information shows that significantly higher exposures occurred when work controls were inadequate. Some of the highest exposure results in the exposure profile are associated with four samples collected at one machine shop during dry deburring operations and include values of 0.77 $\mu g/m^3$ (386 minutes), 2.7 $\mu g/m^3$ (435 minutes), 2.9 $\mu g/m^3$ (398 minutes), and 24 $\mu g/m^3$ (404 minutes). The machinists at this facility deburred copper-beryllium parts at a downdraft table and wore respiratory protection such as an air-purifying respirator with P100 cartridges. Industrial hygiene investigators reported that the downdraft table ventilation system alone could not be relied on to consistently maintain employee exposures to levels below the current PEL. Poor work practices further reduced the effectiveness of the downdraft table (for example, using the downdraft table for the storage of tools and materials, conducting deburring on the edge of the downdraft table as opposed to the center of the table, and using compressed air for cleaning) (MC Pkg I-E-2, 2001; MC Pkg I-E-5, 2000). These findings show that dry deburring copper-beryllium alloys can result in exposures that exceed the current PEL of 2 $\mu g/m^3$ when controls are inadequate.

Because the exposure information for machinists working with low-beryllium materials is a robust dataset drawn from three industrial facilities and six U.S. Navy industrial facilities, OSHA preliminarily concludes that the exposure profile for this group of machinists is likely representative of the exposure profile for machinists working with low-beryllium materials in the precision turned product industry.

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[226] Face velocities at the 5-foot by 4-foot opening (20 ft^2) of the cut-off saw booth ranged from 100 to 150 fpm, an estimated exhaust air volume of 2,500 cubic feet per minute (cfm). At the 18-inch by 36-inch opening (4.5 ft^2) of the enclosed down-draft belt sander, face velocities ranged from 500 to 700 fpm, an estimated exhaust volume of 2,700 cfm. Based on the LEV design guidelines of the American Conference of Governmental Industrial Hygienists (ACGIH), the exhaust air flow rate for the cut-off saw booth is about half of what is recommended. ACGIH guidelines recommend 250 actual cfm per square foot of open face area ($acfm/ft^2$) (ACGIH, 2010 [Figure VS-80-17]). This design criterion translates into an exhaust air flow rate of 5,000 cfm for a 20 ft^2 booth opening. The existing flow rate for the cut-off saw booth is about 2,700 cfm.

[227] A photograph of the machine shop included with the NIOSH report shows that, in addition to two partially enclosed and ventilated booths (sides, back, and top enclosed), workers had access to two additional finishing work stations that were equipped only with LEV. This indicates that workers also had access to machines that were not as fully controlled as those described (NIOSH EPHB 326-14a, 2008). OSHA has no information regarding the extent to which those additional machines were used, if at all.

<u>Non-Machinists</u>

In addition to machinists, OSHA also examined the available exposure data for non-machinists (presented in Appendices 7B and 7C). Job categories that do not work directly with beryllium have less potential for exposure, with a median value below the proposed PEL. Certain jobs, such as chemical finishers and maintenance workers, may have higher beryllium exposures that can exceed an alternative PEL of 0.1 μg/m^3 or the proposed PEL of 0.2 μg/m^3, but individual sample results for these categories are not available for this industry. Based on the available information, OSHA believes that the implementation of controls for the machinists jobs that work directly with beryllium also result in further reductions in exposure for these jobs. Therefore, additional controls for non-machinists jobs are not discussed.

TECHNOLOGICAL FEASIBILITY

<u>Machinists Machining Pure Beryllium and/or High-Beryllium Alloys</u>

Machinists Machining Pure Beryllium and/or High-Beryllium Alloys—Baseline Controls

At facilities where pure beryllium and/or high-beryllium alloys are machined, baseline conditions typically involve some form of LEV, which is used widely in this industry. [228] Additionally, "machining operations are usually performed under a liquid coolant flood which assists in reducing airborne particle dispersion" (SF201, 2011). To these baseline controls, most facilities also add some variation of the following: 1) full or partial enclosures; 2) work practices to minimize exposure, such as prohibiting the use of compressed air and dry sweeping; 3) migration control practices and procedures to prevent the spread of beryllium contamination outside production areas; 4) the use of protective clothing and equipment to minimize inhalation and dermal exposure to beryllium and to prevent contamination of workers' personal (street) clothing and shoes; 5) housekeeping to control surface contamination; and 6) personal hygiene, such as hand washing, to minimize skin contamination (Kelleher et al., 2001; NIOSH HHE 76-103-349, 1976). The median exposure level (see Table IV-41) associated with these conditions is 0.31 μg/m^3, which OSHA believes currently represents best estimate of the median exposure for employees at the approximately 20 companies engaged in machining pure or high-beryllium material.[229]

A detailed discussion of the baseline conditions and controls observed at the two precision machining facilities surveyed by ERG is included in Precision Turned Products Appendix 5. These facilities machine pure beryllium, high-beryllium alloys, and other materials. Although both facilities utilize all of the control methods noted above, significant differences exist in the levels of control achieved (ERG Beryllium Site 1, 2002; ERG Beryllium Site 4, 2003; ERG Beryllium Site 9, 2004). As was evident in these site visits, access to beryllium machining areas

[228] References include ERG Beryllium Site 1 (2002), ERG Beryllium Site 4 (2003), ERG Beryllium Site 9 (2004), NIOSH EPHB 326-16a (2008), Materion PSCS 102 (2011), Materion PSCS 103 (2011), and Materion PSCS 104 (2011).

[229] As noted in the industry profile for this industry, 15 or fewer companies work with pure beryllium and high-beryllium alloys in the United States and no more than six work strictly with pure beryllium (Facility A, 2002; Facility B, 2002).

and control of beryllium migration varies depending on the building layout, and facility work practices, policies, and procedures.

OSHA believes that the working conditions at these sites are representative of the industry. Engineering controls to limit airborne levels of beryllium range from fully enclosed, sealed machines with exhaust ventilation, to partially enclosed or open machines with fixed or movable, worker positioned LEV. The LEV might be optimal (i.e., highly effective in controlling exposure and proactively maintained) or less than optimal (i.e., insufficient in controlling exposure and in need of design enhancements and better maintenance). Additionally, machining might be performed wet (with machining fluid) or dry. The level of protection afforded by personal protective equipment (PPE) varies depending on company policies and procedures. Required PPE ranges from company-provided work uniforms and shoes to complete head-to-toe protection, including the use of respirators. Personal hygiene ranges from an enforced company policy requiring workers to wash their hands and faces each time they leave beryllium machining areas, to giving workers the option to wash potentially contaminated skin areas at their discretion. Housekeeping programs also vary and range from dedicated housekeeping staff, with documented cleaning procedures and schedules that are periodically audited, to a more informal approach where cleaning techniques are not strictly enforced and individual workers are responsible for keeping their workstations clean.

Machinists Machining Pure Beryllium and/or High-Beryllium Alloys—Additional Controls

The median exposure level for workers machining pure beryllium and/or high-beryllium alloys is 0.31 $\mu g/m^3$. Based on the exposure profile in Table IV-42, 25 percent of the exposure results for these workers are less than or equal to 0.2 $\mu g/m^3$. Therefore, 75 percent of machinists machining pure beryllium and/or high-beryllium alloys have exposures that can exceed 0.2 $\mu g/m^3$ and require additional controls to achieve exposure levels at the proposed PEL. To further reduce exposures, additional control options primarily include 1) fully enclosing machining operations or enhancing existing enclosures and LEV, and 2) eliminating or minimizing work practices that increase exposure. Other additional controls that should be considered are discussed in Precision Turned Products Appendix 6 and include housekeeping and migration control procedures to minimize surface contamination that can contribute to worker exposures.

LEV and Enclosures: Exhaust ventilation and process enclosures offer substantial exposure control and, when used with wet methods, represent the best options for controlling machinist exposures. All machining operations at ERG Beryllium Site 1 were fully enclosed and ventilated. At that facility, as shown in Table IV-43, the full-shift PBZ exposure results are characterized by a median of 0.02 $\mu g/m^3$ and a mean of 0.035 $\mu g/m^3$ (range 0.02 $\mu g/m^3$ to 0.11 $\mu g/m^3$). In contrast, control measures were not as fully implemented at ERG Beryllium Site 4 (also referred to as Site 9), some machining operations were not enclosed (i.e., open machining), and some enclosures and/or LEV systems were in need of upgrades to ensure that sufficient exhaust flow and containment. During the site surveys, ERG investigators noted that workers improperly positioned several exhaust ducts by a few centimeters, resulting in less than optimal exhaust flow around the parts being machined, or positioned themselves too close to the point of operation (ERG Beryllium Site 4, 2003; ERG Beryllium Site 9, 2004). Open machining operations were exhausted through the use of moveable exhaust ducts manually positioned close to the point of operation. Those exposure conditions resulted in sample levels notably higher than those found at Site 1. For example, Table IV-43 shows that in sample year 2003 at ERG Beryllium Site 4 (and 9), the median full-shift PBZ exposure level for machinists is 0.1 μg/m^3, with a mean of 1.65 μg/m^3 and a range from 0.02 μg/m^3 to 6.6 μg/m^3.

Table IV-43—Comparison of Full-Shift PBZ Total Beryllium Exposure Levels for Workers Machining Pure Beryllium and/or High-Beryllium Alloys at Two Different Precision Machining Facilities[a,b]

Facility	Year Samples Collected	No. of Samples	Range (μg/m^3)	Mean (μg/m^3)	Median (μg/m^3)
SITE 1					
ERG Beryllium Site 1	*2002*	*6*	*0.02 to 0.11*	*0.035*	*0.02*
SITE 4					
ERG Beryllium Site 4 (as Martyny et al., 2000)	*1996-1997[c]*	*64*	*0.03 to 41.48*	*1.48*	*0.29*
ERG Beryllium Site 4	*2003*	*6*	*0.02 to 6.6*	*1.65*	*0.1*
ERG Beryllium Site 4 (as Site 9)	*2004*	*6*	*0.1 to 2.3*	*0.68*	*0.25*

[a] *Note that ERG Beryllium Sites 4 and 9 are the same facility visited twice over the course of two years (2003 and 2004).*

[b] *Nondetectable results are reported as sampling LOD concentrations.*

[c] *For samples collected from 1996 to 1997, sample duration was 16 hours (two shifts) and all samples were positive for beryllium (LOD was 0.007 μg per filter).*

Sources: ERG Beryllium Site 1, 2002; ERG Beryllium Site 4, 2003; ERG Beryllium Site 9, 2004; Kelleher et al., 2001; Martyny et al., 2000

Although worker exposure at Site 4 was markedly higher than at Site 1, Site 4 was able to make some improvements to reduce exposures over the course of the study period. Table IV-43 shows this reduction in total beryllium exposure levels within the facility over time due to improvements in LEV, machine enclosures, and work practices (ICBD, 2007). In Table IV-43 the initial PBZ samples, collected on machinists at this site from 1996 to1997 by Martyny et al. (2000), are characterized by a median total beryllium exposure level of 0.29 μg/m^3, a mean of 1.48 μg/m^3, and a range from 0.03 μg/m^3 to 41.48 μg/m^3. Subsequent samples collected by ERG in 2003 showed a reduction in exposures (median exposure level and range). The median exposure level in 2003 was about three times lower than in 1997 and the maximum level was about six times lower. However, the mean exposure was slightly higher. During this time period, the site modified the LEV systems for machining operations in the lapping, deburring, grinding, and EDM departments (Kelleher et al., 2001).

In 2003, Site 4 made additional changes, upgrading the ductwork in the mill and lathe departments for the LVHV systems. The effect of these modifications was evaluated by ERG in a return visit in 2004 (reported as ERG Beryllium Site 9). This upgrade reduced the number of unnecessary duct runs and reconfigured transitions and elbows to minimize energy loss. The face velocity of the terminal LEV hood reportedly increased from 2,100 fpm to 4,300 fpm. Personal beryllium exposure to mill and lathe department operators was reportedly reduced from an average of 0.2 μg/m^3 to 0.1 μg/m^3, according to the company's monitoring program.

Full-shift PBZ samples collected in 2004 had a higher median than 2003 (from 0.1 μg/m^3 to 0.25 μg/m^3); however, the mean value and the exposure range were significantly reduced, suggesting a downward trend in exposure for machinists at this facility. While there were only a small number of samples taken at Sites 4 (and 9), results for operators of specific machines demonstrate the extent to which exposures were reduced. During the ERG site visit in February 2004, the surface grinder operation was associated with the highest measured airborne beryllium exposure (2.3 µg/m^3). The surface grinder had a partially enclosed LEV system and utilized flood coolant; however, visible airborne coolant was generated at high speeds and was observed escaping the existing control system. ERG investigators made recommendations for fully enclosing the surface grinder at the time of the visit. The site subsequently designed and installed fully enclosed LEV systems on two surface grinder operations in 2004. As a result, beryllium exposure for the surface grinder operator was reportedly reduced from an average of 1.6 µg/m^3 to 0.08 µg/m^3 (ERG Beryllium Site 9, 2004).

ICBD (2007) reported the results of additional mean PBZ exposure sampling conducted in this facility in 2006 for specific machining operations. These 2006 exposure levels ranged from 0.07 µg/m^3 to 0.13 µg/m^3 and according to the investigators, indicate that the vast majority of workers are exposed to levels of 0.2 µg/m^3 or less. As described above, these reductions are largely the result of improvements in ventilation systems and process enclosures used to capture particles generated during machining, and coolant mist released by the process. In some cases, improvements might also have included changes in operator use and position in relation to the ventilation systems.

Table IV-44—Comparison of 1996 and 2006 Exposure Results at ERG Beryllium Sites 4, by Machine Type

Machining Operation	1996 Mean (µg/m^3)		2006 Mean (µg/m^3)		Percent Reduction in Mean
Deburring	*1.17*		*0.13*		*89%*
Grinding	*3.58*		*0.09*		*98%*
Lapping	*0.22*		*0.08*		*64%*
Lathing	*0.92*		*0.07*		*92%*
Milling	*0.21*		*0.07*		*67%*
Source: Adapted from ICBD, 2007					

The historical perspectives on exposures at the facility presented in Tables IV-43 and IV-44 are possible because the establishment has been the subject of numerous investigations, research studies, and inspections for decades. Comparable facilities that have not been under such intense scrutiny might not have made as many systematic changes.

Ventilation system modifications have also proven effective at other facilities. At the Department of Energy's Rocky Flats Plant, ventilation controls in a machine shop where pure beryllium and/or high-beryllium alloys are machined were modified from a centralized LEV system to a LVHV system. This change reduced the estimated mean exposure level of machinists by 88 percent, from 0.799 µg/m^3 (33 samples) to 0.092 µg/m^3 (29 samples) (Barnard et al., 1996). Barnard et al. (1996) do not include individual PBZ sample results; therefore, these sample results are not included in the exposure profile.

Evaluating the benefit of control technology from another perspective, two relevant studies outside of the beryllium industry investigated the effectiveness of control applications for reducing worker exposures to airborne metalworking fluids during precision machining and showed that significant exposure reductions were associated with properly enclosed and ventilated machining equipment. These studies are significant because airborne metalworking fluid (as mist) can carry particles of the material being machined; therefore, where workers machine beryllium or its alloys, a reduction in airborne metalworking fluid will similarly reduce worker exposure to airborne beryllium carried by the fluid mist.[230]

In the first study, an investigation of the efficacy of different levels of machine enclosures in reducing employee exposure to metalworking fluid mist, Hands et al. (1996) concluded that machining equipment with LEV and total enclosures designed by the original equipment manufacturer (OEM) provides the most effective control of metalworking fluid mist exposure. Over a 6-year period, 455 full-shift PBZ samples were collected at various production machining operations at a major automobile manufacturer. Operations that were sampled included metal cutting (e.g., milling, boring, drilling, reaming) and grinding. Some operations involved manual loading and unloading of machines; others were totally automated. Sample results were placed into three control categories: 1) machining equipment with both LEV and total enclosures designed by the OEM; 2) machining equipment with retrofitted partial or total enclosures, most of which were equipped with LEV; and 3) machining equipment with little or no enclosures (regardless of LEV status). The results showed that employees operating machining equipment with both LEV and OEM enclosures had significantly lower exposures than employees operating equipment that had only of these two control methods. The median exposure level for operators of machining equipment with LEV and OEM enclosures was more than 50 percent lower than the median exposure levels for the other two control categories (0.21 mg/m^3 compared with 0.45 mg/m^3 and 0.48 mg/m^3, respectively) (Hands et al., 1996).

In the second study, Heitbrink et al. (1999) used tracer gas techniques to evaluate the efficacy of a ventilated enclosure in reducing worker exposure to metalworking fluids during face milling operations with a typical automated machining center. A five-sided full enclosure was built around a vertical metal machining center, and an LEV system with an air cleaner was added. Sulfur hexafluoride tracer gas was used to evaluate the efficiency of the enclosure and LEV at capturing tracer gas released near the spindle of the machining center. A real-time respirable aerosol monitor was used to identify any aerosol leak locations around the enclosure, and ventilation smoke tubes and an air velocity meter were used to evaluate air movement around the outside of the enclosure. The results indicated that at an exhaust flow rate of about 530 cfm, the full enclosure was approximately 98 percent efficient at capturing and removing tracer gas released near the spindle of the machining center during the machining operation. Even so, the real-time aerosol monitor and ventilation smoke tubes indicated that the enclosure leaked at times: the rotating cutting tool and flow of the cutting fluid induced periodic air flow into, and contaminated air flow out of, the enclosure through leakage points. This demonstrates the importance of minimizing leakage through appropriate enclosure maintenance (to minimize unintended openings) and maintaining sufficient airflow across necessary openings in the enclosure.

[230] This principle is discussed in more detail earlier in this analysis (see Section 2—Methodology).

Additional exposure reductions can be achieved by adding total machine enclosures to machining operations that are already performed wet. Metalworking fluid can be a carrier of airborne contamination if splashing, spray and mist generated by the machine tool are not contained and captured. This point was demonstrated in an investigation of exposure to cobalt, another toxic metal, during wet grinding of hard metal blades. Linnainmaa (1995) observed that full-shift PBZ exposures were reduced 50 to 91 percent when two semi-automatic minimally enclosed grinding machines with splash guards were fully enclosed. Cobalt exposures before enclosing the machines ranged from 6 μg/m^3 to 33 μg/m^3 (21 samples); after fully enclosing the grinding machines cobalt exposures were reduced to 3 μg/m^3 (three samples), representing a 50 to 91 percent reduction in cobalt exposure. Controlling metalworking fluid is important to exposure control, regardless of the contaminant type or its concentration in the fluid. To the extent that airborne metalworking fluid is a source of exposure, airborne concentrations of any contaminants (including beryllium) carried in the fluid will be reduced by a percent comparable to the degree by which airborne metalworking fluid is controlled (e.g., by enclosing the process or improving LEV, or both). For example, if a hypothetical airborne beryllium concentration of 0.4 μg/m^3 is due to beryllium carried by metalworking fluid mist, adding an enclosure that reduces fluid-borne air contamination by 50 percent will reduce beryllium similarly, to a level of 0.2 μg/m^3.[231]

Work Practices**:** Work practices that can increase worker exposure to beryllium include entering or partially entering the machine tool enclosure during machining operations. Using an aerosol photometer and video exposure monitoring to identify peak metalworking fluid exposures to machine operators in the course of their work, NIOSH investigators observed that entry and even partial entry into a machining center led to higher operator exposures. One worker had his highest metalworking fluid exposure (0.93 mg/m^3) when he was inside a machining center cleaning; another worker had his highest exposures (0.45 mg/m^3 and 0.63 mg/m^3) when he was at the open doors of partially enclosed machining centers, at times with his arm inside (NIOSH ECTB 218-12a, 1997). At ERG Beryllium Site 4, the highest total beryllium exposure level of 6.6 μg/m^3 was obtained on a machinist operating a fully enclosed and ventilated double-sided lapper. However, it was noted that the worker opened the machine enclosure four to five times to check on the progress of the parts. It is likely that this work practice increased the machinist's exposure to beryllium (ERG Beryllium Site 4, 2003). ERG did not take additional sampling of this operation during the 2004 follow-up visit, but it appears likely that the practice of opening the machine enclosures during the machining cycle exposed the worker to higher peaks of exposure as investigated in the NIOSH study regarding identification of peak metalworking fluid exposures. Eliminating or minimizing this work practice will help significantly reduce exposures for machinists. As an alternative, the doors of the fully enclosed and ventilated machine enclosure could be interlocked with the machining cycle such that the enclosure cannot be opened during the machining cycle and the operator has to wait a designated period of time at the completion of the cycle (e.g., 1 to 2 minutes) before the door can be opened to retrieve the machined part. Materion Corporation advocates a similar approach and recommends that enclosure doors and ventilation systems be interlocked to the machine controls in a manner that

[231] Fifty percent of 0.4 μg/m^3 is 0.2 μg/m^3. A 91 percent reduction in an exposure of 0.4μg/m^3 would result in a level of 0.036 μg/m^3.

requires the ventilation to be operating before startup and stops the machine automatically if the doors are opened (Materion SF 201, 2011; Materion SF 102, 2011).

Other work practices can also increase exposure. Researchers at National Jewish Health, Division of Environmental and Occupational Health Sciences, report that the use of both compressed air and dry sweeping can result in significant worker exposure. In some cases, use of compressed air to clean off a worker’s clothes has resulted in the worker's highest source of exposure to beryllium (OSHA-H005C-2006-0870-0155). Only HEPA filter vacuuming or wet cleaning methods should be used in beryllium work areas (Id.). OSHA has also previously recognized that dry sweeping or cleaning with compressed air can increase employee exposure to hazardous substances, restricting those practices in its standards addressing potentially airborne substances such as asbestos (29 CFR 1910.1001(f)(1)(ix)), lead (29 CFR 1910.1025(h)), chromium (29 CFR 1910.1026(j)(2)), and cadmium (29 CFR 1910.1027(k)).

At a precision machining facility where copper-beryllium products are dry machined, industrial hygiene investigators reported that an exposure level of 9.2 μg/m^3 (sampling duration 310 minutes) was attributed to the use of compressed air near the end of the work shift (MC Pkg I-E-2, 2001). The machinist worked at a ventilated downdraft table, grinding and finishing copper-beryllium products such as gimbal rings and tubes. Dry machining methods for this task included using a handheld Dynafile, one or more polishing wheels, and electric deburring tools (MC Pkg I-E-3, 2000). Other than the use of compressed air, work practices (such as keeping the downdraft table clear of tools and materials and positioning the work in the center of the table) were reported to be satisfactory (MC Pkg I-E-2, 2001).

Machinists Machining Pure Beryllium and/or High-Beryllium Alloys—Conclusion

Based on the best available exposure data described in the exposure profile, the median exposure level for machinists machining pure beryllium and/or high-beryllium alloys is 0.31 μg/m^3. The majority (75 percent) of these machinists are exposed to beryllium levels greater than the proposed PEL of 0.2 μg/m^3, and additional controls will be required to reduce their exposures to this level.

The findings from the two ERG facilities, as well as the observations and conclusions noted in the other studies, indicate that it is possible for employers to reduce the exposure level of most machinists to the proposed PEL of 0.2 μg/m^3 or less through a combination of engineering and work practice controls, including (1) implementing, modifying, or enhancing LEV, machine enclosures, and interlocks; (2) conducting wet work; (3) avoiding dry sweeping and the use of compressed air; and (4) avoiding opening enclosures while the beryllium machining is active. The effectiveness of these controls to reduce exposures is demonstrated at ERG Beryllium Site 1 (2002), where all machining operations are fully enclosed and ventilated. The full-shift PBZ exposure results associated with this combination of engineering controls are characterized by a median of 0.02 μg/m^3, a mean of 0.035 μg/m^3, and a range from 0.02 μg/m^3 to 0.11 μg/m^3 (ERG Beryllium Site 1, 2002). At a second facility, ERG Beryllium Site 4 (2003), initial PBZ exposures for machinists ranged from 0.03 μg/m^3 to 41.48 μg/m^3 during the 1996–1997 timeframe. After making a number of changes aimed at reducing beryllium exposure, the facility conducted follow-up sampling and reported that in 2006, mean PBZ exposures for machinists ranged from 0.07 μg/m^3 to 0.13 μg/m^3. Although the authors did not provide median exposures or individual exposure results, they did review the samples and concluded that “the vast majority of machining exposures were less than 0.2 µg/m^3" (ICBD, 2007). The authors attributed the exposure reductions to a combination of improvements over time in LEV, machine enclosures, and work practices such as eliminating the use of compressed air and dry sweeping (ERG Beryllium Site 4, 2003; ERG Beryllium Site 9, 2004; ICBD, 2007, Martyny et al., 2000).

OSHA therefore preliminarily concludes that compliance with the proposed PEL is technologically feasible for the vast majority of machinists working with pure beryllium and/or high-beryllium alloys. For those machinists that require further exposure reductions during specific activities such as during upset conditions or machine cleaning and maintenance, appropriate respiratory protection may be necessary while the machinist cleans and prepares the immediate work area. Such respiratory protection is readily available and thus a technologically feasible means of complying with the proposed rule when engineering and work practice controls are insufficient. For example, a full-facepiece air purifying respirator with an assigned protection factor of 50 would provide a maximum use concentration [MUC] of 10 µg/m^3, sufficient for the highest sample result (7.2 µg/m^3) reported for machinists working with pure or high-beryllium materials.

OSHA seeks additional information and comments regarding whether exposures can reliably be maintained below an alternative PEL of 0.1 µg/m^3 for most workers in this job category most of the time. Based on the limitations on the available information, OSHA is not drawing any conclusion on that issue at this time. OSHA notes, however, that Table IV-42 shows that only 13% of all beryllium exposures by machinists working with pure beryllium or high-beryllium alloys were at 0.1 µg/m^3 or below. Moreover, even under well-controlled conditions, most machinists working with high-beryllium materials using machines such as lappers and some grinding equipment routinely experience exposure levels above 0.1 µg/m^3.

Machinists Machining Low-Beryllium Alloys

Machinists Machining Low-Beryllium Alloys—Baseline Controls

For machinists at facilities where low-beryllium alloys are machined, baseline conditions typically involve limited exposure controls, often consisting only of a partial mechanical barrier. One beryllium industry expert noted that facilities machining low-beryllium alloys typically do so without any special exposure controls (National Jewish, 2004). This expert's judgment is based on direct observation of initial site conditions in at least 15 facilities that machine copper-beryllium alloys. The survey was conducted during the years preceding the 1998 report date (more specific information on the survey period was not provided by the investigator).

OSHA assumes that baseline conditions for facilities working with low-beryllium alloys are representative of conditions present at typical machine shops, irrespective of the types of metals being machined in the shops. For example, Piacitelli et al. (2001) reported on a general survey of 79 small machine shops (fewer than 500 employees each, which including two shops that were machining copper-beryllium on the survey date). This general survey was intended to assess airborne exposures to metal working fluids. In the survey, LEV was observed on only 18 percent of all sampled machines, and screw machines (a type of precision machinery) were the only machines for which LEV was consistently used.[232] Furthermore, 60 percent of the machines were separated from the worker by only a partial enclosure or splashguard. These baseline conditions are associated with a median exposure level of 0.01 µg/m^3. Approximately 85 percent of the surveyed workers machining low-beryllium alloys had exposures less than or equal to 0.2 µg/m^3.

Machinists Machining Low-Beryllium Alloys—Additional Controls

The exposure profile for workers machining low-beryllium alloys (such as copper-beryllium) is based on 80 full-shift PBZ samples reported for machinists in case studies at three precision machine shops, two more recent NIOSH studies, and sample results supplied by the U.S. Navy. The median exposure level for this job category is 0.01 µg/m^3. As noted above, 74 percent of the results (59 samples) are less than 0.1 µg/m^3, and 85 percent (68 samples) are less than or equal to 0.2 µg/m^3. Based on the exposure profile presented in Tables IV-41 and IV-42, the remaining 15 percent of workers machining low-beryllium alloys may have exposures that exceed 0.2 µg/m^3 and require additional controls to further reduce exposures. In the exposure profile, three of the highest exposures (2.7 µg/m^3, 2.9 µg/m^3, and 24 µg/m^3) for workers machining low-beryllium alloys occurred during dry deburring activities and exceeded the current PEL of 2 µg/m^3. Investigators determined that LEV alone could not be relied on to consistently maintain employee exposures below the current PEL during deburring activities and that exposures resulted from poor work practices, such as using compressed air for cleaning and using the LEV incorrectly or interfering with its effectiveness (MC Pkg I-E-2, 2001; MC Pkg I-E-5, 2000).

To further reduce exposures for workers machining low-beryllium alloys, additional control options include implementing the controls embraced as the baseline or installed as additional controls by facilities that machine pure beryllium and/or high beryllium alloys. These control options primarily include using LEV, installing or upgrading full or partial enclosures, and eliminating or minimizing work practices that increase exposure. As noted in the Exposure Profile subsection for Precision Turned Products, 34 full-shift PBZ results from three recent copper-beryllium machining case studies involving EDM and CNC machining were all below 0.1 µg/m^3 (Materion PSCS 102, 2011; Materion PSCS 103, 2011; Materion PSCS 104, 2011). The ram EDM was equipped with an enhanced LEV system, and the CNC machining was done without LEV in an enclosed machining center with machining fluids. Additional control options include housekeeping and migration control programs to minimize surface contamination that could contribute to worker exposures.

Machinists Machining Low-Beryllium Alloys—Conclusion

The median exposure level associated with machinists machining low-beryllium alloys is 0.01 µg/m^3. Based on the exposure profile for this group of workers, exposure levels at or below the

[232] Less than one-quarter (24 percent) of the machines studied had a full or complete enclosure, 22 percent had a partial enclosure, and 38 percent used a splashguard (a one or two-sided partition between the machinist and the cutting zone). Sixteen percent of the machines surveyed had no engineering controls (Piacitelli et al., 2001). Consistent with OSHA's estimate of the prevalence of machine shops that work with low-beryllium alloys, this survey found only two of the 79 surveyed facilities worked with low-beryllium alloys (beryllium-copper) on the date sampled (Piacitelli, 2004). This finding is consistent with OSHA's estimate of the prevalence of machine shops that work with low-beryllium alloys. Earlier in this analysis, in the industry profile for precision turned products industry, OSHA estimates that 10 percent of the precision turned products manufacturing industry ever work with beryllium or its alloys. Since many of the establishments only work with beryllium alloys occasionally, a lesser percent would actually work with beryllium on any given day.

proposed PEL of 0.2 µg/m^3 have already been achieved by 85 percent of the machinists. For those workers who experience higher exposures (15 percent), additional control options include implementing baseline controls that have been adopted by facilities that machine pure beryllium and/or high-beryllium alloys, or additional controls, as discussed the subsections for workers in those facilities (i.e., enclosures, LEV, and/or work practices). Based on the exposure reductions achieved at facilities that machine pure beryllium and/or high-beryllium alloys (such as ERG Beryllium Sites 1 and 4) and recent case studies of copper-beryllium machining (Materion, 2011), exposure levels of 0.2 µg/m^3 or less can reliably be achieved for most workers machining low-beryllium alloys through a combination of engineering and work practice controls. OSHA therefore preliminarily concludes that the proposed PEL of 0.2 µg/m^3 is feasible for most workers machining low-beryllium alloys most of the time.

Additionally, the available information indicates that exposures below an alternative PEL of 0.1 µg/m^3 can be achieved reliably for most workers most of the time in this job category.

As with the process of machining pure or high-beryllium materials, a small percentage of these low-beryllium workers might require appropriate respiratory protection to further reduce exposures during cleaning or upset conditions. Even after additional controls are installed to limit 8-hour TWA exposures to the level of the proposed PEL of 0.2 µg/m^3 or less, occasional elevated exposures could occur. Even these most elevated occasional exposures would be unlikely to exceed the maximum exposures (7.2 µg/m^3) reported for workers currently using LEV in addition to other exposure controls for machining pure or high-beryllium materials. Therefore, a respirator with an APF of 50 would be appropriate (e.g., a full-facepiece air purifying respirator, which will offer an MUC of 10 µg/m^3) if the proposed PEL of 0.2 µg/m^3 is adopted.

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SECTION 7—PRECISION TURNED PRODUCTS, APPENDIX 1—SUMMARY OF BERYLLIUM EXPOSURE CONTROL PROGRAM AT THE CARDIFF ATOMIC WEAPONS ESTABLISHMENT IN THE UNITED KINGDOM, BY JOHNSON ET AL.

Johnson et al. (2001) reported on 217,681 total beryllium PBZ lapel samples collected on 194 employees at the Cardiff Atomic Weapons Establishment (AWE) in Cardiff, Wales, United Kingdom, from 1981 to 1997.[233] Of these, 104,359 samples were obtained on machinists milling and turning pure beryllium. Over the 17-year time period, the estimated annual mean exposure for machinists ranged from 0.12 µg/m^3 to 0.46 µg/m^3 and the estimated annual median exposure ranged from 0.08 µg/m^3 to 0.28 µg/m^3.[234] For all years combined, the estimated average annual mean and median exposures were 0.32 µg/m^3 and 0.14 µg/m^3, respectively. These values include full-shift samples collected during the week as well as shorter-term samples obtained on the weekends (e.g., 3.5, 4.5, and 5-hour sample durations).

Production support departments at the AWE facility included laboratory, inspection, safety, and services/maintenance workers. A total of 57,535 total beryllium PBZ lapel samples were obtained for these workers (34,215 samples for inspection workers; 8,363 samples for laboratory workers; 2,688 samples for safety workers; and 12,269 samples for services/maintenance workers). For all years, the estimated average annual mean exposure ranged from 0.19 µg/m^3 for safety workers to 0.29 µg/m^3 for services/maintenance workers. The laboratory and inspection workers had estimated average annual mean exposures of 0.22 µg/m^3. The estimated average annual median exposure for these departments ranged from 0.11 µg/m^3 (inspection, safety, and services/maintenance) to 0.14 µg/m^3 (laboratory). The highest production support exposures were associated with services/maintenance activities. Total beryllium was analyzed by flame atomic absorption spectroscopy, and the detection limit was 0.05 µg/m^3.

Based on an analysis of median exposures at the Cardiff AWE, Johnson et al. (2001) concluded that the extensive beryllium exposure control program in place was effective in producing low exposures. They noted only one unique case of chronic beryllium disease (CBD) during the 36-year period the facility was in operation. Key components of the exposure control program

[233] The AWE facility was used exclusively for beryllium manufacturing and conducted operations very similar to those at the U.S. Department of Energy's Rocky Flats facility, except that AWE's output was smaller (AWE and DOE, 1997).

[234] The original personal sampling data analyzed by Johnson et al. (2001) did not contain information on sample duration or flow rate. All Cardiff employees wore a personal sampling pump whenever they were in the beryllium work areas. The employees put on and removed the air sampling pumps by themselves (AWE and DOE, 1997). Four technicians maintained the air sampling pumps, handled the sample filters, and performed the analysis of the filters. Johnson et al. calculated "estimated" personal daily average concentrations using calibration information (i.e., an estimated flow rate of 2 liters per minute) and facility records regarding shift durations, which varied depending on the day of the week and the year. In some cases, weekend shift durations varied over time for certain workers. The estimated personal daily average concentrations were not adjusted to 8-hour time-weighted average concentrations.

included ventilation and worker, housekeeping, and material controls. To evaluate program effectiveness, extensive industrial hygiene exposure assessment and medical surveillance programs were developed and implemented.

Ventilation systems at the Cardiff facility were designed so that airflow was directed from clean areas to contaminated areas before passing through an air cleaning device. Supply air entering the facility passed through a roughing filter and a HEPA filter. Beryllium processing machines were partially or completely enclosed and exhausted through LEV systems equipped with single- or double-stage HEPA filters. The LEV face velocity was maintained at 50 fpm. In 1976, a new machine shop with a LVHV exhaust system with flexible ducts was added to the facility. The face velocity of the close-capture exhaust ducts in this new system ranged from 6,000 fpm to 8,000 fpm.

Worker controls consisted of access controls, personal hygiene, personal protective equipment (PPE), and housekeeping. Employee access control zones were designated throughout the facility and strictly enforced. A complete daily change of clothes was provided, and the laundry facility for contaminated clothing and respirators was located next to the change room. Workers were required to decontaminate themselves before eating, drinking, smoking, or using the toilet. Decontamination consisted at a minimum of changing coveralls and shoes and washing hands. Shower facilities were available but their use was not mandatory. Respiratory protection was routinely utilized when additional levels of protection were required.

> *Housekeeping was conducted daily and included the use of HEPA-filtered vacuums or wet techniques such as mopping of floors. Dry sweeping of the floor was prohibited. To evaluate housekeeping procedures, dry swipe samples were collected routinely and any areas detected with high-beryllium levels were subject to immediate cleanup* (Johnson et al., 2001).

Material controls consisted of decontamination procedures and control of wastewater discharge. Materials or items to be removed from beryllium control areas were carefully cleaned until a surface level of less than 0.1 micrograms beryllium per 100 square centimeters ($\mu g/100\ cm^2$) of surface area was measured. Laundry wastewater was collected and/or treated to remove beryllium from the wastewater.

SECTION 7—PRECISION TURNED PRODUCTS, APPENDIX 2—AVAILABLE EXPOSURE DATA FOR NON-MACHINISTS IN FACILITIES MACHINING LOW-BERYLLIUM ALLOYS

In facilities that machine low-beryllium alloys, OSHA determined that the exposures of most non-machinists are consistently low and unlikely to reach an alternative PEL of 0.1 μg/m^3 or exceed the proposed PEL (0.2 μg/m^3). Tables IV-45 through IV-47 in Precision Turned Products Appendix 2 summarize the exposure levels for non-machinists in facilities machining low-beryllium alloys and the breakdown of the nondetectable samples by job category and work group. These data, characterized by a mean of 0.01 μg/m^3, a median of 0.009 μg/m^3, and a range from 0.005 μg/m^3 to 0.037 μg/m^3, represent 33 PBZ total beryllium exposure results for non-machinists in four facilities where copper-beryllium parts are machined. All of the samples are less than 0.1 μg/m^3 and 88 percent of the results (29 of 33 samples) are nondetectable for beryllium. The job categories associated with these results include maintenance (equipment and building), supervisor (not otherwise specified), shipping and receiving, inspector (quality control), and janitor.

Table IV-45—Personal Exposure in the Precision Turned Product Industry for Non-Machinists in Facilities Machining Low-Beryllium Alloys (NAICS 332721)*

Job Category	No. of Samples	Range (μg/m^3)	Mean (μg/m^3)	Median (μg/m^3)
Maintenance (equipment and building)	*9*	*0.005 to 0.037*	*0.014*	*0.01*
Supervisor	*5*	*0.008 to 0.01*	*0.009*	*0.009*
Shipping and receiving	*5*	*0.009 to 0.011*	*0.01*	*0.009*
Inspector (quality control)	*11*	*0.005 to 0.021*	*0.01*	*0.008*
Janitor	*3*	*0.006 to 0.006*	*0.006*	*0.006*
TOTAL	*33*	*0.005 to 0.037*	*0.01*	*0.009*

* *All samples are reported to be full-shift (at least 360 minutes in duration) except for one NIOSH sample with a sampling duration of 327 minutes. Full-shift sample results are based on the actual sampling duration. Nondetectable results are reported as sampling limit of detection concentrations. Eighty-eight percent of the samples (29 of 33 samples) are reported to be nondetectable for beryllium.*

PBZ: personal breathing zone lapel-type samples

Sources: Brush Wellman Machining, 2004; NIOSH EPHB 326-14a, 2008

Table IV-46—Distribution of Full-Shift Total Beryllium PBZ Lapel Exposures in the Precision Turned Product Industry for Non-Machinists in Facilities Machining Low-Beryllium Alloys (NAICS 332721)*

Job Category	Number of Results in Range (μg/m^3)						Total
	≤ 0.1	> 0.1 to ≤ 0.2	> 0.2 to ≤ 0.5	> 0.5 to ≤ 1.0	> 1.0 to ≤ 2.0	> 2.0	
Maintenance (equipment & building)	*9 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*9 (100%)*

Table IV-46—Distribution of Full-Shift Total Beryllium PBZ Lapel Exposures in the Precision Turned Product Industry for Non-Machinists in Facilities Machining Low-Beryllium Alloys (NAICS 332721)*

Job Category	Number of Results in Range (μg/m³)						Total
	≤ 0.1	> 0.1 to ≤ 0.2	> 0.2 to ≤ 0.5	> 0.5 to ≤ 1.0	> 1.0 to ≤ 2.0	> 2.0	
Supervisor	*5 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*5 (100%)*
Shipping & Receiving	*5 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*5 (100%)*
Inspection	*11 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*11 (100%)*
Janitor	*3 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*3 (100%)*
TOTAL	**33 (100%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**33 (100%)**

* *Nondetectable results are reported as sampling limit of detection concentrations. Eighty-eight percent of the samples (29 of 33 samples) are reported to be nondetectable for beryllium.*

PBZ: personal breathing zone lapel-type samples

Sources: Brush Wellman Machining, 2004; NIOSH EPHB 326-14a, 2008

Table IV-47—Number of Nondetectable Sample Results in the Personal Exposure Profile for Non-Machinists in Facilities Machining Low-Beryllium Alloys (NAICS 332721)*

Job Category	Total No. of PBZ Samples by Job Category	Total No. of Nondetectable PBZ Samples by Job Category
Maintenance (equipment & building)	*9*	*7 (78%)*
Supervisor	*5*	*5 (100%)*
Shipping & Receiving	*5*	*5 (100%)*
Inspection	*11*	*10 (91%)*
Janitor	*3*	*2 (67%)*
TOTAL	*33*	*29 (88%)*

PBZ: personal breathing zone lapel-type samples

Sources: Brush Wellman Machining, 2004; NIOSH EPHB 326-14a, 2008

SECTION 7—PRECISION TURNED PRODUCTS, APPENDIX 3—AVAILABLE EXPOSURE DATA FOR NON-MACHINISTS IN FACILITIES MACHINING PURE BERYLLIUM AND/OR HIGH-BERYLLIUM ALLOYS

In facilities that machine pure beryllium and/or high-beryllium alloys, OSHA has no individual PBZ total beryllium air sampling results for non-machinists. The available exposure information is limited to aggregated results for major non-machinist job titles at a precision beryllium machining plant that is the subject of the Kelleher et al. (2001) investigation. At this facility, the summary statistics for non-machinists represent 37 results for 10 job titles based on personal impactor sampling over multiple work shifts (i.e., four impactor samples for all non-machinist job titles except one).[235] These results were obtained in September 1999 and are summarized in Table IV-48 in Precision Turned Products Appendix 3. As shown, the mean and median exposures range from 0.01 μg/m^3 to 0.49 μg/m^3 and 0.01 μg/m^3 to 0.47 μg/m^3, respectively, depending on job title. In all cases, the means and medians for each job title are close in value or identical, indicating that the datasets are fairly symmetrical. For eight of the non-machinist job titles, both the mean and median exposure levels are less than 0.1 μg/m^3. These jobs include manager/administrator, engineer, specialty cell worker (no other information available), shipper, tool grinder (this job category did not machine beryllium), shop manager, inspector, and assembler. The highest mean and median results represent maintenance workers and chemical finishers, who performed acid etching. For maintenance workers, the mean and median exposure levels are 0.19 μg/m^3 and 0.18 μg/m^3, respectively. For chemical finishers, the mean and median exposures are 0.49 μg/m^3 and 0.47 μg/m^3, respectively. Although a limited number of results were obtained for each job title and these data represent only one establishment, the findings are consistent and suggest that most non-machinists in facilities machining pure beryllium or high-beryllium alloys typically have low exposures with some exceptions. Certain jobs, such as chemical finishers and maintenance workers, may have higher beryllium exposures that can exceed an alternative PEL of 0.1 μg/m^3 or the proposed PEL of 0.2 μg/m^3, but individual sample results for these categories are not available for this industry.

At the same precision machining facility, Madl et al. (2007) reported that there has been a clear downward trend in PBZ total beryllium concentrations between 1980 and 2005 for both

[235] Personal impactor samples were collected with Series 290 Marple Personal Cascade Impactors attached to the lapel of the workers for at least two shifts (to ensure adequate collection of beryllium on the impactor media). Samples were analyzed using NIOSH Method 7300 with a LOD of 0.007 μg per sample and a LOQ of 0.030 μg per sample. Results below the LOD were assigned a value of 0.0035 μg per sample (one-half the Method 7300 LOD). (NOTE: OSHA's current sampling procedure for beryllium specifies a calibrated personal sampling pump with a mixed-cellulose ester membrane filter contained in a styrene cassette for a maximum of 8 hours (OSHA ID-125G, 2012; OSHA CSI_Be, 2012). This collection procedure is typically referred to as total dust sampling for beryllium (i.e., total beryllium) and the results would not necessarily be equivalent to personal impactor sampling. Interstage impactor losses are reportedly a potential source of error when trying to compare the results of impactors with total dust samplers (McDermott, 2004).)

machining and non-machining job titles due to administrative and engineering control changes over time. These changes are summarized in Precision Turned Products Appendix 4. Over the 25-year time frame, the mean and median exposure levels for non-machinists decreased from 1.01 μg/m^3 to 0.08 μg/m^3 and 0.12 μg/m^3 to 0.06 μg/m^3, respectively (individual sampling results are not available). For the 2006 to 2007 time period, the mean exposure level for manufacturing support workers and other non-machinists was reported to be approximately 0.05 μg/m^3 (ICBD, 2007).[236]

Collectively, these findings suggest that non-machinists in facilities machining pure beryllium and/or high-beryllium alloys currently experience exposures that are less than 0.1 μg/m^3 a majority of the time. Based on these data, OSHA anticipates that in the precision turned products manufacturing industry, most non-machinists in facilities machining pure beryllium and/or high-beryllium alloys also will not exceed an alternative PEL of 0.1 μg/m^3 or the proposed PEL of 0.2 μg/m^3.

In the event that additional information suggests that current exposures do exceed the levels of interest, methods for controlling exposures would be similar to methods discussed for such jobs in other industries. OSHA notes that the chemical processing operator job category is discussed in detail in this PEA at Section 9—Fabrication of Beryllium Alloy Products, while the maintenance operator job category is discussed in Section 5—Nonferrous Foundries.

Table IV-48—Estimated Personal Exposure Profile in the Precision Turned Product Industry for Non-Machinists in Facilities Machining Pure Beryllium and/or High-Beryllium Alloys (NAICS 332721)[a]

Job Category	Number of Samples	Mean (μg/m^3)	Median (μg/m^3)	Geometric Mean (μg/m^3)
Chemical finisher	*4*	*0.49*	*0.47*	*0.48*
Maintenance worker	*4*	*0.19*	*0.18*	*0.16*
Assembler	*1*	*0.08*	*0.08*	*0.08*
Inspector	*4*	*0.07*	*0.06*	*0.06*
Shop manager	*4*	*0.06*	*0.04*	*0.03*
Tool grinder[b]	*4*	*0.03*	*0.03*	*0.03*
Shipper	*4*	*0.03*	*0.02*	*0.03*
Specialty cell worker[c]	*4*	*0.01*	*0.01*	*0.01*
Engineer	*4*	*0.01*	*0.01*	*0.01*
Manager/administrator (front office)	*4*	*0.01*	*0.01*	*0.01*

[a] Full-shift personal breathing zone (PBZ) sample results are based on personal impactor sampling over a period of at least two work shifts. The study investigators assigned a value of 0.0035 μg/sample for results below the analytical limit of detection (0.007 μg/sample). Samples were collected in September 1999. Individual sample results, range, and overall standard deviation are not available.

[b] Tool grinders do not machine beryllium.

[c] No information is provided regarding the work tasks of specialty cell worker.

Source: Kelleher et al., 2001

[236] Estimate is based on a bar chart (see ICBD, 2007). Individual exposure values are not available.

SECTION 7—PRECISION TURNED PRODUCTS, APPENDIX 4—EXPOSURE CONTROL CHANGES AT A PRECISION BERYLLIUM MACHINING FACILITY (1996 TO 1999)

Table IV-49—Exposure Control Changes at a Precision Beryllium Machining Plant (1995 to 1999)

Year(s)	Change Category	Description of Change
1995–1996	*Administrative*	*Eliminated use of compressed air for cleaning.*
1996–1997	*Administrative*	*Implemented wet/vacuum cleaning methods; discouraged dry sweeping.* *Implemented mandatory work uniforms and dedicated work shoe policy.*
1996–1997	*Engineering*	*Controlled access to production areas via a clean side/dirty side transition room.* *Separated beryllium dust/fume/mist LEV ductwork and dust collectors from beryllium chips.* *Changed process layout and located beryllium dust/fume/mist operations in close proximity to each other.* *Installed enclosures on deburring, grinding, EDM, lapping, and tool and die operations.* *Installed vacuum cleaning systems for machining operations.* *Installed mist eliminators on some CNC milling machines.*
1998	*Engineering*	*Installed LEV in EDM and updated/modified LEV systems for deburr, grind, and lap departments.*
1999	*Engineering*	*Replaced LEV ductwork for lather and milling operations.* *Added additional vacuum systems to some departments.*

Source: Adapted from Madl et al. (2007) and Kelleher et al. (2001)

SECTION 7—PRECISION TURNED PRODUCTS, APPENDIX 5—

BASELINE CONDITIONS AND CONTROLS AT THE TWO PRECISION

MACHINING FACILITIES SURVEYED BY ERG (ERG BERYLLIUM

SITES 1, 4/9)

Detailed Discussion of the Baseline Conditions and Controls Observed at the Two Precision Machining Facilities Surveyed (ERG Beryllium Sites 1, 4/9)

Access Control, PPE, and Personal Hygiene: At **ERG Beryllium Site 1**, the facility has designed and implemented a safety zone approach to controlling exposure. Safety zones are identified as minimum, medium, and maximum based on the potential hazard and the required protective measures. In the minimum safety zone, workers enter the facility, take breaks, eat meals, and perform general administrative activities without any special controls or PPE. The medium safety zone is the transition between the minimum and maximum safety zones and includes the locker room, shower and hygiene facilities, PPE storage, and clothes laundering capabilities. The maximum safety zone (also called the milling room) is where the beryllium machining processes take place and requires full protective gear to be donned before entering. Although the milling room has strict PPE requirements prior to entry, there is a door leading from the office area directly into the milling room that provides an opportunity for employees and materials to move between these two areas unimpeded.

In the medium safety zone (i.e., the change room), workers change out of their personal shoes and don the following employer-provided protective clothing and equipment: work shoes, half-face air-purifying respirator with HEPA filters or a loose fitting powered air-purifying respirator with HEPA filters, hat, disposable coveralls, shoe covers, and latex gloves. The gloves can also be removed and put on in the milling room. Workers wear their personal clothing underneath the disposable coveralls. The coveralls are of a lightweight material, but it was noted that they appear to increase the wearer's thermal load.[237] Workers commonly wear short-sleeved shirts to work even when it is snowing outside, and several were observed working with the sleeves of their coveralls pushed up to their elbows or with the sleeves cut short. Such actions defeat the purpose and protective nature of the long-sleeved coveralls.

To exit the milling room and enter the change room, workers enter a transition zone in the milling room that is located next to the door leading into the change room. The transition zone is not separated from the general work areas in the milling room, and it was noted that a machinist had to move through this area in order to access the rear of the milling machine. In the transition zone, workers remove and discard their gloves and shoe covers in designated waste receptacles, remove and hang their coveralls and hats on closely spaced hooks on the wall in the milling room, and vacuum the tops and bottoms of their work shoes with a HEPA vacuum cleaner. Workers submit their coveralls for laundering at least twice a week and more often if necessary.

[237] Thermal load refers to the collective factors which can increase body temperature.

It was also noted that the same hats are always worn, which could result in the hats becoming sources of contamination rather than protection. From the transition zone, workers walk to the door leading into the change room, step onto a sticky mat in front of the door, and then pass through the door. Sticky mats limit the spread of beryllium contamination from one work area to another that may be transported by shoes. Once inside the change room, workers remove and store respirators in covered containers and wash their hands and faces. Showers are available, but most workers do not shower before leaving the facility.

Because the transition zone in the milling room is not separated from the general work areas by a physical barrier, machinists that need to access the rear of one of the milling machines might contaminate the floor of the transition zone. This contamination could then be transferred to work shoes after employees remove their shoe covers and walk to the change room door. The sticky mat in front of the change room door is a good way to limit the spread of contamination to the floor of the change room, but it may not be sufficient for the number of people passing to and from the milling room. The mat was observed to be fully loaded with dirt, which could result in insufficient decontamination and/or contamination transfer from the mat to the shoes of exiting workers. The closely spaced wall hooks in the transition zone are another potential source of contamination. Because workers' coveralls are bunched together on the hooks, beryllium contamination could potentially be transferred from the outside of the coveralls to the inside. This contamination transfer could occur within the same garment or between separate garments and result in workers contaminating their personal clothing or skin.

At ERG Beryllium Site 4/9, workers enter the building through a rear entrance and immediately proceed into a change room where they are required to change into company-provided uniforms and work shoes. From the change room, workers enter the beryllium machining areas of the facility. At the time of the ERG surveys, glove-use was not required, and although gloves were readily available, they were generally not worn in the plant. Some workers were observed using gloves during certain operations. When workers perform jobs that may result in skin contamination, they are allowed to leave their workstations and wash the affected skin areas. Respiratory protection is generally not worn in the plant, and workers typically do not shower before leaving at the end of the work shift.

Office workers typically enter through the front of the facility, which is open to the public. Before entering the beryllium machining areas of the plant from the office area, workers are required to don lab coats and shoe covers over their street clothing. A change room is available with lab coats and shoe covers for this purpose. However, workers entering the offices from the machining areas are not required to wear shoe covers and may potentially contaminate the office floors. Access between the plant floor and the office areas is otherwise unimpeded. Since all employees have access to the production area, all employees are considered to be beryllium exposed. As such, they are tested every two years using the beryllium lymphocyte proliferation test. All employees also undergo training before beginning employment and annually thereafter. The company has created a training video to educate workers on the hazards associated with beryllium and the measures the company is taking to control exposure.

Engineering Controls: At **ERG Beryllium Site 1**, each machining center in the milling room is under negative pressure and completely enclosed with steel-framed Plexiglas. Local exhaust ventilation (LEV) is provided continuously whether the machines are open or closed through a centralized 6,000 cfm exhaust system located in an adjacent room in the minimum safety zone. Exhaust air passes through HEPA filters prior to discharge. The differential pressure across the filters is checked on a daily basis by reading a pressure gauge. The ventilation system is serviced and maintained by an independent contractor annually. The contractor's personnel are trained in hazardous materials and reportedly understand the control measures required for beryllium.

At **ERG Beryllium Site 4/9**, all beryllium machining equipment is supplied with LEV. However, only about 65 percent of the machining equipment is fully enclosed, with the remainder open or partially enclosed. For the open machining equipment, workers manually position a flexible exhaust duct close to the point-of-operation. Ventilation smoke tubes used to check the exhaust flow around the point-of-operation indicated that the exhaust ducts are generally well positioned by the machinists. However, this was not true in all cases. Several exhaust ducts were improperly positioned, though only by a few centimeters, which resulted in less than optimal exhaust flow around the piece of beryllium being machined. In one case, where beryllium air sampling was not performed, air jets coming out of the machine at the tool head interfered with the exhaust flow entirely, creating a reverse flow that blew debris out of the control zone.

Local exhaust ventilation is provided through the use of two different types of systems. The first type is a low volume, high velocity (LVHV) system that produces 4,200 fpm linear air velocity through a main 12-inch diameter duct. There are seven of these systems for all dry machining operations. These systems are generally designed to deliver a minimum of 10,000 fpm of face velocity at point-of-operation hoods. The point-of-operation hoods are positioned as close as possible (one to two inches) to the source to maximize particle capture efficiency. The second type of LEV is a high volume, low velocity (HVLV) system that produces 4,800 fpm linear air velocity through a main 18-inch diameter duct. There are five of these. Through experience, the facility has learned that the first system is more effective at exhausting large machining debris, and the second system is more effective at exhausting fine aerosols. The current design layout takes the exhaust system differences into consideration.

At the time of the first ERG survey, the ductwork had not been designed to minimize energy losses, and work occasionally had to be curtailed to ensure sufficient operating velocity and pressure on some machines. Major changes were needed to take place to bring the LEV system into compliance with recognized design standards and to ensure that sufficient exhaust ventilation was always available, particularly in the beryllium metal/oxide composite area.

In 2003, the site upgraded the LVHV system ductwork in the mill and lathe departments. This upgrade reduced the number of unnecessary duct runs and reconfigured transitions and elbows to minimize energy loss in the system. This upgrade reportedly increased the face velocity of the terminal hood from 2,100 fpm to 4,300 fpm. Personal beryllium exposure to mill and lathe department employees was reportedly reduced from an 8-hour time-weighted average (TWA) of approximately 0.2 $\mu g/m^3$ to 0.1 $\mu g/m^3$.

In 2004, the site installed full enclosures on two of the surface grinder operations to contain visible airborne coolant that is generated at high speeds. The surface grinder operator exposure to beryllium was reportedly reduced from an average of 1.6 $\mu g/m^3$ (8-hour TWA) to 0.08 $\mu g/m^3$.

The ventilation systems at ERG Beryllium Site 4 (and 9) are serviced and maintained by the internal maintenance crew on an as needed basis. These personnel are trained in hazardous materials and reportedly understand the control measures required for beryllium.

Work Practices and Housekeeping: At **ERG Beryllium Site 1,** worker compliance with company established work practices and procedures is reported to be excellent. Work practices and procedures are detailed, well documented, and audited by senior management on a weekly and monthly basis. Audit findings are documented, tracked, and communicated throughout the organization. Housekeeping activities are also documented and tracked according to a daily, weekly, monthly, and quarterly schedule of requirements. The facility employs a full-time worker dedicated to and responsible for completing the housekeeping schedule. The housekeeping program includes the use of HEPA-filtered vacuums for cleaning.

ERG noted potential sources of exposure involving the use of tools to remove parts from machining equipment, and the removal of contaminated debris (metal scraps and turnings) from machining equipment. Some machining equipment requires that parts be held securely in place with screws. To remove these parts after machining, tools must be used to loosen the screws. The tools can become contaminated with beryllium when they come into contact with machined parts, and contamination can be spread when these tools are moved back and forth between machining equipment without proper cleaning. Work practices for removing contaminated debris from machining equipment are also a concern. The highest levels of surface contamination were noted in areas where chips, shavings, and other debris are removed from machining equipment. Such findings might necessitate changes in clean-out procedures and/or housekeeping activities.

At **ERG Beryllium Site 4/9),** work practices and housekeeping activities were less formal than those at ERG Beryllium Site 1 and were not documented at the time of the surveys. Although there was no visible mist in the air from machining fluids and no apparent dust collection on surfaces, small metallic chips were visible on the floor. A vacuum system was available for cleaning but not always used and some dry sweeping of dust was noted during the site surveys. Machinists were responsible for keeping their workstations clean, and visible build-up of machining debris on work surfaces was not supposed to occur. Chips, turnings, and other machining debris were brushed away using a small hand brush and dust pan and disposed of in containers located near the work area. Workers were generally aware that exposure controls were necessary but it was not clear if there were company-established work practices and procedures that must be followed. For example, on one EDM cutting machine, dust control was achieved by placing a wet cloth over the material being cut. Although this method may have been effective, it is unorthodox.

SECTION 7—PRECISION TURNED PRODUCTS, APPENDIX 6 - COMPARISON OF BERYLLIUM SURFACE CONTAMINATION RESULTS AT TWO FACILITIES MACHINING PURE BERYLLIUM AND/OR HIGH-BERYLLIUM ALLOYS

Comparison of Beryllium Surface Contamination Results at Two Facilities Machining Pure Beryllium and/or High-Beryllium Alloys

Beryllium surface contamination, which can contribute to worker exposure by inhalation and other routes, can be controlled through the use of effective housekeeping programs. Table IV-50 compares beryllium surface contamination results by facility and sampling areas (i.e., machining areas, change rooms, lunch/break rooms, and offices). Although ERG Beryllium Site 1 had a more sophisticated housekeeping program than ERG Beryllium Site 4 at the time of the surveys, this difference is not readily apparent when reviewing the surface sample results in Table IV-50. The median surface contamination levels for machining areas and lunch/break rooms at ERG Beryllium Site 1 are 3.70 µg/100 cm^2 and 0.38 µg/100 cm^2, respectively. At ERG Beryllium Site 4, the median surface contamination levels for machining areas and lunch/break rooms are greater; i.e., 4.15 µg/100 cm^2 and 4.08 µg/100 cm^2, respectively. However, when the surface sample results for change rooms and offices are compared, the opposite is noted; the median surface contamination levels for the change room and offices at ERG Beryllium Site 1 (3.33 µg/100 cm^2 and 0.71 µg/100 cm^2) are greater than those for ERG Beryllium Site 4 (0.85 µg/100 cm^2 and less than 0.04 µg/100 cm^2). These inconsistencies might be due to the time of day when the samples were collected. All surface contamination samples were collected during production shifts and did not necessarily indicate the levels that could be achieved after cleaning. Additionally, it was noted during the ERG Beryllium Site 1 survey that the worker in charge of housekeeping was ill at the time of the site visit and daily cleaning had not been performed.

Although the surface contamination data in Table IV-50 does not substantiate the effectiveness of one housekeeping program over another, it clearly shows that beryllium surface contamination is present throughout the facilities and that housekeeping needs improvement. Surface sampling conducted after workplace cleaning should show a reduction in workplace contamination and can be used to compare the effectiveness of cleaning methods and schedules as well as work practices. Further, an OSHA project consultant states that housekeeping must be conducted for each shift and disciplined (i.e., well defined and followed) in all industries where beryllium is used or handled to achieve 0.2 µg/m^3 or 0.1 µg/m^3 exposure levels (Corbett, 2006). While this is rarely the only control, it should be a component of the overall exposure control plan.

Table IV-50—Comparison of Beryllium Surface Contamination Results by Sample Area at Two Facilities Machining Pure Beryllium and/or High-Beryllium Alloys[a]

Sample Areas	Facility	Number of Samples	Beryllium Concentration (µg/100 cm^2)		
			Range	Mean[b]	Median[b]

Table IV-50—Comparison of Beryllium Surface Contamination Results by Sample Area at Two Facilities Machining Pure Beryllium and/or High-Beryllium Alloys[a]

Sample Areas	Facility	Number of Samples	Beryllium Concentration (μg/100 cm²)		
			Range	Mean[b]	Median[b]
Machining[c]	*ERG Beryllium Site 1[d]*	*17*	*0.07 to 315*	*29.52*	*3.70*
	ERG Beryllium Site 4	*54*	*0.04 to 195*	*19.24*	*4.15*
Change Room[e]	*ERG Beryllium Site 1[d]*	*2*	*0.46 to 6.2*	*3.33*	*3.33*
	ERG Beryllium Site 4	*7*	*0.42 to 11.72*	*3.64*	*0.85*
Lunch/Break Rooms[f]	*ERG Beryllium Site 1[d]*	*3*	*0.28 to 0.43*	*0.36*	*0.38*
	ERG Beryllium Site 4	*4*	*1.34 to 6.1*	*3.90*	*4.08*
Offices[g]	*ERG Beryllium Site 1[d]*	*5*	*0.04 to 3.27*	*1.45*	*0.71*
	ERG Beryllium Site 4	*7*	*0.04 to 1.03*	*0.20*	*0.04*

[a] *Samples were collected during production shifts and do not necessarily represent the levels that can be achieved after cleaning.*

[b] *Nondetectable results are reported at the surface area-adjusted analytical limit of detection.*

[c] *Machining wipe samples were collected in milling, lathing, lapping, grinding, and EDM areas on work benches, equipment and tool handles, equipment housings and control panels, tool boxes, computers, desks, chairs, walls, doors, floors, and other miscellaneous work surfaces.*

[d] *Daily cleaning for the day shift at ERG Beryllium Site 1 was not performed during the site survey due to worker illness.*

[e] *Change room wipe samples were collected on benches, lockers, floors, doors, shoes, and boots.*

[f] *Lunch and break room wipe samples were collected on table, floor, microwave, and other surfaces.*

[g] *Office wipe samples were collected on desk, table, floor, shelf, and other surfaces.*

Sources: ERG Beryllium Site 1, 2002; ERG Beryllium Site 4, 2003

During the course of the ERG site visits to the two beryllium machining facilities, investigators noted numerous opportunities for reducing beryllium surface contamination and migration. To optimize migration control at both facilities, investigators recommended changes to the facility layout and the sequence of work practices during transitions from production to non-production areas. These recommendations include the following (ERG Beryllium Site 1, 2002; ERG Beryllium Site 4, 2003):

- Designate a single entry into beryllium machining areas.
- Utilize tacky mat floor covering designed for three foot falls per foot to increase effectiveness.
- Cover work shoes with disposable shoe covers, remove work shoes, or otherwise clean work shoes prior to entering adjacent office or support areas from transition areas. In addition, use tacky rollers to clean dust off floors.
- Don disposable protective gloves before handling any potentially contaminated articles.
- Wear disposable gloves at all times inside transition, change, and machining areas. Do not remove gloves until immediately before exiting the change room into non-production areas.

- Provide glove and shoe cover disposal receptacles at all transition areas.
- Provide containers of clean disposable gloves and shoe covers at the entrance into transition and machining areas as well as at operator workstations.
- Provide hand wipes wherever clean gloves are stored to facilitate hand washing prior to donning clean gloves.
- Provide waste receptacles with lids and foot pedals. This practice will make it unnecessary to touch the lid to open the receptacle and will alleviate the temptation of workers to throw potentially contaminated trash from any distance.
- Eliminate all porous surfaces, especially fabric-covered chairs, to the extent feasible, unless they are disposable and are disposed of regularly.
- Consider designs and techniques to control the transfer of shoe contamination from production areas to transition areas and/or change rooms. For example, sticky mats need to be of sufficient size to adequately remove foot contamination.
- Place all reusable PPE in covered storage containers.
- Take showers at the end of the work shift.
- Study work practice sequences at transition areas and change rooms to identify all sources of potential contamination, and develop work practice sequences that minimize migration of beryllium particles from production areas into non-production areas.

Investigators also presented detailed site-specific recommendations and an alternative facility layout with a four zone concept to control beryllium migration (ERG Beryllium Site 1, 2002; ERG Beryllium Site 4, 2003). The alternative design should be considered for new facilities and renovation or expansion of existing facilities.

SECTION 8—COPPER ROLLING, DRAWING, AND EXTRUDING

INDUSTRY PROFILE

Copper rolling, drawing, and extruding mills produce copper and copper alloy rod, bar, sheet, strip, plate, pipe, tube, and wire.[238] The metal-forming processes used to produce copper-beryllium alloy products (which typically contain 2 percent or less beryllium) are common to other metals and, depending on the product, may include rolling, extrusion, and hot or cold drawing. These processes may be accompanied by annealing, pickling or metal cleaning, and slitting or cutting operations. For more information on the nature of these processes, refer to Copper Rolling, Drawing, and Extruding Appendix 1.

In order to estimate the number of affected establishments and employees, OSHA considered several sources. The U.S. Census Bureau (2010) reported 96 establishments engaged in copper rolling, drawing, and extruding. These establishments employed 9,849 workers overall, with an estimated 7,625 in production occupations.[239] From this information, OSHA estimates the average number of total workers and production workers per establishment are approximately 102.6 and 79.4, respectively.[240]

Data from the 2002 Economic Census show that the number of companies in this industry manufacturing products from alloyed copper (as opposed to unalloyed copper) is considerably smaller than the total (U.S. Census Bureau, 2002). Of the 91 firms reported for NAICS 331421 in 2002, 16 firms with 19 establishments produced copper alloy wire; 14 firms with 24 establishments produced copper alloy rod, bar, and shapes; 11 firms with 17 establishments produced copper alloy sheet, strip, and plate; and 8 firms with 26 establishments produced copper alloy pipe and tube.[241] The remaining firms presumably produced rolled, drawn, or extruded products out of unalloyed copper.

Copper-beryllium is one of many copper alloys (e.g., brass and bronze) used by firms producing products from copper alloys. A list of copper-beryllium product suppliers maintained by the Copper Development Association (CDA) includes eight companies with a total of 12 establishments that produce rolled and drawn copper-beryllium products (CDA, 2002). OSHA identified three additional establishments engaged in redrawing or rerolling copper-beryllium alloy materials. While these 15 establishments may not all perform extrusion, OSHA judges that exposures during extruding operations can be controlled similarly to exposures caused during drawing operations. See Data Sources within this section, for information on sources of exposure data during rolling, drawing, and extruding operations.

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[238] See this PEA at Chapter IV, Section 3 (Beryllium Production) for more information about the production of copper-beryllium alloys.
[239] OSHA estimated the number of production workers based on the ratio of production workers to total employment in NAICS 331421, as reported in the 2010 County Business Patterns.
[240] Average total workers per establishment = 9,849/96, and average production workers per establishment = 7,625/96
[241] Some firms might produce products in more than one of these categories.

Based on this information, OSHA estimates that 15 establishments in this industry are currently engaged in rolling, drawing, or extruding copper-beryllium products. Assuming these 15 establishments are typical of other establishments in this industry (average total and production employment of 102.6 and 79.4 workers, respectively), they would be expected to employ approximately 1,539 total workers and 1,191 production workers (U.S. Census Bureau, 2010). These 15 establishments are classified in NAICS code 331421.[242]

Other establishments redraw wire (purchased from establishments in NAICS code 331421) to customer specifications. These redrawing establishments are classified in the NAICS industry 331422, Copper Wire (Except Mechanical) Drawing. The 2010 County Business Patterns shows 114 establishments in this industry, employing 9,847 employees, and including an estimated 7,498 production workers. From this information, OSHA estimates that the average numbers of total and production workers in the copper wire drawing industry are 86.4 and 65.8, respectively.[243]

No published data exist on the number of such establishments that handle copper-beryllium alloys, but estimates from Brush Wellman's customer database show 59 such facilities (Kolanz, 2001). If these establishments were typical in size for the rest of the industry and employ, on average, about 86.4 total workers and 65.8 production workers, their total and production employment would total 5,096 and 3,880, respectively.[244] The statistics for NAICS 331422 are also shown in Table IV-51.

Table IV-51—Copper Rolling, Drawing, and Extruding (NAICS 331421 and 331422)—2010

NAICS	Affected Establishments	Affected Employees
331421, Copper Rolling, Drawing, and Extruding	*15*	*1,539*
331422, Copper Wire (Except Mechanical) Drawing	*59*	*5,095*
Sources: U.S. Census Bureau, 2010; OSHA Office of Regulatory Analysis		

PROCESS DESCRIPTION

With cold and hot working, shapes commonly manufactured include rods, bars, tubes, rings, and some special cross-sectional shapes, all in a wide range of sizes. Rolling and drawing mills use conventional metal rolling, extruding, and drawing (hot and cold) processes to produce copper-beryllium alloy products. In most cases, these operations include metal cleaning and annealing processes. Pickling, slitting, and cutting may also be conducted.

During cold work, metals are shaped while keeping the working temperature below the recrystallization temperature. The power required to shape metals during cold work is higher than that required for hot work. Some characteristics of cold work include:

[242] Total number of all workers = 15*102.6, and total number of production workers = 15*79.4
[243] Average number of total workers per establishment = 9,847/114, and average number of production workers per establishment = 7,498/114
[244] Total number of all workers = 59*86.4, and total number of production workers = 59*65.8

- Precise dimensional control
- Better surface finish than hot work because no oxidation takes places
- Hardness and strength of metals are increased
- Cold worked metals can have increased brittleness and may have to be annealed
- Cold worked metals may have to be heat treated to remove residual stress

During hot work, metals are shaped by increasing the working temperature above the recrystallization temperature, allowing metals to become more plastic. Refinement of grain occurs during hot working because the metal crystals are broken down into smaller crystals. This refinement improves the elasticity of the metal. As a consequence, less power is required by the press to shape the metal. Some characteristics of hot work include:

- Strength and hardness of metals are decreased
- Porosity of metals can be eliminated
- More variety of shapes and sized can be created in comparison to cold work
- Mechanical properties such as toughness, ductility, and elongation are improved

Rolling: During the rolling process, material (either ingots or otherwise initially formed products) passes through a rolling press, which is adjusted to conform to the desired thickness of the rolled product. This process normally reduces the cross-section of the product and increases its length.

As a result of rolling, the material grains are elongated in the direction of rolling. During hot rolling, after the material crosses the point of operation, the material grains refine. During cold rolling, after the material crosses the point of operation, the material grains do not refine. For desired dimensions and clean surface, the product being rolled is usually annealed and pickled (or cleaned) before the final rolling pass is made.

Drawing: When referring to the manufacture of tube, rod, bar, or wire, drawing means pulling (stretching) metal through a die or succession of dies (draw bench) to reduce the metal's diameter, alter cross-sectional shape, or increase hardness. The leading tip of the work piece is pointed to get through the die and then gripped with a clamp. The rest of the work piece is then pulled through the die. For tube drawing, the beginning stock is a tube, and a mandrel (metal bar around which other metal may be bent/shaped) may or may not be inserted into the die orifice. When a mandrel is used, the tubing is pulled between the mandrel and the die.

Extruding: Extrusion forces metal to flow by compression through a die with an orifice of a smaller cross-sectional area than the original billet. The resulting product is an elongated shape or tube of uniform cross section, including rods, tubes, molding trim, structural shapes, brass cartridges, and metal-clad cables.

For more information on the common operations and equipment in the Copper Rolling, Drawing, and Extruding application group, refer to Copper Rolling, Drawing, and Extruding Appendix 1 of this section.

Materion Corporation, an integrated manufacturer, produces rolled, drawn, and extruded products at its Elmore, Ohio, and Reading, Pennsylvania, facilities.[245,246] The Beryllium Alloy Production subsection of the Beryllium Production chapter provides descriptions of the relevant processes at the Elmore, Ohio facility. This section covers all rolling, drawing, and extruding performed in the Materion facility in Reading, Pennsylvania.

Several rolling, drawing, and extruding facilities that OSHA contacted provided descriptions of their production methods. One facility, a Materion Co. copper-beryllium rolling and drawing facility, uses a cold drawing process to manufacture copper-beryllium tubing (Facility A, 2000). This Materion facility in Reading, PA, receives solid bars or rods from the Materion facility in Elmore, OH, to produce tubes and other products. Any other facility in the country that performs rolling, drawing, or extruding of beryllium alloys would similarly receive the solid rods or bars from the Materion plant in Elmore, OH. This operation involves repeated drawings to get the proper diameter and wall thickness. After each drawing, the metal is cleaned, annealed, and sometimes pickled before drawing again. During the drawing process, operators load 20-foot lengths of tubing onto a trolley that pulls the tubing through the dies. The tubing is oiled to prevent dust generation when it is pulled through the dies. Because the alloy gets harder and more brittle after drawing, annealing (using electric furnaces) is required to keep the alloy workable. Sometimes pickling is required, and during this process, the tubing is submerged in a heated (180°F) sulfuric acid bath, followed by a dip in chromic acid/sulfuric acid, and then in primary, secondary, and tertiary rinsing tanks. Once desired dimensions are achieved after the drawing, annealing, and surface preparation (i.e., cleaning or pickling) processes, tubing tag ends are cut off using a chip saw blade.

A total of 350 workers, including 200 to 225 mill workers, are employed at this plant. Of these mill workers, 6 to 12 are engaged in copper-beryllium cleaning and drawing processes. The mill produces a number of metal products, and the production of copper-beryllium represents only a small part of its activity. Table IV-52 presents job categories and work groups for employees at this Materion facility. OSHA believes these job groups are representative of the Copper Rolling, Drawing, and Extruding application group. In smaller facilities, a single worker may be responsible for tasks in one or more different job groups identified in Table IV-52.

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[245] The Materion Elmore, Ohio, facility produces beryllium metal and beryllium oxide for use in ceramic applications. It is an integrated facility that encompasses activities beyond beryllium production. Besides producing pure beryllium and beryllium oxide, a large part of the operation is devoted to manufacturing a range of beryllium alloy products. Because of this integrated nature, the activities at the Elmore and Reading plants overlap. Information on rolling, drawing, and extruding activities at the Elmore facility is included in Section 3—Beryllium Production of Chapter IV of the Preliminary Economic Analysis.

[246] Materion Corporation used to be called Brush Wellman. In 2011, however, subsequent to the collection of the information presented in this chapter, the name changed. “Brush Wellman” is used whenever the data being discussed pre-dated the name change.

Table IV-52—Job Categories and Work Groups for Employees in a Brush Wellman Copper-Beryllium Rolling and Drawing Establishment (NAICS 331421 and 331422)[a]

Job Category	Work Group/Job Title
Administrative	• *Engineering technician* • *Expediter* • *Office*
Production Support	• *Wastewater treatment facility* • *Plant maintenance (electrical, instrumentation, wastewater treatment)* • *Maintenance engineers (plant, office)* • *Metallurgical lab (lab technician, services manager, quality engineers and administrator)*
Production: Rod and Wire (bulk products)	• *Point and chamfer* • *Bulk pickling and annealing (tasks performed by same operator)[b]* • *Wire drawing (swager pointer and bull blocks)* • *Rod and wire packing* • *Rod/tubing straightening* • *Die grinding*
Production: Strip Metal	• *Strip annealing* • *Strip rolling (Z-Mill)* • *Strip slitting* • *Strip pickling* • *Inspection* • *Shipping and receiving*

[a] *Based on an analysis of the operations at Brush Wellman's Reading, Pennsylvania, facility.*

[b] *Bulk refers to rod and wire products.*

Source: Brush Wellman Reading, 2004

OSHA contacted another establishment characterized as a wire redraw mill. This facility buys copper-beryllium alloy wire and re-gauges it according to customer specifications, using a cold draw process in which the wire is run through diamond dies several times to achieve the desired diameter. Between draws, the wire is annealed and aged in an 8-foot-long strand furnace. At this establishment, 30 workers handle the wire, while only two individuals work with the furnace. The annealing process may take an entire shift, including set-up and run time. The establishment's customers are primarily in the electronics parts and automotive industries. The company representative estimated that perhaps four or five companies nationwide are engaged in similar types of operations (Facility B, 2000).

OSHA also contacted several nonferrous rolling mills producing copper-beryllium plate, strip, and foil. These establishments reported a similar sequence of processes. Purchased copper-beryllium alloy is first rolled, then annealed and cleaned, and finally slit to produce the desired width. One manufacturer stated that its annealing process uses a gas-fired furnace with a 10-foot-long "hot box" containing a hydrogen atmosphere. The metal is passed through the furnace and then through a 30-foot-long cooling chamber. There is a canopy hood over the hot box to vent combustion byproducts (Facility C, 2000).

EXPOSURE PROFILE

The data sources used to estimate the beryllium exposure profile for the copper rolling, drawing, and extruding application group are described first in Data Sources for this section on Copper Rolling, Drawing, and Extruding. The exposure profile and discussion follow in Exposure Profile subsection.

Data Sources

To estimate the personal exposure profile for copper-beryllium rolling, drawing, and extruding workers, OSHA relied on 650 sample results provided by Brush Wellman Inc. on rolling and drawing operations (Brush Wellman Reading, 2004).[247] These data derive from personal breathing zone (PBZ) lapel sampling conducted at the Brush Wellman Reading, Pennsylvania, rolling and drawing facility from 1977 to 2000, and represent the best available data to estimate beryllium exposure in this application group. A majority of the sample results (502 samples) were obtained in 2000 during a facility-wide baseline assessment of workers' baseline exposures. The remaining 148 samples were obtained from the Reading plant from 1977 to 1999.

OSHA supplemented the Brush Wellman Reading data with exposure information obtained by Schuler *et al.* during a plantwide medical survey of the Brush Wellman Reading facility (Schuler *et al.* [ATS Abstract], 2002; Schuler *et al.* [ATS Poster], 2002; Schuler *et al.*, 2005).[248] Schuler *et al.* investigated the prevalence of beryllium sensitization and disease at the facility and determined airborne beryllium levels in various jobs and processes by evaluating historical air sampling data collected between 1969 and 2000. Schuler *et al.* report information about the nature of exposures, but do not provide individual exposure samples. As such, there are no individual exposure samples that OSHA can incorporate in the exposure profile. OSHA notes that there may be substantial overlap in the data discussed in Schuler *et al.* and the 650 individual PBZ samples used in the exposure profile. However the Agency does not have sufficient information to determine which and how many exposure samples overlap.

No exposure information specific to extrusion is included in the Brush Wellman Reading data or the Schuler *et al.* articles. Extrusion, a hot working process that causes surface oxidation, presents exposure potential and will generally require exposure controls .To address potential extrusion exposures, OSHA examined the results of an industrial hygiene survey of a copper-beryllium extruding process (MC Pkg I-F, 2000; MBC-J, 2007).

OSHA also reviewed air sampling data presented in published articles pertaining to the processing of copper-beryllium alloys. However, these exposure data do not include individual

[247] The Materion facility in Reading, PA, does not perform extrusion activities. OSHA does not have individual full-shift exposure samples regarding extrusion operations, but based on an industrial hygiene survey of a copper-beryllium extruding process (MC Pkg I-F, 2000; MBC-J, 2007), OSHA believes exposures during extruding activities can be controlled using the same methods for rolling and drawing activities.

[248] Schuler *et al.* do not explicitly state that the copper-beryllium alloy facility described in their articles is the Brush Wellman Reading, Pennsylvania, facility (Schuler *et al.* [ATS Abstract], 2002; Schuler *et al.* [ATS Poster], 2002; Schuler *et al.*, 2005). Information confirming the identity of the facility as the Brush Wellman Reading facility was obtained from NIOSH beryllium research updates (NIOSH Beryllium Research, 2005; Schuler, 2007).

sample results (only aggregated summary results are provided), and in many cases, the data represent ambient (general area) monitoring and therefore could not be directly incorporated into the exposure profile. Where appropriate, the exposure profile discussion is supplemented with summary exposure data from the published literature for comparative purposes.

Finally, OSHA reviewed unpublished exposure data for beryllium from the Agency's Integrated Management Information System (IMIS). As noted in Section 2—Methodology, the IMIS database is not designed to capture information pertaining to workplace conditions and controls, and when evaluating job descriptions with potential beryllium exposure, it is not possible to determine whether beryllium was included in the sample analysis request because there was known potential workplace exposure to beryllium or because it was part of a routine metal screening. Additionally, information on sampling durations and sampling limits of detection (LODs) (for nondetectable samples) was not available in the particular dataset OSHA reviewed for this analysis. Therefore, OSHA used the IMIS results in a supporting role to supplement the exposure profile for the copper rolling, drawing, and extruding application group.

Brush Wellman Reading Rolling and Drawing Exposure Data

The Reading facility primarily manufactures thin-gauge strip and wire products using a variety of processes, including rolling, drawing, pickling, heat treating (e.g., annealing), cleaning (e.g., degreasing), and welding. The copper-beryllium alloys used in these processes generally contain 0.1 percent to 2 percent beryllium (OSHA-H005C-2006-0870-0081).[249,250] The 650 PBZ total beryllium lapel samples were analyzed using National Institute for Occupational Safety and Health (NIOSH) Methods 7102 (Beryllium and Compounds, as Be) or 7300 (Elements by ICP), and the analytical LOD was reported to be 0.1 micrograms (μg) beryllium per filter.[251] For sample results less than the LOD, Brush Wellman used a sample mass one-half the LOD to calculate the sampling LOD concentrations (Kent, 2005). All the Brush Wellman Reading, Pennsylvania, sample data are included in the exposure profile for the copper rolling, drawing, and extruding application group.

Extrusion Exposure Data

The Materion Reading facility does not conduct extrusion activities. To gain an understanding of the beryllium exposures associated with extrusion, OSHA examined the results of an industrial hygiene survey of a copper-beryllium extruding process at another facility conducted in 2000 (MC Pkg I-F, 2000). This survey provides the only data available that are representative of establishments engaged in copper-beryllium extrusion processes (with the exception of extruding data from Materion's primary production facility in Elmore, Ohio).

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[249] The Reading facility primarily processes copper-beryllium and some nickel-beryllium alloys. Other beryllium alloys include gold and lead. Information on individual data points was not presented to OSHA, but the Agency assumes that the exposure data represents the full spectrum of beryllium alloys handled at the Reading facility.

[250] The OSHA Beryllium Docket contains a summary of baseline exposure sampling conducted at the Reading facility in 1999 (OSHA-H005C-2006-0870-0093). The docket exhibit (submitted by Materion) does not specifically state that the copper-beryllium alloy processing facility, which is the source of the exposure data, is the Brush Wellman Reading facility; however, Materion has explicitly acknowledged this fact to OSHA (Brush Wellman Reading, 2004). The individual exposure results OSHA obtained from Brush Wellman (1977 to 2000) include the findings of the 1999 baseline sampling that are summarized in the OSHA Beryllium Docket (OSHA-H005C-2006-0870-0093).

[251] Schuler *et al.* (2005) reported that the LOD for beryllium air samples collected at the Reading facility from 1969 to 2000 ranged from 0.008 μg to 0.10 μg.

OSHA did not incorporate the eight samples reported in the industrial hygiene survey because the samples do not represent full-shift exposures. The survey reported on eight PBZ samples collected over 2-hour sample periods on two consecutive days for the four jobs involved with the extrusion process. Six of the 8 samples resulted in non-detectable exposures, and 2 samples resulted in exposures of 1.6 µg and 1.9 µg for 2-hour samples measured from a press operator assistant on two consecutive days. These exposures occurred during tool cleaning and refinishing and not during the actual extruding process (i.e., operating the extruding press).

The jobs sampled included the press operator (operates control panel about 18 feet from the press); the press operator assistant (places ram cap on punch, lubes die, and cleans die and ram cap after each cycle); the material handler (operates crane to move billet); and the billet assembler (moves heated billets from pre-heat furnace to press and finished billets from press to conveyor). All four workers wore respiratory protection while they performed their jobs (MC Pkg I-F, 2000).

All tasks in the extrusion process resulted in nondetectable exposure levels (individual sampling LOD concentrations were not provided) except for the press operator assistant (who had detectable exposures as mentioned above), for whom a task-based sample is available (MC Pkg I-F, 2000). The measured beryllium exposures for the press operator assistant were 1.6 µg/m^3 and 1.9 µg/m^3 over the 2-hour sample periods and 0.39 µg/m^3 and 0.51 µg/m^3, respectively, if time-weighted for 8 hours assuming no additional beryllium exposure (based on the experience of the other workers).[252] The samples were collected during a period when the press operator assistant was buffing, sanding (i.e., refinishing), and cleaning ram caps and die rings. The investigators noted that the use of a ventilated workstation (e.g., a ventilated glovebox or partially enclosed hood) would significantly reduce the exposure levels associated with the tool refinishing and cleaning operations (MC Pkg I-F, 2000). Other than the tool refinishing and cleaning operations, the extrusion process appeared to present a low potential for exposure to beryllium.

As mentioned previously, because these data are less than full-shift, OSHA did not incorporate the results into the exposure profile for this application group. In the absence of additional well-characterized data, however, these results suggest that tool refinishing and cleaning tasks associated with extruding processes may result in elevated beryllium levels. This is generally consistent with the findings for other workers who perform finishing operations such as polishing and grinding in other industries (elsewhere in this analysis, see the discussion on grinding/finishing operators in Section 5—Nonferrous Foundries, and on dental technicians grinding beryllium alloys in Section 11—Dental Laboratories).

Additionally, OSHA examined the extrusion exposure data from the Materion Elmore, OH facility. These samples are provided in the exposure profile of Section 3—Beryllium Production. OSHA did not include these exposure samples in the exposure profile for this section because the samples are reported by Materion as "hot rolling or hot extrusion" and the Agency cannot distinguish the exposure samples that belong to rolling operations from those that belong to extruding operations (Brush Wellman Elmore, 2004; NIOSH Elmore database, 2011).

[252] The survey report does not discuss the nature of the extrusion operations at the facility surveyed (MC Pkg I-F, 2000).

However, from this Materion data, OSHA is able to characterize a range of exposures that may possibly result from extrusion and extrusion-related activities. Materion provided two datasets from its “hot rolling or hot extrusion” operations at the Materion Elmore facility. The first is a 1999 survey that contains 150 samples that range from 0.01 μg/m^3 to 5.6 μg/m^3 (Brush Wellman Elmore, 2004). The second is a 2007-2008 NIOSH study that contains 17 samples that range from 0.3 μg/m^3 to 0.61 μg/m^3 (NIOSH Elmore database, 2011). OSHA notes that the 2 samples obtained for the press operator assistant from the industrial hygiene survey fall within range of the Materion Elmore datasets. However, these 2 samples (8-hour TWAs of 0.39 μg/m^3 and 0.51 μg/m^3) of are on the higher end of exposures in the Materion Elmore datasets, as 95 percent of exposures in the 1999 dataset are less than or equal to 0.2 μg/m^3, and 87 percent of exposures in the 2007-2008 dataset are less than or equal to 0.2 μg/m^3.

OSHA believes that exposures that occur when operating the extruding press may be lower than exposures that occur during extruding-related activities such as tool cleaning and refinishing (Brush Wellman Elmore, 2004; MC Pkg I-F, 2000; NIOSH Elmore database, 2011). Furthermore, the vast majority of exposures for hot rolling/hot extrusion operations at the Materion Elmore facility are at or below 0.2 μg/m^3 and are associated with specific engineering controls that were in place at the time of sampling. These engineering controls are close-capture exhaust hoods on cut-off saws and partially enclosed exhaust hoods for die-grinding work. OSHA believes that if similar controls are implemented during copper-beryllium extruding operations, exposures will be similarly controlled at levels of 0.2 μg/m^3 or less most of the time.

For extrusion-related activities that create exposures, such as tool cleaning and refinishing, OSHA believes that the local exhaust ventilation controls discussed for grinding/finishing operators in Section 5—Nonferrous Foundries, and for dental technicians grinding beryllium alloys in Section 11—Dental Laboratories, will be sufficient to control most of these exposures at or below 0.2 μg/m^3.

Published Literature on Rolling and Drawing

The published literature also addresses workers that process copper-beryllium alloys. The available reports cover five facilities that process copper-beryllium alloys, including the Materion Reading facility.[253] Workers at these sites performed the following types of tasks:

- Cutting (wet and dry), trimming, drilling, deburring, grinding, punch pressing, hand polishing and buffing (with an abrasive pad), annealing, pickling (hydrochloric, nitric, or sulfuric acid), and/or transporting 2 percent copper-beryllium alloy for a metal parts manufacturer producing bellows. Nearby workers sanded and ground copper-beryllium alloy (Balkissoon and Newman, 1999).
- Drawing out heated 1.8-percent copper-beryllium wire to make it finer (Hasejima *et al.*, 1995).

[253] These references include four reports that do not pertain to Brush Wellman Inc.: Balkissoon and Newman (1999), Hasejima *et al.* (1995), Tarlo *et al.* (2001), and Yoshida *et al.* (1997). Additionally the references include a series of reports by Schuler *et al.*, Day *et al.*, and Thomas *et al.* that all report studies of the Brush Wellman Reading, Pennsylvania, facility (Schuler *et al.*_ATS Abstract, 2002; Schuler *et al.*_ATS Poster, 2002; Schuler *et al.*, 2005; Day *et al.*, 2007; Thomas *et al.*, 2009).

- Brushing and cleaning copper-beryllium castings (about 5 to 10 percent of the time) using hand-held grinders or files (Tarlo *et al.*, 2001). Alloying copper-beryllium; manufacturing copper-beryllium metal molds; cold-rolling, drawing, and heat-treating copper-beryllium; and slitting copper-beryllium (Yoshida *et al.*, 1997). Annealing, inspection, pickling, rolling, slitting, and shipping and receiving in the strip production areas of a beryllium alloy strip and wire finishing facility. Die grinding, point and chamfer, drawing (bull blocks), rod straightening, wire annealing, and pickling in the rod and wire production areas. Production support activities, including maintenance (mechanics), quality assurance (metallurgical laboratory), and wastewater treatment. Administrative work, including human resources and accounting (Schuler *et al*. [ATS Abstract], 2002; Schuler *et al.* [ATS Poster], 2002; Schuler *et al.*, 2005; Day *et al.*, 2007; Thomas *et al.*, 2009).

Information on these reports is provided briefly below. The industrial hygiene exposure data from the above mentioned reports are summarized in Copper Rolling, Drawing, and Extruding Appendix 2. None of the data reported in these studies were used in the exposure profile for reasons discussed below.

Balkissoon and Newman

Balkissoon and Newman (1999) reported on two cases of chronic beryllium disease (CBD) at a metal parts manufacturer producing springy pressure control devices (bellows) from 2 percent copper-beryllium alloy. The affected workers' activities included annealing, pickling, and other operations common to rolling, drawing, and extruding facilities. Exposure data from this study were not included in the exposure profile as reported samples appear to be area samples, not individual samples.

Beryllium air samples were collected at this metal parts manufacturing facility in four separate years (1987, 1988, 1991, and 1993) and yielded results ranging from nondetectable to 20 $\mu g/m^3$. In 1987, all sample results were below 2 $\mu g/m^3$ in the affected employees' work areas. Also in 1987, Beryllium levels of 10 $\mu g/m^3$ and 20 $\mu g/m^3$ were recorded on two occasions in another (unspecified) area of the plant where the affected workers did not recall spending time.

Repeat air sampling in 1988, 1991, and 1993 yielded nondetectable results. The LOD was not provided. Areas where the two workers with chronic beryllium disease (CBD) worked were not resampled in 1991 or 1993, however. These results were not included in the exposure profile because information regarding the number of samples collected, sample type and duration, and the specific sampling locations was not provided (i.e., individual sample results were not provided). Inadequacies in ventilation were not specified but might be implied because workers described strong "fume exposures" when unloading the annealing furnaces. Eating and smoking were permitted in the work area. No respirators were used, and showering and changing clothing were not required. In 1990, the facility installed "high-efficiency" dedicated exhaust systems (Balkissoon and Newman, 1999).

Yoshida et al.

Yoshida *et al.* (1997) investigated beryllium air levels and worker sensitization during a 4-year survey (1992 to 1995) at two copper-beryllium manufacturing factories in Japan. Operations at one of the factories[254] included cold rolling, drawing, heat treatment (not specified but may have included annealing), and slitting. For each process, ambient (general area) beryllium levels were determined twice a year using high-volume air sampling pumps. Samples were analyzed by an atomic absorption spectrophotometer equipped with a graphite furnace. Sixteen general area sampling locations were used for cold-rolling, drawing, and heat-treatment processes; eight sampling locations were used for slitting. No samples were obtained during 1992. Beryllium levels associated with the slitting operation were only determined during 1993 and were reported to be less than 0.01 µg/m^3 (Yoshida *et al.*, 1997). In 1993, airborne beryllium levels ranged from 0.01 µg/m^3 to 0.28 µg/m^3 with a geometric mean of 0.19 µg/m^3 for rolling, drawing, and heat treatment. After workplace cleaning and ventilation improvements, beryllium levels in both 1994 and 1995 ranged from 0.01 µg/m^3 to 0.04 µg/m^3, with a geometric mean of 0.03 µg/m^3.

OSHA did not include these samples in the exposure profile because they are not personal breathing zone samples and individual general area sample results and sample durations were not provided.

Schuler et al.

Schuler *et al.* reported on a survey of work processes, sensitization, and CBD at a copper-beryllium alloy plant (Schuler *et al.* [ATS Abstract], 2002; Schuler *et al.* [ATS Poster], 2002; Schuler *et al.*, 2005). Although not specifically stated in the survey reports, the copper-beryllium alloy plant that Schuler *et al.* reported on was a medical study of the Brush Wellman Reading, Pennsylvania, facility. Information confirming the identity of the facility as the Brush Wellman Reading facility was obtained from NIOSH beryllium research updates (NIOSH, 2005; Schuler, 2007). Schuler et al. investigated the prevalence of beryllium sensitization and disease at the facility and determined airborne beryllium levels in various jobs and processes by evaluating historical air sampling data collected between 1969 and 2000.

Workers with CBD at this facility were more likely to have worked at jobs in the rod and wire production area of the plant. These jobs included annealing, pickling, degreasing, cold wire drawing, cold straightening, and high-speed machining (point and chamfer). During the straightening process, rods are fed into a roller in order to bend to the rod to a desired shape. In the point and chamfer operations, one end of the rod is pointed, the other end is chamfered (angled) in order to prevent cracks in the material during further processing.

Schuler *et al.* (2005) estimated airborne beryllium levels by evaluating historical sampling data. Air samples obtained from 1969 to 2000 included 650 personal (lapel, and used in the exposure profile as previously described in the section on Brush Wellman Reading Rolling and Drawing Exposure Data), 4,524 general area, and 815 short-duration (3 to 5 minutes) high-volume (SD-HV) breathing zone task samples. Median plantwide values for personal, general area, and SD-HV task samples were 0.02 µg/m^3, 0.09 µg/m^3, and 0.44 µg/m^3, respectively. Ninety-nine percent of all personal samples were below 2 µg/m^3, and 93 percent were below 0.2 µg/m^3. All personal sample results greater than 2 µg/m^3 were collected in the late 1970s. The highest median values among specific jobs or processes were found in wire annealing and pickling (0.12 µg/m$^{3)}$ and wastewater treatment (0.11 µg/m^3) (Schuler *et al.*, 2005).

[254] The other factory performed metal mold manufacturing operations and no information was provided regarding these operations.

Ninety-three percent of the general area sample results were less than 0.2 µg/m^3. Among the general area samples, wire annealing and pickling had the highest arithmetic mean (2.77 µg/m^3) compared to all the other processes (less than 0.01 µg/m^3 to 0.33 µg/m^3). Schuler *et al.* reported that 90 percent of the SD-HV task samples were below 5 µg/m^3 (OSHA's current ceiling concentration), and 97 percent were less than 25 µg/m^3 (OSHA's current maximum peak concentration for 30 minutes). A majority of the SD-HV task samples were obtained from wire annealing and pickling in the rod and wire area, and slitting in strip operations. Median values for the SD-HV samples in the rod and wire and strip areas were 0.46 µg/m^3 and 0.40 µg/m^3, respectively. No SD-HV task samples were taken in production support or administration areas (Schuler *et al.*, 2005).

Day et al.

Day *et al.* (2007) evaluated beryllium levels in workplace air, on work surfaces, on cotton gloves worn by employees over nitrile gloves, and on the necks and faces of employees after an improved particulate migration control program (including dermal protection in production areas) was completed in 2002 at a beryllium alloy strip and wire finishing facility. The air samples were not included in the exposure profile because they are general area samples and the exposure profile includes only PBZ samples. Surface wipe and cotton glove samples are provided in Copper Rolling, Drawing, and Extruding Appendix 2 for the reader. Although not specifically stated in the article, this facility was the Brush Wellman Reading facility.[255] These results reflect current conditions at the facility and an enhancement to the baseline conditions associated with the exposure profile for this application group.

Ten general area air samples were collected: nine near production processes throughout the facility and one in an administrative area. Samples were analyzed using NIOSH Method 7300 and the analytical limit of detection for beryllium was reported to be 0.004 µg per filter. Six of the nine production air samples were obtained near strip production processes (i.e., strip annealing, rolling, pickling, slitting, and shipping and receiving), and the remaining three were collected near rod and wire production processes (i.e., rod straightening, wire annealing, and pickling). The geometric mean beryllium concentration for all general area air samples was 0.003 µg/m^3 and ranged from 0.0007 µg/m^3 in administration to 0.0238 µg/m^3 in wire annealing and pickling (Day *et al.*, 2007).

Thomas et al.

Thomas *et al.* (2009) also reported on a study of a copper-beryllium facility that is presumed to be the Brush Wellman Reading facility.[256] Samples were collected in three time periods: from 1995 to May 2000, June 2000 to December 2001, and June 2002 to July 2007. In 2000, 7 percent of the workers at the facility were sensitized to beryllium, and working near the wire annealing and pickling process was believed to be the major risk factor. After the facility implemented a preventive program consisting of process enclosure, migration control, and skin and respiratory protection, Thomas *et al.* (2009) assessed the program's ability to prevent beryllium sensitization. As part of this process, Thomas *et al.* (2009) mentioned 2,394 airborne beryllium

[255] Information confirming the identity of the facility as the Brush Wellman Reading facility was obtained from NIOSH beryllium research updates (NIOSH Beryllium Research, 2005; Schuler, 2007).

[256] Two Brush Wellman environmental health and safety professionals are among the authors of this multi-author publication, and the facility description and operations are consistent with OSHA's knowledge of the Reading facility.

full-shift personal lapel samples the facility collected from 1995 to 2007 and the evolution of the preventive program by year and type of control. OSHA does not have individual samples from Thomas *et al.* (2009) and as such this information was not included in the profile. The reporting period overlaps with the periods covered by the datasets that OSHA obtained from Brush Wellman (Brush Wellman Reading, 2004). OSHA cannot verify the exact overlap of Thomas *et al.* (2009) with the data included in the exposure profile.

IMIS Data

For the time period June 1978 to September 2008, the IMIS database includes a total of 171 PBZ lapel-type samples in the matching SIC codes 3351 (Rolling, Drawing, and Extruding of Copper, Brass, Bronze, and Other Copper Alloys); 3356 (Rolling, Drawing, and Extruding of Nonferrous Metals Other Than Copper and Aluminum); and 3357 (Drawing and Insulating of Nonferrous Wire) (OSHA, 2009). Table IV-53 summarizes the positive IMIS findings for these SIC codes. Only positive PBZ results are included in the IMIS analysis, because the sampling LOD concentrations for nondetectable samples were not included in the dataset available to OSHA. As shown in Table IV-53, 33 percent of the samples (18 of 55) collected at SIC 3351 establishments were positive for beryllium and are characterized by a mean of 0.39 μg/m^3, a median of 0.28 μg/m^3, and a range from 0.01 μg/m^3 to 1.2 μg/m^3.

OSHA notes that some establishments in the IMIS database have been inadvertently misclassified. For example, two establishments in the database under SIC group 3351 are covered in secondary smelting, refining, and alloying and are known to be appropriately classified in SIC group 3341 (Secondary Smelting, Refining, and Alloying of Nonferrous Metal, except copper and aluminum). The job descriptions associated with the positive results in this example include ball mill operator, caster helper, furnace operator, melter, melter/pourer, operator, and utility worker. For SIC 3356 establishments, 9 percent of the samples (9 of 99) were positive for beryllium, with a mean of 0.5 μg/m^3, a median of 0.2 μg/m^3, and a range from 0.004 μg/m^3 to 2.5 μg/m^3. The job descriptions associated with the positive results include forge shop helper, lathe operator, lead man atomization, metal conditioner, mill room operator, skilled laborer, and one unspecified job description. And for SIC 3357, 17 samples were collected at five establishments, but none of the results were positive for beryllium.

The positive results for the three SIC codes combined are characterized by a mean of 0.43 μg/m^3, a median of 0.22 μg/m^3, and a range from 0.004 μg/m^3 to 2.5 μg/m^3. However, since a majority (84 percent) of the sample results were nondetectable for beryllium, the summary statistics (for the positive results) might overestimate exposures for this application group.

Table IV-53—OSHA IMIS PBZ Total Beryllium Air Sampling Results for Establishments Rolling, Drawing, and Extruding Nonferrous Metals (SIC Groups 3351, 3356, and 3357)[a]

SIC Code	Total Number of Establishments	SIC Description	No. PBZ Samples with Positive Results/Total No. PBZ Samples[b]	Job Descriptions (for Positive Results Only, as listed in the IMIS database)	Range[c] (μg/m³)	Mean[c] (μg/m³)	Median[c] (μg/m³)
3351	*12*	*Rolling, Drawing, Extruding Copper, Brass, Bronze, and other Copper Alloys*	*18/55 (33% positive)*	*Ball mill operator; caster helper; furnace operator; melter; melter/pourer; operator; utility*	*0.01 to 1.2*	*0.39*	*0.28*
3356	*21*	*Rolling, Drawing, Extruding Nonferrous Metals Other Than Copper and Aluminum*	*9/99 (9% positive)*	*Helper forge shop; lathe operator; lead man atomization; metal conditioner; mill room operator; skilled laborer*	*0.004 to 2.5*	*0.5*	*0.2*
3357	*5*	*Drawing and Insulating Nonferrous Wire and Cable*	*0/17 (0% positive)*	*N/A*	*None*	*None*	*None*
Total	**38**		**27/171 (16% positive)**		**0.004–2.5**	**0.43**	**0.22**

[a] Information regarding worker activities, the engineering controls in place, personal protective equipment worn during sampling, sampling durations and nondetectable sampling limit of detection concentrations is not available.

[b] Includes all PBZ samples by SIC code and all positive results regardless of the job description. Note that for each SIC code other types of samples may have been obtained such as area, screening, bulk, or wipe samples.

[c] The range, mean and median results are based on positive sample results only. All positive PBZ results are included.

N/A: not applicable

Source: OSHA, 2009.

Exposure Profile

To estimate the exposure profile for the rolling, drawing, and extruding sector, OSHA used the sample results (650 total samples) obtained by Brush Wellman from its Reading, Pennsylvania, facility (note that extruding is not conducted at the Reading facility). To characterize extruding exposures, OSHA examined 8 extrusion samples from an industrial hygiene operation and 167 hot rolling/extrusion samples from the Materion Elmore facility. OSHA believes that exposures that occur during operation of the extrusion press are similar to those that occur during operation of the drawing press (Brush Wellman Elmore, 2004). OSHA recognizes the limitations associated with these datasets; however, these data represent the best available exposure information for the rolling, drawing, and extruding application group. To determine the exposure profile, OSHA divided the sample results into three job categories: administrative, production support, and production. The production job category was further subdivided into the type of product that was processed: 1) rod and wire and 2) strip metal.[257] These job groupings were suggested by NIOSH as a logical division of beryllium workers at a facility in the rolling, drawing, and extruding application group (Schuler *et al.*, 2005; Day *et al.*, 2007; Thomas *et al.*, 2009).[258]

The exposure profile for the copper rolling, drawing, and extruding application group is shown in Tables IV-54 and IV-55 by major job category. A detailed exposure breakdown by type of work within each major job category is included in Copper Rolling, Drawing, and Extruding Appendix 3. Tables IV-54 and IV-55 summarize all the available full-shift PBZ (lapel-type) total beryllium exposure data and report the distribution of the results in relation to the proposed and current Permissible Exposure Limits (PELs) for beryllium.

Table IV-54—Personal Exposure Profile for the Copper-Beryllium Rolling, Drawing, and Extruding Application Group (NAICS 331421 and 331422)[a,b]

Job Category	No. of Samples	Range (µg/m³)	Mean (µg/m³)	Median (µg/m³)
Administrative	*68*	*0.01 to 0.11*	*0.022*	*0.017*
Production support	*52*	*0.01 to 0.33*	*0.04*	*0.022*
Rod and wire production (bulk products)	*210*	*0.01 to 7.8*	*0.25*	*0.055*
Strip metal production	*320*	*0.006 to 0.72*	*0.041*	*0.017*
TOTAL	**650**	**0.006 to 7.8**	**0.11**	**0.024**

[a] *Full-shift PBZ results are based on the actual sample duration (400 minutes or longer). Nondetectable results are reported at one-half the analytical LOD (i.e., 0.05 µg beryllium per filter).*

[b] *The exposure profile is a summary of full-shift PBZ total beryllium sample results for workers at the Brush Wellman Inc. Reading, Pennsylvania, alloy rolling and drawing mill from 1977 through 2000. Note that this facility does not conduct extruding.*

Source: Brush Wellman Reading, 2004.

[257] The work groups/job titles included with each job category appear in Table IV-52.
[258] Although OSHA (and contractor ERG) initially considered other methods of classifying workers (e.g., in materials presented to a panel convened under the Small Business Regulatory Enforcement Fairness Act of 1996 (SBREFA), more recent publications support the NIOSH groupings, now also adopted by OSHA.

Table IV-55—Distribution of Full-Shift PBZ Exposure Results for Total Beryllium in the Copper-Beryllium Rolling, Drawing, and Extruding Application Group (NAICS 331421 and 331422)[a,b]

Job Category	Number of Results in Range (μg/m^3)						Total
	<0.1	≥ 0.1 to ≤ 0.2	> 0.2 to ≤ 0.5	> 0.5 to ≤ 1.0	> 1.0 to ≤ 2.0	> 2.0	
Administrative	*67 (98.5%)*	*1 (1.5%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*68 (100%)*
Production support	*48 (92%)*	*3 (6%)*	*1 (2%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*52 (100%)*
Rod and wire production (bulk products)	*146 (70%)*	*29 (13%)*	*22 (11%)*	*4 (2%)*	*4 (2%)*	*5 (2%)*	*210 (100%)*
Strip metal production	*299 (92%)*	*15 (5%)*	*6 (2%)*	*2 (1%)*	*0 (0%)*	*0 (0%)*	*320 (100%)*
TOTAL	**558 (86%)**	**48 (7%)**	**29 (4%)**	**6 (1%)**	**4 (1%)**	**5 (1%)**	**650 (100%)**

[a] *Full-shift PBZ sample results are based on the actual sample duration (400 minutes or longer). Nondetectable results are reported at one-half the analytical LOD (i.e., 0.05 µg beryllium per filter).*

[b] *The distribution represents full-shift PBZ total beryllium sample results for workers at the Brush Wellman Inc. Reading, Pennsylvania, alloy rolling and drawing mill from 1977 through 2000. Note that this facility does not conduct extruding.*

Source: Brush Wellman Reading, 2004.

As shown in Table IV-54, the median exposure level for each of the four major job categories at the Brush Wellman Reading facility is less than 0.1 µg/m^3, but the exposure levels of a few workers are notably higher, with the highest exposure result (7.8 µg/m^3) associated with bulk pickling and annealing workers in the rod and wire production (bulk products) job category. Table IV-55 shows that the vast majority (93 percent) of the exposure results are less than or equal to 0.2 µg/m^3, with another 4 percent falling between 0.2 µg/m^3 and 0.5 µg/m^3, and 3 percent exceeding 0.5 µg/m^3. Although the exposure profile shows that elevated beryllium exposures can occur in the rolling, drawing, and extruding application group, most workers (86 percent) are not exposed to beryllium levels at or above 0.1 µg/m^3. These findings are substantiated by a similar analysis of the Reading facility's historical air sampling data by Schuler *et al.* (2005). Additionally, the positive IMIS results for the copper rolling, drawing, and extruding application group range from 0.004 µg/m^3 to 2.5 µg/m^3. Except for one value at the lower end of the range, this range of values is included within the exposure profile range (0.006 µg/m^3 to 7.8 µg/m^3) and lends additional support to the validity of the exposure profile.

Information in the published literature on other facilities lends support to the exposure profile for this application group. As noted, Yoshida *et al.* (1997) report that initial ambient (general area) air monitoring results ranged from 0.01 µg/m^3 to 0.28 µg/m^3 with a geometric mean of 0.19 µg/m^3 for cold-rolling, drawing, and heat-treating processes at a Japanese copper-beryllium parts manufacturing factory in 1993. After workplace cleaning and ventilation improvements (not otherwise specified), beryllium levels in both 1994 and 1995 were reduced to levels ranging from 0.01 µg/m^3 to 0.04 µg/m^3, with a geometric mean of 0.03 µg/m^3. Ninety-seven percent of the sample results summarized in the exposure profile for this application group are in the range Yoshida *et al.* reported prior to making workplace changes.

As noted in the subsection on Extrusion Exposure Data in this Copper Rolling, Drawing, and Extruding section, the Brush Wellman Reading data do not reflect copper-beryllium extruding operations. The only extruding data available represent partial-shift sampling (i.e., 2 hours) and suggest that most extruding tasks have low exposures (MC Pkg I-F, 2000). Plantwide, 93 percent of all PBZ sample results were 0.2 μg/m^3 or less during the 2-hour periods monitored. However, tool cleaning and refinishing activities generate higher exposures. In this case, values of 1.6 μg/m^3 and 1.9 μg/m^3 were measured during the 2-hour sampling period on the press operator assistant who was performing tool cleaning and refinishing. Based on the available information, the activities associated with tool cleaning and refinishing can generate notable exposures when adequate controls are lacking. Materion provided all of the results as representative of extruding processes in general, including tool cleaning and refinishing associated with extruding equipment maintenance; both values are included within the range of values representing the exposure profile (i.e., 0.006 μg/m^3 to 7.8 μg/m^3).[259]

The exposure profile for the copper rolling, drawing, and extruding application group represents the best available exposure data and is based on the results of Brush Wellman's Reading, Pennsylvania, copper-beryllium rolling and drawing mill. Other information, including several published articles, the IMIS data, and a survey of a copper-beryllium extrusion process, provide additional data in support of the exposure profile. Based on these findings, OSHA believes that the exposure profile is representative of the rolling, drawing, and extruding application group. The primary job categories with potential beryllium exposure in this application group are discussed below.

Administrative Workers

Table IV-54 shows that the exposure profile for administrative workers ranges from 0.01 μg/m^3 to 0.11 μg/m^3, with a mean of 0.022 μg/m^3 and a median of 0.017 μg/m^3. These values represent 68 full-shift PBZ total beryllium results for administrative workers in the Materion facility in Reading, PA, a copper-beryllium rolling and drawing establishment. These workers spend a majority of their time in office areas and rarely enter production areas of the facility. In this facility, administrative workers include plant management, secretarial staff, engineers, production planners, accountants, and human resources personnel. As listed in Table IV-55, 67 of the 68 results are less than 0.1 μg/m^3, with only one result slightly above 0.1 μg/m^3, with a value of 0.11 μg/m^3. These results suggest that administrative workers in the Reading, PA, facility typically are not exposed to beryllium because they either do not enter or spend limited time in beryllium work areas. Potential beryllium exposure could occur when administrative workers enter production areas of the facility, or beryllium contamination from beryllium work areas is inadvertently transferred to administrative areas. OSHA believes that any administrative personnel in any other copper rolling, drawing, and extruding facility that work with beryllium will be similarly exposed if these workers enter production areas or if beryllium contamination is inadvertently transferred to administrative areas.

Production Support Workers

The exposure profile for production support workers, summarized in Tables IV-54 and IV-55, is based on 52 full-shift PBZ total beryllium sample results reported for production support workers at Materion's Reading, Pennsylvania, copper-beryllium rolling and drawing facility. This is the only source of individual full-shift exposure data for this job category. Production

[259] The tool cleaning and refinishing activities are similar to the bench grinding activities described in the cleaning/finishing operator sections of Section 5—Nonferrous Foundries, elsewhere in this analysis.

support jobs at this facility include wastewater treatment, mechanical maintenance (i.e., electrical, mechanical, and wastewater treatment maintenance workers; maintenance engineers, supervisors, and janitors), and quality assurance (metallurgy laboratory workers). Production support workers spend at least part of a typical work day in the beryllium production areas of the facility. Day *et al.* (2007) reported that the work performed by these workers requires frequent entry into the production areas. As shown in Table IV-54, production support is characterized by a mean of 0.04 $\mu g/m^3$, a median of 0.022 $\mu g/m^3$, and a range from 0.01 $\mu g/m^3$ to 0.33 $\mu g/m^3$. Table IV-55 shows that 92 percent of the exposure results are less than 0.1 $\mu g/m^3$, with another 6 percent in the range of 0.1 $\mu g/m^3$ to 0.2 $\mu g/m^3$, and one sample (2 percent) exceeding 0.2 $\mu g/m^3$, with a value of 0.33 $\mu g/m^3$.

The only production support result that exceeded 0.2 $\mu g/m^3$—one sample result (2 percent) of 0.33 $\mu g/m^3$—was associated with wastewater treatment activities. The industrial wastewater treatment facility at the Materion Reading facility treats process wastewater containing dilute acids and caustics. Sludge from the treated wastewater is dewatered in a filter press, collected in a container, and removed from the facility by a licensed contractor for landfill disposal. [260] Worker activities include waste handling (universal and process-related waste) and operating and maintaining the industrial wastewater treatment facility. [261] Operators containerize, seal, label, and transport universal and process-related waste to a designated storage pad. Potential sources of beryllium exposure include filter press blowouts, waste handling, surface contamination due to inadequate decontamination (e.g., equipment or waste drums),or housekeeping. Prior to the collection of these exposure samples, wastewater treatment workers performed maintenance activities in the facility (an additional source of potential exposure) as well as in the wastewater treatment plant.

Beryllium contamination of the wastewater treatment plant occurs when there is a “blow-out” (malfunction resulting in material release) in the wastewater filter press. Blow-out sludge that is not cleaned up and is allowed to dry can become dispersed within the work area. Filter press blow-outs at the Reading facility occurred frequently in the past, but more recently reportedly occur about one to two times per year (Cairnie, 2005). Copper Rolling, Drawing, and Extruding Appendix 3 shows that although wastewater treatment operator exposures can be as high as 0.33 $\mu g/m^3$, the median exposure level associated with these workers is 0.11 $\mu g/m^3$, signaling that facilities with wastewater treatment operations have already achieved or can achieve low exposure levels for these workers most of the time. This exposure of 0.11 $\mu g/m^3$ was obtained when the filter press did not malfunction (i.e., there was no sludge released).

[260] A filter press uses high pressure to dewater (i.e., force water out of) wastewater treatment sludge and consists of a stack of filter plates held tightly together (closed) by hydraulic pressure. The filter plates have either a molded or machined filtration drainage surface that supports some type of filter media (e.g., a polypropylene filter cloth). A slurry (i.e., a mixture of solids and liquids) is pumped into the filter plates under pressure. The clear filtered liquid passes through the cloth, against the drainage surface of the plates, and out the discharge ports; the solids are retained on the filter cloth, forming a cake that is discharged when the filter plates are separated. Blow-outs occur when there is a buildup of hydraulic pressure caused by a blockage in the filter press or settling tank, a failed seal, or inadequate cleaning/maintenance of the sealing surfaces on the filter plates. To maintain an effective sealing surface, plate surfaces must be cleaned after each cycle (i.e., after releasing each dewatered sludge cake) to remove residual sludge (Komline-Sanderson, 2004).

[261] Universal waste includes items such as used batteries and fluorescent light bulbs. Examples of process-related waste include contaminated Tyvek™ coveralls, broken carbon rollers, vacuum sweepings, furnace insulation, felt wipes potentially contaminated with metal oxides, and pickling brushes and sludge.

To provide additional insight into the exposure profile for production support workers, OSHA also examined the IMIS data for relevant exposure information in SIC codes 3351, 3356, and 3357. Of the 171 PBZ sample results associated with these SIC codes, OSHA identified three results for SIC 3356 establishments with job descriptions consistent with production support workers, including two results for laboratory technicians and one result for a waste technician. All three results were nondetectable for beryllium and suggest that exposures are low for these types of activities. Although limited, these results provide additional support for the production support exposure profile.

Based on the available information in the data sources, and supported by the IMIS findings, OSHA believes that the exposure profile for production support workers is representative of production support exposures in the copper rolling, drawing, and extruding industry.

Rod and Wire Production Workers

Production workers operate production equipment and spend most of a typical workday in the beryllium production areas of the facility. Rod and wire (bulk) production workers include those engaged in the specific processes or jobs associated with rod and wire production, including wire annealing and pickling; wire drawing; straightening, which involves rod or tubing fed into a roller and cut to length with a shear cut; point and chamfer, which is a high-speed, high-volume cutting operation in which one end of the rod is pointed and the other end is chamfered (angled); rod and wire packaging; and die grinding (maintenance of carbide dies). Each of these processes is equipped with local exhaust ventilation (LEV) except for the rod/tube straightening process, where the finished product (free of surface oxidation) is cut to length prior to packaging and shipping, and rod and wire packaging (finished product is loaded into boxes, sealed, and labeled for shipping). Other controls include wet methods to contain loose surface oxides during handling (for annealing wire coils), housekeeping (to minimize beryllium contamination and migration), and personal protective equipment (PPE).

The exposure profile for rod and wire production workers is summarized in Tables IV-54 and IV-55 and represents the best available exposure data for this job category. As shown in Table IV-54, the exposure levels for rod and wire production workers range from 0.01 µg/m^3 to 7.8 µg/m^3, with a mean of 0.25 µg/m^3 and a median of 0.055 µg/m^3. These values represent 210 full-shift PBZ total beryllium sample results obtained from rod and wire production workers in one copper-beryllium rolling and drawing establishment (Brush Wellman Reading, 2004). Eighty-three percent of the exposure results are 0.2 µg/m^3 or less, and seventy percent are less than 0.1 µg/m^3. Eleven percent of the values fall between 0.2 µg/m^3 and 0.5 µg/m^3, another 4 percent fall between 0.5 µg/m^3 and 2.0 µg/m^3, and 2 percent exceed the current PEL of 2.0 µg/m^3 (see Table IV-55).

Several rod and wire production processes with exposures that can exceed 0.2 µg/m^3 are rod/tube straightening (0.012 µg/m^3 to 0.22 µg/m^3), wire drawing (0.014 µg/m^3 to 0.38 µg/m^3), and point and chamfer (0.01 µg/m^{3}to 1.58 µg/m^3). See Copper Rolling, Drawing, and Extruding Appendix 3 for a detailed distribution of these individual tasks. For both straightening and drawing, exposures have been linked to co-location issues at the Materion Reading facility. Both of these processes are located near bulk annealing and pickling, which is thought to be the primary source of exposure for these workers. In the case of point and chamfer, key sources of exposure are thought to be poor work practices (e.g., setting up and servicing the LEV hoods) and inadequate housekeeping (Corbett, 2004).

According to Table IV-60 in Copper Rolling, Drawing, and Extruding Appendix 3, the rod and wire production worker process with the highest beryllium exposures is bulk product annealing and pickling (0.02 µg/m^3 to 7.8 µg/m^3). Although exposures associated with this process can be considerably higher than is typical for other rod and wire production workers, Table IV-61 shows that exposures are not uniformly elevated: 62 percent of the available samples are 0.2 µg/m^3 or less and 85 percent are less than or equal to 0.5 µg/m^3.

Bulk pickling and annealing refers to a high-temperature (> 1,000°F) rod and wire annealing process. The pickling and annealing steps occur in the same immediate work area and are controlled by the same worker. Product is loaded into gas-fired annealing furnaces containing an inert or reducing atmosphere consisting of nitrogen and hydrogen. Canopy hoods with side curtains are located above the furnace openings (entry and exit doors) to exhaust any leakage of furnace atmosphere or combustion emissions. After annealing, rod and wire products are pickled in strong acid (e.g., sulfuric) to remove surface metal oxides that form during the annealing process. The sulfuric acid pickling tank is equipped with a push-pull LEV system to control acid mist generated during the pickling process. Rinse tanks, composed of hot caustic and soft water, do not have exhaust ventilation. The products are rinsed to remove residual strong acid.

The sulfuric acid pickling solution used to remove surface metal oxides that form during annealing reportedly contains significant concentrations of beryllium (Corbett, 2004). Aerosols containing beryllium may be released into the work environment when product is lowered into the pickling bath because bubbling and effervescing occur. Although the pickling tank is equipped with LEV, this push-pull system reportedly could be made more effective (Kent, Dec. 2004). Ventilation design criteria for open surface tanks, such as the pickling bath, are specified by ACGIH. ACGIH recommends that operations involving large parts, containers, or mechanisms that would interfere with (obstruct and deflect) the push jet should be analyzed carefully to determine whether push-pull ventilation is appropriate, and if so, how the push-pull ventilation system should be designed (see Group 13.72 in ACGIH, 2010). It is possible that the push-pull system in existence at the Reading, Pennsylvania facility when the exposure profile data were collected does not meet the recommended design criteria, because the bulk product processed in the sulfuric acid pickling tank is large and heavy and could interfere with the push jet. If push-pull ventilation is appropriate for the pickling operation, the system may need to be redesigned. For example, the ACGIH recommends design criteria for the push nozzle manifold, push nozzle angle, nozzle openings, exhaust hood opening, liquid surface level, push nozzle supply air, total push supply air, and exhaust flow, which could improve the effectiveness of the system.

Additionally, handling of coiled wire product during bulk annealing and pickling tends to be problematic. Coiled wire must be manually spread apart on a hoist rack prior to pickling to achieve the desired results (i.e., uniform surface contact with pickling solutions and consistent gauge reduction throughout the coil). Beryllium-containing oxide scale generated during the annealing process can "flake off" during subsequent handling/processing and become airborne.[262]

The IMIS data include at least 29 sample results (out of the 171 total samples described in Data Sources within this Copper Rolling, Drawing, and Extruding section) with job descriptions consistent with production workers in the copper rolling, drawing, and extruding application group, including three results for drawing, four results for extruding, three results for rolling, 15 results for furnace operators, one result for pointing, one result for metal conditioning (which may or may not represent chemical cleaning such as pickling), and two inspection results. [263] With two exceptions, all the results are nondetectable for beryllium. The two positive results include 0.78 $\mu g/m^3$ for a furnace operator in an SIC 3351 establishment in March 1997 and 2.5 $\mu g/m^3$ for a metal conditioner in August 1991 in an SIC 3356 establishment. The IMIS results in conjunction with the available data suggest that most rod and wire production workers in the copper rolling, drawing, and extruding application group have low exposures, with a few exceptions. Based on the available information, OSHA therefore preliminarily concludes that the exposure profile for rod and wire (bulk) production workers is consistent with exposures in the copper rolling, drawing, and extruding application group.

Strip Metal Production Worker

Similar to bulk metal production workers, strip metal production workers also operate production equipment and spend most of a typical workday in the beryllium production areas of the facility. These workers produce sheets and plates of beryllium alloys. Strip metal production workers include those involved with the following jobs or processes: strip rolling, slitting, pickling, annealing, degreasing (i.e., cleaning to remove oils and grease from the surface of the alloy), inspection, and shipping and receiving. As shown in Table IV-54, the exposure profile for this job category is based on 320 full-shift PBZ total beryllium exposure results obtained for strip metal production workers at Materion's Reading, Pennsylvania, rolling and drawing facility. These results are characterized by a mean of 0.041 $\mu g/m^3$, a median of 0.017 $\mu g/m^3$, and a range from 0.006 $\mu g/m^3$ to 0.72 $\mu g/m^3$. Ninety-two percent of the exposure results for this job category are less than 0.1 $\mu g/m^3$, while ninety-eight percent of the results are less than or equal to 0.2 $\mu g/m^3$. See Table IV-55 for more details.

At the time of sampling, the facility had in place partial enclosures for the strip annealing, pickling, and cold-rolling processes. These controls contributed to the lower exposures measured in strip metal production workers. High efficiency particulate air (HEPA)-filtered vacuums are used to clean the slitting machine, and the scrap-baling operation (performed using the slitting machine) is equipped with partially enclosed LEV. No special controls or PPE are used by shipping and receiving workers. Strip inspection workers use specialized work practices for

[262] Prior to 2000, annealed coils were sprayed with water before "spreading" to control the generation of airborne beryllium oxide. In 2000, the facility added the acid process after annealing operations to manage oxide scale and discontinued the spraying of the annealed coils.
[263] Note that the IMIS data do not provide information about the type of product processed. For example, at Brush Wellman's Reading facility, both bulk and strip products are annealed. However, in IMIS, it is not possible to know what type of product a furnace operator, presumably operating an annealing furnace, was processing when the PBZ samples were obtained. Thus, it is impossible to know to which production category the IMIS data are most applicable: bulk products and/or strip products.

disposing shop wipes (used to wipe strip rolls during visual inspection) and HEPA-filtered vacuums for housekeeping in the immediate work area.

Individual processes with exposures that can exceed 0.2 μg/m^3 include strip annealing (0.006 μg/m^3 to 0.72 μg/m^3), rolling (0.01 μg/m^3 to 0.31 μg/m^3), slitting (0.01 μg/m^3 to 0.23 μg/m^3), and pickling (0.011 μg/m^3 to 0.28 μg/m^3) (see Copper Rolling, Drawing, and Extruding Appendix 3). The highest strip metal production exposure results are associated with annealing metal strip. High-temperature annealing (> 1,000ºF) can generate a loose beryllium-containing oxide scale that can flake off during subsequent processing and handling and become airborne (Materion SF 105, 2011). Other sources of exposure associated with strip annealing include service and maintenance tasks such as replacing felt wipes at the furnace entry and exit points, removing oil contamination, and dislodging/removing jammed or broken/torn strip from inside the furnace.

Rolling exposures among strip metal production workers have been associated with beryllium-containing aerosols released during rolling, changing/handling contaminated oil filters and bins for beryllium alloy scrap, and housekeeping of beryllium-containing settled dust on equipment and work surfaces. Sources of beryllium exposure associated with the slitting process include slitter head set-up and removal, and contaminated baling scrap. Pickling exposures are thought to be due to housekeeping (dried contaminated salts getting dispersed in the air), maintenance tasks such as removing and cleaning the Scotch-Brite™ brushes inside the pickler lines (brushes prevent product blemishes), and undesirable work practices such as not replacing the covers on the pickling tanks.

As noted above, the available IMIS data include at least 29 sample results with job descriptions consistent with production workers in the copper rolling, drawing, and extruding application group. All but two of these results are nondetectable for beryllium and suggest that exposures for production workers within this application group are generally low. Based on the available exposure data and the IMIS results, OSHA judges that the exposure profile for strip metal production workers is representative of this application group.

TECHNOLOGICAL FEASIBILITY

Administrative Staff

Administrative Staff—Baseline Controls

Administrative staff members do not work directly with beryllium, although they can be exposed to beryllium released from processes associated with other job categories if they enter production areas, or if beryllium contamination migrates into in administrative areas from production areas. In facilities that have put in place the Materion Beryllium Worker Protection Model (described in Section 2—Methodology), baseline controls include restricted access to production areas and rigorous procedures to limit the spread of contamination to nonproduction areas.

Administrative Staff—Additional Controls

As shown in Tables IV-54 and IV-55, the median exposure level for administrative staff is 0.017 μg/m^3, and 100 percent of the workers in this job category have exposures of 0.2 μg/m^3 or less. In the event that administrative workers receive higher exposures, implementing or improving engineering and work practice controls for production workers and beryllium work areas will result in reduced exposures for administrative workers who receive their exposures from entering beryllium work areas or interacting with production workers. For those administrative workers who do not enter production areas, improvements in beryllium migration control will result in reduced exposures.

Administrative Staff—Conclusions

Based on the information described in this section, OSHA preliminarily concludes that the proposed PEL of 0.2 μg/m^3 can be achieved for most administrative workers most of the time by limiting the entry of nonessential personnel into beryllium work areas and by practicing good migration control, as outlined in the Materion Beryllium Worker Protection Model. This level has already been achieved for all of the workers in this job category. When the exposures of workers in other job categories that work directly with beryllium alloys are reduced to 0.2 μg/m^3 or less, exposure levels will also be reduced for most of the remaining 1.5 percent of administrative staff members who occasionally experience exposure levels between 0.1 μg/m^3 and 0.2 μg/m^3. OSHA preliminarily concludes that the proposed PEL of 0.2 μg/m^3 can be achieved for most of the administrative operations most of the time. Furthermore, an exposure level less than 0.1 μg/m^3 can also be achieved for the vast majority of administrative operations most of the time.

Production Support Workers

Production Support Workers—Baseline Controls

Exposure conditions for production support workers at the Reading, Pennsylvania copper-beryllium rolling and drawing facility vary depending on the time period and the task. Prior to and during the facility-wide exposure assessment in 2000, standardized work practices and procedures to limit personal exposure for all workers and beryllium migration were not in place because airborne beryllium levels were predominantly below the current OSHA PEL of 2 μg/m^3, suggesting at that time little need for additional engineering controls or PPE (Thomas *et al.*, 2009). Baseline exposure conditions for production support workers, which were in effect when the exposure profile samples were taken (1977-2000), are the following:

- **Wastewater Treatment Operators.** Minimal level of protective clothing and respiratory protection, housekeeping (HEPA vacuums), and work practices, including use of decontamination areas to limit beryllium migration and personal exposure.
- **Mechanical Maintenance Workers.** No special controls or PPE.
- **Quality Assurance Workers (metallurgical lab staff).** LEV for sample preparation and chemical etching.

These conditions are associated with a median exposure level of 0.022 μg/m^3 for production support workers.

Production Support Workers—Additional Controls

With the exception of wastewater treatment operators, sample results for all production support activities are below 0.2 μg/m^3. Additional controls are not required for the other workers in this job category. Furthermore, as shown in Table IV-61 in Copper Rolling, Drawing, and Extruding Appendix 3, only one of the three wastewater treatment operator samples (0.33 μg/m^3) exceeds 0.2 μg/m^3. The remaining two samples resulted in levels of 0.11 μg/m^3 or less. While OSHA acknowledges the limited number of samples available for wastewater treatment operators, it represents the best information available. The exposure samples that exceed the proposed PEL of 0.2 μg/m^{3}and the alternative PEL of 0.1 μg/m^3 show that exposures can occur during these operations. To lower wastewater treatment operator exposures further, existing controls need to be enhanced. These enhancements primarily include taking steps to reduce malfunction of filter presses that result in blowouts, and improving housekeeping work practices when blowouts occur.

As discussed in the subsection on Production Support Workers within this Copper Rolling, Drawing, and Extruding section, Cairnie (2005) explains that beryllium contamination of the wastewater treatment plant occurs when there is a blow-out, i.e., malfunction resulting in material release in the wastewater filter press. Blow-out sludge that is not cleaned up and is allowed to dry can become dispersed within the work area. OSHA judges that blow-outs to the filter press may continue to create high exposure scenarios to wastewater treatment workers, and the following controls could reduce exposures by preventing blow-outs, and reducing exposures when blow-outs occur.

Administrative and Work Practice Controls: Materion Corporation's Reading facility has already shown that these blowouts can be reduced to once or twice per year by taking steps that prevent the malfunctions (Cairnie, 2005). Steps include *utilizing* standard operating procedures to ensure that the filters are checked, cleaned, and serviced on appropriate schedules to keep them functioning as intended, and to guide production support operators while closing, labeling, and preparing waste drums for storage. As noted above, when blowouts are prevented, the maximum exposure level for a wastewater treatment operator is 0.11 μg/m^3.

Housekeeping: Keeping work areas clean is another means of controlling exposure to beryllium, because beryllium-containing particles and solutions on work surfaces and clothing can be a source of employee exposure through dispersion into the air and from hand to face contact (Knudson and Kolanz, 2009). Poor housekeeping is also a major source of beryllium that can be carried out of the work area (i.e., beryllium migration). Policies and housekeeping measures to prevent the spread of contamination are also principles of the Materion Beryllium Worker Protection Model.

Yoshida *et al.* (1997) reported that effective workplace cleaning contributed to a reduction in ambient (general area) beryllium levels in a Japanese rolling and drawing establishment. Airborne beryllium levels decreased from a geometric mean of 0.19 μg/m^3 to a geometric mean of 0.03 μg/m^3 (an 84-percent reduction) through a combination of ventilation and housekeeping improvements. Local exhaust ventilation was enhanced, presumably because it was less than optimal, and the workplace was cleaned to remove deposited particulate materials. The study did not specify the enhancements made to the ventilation system nor the details of the housekeeping improvements.

After the completion of baseline exposure sampling in 2000, the Reading rolling and drawing facility adopted a new housekeeping system. Prior to 2000, housekeeping was a weekly task performed by the manufacturing departments. Beginning in 2000, beryllium migration controls were implemented (e.g., the use of skid-resistant shoe covers or "booties" and sticky/tacky floor mats and entrances/exits) and housekeeping was systematically completed on a shift-to-shift basis. Separate housekeeping protocols (checklists) that outline the items to clean, the cleaning method to use, and the frequency of cleaning (i.e., daily, weekly, monthly, or semiannually) were developed for all areas of the facility. Housekeeping checklists are posted throughout the facility and must be completed and signed by workers when the required cleaning has been performed. Housekeeping methods have also been enhanced; cleaning methods are limited to wet methods and HEPA-filtered vacuums. Wet floor sweepers with dual water supplies are utilized so the floors are always washed with a "clean" supply of water.

Although exposure measurements that specifically demonstrate the benefit of enhanced housekeeping are not available, OSHA anticipates that effective housekeeping protocols will be sufficient to further reduce worker exposures from 0.11 $\mu g/m^3$ to levels below 0.1 $\mu g/m^3$.

Other Control Options: As noted earlier, the Materion Beryllium Worker Protection Model (outlined in Section 2—Methodology) encourages practices that limit both worker contact with and the spread of beryllium. Consistent use of adequate protective clothing prevents contamination of workers' clothing and external body surfaces (e.g., skin and hair). Additionally, limited evidence suggests that resuspended beryllium particles from contaminated work clothing may contribute to inhalation exposure of the worker, as demonstrated in a pilot laboratory study by Cohen and Positano (1986). These investigators showed that the average total airborne beryllium concentrations from unwashed new and old shirts were 0.04 ± 0.05 $\mu g/m^3$ and 0.39 ± 0.36 $\mu g/m^3$, respectively. Although this study was designed to show how the aging process affects fabrics' abilities to accumulate toxic dusts, it also demonstrates the extent to which beryllium dust from clothing can influence worker exposures, thereby supporting aspects of the Materion Beryllium Worker Protection Model such as keeping work clothes clean and eliminating causes of beryllium migration. Work clothing contamination and dust resuspension (resulting in breathing zone exposure) can be minimized by anticipating job tasks with the potential for contamination, donning protective clothing and equipment (such as disposable Tyvek coveralls), and removing protective clothing and equipment after the task is complete.

Production Support Workers—Conclusion

The median exposure level for production support workers is 0.022 $\mu g/m^3$. Based on the exposure profile, exposure levels at or below the proposed PEL of 0.2 $\mu g/m^3$ have already been achieved for 98 percent of production support workers, while nearly as many (92 percent) also already have exposures less than 0.1 $\mu g/m^3$.

For those workers who experience higher exposures, such as wastewater treatment operators, additional controls primarily include work practice and housekeeping improvements to limit personal exposure and workplace contamination. At Materion Corporation's Reading facility, efforts to reduce the frequency of filter press blowouts have succeeded in limiting this source of exposure to once or twice per year (Cairnie, 2005). Eliminating this type of filter malfunction limits worker exposure to 0.11 $\mu g/m^3$ or less. On rare upset occasions (e.g., when blowouts might still occur), respiratory protection will be required during the initial cleanup. A respirator that offers an assigned protection factor of 10 (e.g., a half-facepiece air purifying respirator) will provide protection up to 2.0 $\mu g/m^3$ (the maximum use concentration for that protection factor).

This would be sufficient protection for the most highly exposed production support workers as a result of upset conditions such as filter malfunction..

Housekeeping improvements and the use of adequate protective clothing and equipment could further reduce exposure. Yoshida *et al.* (1997) found that enhanced work practices, in combination with ventilation improvements, reduced exposures by 84 percent, to a geometric mean of 0.03 µg/m^3.

Based on the available information, OSHA preliminarily concludes that the proposed PEL of 0.2 µg/m^3 is feasible for most production support operations most of the time. Additionally, OSHA finds that an alternative PEL of 0.1 µg/m^3 can be achieved most of the time for most production support operations.

Rod and Wire Production Workers

Rod and Wire Production Workers—Baseline Controls

The median exposure level associated with rod and wire production workers is 0.055 µg/m^3. As previously noted in this section, the rod and wire production processes at the Reading facility include die grinding, point and chamfer, rod/tube straightening, wire annealing and pickling, and wire drawing. Based on the best available information, the exposure conditions for these processes at the time of the baseline exposure assessment include the following:

- **Point and Chamfer.** LEV hoods at both ends of the rod.
- **Bulk (rod and wire) Pickling and Annealing.** Inert atmosphere annealing furnaces (inert atmosphere reduces surface oxides); LEV to control potential emissions from annealing furnaces (canopy hoods with side curtains at entry/exit) and pickling tanks (push-pull LEV), although the exhaust ventilation for the pickling tanks might be less than optimal; wet methods to control loose beryllium oxide scale on annealed parts; protective clothing and respiratory protection; and work practices and housekeeping to limit beryllium migration and personal exposure.
- **Wire Drawing (bull blocks/swager pointer).** LEV hoods connected to a portable HEPA-filtered vacuum; protocols for work practices and housekeeping.
- **Rod and Wire Packing (packaging operation).** No controls or PPE in use.
- **Rod/Tubing Straightening.** No controls or PPE used.
- **Die Grinding (die maintenance; grinding/polishing operation).** Manually controlled LEV for small lathes.

Rod and Wire Product Workers—Additional Controls

Based on the exposure profile, overall, 17 percent of rod and wire production workers have exposures that exceed 0.2 µg/m^3 and therefore require additional controls to further reduce exposures. Within this job category, the highest beryllium concentrations (up to 7.8 µg/m^3) and the greatest number of sample results exceeding 0.2 µg/m^3 (30 out of 210 results, or 14 percent) are associated with bulk pickling and annealing workers (see Copper Rolling, Drawing, and Extruding Appendix 3). As noted, other rod and wire production workers with exposure results that exceed 0.2 μg/m^3 include rod/tube straightening (one result, 0.22 μg/m^3), wire drawing (two results, 0.22 μg/m^3 and 0.38 μg/m^3), and point and chamfer (two results, 0.29 μg/m^3 and 1.58 μg/m^3).

As discussed earlier, in June of 2000, the Reading facility launched the Materion Beryllium Worker Protection Model**.** This enhanced, multifaceted beryllium exposure control program included "improved workplace orderliness and cleanliness, enhanced dermal protection in the form of polymer gloves and long-sleeved uniforms, dust migration control measures (e.g., tacky mats at entrances/exits and company clothing and boots that do not leave the facility), administrative controls (e.g., routine decontamination procedures in work areas), limiting airborne beryllium concentrations through engineering upgrades, such as enclosure and ventilation of high-risk processes to reduce airborne exposures to predominantly less than 0.2 μg/m^3, and extensive training and involvement of workers" (Thomas *et al.*, 2009). Because earlier air sampling had revealed that the bulk annealing and pickling operation was the primary source of beryllium exposure in the rod and wire production area, the facility implemented the following controls as part of its ongoing beryllium control program:

- Created an interim RAZ. The bulk pickling and annealing area was isolated from the rest of the facility by enclosing the operation with floor-to-ceiling walls that contain two rapid access doors. The area was placed under negative pressure (10 percent differential between the exhaust and supply flow rates) and the air exchange rate was significantly increased to about 15 air changes per hour. (The facility's long-range plan is to investigate bulk pickling and annealing separately to identify and characterize the source(s) of exposure; implement needed controls; and eliminate the RAZ.) Materion has not since conducted another air sampling campaign that would characterize PBZ exposures for workers inside the RAZ.

- Created a transition zone between the RAZ and the rest of the production operations. To enter the bulk pickling and annealing area, workers must enter through a transition zone where they are required to don PPE, including respiratory protection. The transition zone also contains a designated decontamination station where workers clean their respirators and dispose of contaminated clothing.

- Implemented PPE requirements for the RAZ. To enter the RAZ, workers proceed to the transition zone and don full body coveralls over their company-provided work uniforms, gloves, and loose-fitting power air-purifying respirators with HEPA filters. This PPE is required to be used at all times while working in the RAZ. Prior to 2000, respirator use was primarily voluntary and only required for certain tasks. The use of work uniforms and dedicated work boots was an optional work practice for employees, and no special PPE was required to work in bulk pickling and annealing.

- Required daily showers, the timing of which was not specified, for employees in the bulk pickling and annealing area. This includes all employees that enter or work in the RAZ.

- Implemented work practice controls to address beryllium oxide scale on coiled wire product. If flaking oxide is observed on coils, workers must notify their supervisor and follow a protocol to remove as much scale as possible before pickling. This protocol includes wetting the coil with water before handling, rinsing the coil in the caustic and soft water rinse tanks, spreading the coil, loading the coil into the pickling tank, and cleaning up the work area afterwards.

Prior to the creation of the RAZ, the enhanced exposure controls primarily consisted of separating production and nonproduction work areas, using dermal protection, and limiting beryllium migration. Table IV-56 summarizes the series of enhanced exposure controls implemented at the Reading facility from 2000 to 2007.

Table IV-56—Summary of Exposure Controls Over Time at the Brush Wellman Reading, Pennsylvania, Copper-Beryllium Rolling and Drawing Facility (NAICS 331421 and 331422)

Year	Control Category	Control Description
2000	*Administrative*	• *Banned smoking and street clothes in production areas.* • *Required all employees to keep work clothes and boots on site in locker rooms.* • *Required end-of-shift showering/clothing changes for cohort (new male workers in production areas) (Note: mandatory showering phased in by 2004 for existing workers).*
	PPE	*Required polymer gloves for the cohort (new employees in production areas).*
2001	*Engineering*	• *Installed plastic curtains at entrances/exits to production areas.* • *Attached die grinder and polisher to LEV system.*
	Administrative	*Installed shower trailers for women and vendors, but use not required.*
	PPE	*Required facility uniforms (long sleeve shirts and pants), supplied and laundered by the company, for all production area workers.*
2002	*Engineering*	*Enclosed wire annealing/pickling process and placed under negative pressure (created RAZ).*
	Administrative	• *Required RAZ workers to shower before leaving.* • *Installed RAZ-only locker room for changing in/out of RAZ PPE.* • *Prescribed decontamination procedures, including housekeeping checklist with item/location, frequency, and method of cleaning.* • *Required production workers to clean work areas 15 minutes per shift and one hour per month.* • *Required wet methods and/or HEPA-filtered vacuums for cleaning.* • *Required workers to remove gloves and wash hands before eating, drinking, or smoking.* • *Required visibly dirty uniforms to be changed and incident-causing potential clothing contamination to be reported to management.*
	PPE	• *Required over-shoe booties, lab coats, and polymer gloves for office workers, visitors, and vendors entering production areas.* • *Required powered air-purifying respirators, company clothing, outer coveralls, rubber boots, and outer gloves for RAZ workers.* • *Required polymer gloves for all workers in production areas.*

Table IV-56—Summary of Exposure Controls Over Time at the Brush Wellman Reading, Pennsylvania, Copper-Beryllium Rolling and Drawing Facility (NAICS 331421 and 331422)

Year	Control Category	Control Description
2003	*Engineering*	• *Installed tacky mats and boot scrubbers at production area exits.* • *Installed boot lockers in area separate from locker rooms.*
	Administrative	• *Banned eating and drinking in production areas.* • *Implemented blue/gray zone designations indicating the type of clothing/PPE required.*
2004	*Administrative*	*Required showering before leaving facility for all maintenance and strip pickling workers and all janitorial, mechanical, electrical, and general contracting vendors who were in production areas.*
2005	*Engineering*	*Installed new operator booth for one rolling mill.*
2006/2007	*Engineering*	• *Installed new LEV systems over one annealing furnace, a roll grinder, and slitter.* • *Increased hood capture ventilation over one strip pickler.* • *Installed new fan to increase number of air exchanges from five to 15 per hour in the RAZ.*
Source: Adapted from Thomas et al., 2009.		

The combination of enhanced controls (enclosure and improved ventilation of high-risk processes, dermal protection, and migration control measures) was reportedly effective in reducing airborne beryllium levels after the preventive program was launched, although it is not possible to determine the contribution of the individual components of the program (Thomas *et al.*, 2009). Although only four full-shift PBZ samples were collected in the rod and wire area after the January 2002 enclosure of the bulk annealing and pickling processes, these samples show dramatic improvement. The samples were obtained outside the RAZ in the other rod and wire areas (such as wire drawing, rod straightening, point and chamfer, rod and wire packing and die grinding) and included results of 0.0080 μg/m^3, 0.0087 μg/m^3, 0.0100 μg/m^3, and 0.0170 μg/m^3 (Thomas *et al.*, 2009).[264] Although limited in number, these results provide evidence that the multifaceted control program was effective in reducing PBZ exposures below 0.1 μg/m^3 in the non-RAZ rod and wire areas of the facility. These results are notably lower than the samples obtained before the controls were implemented: prior to January 2002 (before enclosure of bulk annealing and pickling), PBZ exposures in the non-RAZ rod and wire areas ranged from 0.01 μg/m^3 to 1.58 μg/m^3. For this same time period, Thomas *et al.* (2009), who had access to a larger dataset than OSHA, reported that non-RAZ exposures ranged from less than 0.01 μg/m^3 to 2.47 μg/m^3.

Based on the available data (i.e., the four full-shift PBZ results), and until additional exposure information becomes available, OSHA concludes that the combined effect of the enhanced exposure control program is sufficient to reduce exposures for non-RAZ workers to below 0.1 μg/m^3. Components of the enhanced control program, such as improved housekeeping and work practices, were helpful in reducing exposures associated with the point and chamfer process. In the case of the straightening and wire drawing processes, worker exposures were primarily

[264] The specific non-RAZ rod and wire processes where the samples were obtained and the dates the samples were collected are not available (Thomas *et al.*, 2009).

attributed to the close proximity of bulk annealing and pickling. Enclosing and placing the bulk annealing and pickling process under negative pressure will eliminate all such exposures for these workers.

The Reading facility was visited again in June 2003, after the bulk annealing and pickling processes were enclosed and the improved beryllium migration control program, including dermal protection in production areas, was completed.[265] In order to evaluate dermal exposure to beryllium in the workplace, the investigators collected 10 general area air samples. (Day *et al.*, 2007).

Nine of the post-control samples were collected near production processes throughout the facility, and one sample was collected in an administrative area. Two of the nine production samples were collected near rod and wire production processes (i.e., rod straightening, wire annealing, and pickling), and seven of the samples were collected near strip production processes (i.e., annealing furnaces I and II; rolling mills I and II; pickling; slitting; and shipping and receiving). Again, the beryllium results for the general area samples were all significantly below 0.1 µg/m^3 and ranged from 0.0007 µg/m^3 to 0.0238 µg/m^3, with a mean of 0.0056 µg/m^3 and a median of 0.0018 µg/m^3. These results are summarized by work area/location in Table IV-57.

Table IV-57—General Area Air Sampling Results for the Brush Wellman Reading, Pennsylvania, Copper-Beryllium Rolling and Drawing Facility in June 2003[a]

Work Area/Location	Location	Beryllium Concentration (µg/m^3)
Administrative	*Front Offices*	*0.0007*
Production Support[b]	—	—
Production: Rod and Wire (bulk products)	*Rod Straightening*	*0.0021*
	Wire Annealing and Pickling	*0.0238*
Production: Strip Metal	*Annealing Furnace I*	*0.0009*
	Annealing Furnace II	*0.0014*
	Pickling	*0.0159*
	Rolling Mill I	*0.0013*
	Rolling Mill II	*0.0030*
	Shipping and Receiving	*0.0010*
	Slitting	*0.0061*

[a] General area samples collected continuously (24 hours per day for 3 days per week over 2 weeks) using stationary samplers operating at 15 liters per minute. Samples were analyzed using NIOSH Method 7300 and the analytical LOD for beryllium was reported to be 0.004 µg.

[b] Air samples were not collected in production support areas.

Source: Adapted from Day et al., 2007.

Although Day *et al.* (2007) stated that the air sampling results were not representative of PBZ exposure, they did use the general area airborne beryllium concentrations as an indirect measure of personal exposure to investigate correlations between concentrations of beryllium in the air

[265] Day *et al.* (2007) do not explicitly state that the copper-beryllium alloy facility described in their article is the Brush Wellman Reading, Pennsylvania, facility. Information confirming the identity of the facility as the Brush Wellman Reading facility was obtained from NIOSH beryllium research updates (NIOSH Beryllium Research, 2005; Schuler, 2007).

and on workers and surfaces in the facility. OSHA also recognizes that the general area air sampling results are not representative of PBZ exposure. However, in this case no other air sampling results are available to approximate the exposures of RAZ workers after enclosing the bulk annealing and pickling processes and implementing the enhanced beryllium migration control program. In the absence of PBZ data, the general area air sampling results obtained by Day *et al.* do offer strong evidence that airborne concentrations were very low in the RAZ and provide the best estimate of RAZ workers' PBZ exposures after the facility implemented the enhanced exposure controls. In the interim, and until PBZ exposure data become available, OSHA estimates that the changes implemented at the Reading facility after 2000 reduced worker exposure in the bulk annealing and pickling area to approximately 0.238 $\mu g/m^3$. To obtain this value, OSHA applied a safety factor of 10 to the 0.0238 $\mu g/m^3$ maximum general area result reported by Day *et al.* for the bulk annealing and pickling process.[266]

This approach (i.e., applying a safety factor of 10) likely overestimates exposure for this group of workers. Investigators also sampled both PBZ exposure levels and general area concentrations for strip metal workers. From those sample results, OSHA calculates that the area concentration obtained by Day *et al.* (2007) does underestimate worker PBZ exposure but suggests that the values differ by a ratio closer to 3 than to 10. Calculations show that compared to maximum post-control PBZ exposure levels of 0.054 $\mu g/m^3$ obtained for the strip metal production workers, the highest post-control multi-shift general area air sample of 0.0159 $\mu g/m^3$ (associated with strip pickling) underestimates the strip metal workers' actual maximum PBZ exposure by a factor of approximately 3.[267] This suggests that, although less protective than a safety factor of 10, a safety factor between 3 and 4 might be appropriate for estimating worker PBZ exposures for bulk annealing and pickling operations (RAZ zone) from area samples.

Balkissoon and Newman (1999) reported maximum airborne (area) concentrations of 10 $\mu g/m^3$ and 20 $\mu g/m^3$ on two occasions in 1987 at a copper-beryllium parts manufacturer where workers' activities included annealing, pickling, and other operations common to the rolling, drawing, and extruding industry. Repeat air sampling in 1988, 1991, and 1993 yielded nondetectable results. Sampling LOD concentrations were not provided. The facility reportedly installed high-efficiency LEV systems in 1990. Without knowing the LOD, it is difficult to interpret the extent

[266] A safety factor of 10 is a common protective safety factor value applied when faced with substantial unknown in toxicology and exposure evaluations. Other safety factors can also be used, but 10 is a typical starting value when little information is available. For example, OSHA uses a safety factor of 10 for a "passing" score in a quantitative respirator fit test. In that case a safety factor of 10 is used because protection factors in the workplace tend to be much lower than the fit factors achieved during fit testing. The use of a safety factor is a standard practice supported by most experts to offset this limitation. This is discussed in the Federal Register at 63 FR 1225 and at http://www.osha.gov/dte/library/respirators/major_requirements.html.

[267] The post-intervention PBZ exposure was not sampled for wire and rod workers in the RAZ zone, but the general area concentration was sampled. By using all the available information, OSHA finds that it is possible to estimate the effect of the intervention controls on PBZ exposure in the RAZ zone. To accomplish this, OSHA used available information from another group of workers (strip metal workers) to calculate the difference between the maximum measured PBZ beryllium exposure level and the maximum general area beryllium concentration. The actual ratio could be calculated for strip metal workers because, for those workers, BOTH the PBZ exposure and the area concentration were measured: [PBZ]/[Area] = 0.054/0.0159 = 3.4. The resulting value of 3.4 is the ratio of the PBZ beryllium exposure level to the area beryllium concentration. This value is approximately 1/3 of the safety factor (10) that OSHA is applying to the general area concentration in the RAZ zone in estimating the post-intervention exposure levels of rod and wire workers in that zone; therefore, OSHA finds that the safety factor of 10 is more than sufficiently protective for this exposure determination, and a lower safety factor might also be justified.

to which the LEV system reduced the airborne concentrations to which workers were exposed, although the investigators presumably would have been interested in levels comparable to the current PEL of 2 μg/m^3 or less, suggesting an 80- to 90-percent reduction in airborne beryllium due to the newly installed ventilation system.[268] It is important to note that the initial concentrations are considerably higher than the levels in the exposure profile for this application group.

Rod and Wire Production Workers—Conclusion

The median exposure level for rod and wire production workers at the Reading, Pennsylvania, copper-beryllium rolling and drawing facility is 0.055 μg/m^3. Exposure levels of 0.2 μg/m^3 or less have already been achieved for 83 percent of workers in this job category, and seventy percent of workers had exposures less than 0.1 μg/m^3. Rod and wire production processes associated with higher exposures include bulk pickling and annealing, point and chamfer, wire drawing, and rod/tube straightening. Multiple controls are required to reduce the exposures of this group of workers.

As mentioned previously, the Reading facility implemented the Materion Beryllium Worker Protection Model, which sought to reduce exposures through multiple exposure pathways. This program included targeted engineering controls, including enclosure of the bulk annealing and pickling process into a RAZ zone, emphasis on reducing dust migration and skin and clothing contamination, improved workplace cleanliness and orderliness, and worker training and involvement. After the start of the enhanced preventive program, four full-shift PBZ sample results obtained for the non-RAZ production processes (not otherwise specified) were all below 0.1 μg/m^3 and, although limited in number, suggest that the additional controls have effectively reduced exposures to levels at or below the proposed PEL of 0.2 μg/m^3, as well as below an alternative PEL of 0.1 μg/m^3.[269]

No other PBZ results are available for the non-RAZ and RAZ production processes. However, two multi-shift general area air samples demonstrate how these controls influenced airborne beryllium concentrations. One area sample obtained near the rod/tube straightening process had a beryllium concentration of 0.0021 μg/m^3, further suggesting that the enhanced, multifaceted prevention program has been successful in reducing non-RAZ rod and wire production exposures (see Table IV-57) (Day *et al.*, 2007). A second multi-shift general area sample obtained in the RAZ area (i.e., bulk annealing and pickling) after the start of the enhanced preventive program showed a beryllium concentration of 0.0238 μg/m^3 in that area. In the absence of PBZ data, OSHA has relied on these general area sample results to estimate PBZ exposures for the RAZ area after the facility implemented additional controls. Applying a safety factor of 10 to the area sample, and then using the resulting value as an estimate of PBZ exposure in the RAZ area, OSHA estimates that with the additional controls in place, RAZ-area worker exposure levels are approximately 0.238 μg/m^3. This level may overestimate the true PBZ exposure of this subgroup

[268] An investigator interested in whether a new ventilation system reduced airborne concentrations below the current PEL of 2 μg/m^3 would likely have sampled for sufficient time to achieve LODs at 2 μg/m^3 or less. For this reason, one might assume that the LOD was equal to 2 μg/m^3 (and beryllium concentrations were reduced from 10 μg/m3 or 20 μg/m^3 to 2 μg/m^3 or less). The available information, however, is insufficient to confirm this LOD (Balkissoon and Newman, 1999).

[269] Non-RAZ production processes include point and chamfer, wire drawing, rod/tube straightening, rod and wire packing, and die grinding.

of workers by up to three times, as suggested in the discussion of additional controls for this group, which showed that a safety factor of 3 might be more accurate than a safety factor of 10.

Based on the best available information, OSHA preliminarily concludes that the proposed PEL of 0.2 μg/m^3 and an alternative PEL of 0.1 μg/m^3 are feasible for most rod and wire production operations most of the time. However, the available information is not sufficient to confirm that the proposed PEL of 0.2 μg/m^3 can be achieved reliably for certain rod and wire production workers, such as those working inside the RAZ. Workers whose exposures exceed 0.2 μg/m^3 would need to wear appropriate respiratory protection during high-exposure tasks.

Strip Metal Production Workers

Strip Metal Production Workers—Baseline Controls

As noted in the Data Sources subsection of this Copper Rolling, Drawing, and Extruding section, the strip metal production processes at the Reading copper-beryllium rolling and drawing facility include strip rolling, annealing, pickling, slitting, inspection, and shipping and receiving. The median exposure level associated with these production workers is 0.017 μg/m^3. Ninety-two percent of the exposure results associated with this job category are less than 0.1 μg/m^3, and 97 percent of the results are less than or equal to 0.2 μg/m^3. Based on the best available information, the exposure conditions associated with these processes at the time of the baseline exposure assessment include the following:

- **Strip annealing.** Inert atmosphere annealing furnaces with felt wipes on strip rolls and canopy hoods at entry and exit points. Half-inch-thick felt wipes on the rolls that the strip passes through help to contain the furnace atmosphere inside the furnace. Canopy hoods are partially enclosed with overlapping vertical strip panels (side curtains) on three of four sides. Operator control booths available for operator cooling/comfort purposes.

- **Strip rolling (Z-mill).** Canopy hood with vertical overlapping panels that run the length of the mill and include the reels at both ends of the mill. Operator control booths available for operator cooling/comfort purposes.

- **Strip slitting.** No special controls or PPE.

- **Strip pickling.** Partially enclosed pickling tanks with LEV.

- **Strip inspection.** No special controls or PPE known at the time of the baseline exposure assessment.

- **Shipping and receiving (strip product).** No special controls or PPE.

Strip Metal Production Workers—Additional Controls

Based on the exposure profile, approximately 3 percent of strip metal production workers have exposures that can exceed 0.2 μg/m^3 and require additional controls to further reduce exposures. The three highest beryllium sample results for strip metal production workers (0.47 μg/m^3, 0.54

μg/m^3, and 0.72 μg/m^3) are all associated with the strip annealing process.[270] Other strip metal production tasks in which beryllium exposures can exceed 0.2 μg/m^3 include strip rolling (one result, 0.31 μg/m^3), strip pickling (three results: 0.23 μg/m^3, 0.24 μg/m^3, and 0.28 μg/m^3), and strip slitting (one result, 0.23 μg/m^3). Despite these examples, for each of these subcategories, 97 percent of the sample results are below 0.2 μg/m^3, and 92 percent are also below 0.1 μg/m^3.

The enhanced beryllium exposure control program launched in 2000 at the Reading rolling and drawing facility is described in Rod and Wire Product Workers—Additional Controls and summarized in Table IV-56. In addition to enclosing the bulk annealing and pickling process and enhancing housekeeping, migration control, personal hygiene, and PPE, the facility installed new ventilation systems for several of the strip metal processes (i.e., one annealing furnace, one slitter, and one strip pickler). For example, in the strip pickling area the facility installed enhanced LEV for the scrap-baling operation and added HEPA-filtered vacuums for cleaning the slitter heads. In the strip inspection area, more recent controls include a standardized procedure for disposing of shop wipes that are used to wipe the roll during inspection and HEPA-filtered vacuums for housekeeping in the immediate work area. Wipes are removed carefully, folded, placed inside a plastic zip bag, and then thrown away.

After the facility implemented the enhanced control program, 16 full-shift PBZ samples obtained from workers performing the strip production processes ranged from less than 0.010 μg/m^3 to 0.054 μg/m^3, with a mean and median of 0.018 μg/m^3 (individual sample results not available) (Thomas *et al.*, 2009). Additionally, seven multi-shift general area samples collected in the strip production areas were all less than 0.1 μg/m^3, ranging from 0.0009 μg/m^3 to 0.0159 μg/m^3 (see Table IV-57). Thus, the available information suggests that the combination of additional controls in the enhanced exposure control program has been effective in reducing beryllium exposures to even the most highly-exposed workers in strip metal production to below 0.1 μg/m^3 at the Reading rolling and drawing facility.

Strip Metal Production Worker—Conclusion

The median exposure level for strip metal production workers is 0.017 μg/m^3. Based on the exposure profile, exposures at or below 0.2 μg/m^3 have already been achieved for 97 percent of these workers. As noted in Rod and Wire Production Workers—Additional Controls, the Reading rolling and drawing facility implemented an enhanced exposure reduction program, including engineering, housekeeping, and work practice controls. After the implementation of the enhanced preventive program, 16 full-shift PBZ samples and seven multi-shift general area samples collected in the strip production areas were all less than 0.1 μg/m^3. Based on the information described in this section, OSHA preliminarily concludes that the proposed PEL of 0.2 μg/m^3 and an alternative PEL of 0.1 μg/m^3 can be achieved for the vast majority of strip metal production operations most of the time.

[270] Not all strip annealing process exposure levels are elevated. As shown in Appendix 8C (Table IV-61), of the 71 total sample results associated with workers performing the strip annealing process, only these three exceed 0.2 μg/m^3.

Technological Feasibility—Conclusion

OSHA's exposure profile for copper rolling, drawing, and extruding includes four job groups with beryllium exposure: strip metal production, rod and wire production, production support, and administrative work. Exposure profiles for these jobs are based on personal breathing zone lapel sampling conducted at the Brush Wellman Reading, Pennsylvania, rolling and drawing facility from 1977 to 2000.

Prior to 2000, the Reading facility had limited engineering controls in place. Equipment in use included LEV in some operations, HEPA vacuums for general housekeeping, and wet methods to control loose dust in some rod and wire production operations. The exposure profile shows very low exposures for all four job groups. All had median exposure values below 0.1 $\mu g/m^3$, and in strip metal production, production support, and administrative work, over 90 percent of samples were below 0.1 $\mu g/m^3$. In rod and wire production, 70 percent of samples were below 0.1 $\mu g/m^3$.

To characterize exposures in extrusion, OSHA examined the results of an industrial hygiene survey of a copper-beryllium extruding process conducted in 2000 at another facility. The survey reported eight PBZ samples, which were not included in the exposure profile because of their short duration (2 hours). Samples for three of the four jobs involved with the extrusion process (press operator, material handler, and billet assembler) were below the limit of detection (LOD, level not reported). The two samples for the press operator assistant, taken when the assistant was buffing, sanding, and cleaning extrusion tools, were very high (1.6 and 1.9 $\mu g/m^3$). Investigators recommended a ventilated workstation to reduce exposure during these activities. OSHA believes exposures during other extruding tasks can be controlled similarly to exposures caused during drawing operations.

OSHA preliminarily concludes that the proposed PEL of 0.2 $\mu g/m^3$ is feasible for administrative, site support, rod and wire (bulk) production workers, and strip metal production workers, and that an alternative PEL of 0.1 $\mu g/m^3$ is also feasible for all of these job groups.

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SECTION 8—COPPER ROLLING, DRAWING, AND EXTRUDING, APPENDIX 1—SUMMARY OF COMMON OPERATIONS AND EQUIPMENT IN THE COPPER ROLLING, DRAWING, AND EXTRUDING APPLICATION GROUP

Table IV-58—Summary of Common Operations and Equipment in the Copper Rolling, Drawing, and Extruding Application Group

OPERATION	DESCRIPTION AND EQUIPMENT
Principal Forming Operations:	
Rolling:	*Rolling transforms cast metal into intermediate or final products. Metal is passed between cylindrical work rolls (rollers) and is reduced in thickness (gauge reduction or forming) by the pressure exerted by the rotating rolls. Process equipment includes several different types of rolling mills, such as tandem mills, cluster mills, Sendzimir mills (Z-mills), and special rolling mills (which fabricate previously rolled stock into finished products and typically are referred to by the product being run). The primary equipment used to roll nonferrous metal includes a two- or four-high rolling stand, work rolls, back-up rolls, drive motors, roll bending and gap adjustment hydraulic systems, gauge and shape controls, and coil/recoil and core handling systems. One set of this equipment comprises a mill stand. The work rolls are arranged vertically while the nonferrous metal is fed horizontally into the mill. Roll force is supplied by the work rolls (via drive motor) perpendicular to the surface of the metal. Frictional forces that develop between the rolls and work piece carry the rolled product through the mill. Two-high means metal is deformed between two steel work rolls; four-high is a two-high roller with backup/support rolls used to reinforce the smaller working rolls.*
Hot Rolling	*Rolling above the recrystallization temperature of the alloy being processed.**
Cold Rolling	*Rolling below the recrystallization temperature of the alloy being processed.*
Extrusion	*Extrusion forces metal to flow by compression through a die (material shaping tool or tooling) with an orifice of a smaller cross-sectional area than the original billet. The resulting product is an elongated shape or tube of uniform cross-section, including rods, tubes, molding trim, structural shapes, brass cartridges, and metal-clad cables. Most extrusion products are manufactured using extrusion presses that are horizontal in configuration and operated hydraulically or mechanically. In direct (forward) extrusion, a heated billet is placed into a heated part of the press called the container and pushed through the die by ram pressure. The direction of the metal flow is in the same direction as the ram travel. The final step is to cut off the extruded metal at the end of the extrusion cycle. Indirect (backwards) extrusion is similar to direct extrusion except that the metal billet is forced through a die located in the ram stem, leaving the die in the opposite direction as the ram travel.*
Drawing	*When referring to the manufacture of tube, rod, bar, or wire, drawing means pulling (stretching) metal through a die or succession of dies (draw bench) to reduce the metal's diameter, alter cross-sectional shape, or increase hardness. The leading tip of the work piece is pointed to get through the die and then gripped with a clamp. The rest of the work piece is then pulled through the die. For tube drawing, the beginning stock is a tube, and a mandrel (metal bar around which other metal may be bent/shaped) may or may not be inserted into the die orifice. When a mandrel is used, the tubing is pulled between the mandrel and the die.*

Table IV-58—Summary of Common Operations and Equipment in the Copper Rolling, Drawing, and Extruding Application Group

OPERATION	DESCRIPTION AND EQUIPMENT
Forging	*Forging uses compressive forces to press, pound, or squeeze metal into high-strength parts called forgings. Forging is usually (but not always) a hot-working operation performed by preheating the metal stock to a desired temperature before it is worked. Forgings are produced using hammers, presses, and upsetters. Hammers pound the metal stock into shape with controlled high-pressure impact blows, whereas presses squeeze the metal vertically using controlled high pressure. Upsetters are presses used horizontally for a forging process called "upsetting."* *Four basic techniques of forging are used in the forming categories: (1) closed die forging, (2) open die forging, (3) rolled ring forging, and (4) cold forging. In all these techniques, the metal stock is forced to take the desired shape by exerting pressure on dies or rolls. Closed die forging (also called impression die forging) pounds or presses the heated metal stock between two steel dies that contain a precut profile of the desired part. Hydraulic presses, mechanical presses, and forging hammers are used for closed die forging. Open die forging is performed between flat dies with no precut profiles; the forging is shaped by turning the metal stock and controlling the pressure of the hammer or press. Rolled ring forging is used to make seamless rings by punching a hole in a thick, round piece of metal stock and then rolling and squeezing (or pounding) the donut-shaped metal into a thin ring. Cold forging is a variation of closed die forging and includes many processes (bending, cold drawing, extrusions, and others) to yield a wide range of part shapes.*
Ancillary Surface and Heat-Treatment Processes:	
Heat treatments	*Heat-treating operations involve the heating and cooling of metals. Heat treatment is performed to improve the structural and physical properties of a metal. All heat treating processes involve three basic steps: (1) heating in a furnace (batch or continuous furnaces), (2) "soaking" in the furnace until the entire part has been evenly heated throughout; and (3) cooling. The common forms of heat treatment for nonferrous metals include annealing and solution heat treating. In copper forming, solution heat treatment is performed following all major forming operations, especially hot rolling and extrusion.* **Annealing** *consists of heating the metal to a specific temperature, soaking, and cooling to room temperature. The temperature and method of cooling depend on the type of metal. When an annealed part is cooled in the furnace it is called a "full anneal" heat treatment; when an annealed part is removed from the furnace and cooled in air, it is called a "normalizing" heat treatment. Homogenizing is a type of annealing where the work piece is heated to an appropriate temperature for 4 to 48 hours and then allowed to air cool. Copper annealing may incorporate a quenching step. Cooling water quenches may consist of immersing the work piece in a tank with flowing cooling water or by spray quenching. For extrusion, an oil-water solution is sometimes used.* **Solution heat treatment** *is performed to increase the tensile strength of many nonferrous alloys. After an alloy has been heated to a specified temperature, it is quenched or cooled rapidly, followed by a process of aging or precipitation hardening (also known as age hardening or precipitation heat treatment). Precipitation hardening occurs under controlled conditions. When the metal is heated to a low temperature for several hours and then air-cooled, the precipitation hardening process is called artificial aging. Press heat treatment is solution heat treating immediately following the extrusion process. In this procedure, the work piece is extruded at the required temperature and quenched with cooling water or emulsified or soluble oils as it emerges from the die or press.*

Table IV-58—Summary of Common Operations and Equipment in the Copper Rolling, Drawing, and Extruding Application Group

OPERATION	DESCRIPTION AND EQUIPMENT
Surface treatments	*Surface treatments may be used for cleaning purposes, to provide a desired finish for a formed product, or to prepare the metal surface for subsequent coating by processes such as anodizing, conversion coating, electroplating, painting, and porcelain enameling. Acid and alkaline solutions, solvents, and detergents are used to clean metal surfaces. Alkaline cleaning may precede annealing to limit the amount of oil introduced into the furnace. Vapor or solvent degreasing is an alternative to alkaline cleaning and is generally used to remove oils and greases (lubricants) applied to the surface of nonferrous metals during mechanical forming operations. When acids are used to treat the surface of metals, it is referred to as pickling. Surface treatments and their associated rinses usually consist of a single line of successive open surface tanks.*
Tumbling/burnishing	*Tumbling or burnishing is typically performed in rotating barrels or vibrating drums and is used to polish, remove sharp corners, or smooth parts for cosmetic and functional purposes.*
Miscellaneous operations	*Miscellaneous operations include hydrotesting, sawing, and milling. In hydrotesting, parts are submerged in a water bath and subjected to high pressure, air pressure, or ultrasonic signals to check for surface defects or subsurface imperfections. Sawing is done to cut metal products to size or to remove defects, and milling is used to remove surface irregularities and oxides.*

* *Recrystallization: metals and alloys are characterized by a range of recrystallization, defined by temperature, whereby the grain structure of the metal can be refined.*

Sources: Army, 1996; EPA 800B89001; EPA-453/R-92-001; FIA, 2009; Soule, 1984

SECTION 8—COPPER ROLLING, DRAWING, AND EXTRUDING, APPENDIX 2—SUMMARY OF PUBLISHED ARTICLES REPORTING ON ACTIVITIES AND WORK CONDITIONS FOR WORKERS PROCESSING COPPER-BERYLLIUM ALLOYS

Table IV-59—Summary of Recently Published Articles Reporting on Activities and Work Conditions for Workers Processing Copper-Beryllium Alloys

Source	Overview	Worker Activities	Exposure Information	Controls Information
Hasejima et al., 1995 (abstract only)	*CBD diagnosed in a 24-year-old Japanese factory worker exposed to 1.8% Cu-Be alloys.*	*Job task involved drawing out heated Cu-Be wire to make it finer (i.e., reduce the diameter).*	*Information not provided.*	*Information not provided.*
Yoshida et al., 1997	*Beryllium air levels (area samples) and worker sensitization were examined during a 4-year survey (1992–1995) conducted at two Cu-Be manufacturing factories in Japan (designated as A and B).*	*The Factory A work environment was subdivided into a Cu-Be alloy process (A1) and a Cu-Be metal mold manufacturing process (A2).* *The Factory B work environment was subdivided into a Cu-Be cold-rolling, drawing, and heat-treatment process (B1) and a Cu-Be slitting operation (B-2).*	*GM (Range) µg/m^3* *Process A-1:* *0.16 (0.01-0.59) 1992* *0.26 (0.01-0.74) 1993* *0.22 (0.01-1.85) 1994* *0.24 (0.01-1.04) 1995* *Process A-2:* *0.01 (0.01-0.04) 1992* *0.02 (0.01-0.06) 1993* *0.02 (0.01-0.05) 1994* *0.01 (0.01-0.03) 1995* *Process B-1:* *not determined 1992* *0.19 (0.01-0.28) 1993* *0.03 (0.01-0.04) 1994* *0.03 (0.01-0.04) 1995* *Process B-2:* *not determined 1992* *less than 0.01 1993* *not determined 1994* *not determined 1995* *Individual area sample results not provided.*	*No information provided regarding processes A-1, A-2, and B-2.* *Airborne beryllium levels in process B-1 decreased because the LEV system was improved and the workplace was cleaned of deposited particulate materials.*
Balkissoon and Newman, 1999	*Two confirmed cases of CBD at a facility that processes 2% Cu-Be alloy (a metal parts manufacturer producing bellows—springy pressure-control*	*Worker 1 (1980 to 1991): Cut 2% Cu-Be tubes and operated a grinding wheel that generated fine dust. Unloaded annealing furnaces that were associated with strong "fume" exposures. Placed parts in pickling*	*In 1987 all beryllium air samples in these employees' work areas were below 2 µg/m^3 8-hour TWA.* *Beryllium levels of 10 µg/m^3 and 20 µg/m^3 were recorded on two*	*Inadequacies in ventilation (implied; no specifics provided).* *No change of clothing or showering required.*

Table IV-59—Summary of Recently Published Articles Reporting on Activities and Work Conditions for Workers Processing Copper-Beryllium Alloys

Source	Overview	Worker Activities	Exposure Information	Controls Information
	devices).	*tanks containing sulfuric, hydrochloric, or nitric acid. Cu-Be dust accumulated on the worker's hands, face, and clothes routinely. Nearby workers sanded/ground Cu-Be parts.* *Worker 2 (1972 to 1992): Performed wet and dry cutting, trimming, drilling, grinding, punch pressing, deburring, and transportation of 2% Cu-Be alloy. Hand-polished and buffed parts with an abrasive pad. Unloaded annealing furnaces and described "fume" exposures from doing so.*	*occasions in another area of the plant where these workers did not recall spending time.* *Repeat beryllium air sampling in 1988, 1991, and 1993 yielded nondetectable results. However, areas where the two CBD cases worked were not re-sampled in 1991 or 1993.* *Note: Sample type not specified, but appears to be general area sampling. Individual sample results not provided.*	*No respirators used.* *Eating and smoking permitted in the work area.* *High-efficiency dedicated vacuum exhaust systems installed in 1990.*
Tarlo et al., 2001	*Two biological sisters working at the same (Canadian) factory developed CBD from a Cu-Be alloy.*	*Sibling 1:* *Employed for > 8 yrs at a casting factory. Primary responsibilities were brushing and cleaning metal castings. About 5 to 10% of the castings would be a 2% Cu-Be alloy.* *Sibling 2:* *Worked in the same casting factory for 9 years, also cleaning castings.* *Casting cleaners used hand-held grinders or files to finish the surface of molds.*	*Sibling 1 stated that her work environment was very dusty and poorly ventilated.* *Seven years before the onset of CBD symptoms, beryllium air sampling results were within acceptable guidelines (2 μg/m^3 8-hour TWA and 10 μg/m^3 STEL). Repeat air sampling after the diagnosis of sibling 1 indicated elevated PBZ levels of beryllium in the work area of the sisters, up to 17.8 μg/m^3.* *Individual PBZ sample results not provided.*	*Inadequacies in ventilation (implied; no specifics provided).* *Sibling 1 wore a "paper mask" the last two years of her employment.*
Schuler et al. (ATS Abstract), 2002; Schuler et al. (ATS Poster), 2002; Schuler et al., 2005	*Work processes, sensitization, CBD, and beryllium exposures were investigated at a Cu-Be alloy plant.**	*Rod and wire production: point and chamfer (high-speed machining), wire annealing and pickling, wire drawing, wire rolling, straightening, die grinding, and rod and wire packing.* *Strip metal production: strip annealing, strip rolling, slitting, strip*	*For the period 1969 to 2000, the facility collected 650 personal (lapel), 4,524 general area, and 815 short-duration high-volume (SD-HV) breathing zone task samples. Median plantwide values for personal, general area, and SD-HV samples were 0.02 μg/m^3, 0.09 μg/m^3, and 0.44 μg/m^3,*	*No systems in place to prevent migration of beryllium from production areas into support areas.* *Respirator use primarily limited to intermittent tasks where high exposure had been*

Table IV-59—Summary of Recently Published Articles Reporting on Activities and Work Conditions for Workers Processing Copper-Beryllium Alloys

Source	Overview	Worker Activities	Exposure Information	Controls Information
		pickling, inspection, degreasing, shipping and receiving, salt baths, cadmium plating, welding, and deburring. *Production support: maintenance mechanics, quality assurance (metallurgy lab), wastewater treatment.* *Administration: plant and office.*	*respectively. Ninety-nine percent of all personal samples were below 2 µg/m³, and 93% were less than 0.2 µg/m³; 97% of the general area samples were below 0.5 µg/m³; 90% of the SD-HV task samples were less than 5 µg/m³, and 97% were below 25 µg/m³. Wire annealing and pickling had the highest median (0.12 µg/m³) among personal samples and the highest arithmetic mean (2.77 µg/m³) among general area samples. Individual PBZ sample results not provided.*	*found or could potentially occur.* *After the completion of the Schuler et al. investigation, the wire annealing and pickling area was enclosed with walls and placed under negative pressure relative to adjacent areas. Access to the area was restricted, and protective work clothing (over garments), gloves, and powered air-purifying respirators were required for entry.*
Day et al., 2007	*Levels of beryllium in workplace air, on work surfaces, and on employees (hands, neck, and face) were evaluated after the 2002 implementation of an improved particulate-migration control program in a beryllium alloy facility, including dermal protection in production areas.***	*Production, production support, and administration.* *Production included 1) strip production (annealing, inspection, pickling, rolling, slitting, shipping/receiving) and 2) rod and wire processes (die grinding, point and chamfer, rod straightening, wire drawing, wire annealing, pickling).* *Work in production support included maintenance (mechanics), quality assurance (metallurgical laboratory), and waste water treatment. Production support work required frequent entry into production areas.* *Administration limited to front office area (human resources and accounting). Administration work*	*Collected 10 general area samples; 252 wipes from routinely handled work surfaces; 113 thin cotton glove samples worn by employees, and 109 neck wipes and 109 face wipes from the same employees.* *General area sample results: GM beryllium concentration among all general area samples was 0.003 µg/m³ and ranged from 0.0007 µg/m³ (administration) to 0.0238 µg/m³ (wire annealing and pickling).* *Surface wipe sample results: GM beryllium concentration was 0.77 µg/100 cm² and ranged from 0.05 µg/100 cm² in administration to 13.6 µg/100 cm² in wire annealing and pickling.* *Cotton glove samples: GM beryllium mass on cotton glove samples was 13.4 µg and ranged from 0.007*	*Workers protected by comprehensive prevention program improved during 2000 and 2001. Program included improvements to existing ventilation and migration control strategies using isolation, engineering and administrative controls, and PPE, especially in work areas associated with elevated risk of beryllium sensitization. All workers wore single-use, disposable nitrile gloves and company-supplied long-sleeved work clothing; respirators with HEPA filters were worn when inhalation exposures were*

Table IV-59—Summary of Recently Published Articles Reporting on Activities and Work Conditions for Workers Processing Copper-Beryllium Alloys

Source	Overview	Worker Activities	Exposure Information	Controls Information
		rarely required entry into production areas.	*µg for an administration worker to 2,534 µg for a worker in rod straightening.* *Skin wipe samples: GM beryllium mass on neck wipe samples was 0.04 µg and ranged from less than the LOD in administration workers to 0.58 µg for a worker in rod straightening. GM of the face wipe samples was 0.04 µg and ranged from less than the LOD in administration workers to 1.44 µg for a worker in rod straightening.*	*likely to exceed 0.2 µg/m^3 and during designated tasks.* *Within wire annealing and pickling, controls were designed to minimize exposure and migration of contamination to other areas. Engineering controls included isolation from remainder of facility and increased ventilation, and tacky floor mats. Administrative controls included restricting access, minimizing number of employees in area, dedicating tools and equipment to area, and implementing specific protocols for entering/exiting area. Employees in area required to wear hooded PAPR respirators with HEPA filters, coveralls, rubber boots, and inner (nitrile) and outer (cotton, acid resistant or leather) gloves.*
Thomas et al., 2009	*NIOSH investigators assessed a multifaceted program to prevent beryllium sensitization among new employees at a copper-beryllium alloy processing facility (described also by Schuler et al. and Day et al.). As part of this*	*See Day et al. (2007) above.*	*Thomas et al. grouped and analyzed 2,394 full-shift PBZ lapel samples collected by the facility into three time periods—1995 to May 2000, June 2000 to December 2001, and January 2002 to July 2007—to reflect the workplace conditions experienced by employees during the evolution of the enhanced*	*See Day et al. (2007) above.*

Table IV-59—Summary of Recently Published Articles Reporting on Activities and Work Conditions for Workers Processing Copper-Beryllium Alloys

Source	Overview	Worker Activities	Exposure Information	Controls Information
	assessment, NIOSH described the evolution of the preventive program and calculated mean airborne beryllium levels in the facility before and after the preventive program.		*preventive program.* *Descriptive statistics for the airborne beryllium concentrations are summarized in a detailed table by time period (1995 to 2007) and process group.*	

* *Schuler et al. do not explicitly state that the copper-beryllium alloy plant is a Brush Wellman facility; however, Brush Wellman has acknowledged that the study facility is the Brush Wellman Reading, Pennsylvania, plant (Brush Wellman Reading, 2004).*

** *Day et al. (2007) do not explicitly state that the copper-beryllium alloy facility described in their paper is the Brush Wellman Reading, Pennsylvania, facility. Information confirming the identity of the facility as the Brush Wellman Reading facility was obtained from NIOSH beryllium research updates (NIOSH Beryllium Research, 2005; Schuler, 2007).*

CBD: chronic beryllium disease
2% Cu-Be alloy: 98% copper and 2% beryllium
1.8% Cu-Be alloy: 98.2% copper and 1.8% beryllium
GM: geometric mean
HEPA: high efficiency particulate air (filter)
PAPR: powered air-purifying respirator
TWA: time-weighted average
STEL: short-term exposure limit (15-minute TWA)
PBZ: personal breathing zone
PPE: personal protective equipment

SECTION 8—COPPER ROLLING, DRAWING, AND EXTRUDING, APPENDIX 3—DETAILED PERSONAL EXPOSURE PROFILE FOR THE COPPER ROLLING, DRAWING, AND EXTRUDING APPLICATION GROUP

Table IV-60—Personal Exposure Profile for the Copper Rolling, Drawing, and Extruding Application group (NAICS 331421 and 331422)[a,b]

Job Category and Work Group	No. of Samples	Range (μg/m^3)	Mean (μg/m^3)	Median (μg/m^3)
ADMINISTRATIVE	**68**	**0.01 to 0.11**	**0.022**	**0.017**
Engineering technician; expediter	*57*	*0.01 to 0.11*	*0.022*	*0.017*
Office	*11*	*0.01 to 0.062*	*0.021*	*0.013*
PRODUCTION SUPPORT	**52**	**0.01 to 0.33**	**0.04**	**0.022**
Wastewater treatment	*3*	*0.077 to 0.33*	*0.17*	*0.11*
Maintenance (plant and office)	*44*	*0.014 to 0.1*	*0.028*	*0.02*
Quality assurance (metallurgical lab)	*5*	*0.01 to 0.13*	*0.066*	*0.061*
PRODUCTION: Rod and Wire (bulk products)	**210**	**0.01 to 7.8**	**0.25**	**0.055**
Point and chamfer	*49*	*0.01 to 1.58*	*0.073*	*0.028*
Bulk pickling and annealing (same operator)	*78*	*0.02 to 7.8*	*0.57*	*0.12*
Wire drawing (swager pointer and bull blocks)	*30*	*0.014 to 0.38*	*0.076*	*0.058*
Rod and wire packing	*18*	*0.016 to 0.17*	*0.034*	*0.025*
Straightening	*34*	*0.012 to 0.22*	*0.048*	*0.031*
Die grinding	*1*	*0.018 to 0.018*	*0.018*	*0.018*
PRODUCTION: Strip Metal	**320**	**0.006 to 0.72**	**0.041**	**0.017**
Strip annealing	*71*	*0.006 to 0.72*	*0.062*	*0.026*
Strip rolling (Z-mill)	*55*	*0.01 to 0.31*	*0.036*	*0.017*
Strip slitting	*33*	*0.01 to 0.23*	*0.043*	*0.017*
Strip pickling	*73*	*0.011 to 0.28*	*0.048*	*0.033*
Strip inspection	*30*	*0.007 to 0.12*	*0.021*	*0.016*
Shipping and receiving	*58*	*0.011 to 0.12*	*0.019*	*0.017*
TOTAL	**650**	**0.006 to 7.8**	**0.11**	**0.024**

[a] *Full-shift personal breathing zone (PBZ) results are based on the actual sample duration (400 minutes or longer). Nondetectable results are reported at one-half the analytical limit of detection (i.e., 0.05 micrograms beryllium per filter).*

[b] *The exposure profile is a summary of full-shift PBZ total beryllium sample results for workers at the Brush Wellman Inc. Reading, Pennsylvania, alloy rolling and drawing mill from 1977 through 2000. Note that this facility does not conduct extruding.*

Source: Brush Wellman Reading, 2004

Table IV-61—Distribution of Full-Shift PBZ Exposure Results for Total Beryllium in the Copper Rolling, Drawing, and Extruding Application group (NAICS 331421 and 331422)[a,b]

Job Category and Work Group	Number of Results in Range (µg/m³)						Total
	≤ 0.1	> 0.1 to ≤ 0.2	> 0.2 to ≤ 0.5	> 0.5 to ≤ 1.0	> 1.0 to ≤ 2.0	> 2.0	
ADMINISTRATIVE	**67 (98.5%)**	**1 (1.5%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**68 (100%)**
Engineering technician; expediter	*56 (98%)*	*1 (2%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*57 (100%)*
Office	*11 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*11 (100%)*
PRODUCTION SUPPORT	**49 (94%)**	**2 (4%)**	**1 (2%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**52 (100%)**
Wastewater treatment	*1 (33.3%)*	*1 (33.3%)*	*1 (33.3%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*3 (100%)*
Maintenance (plant and office)	*44 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*44 (100%)*
Quality Assurance (metallurgical lab)	*4 (80%)*	*1 (20%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*5 (100%)*
PRODUCTION: Rod and Wire (bulk products)	**147 (70%)**	**28 (13%)**	**22 (11%)**	**4 (2%)**	**4 (2%)**	**5 (2%)**	**210 (100%)**
Point and chamfer	*44 (90%)*	*3 (6%)*	*1 (2%)*	*0 (0%)*	*1 (2%)*	*0 (0%)*	*49 (100%)*
Bulk pickling and annealing (same operator)	*32 (41%)*	*16 (21%)*	*18 (23%)*	*4 (5%)*	*3 (4%)*	*5 (6%)*	*78 (100%)*
Wire drawing (swager pointer and bull blocks)	*25 (83%)*	*3 (10%)*	*2 (7%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*30 (100%)*
Rod and wire packing	*17 (94%)*	*1 (6%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*18 (100%)*
Straightening	*28 (82%)*	*5 (15%)*	*1 (3%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*34 (100%)*
Die grinding	*1 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*1 (100%)*
PRODUCTION: Strip Metal	**297 (93%)**	**15 (4%)**	**6 (2%)**	**2 (1%)**	**0 (0%)**	**0 (0%)**	**320 (100%)**
Strip annealing	*62 (87%)*	*6 (9%)*	*1 (1%)*	*2 (3%)*	*0 (0%)*	*0 (0%)*	*71 (100%)*
Strip rolling (Z-mill)	*51 (93%)*	*3 (5%)*	*1 (2%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*55 (100%)*
Strip slitting	*30 (91%)*	*2 (6%)*	*1 (3%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*33 (100%)*
Strip pickling	*68 (93%)*	*2 (3%)*	*3 (4%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*73 (100%)*
Strip inspection	*29 (97%)*	*1 (3%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*30 (100%)*
Shipping and receiving	*57 (98%)*	*1 (2%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*58 (100%)*
TOTAL	**560 (86%)**	**46 (7%)**	**29 (4%)**	**6 (1%)**	**4 (1%)**	**5 (1%)**	**650 (100%)**

[a] *Full-shift personal breathing zone (PBZ) sample results are based on the actual sample duration (400 minutes or longer). Nondetectable results are reported at one-half the analytical limit of detection (i.e., 0.05 µg beryllium per filter).*

[b] *The distribution represents full-shift PBZ total beryllium sample results for workers at the Brush Wellman Inc. Reading, Pennsylvania, alloy rolling and drawing mill from 1977 through 2000. Note that this facility does not conduct extruding.*

Source: Brush Wellman Reading, 2004

SECTION 9—FABRICATION OF BERYLLIUM ALLOY PRODUCTS

INDUSTRY PROFILE

Beryllium alloys (most typically copper-beryllium less than or equal to 2 percent beryllium) are used to make light-gauge springs, electronic connectors, and other stamped and formed metal products. The subsection on Light-Gauge Spring Manufacturing in this section on Fabrication of Beryllium Alloy Products shows the one NAICS classification associated with light-gauge spring manufacturing and the subsection on Electronic Connectors and Other Stamped and Formed Metal Products shows the three NAICS classifications associated with electronic connectors, and other stamped and formed metal products manufacturing.

Light-Gauge Spring Manufacturing

Beryllium alloy wire is commonly used to produce coil springs for electronic applications in automobile, aerospace, telecommunications, computers, and other sectors. Information from industry contacts and literature discussed below suggest that copper-beryllium is used almost exclusively in the manufacture of light-gauge springs (NAICS 332612) and has little application in the manufacture of heavy-gauge springs (NAICS 332611).

Copper-beryllium alloys are used in the manufacture of most major types of light-gauge springs, including:

- Coil springs:
  - *Compression springs:* Coiled helical springs that resist compressive force applied axially (Acxess Spring, 2006; MW Industries, 2012).
  - *Extension springs:* Springs wound with initial tension that holds the coils together and offers resistance to pulling. These springs have many different styles of hooked or looped ends (Acxess Spring, 2006; MW Industries, 2012).
  - *Torsion springs:* Springs designed to offer resistance to applied torque. When deflected, they will reduce in coil diameter and extend in overall length (Acxess Spring, 2006; MW Industries, 2012).
- Constant force springs: Springs that consist of a rolled strip of metal, usually tightly wrapped on a drum. These springs exert nearly constant restraining force to resist uncoiling (Spring-I-Pedia, 2011; Trakar, 2012).
- Flat springs: In its simplest form, a flat spring is made from a flat sheet, strip, or plate of metal that has been bent so that when pressure is applied to its outside ends, it flexes at the bend. However, flat springs can have more complex designs that include multiple bends as well as cuts and holes. A leaf spring is a type of narrow flat spring bent in an arch (Atlantic Precision Spring, 2012; JobShop.com, 2006, Rapid Sheet Metal, 2011).

According to industry contacts and product literature, the outer diameter of copper-beryllium coil springs ranges from 0.002 inches to 0.8 inches but does not usually exceed 0.125 inches (Witham, 2001; Wood, 2001). Copper-beryllium alloys used in spring manufacturing range from 0.15 to 2.0 percent beryllium by weight (CDA, 1996; CDA, 1998; Brush Wellman MSDS No. A10, 2005; Acxess Spring, 2006).

Copper-beryllium alloys have several characteristics that make them good spring materials, including electrical and thermal conductivity, high strength and hardness, good corrosion and fatigue resistance, and non-magnetic properties (USGS, 2000). These alloys can be used in a wide range of temperatures with little loss of mechanical property (NGK, 2012). Because of the high mechanical strength of copper-beryllium alloys, their use allows the production of smaller and lighter springs with the same spring pressure when compared with other materials, such as phosphor bronze (NGK, 2012).

Copper-beryllium springs are used primarily in electronic components and equipment but are also used as electrical conductors in high-temperature environments, where magnetic fields present a problem, where corrosion resistance is needed, and in applications where springs are exposed to sub-zero temperatures (Acxess Spring, 2006; Silberstein, 2007).

Number of Establishments and Employees

The 2010 County Business Patterns data show 323 establishments with 10,329 total employees for the light spring manufacturing industry (see Table IV-62). Of these establishments, most (93.3 percent) employ fewer than 100 employees. According to industry contacts and a review of spring manufacturer websites, most spring manufacturers potentially use copper-beryllium alloys, though copper-beryllium springs typically account for only a small percentage of their overall business. All coil spring manufacturers contacted indicated that they use copper-beryllium (Bollinger, 2001; Briere, 2001; Germain, 2001; Leahy, 2001; Victorian, 2001; Witham, 2001). However, three of the manufacturers indicated that copper-beryllium springs accounted for 3 percent or less of their business, and a fourth indicated that copper-beryllium springs accounted for a very small percentage (Bollinger, 2001; Germain, 2001; Leahy, 2001; Witham, 2001). The remaining two contacts did not supply this information.

Table IV-62—Spring Manufacturing (2010)

NAICS Industry	Affected Establishments	Affected Employees
332612, Light Gauge Spring Manufacturing	*323*	*10,329*
Sources: U.S. Census Bureau, 2010; OSHA Office of Regulatory Analysis		

A representative of the Spring Manufacturers Institute (SMI) also indicated that copper-beryllium springs account for only a small part of the overall coil spring market. However, any spring manufacturer could produce them because no special equipment is required. According to the SMI representative, the spring business is based almost entirely on custom orders, with manufacturers producing springs to customer specifications (Wood, 2001). Therefore, virtually any spring manufacturer could receive an order for copper-beryllium springs. Based on information from manufacturers, the SMI, and spring manufacturer websites, OSHA estimates that all light-gauge spring manufacturers are manufacturing copper-beryllium springs, at least on an occasional basis.

Overview of Spring Manufacturing Technology

The processes used in manufacturing springs depend on the type of spring being produced. The process for steel alloy coiled springs is described below and includes coiling, hardening or heat treating, and finishing (Madehow.com, 2009). The process for copper-beryllium springs is similar. One spring manufacturer reports that after copper-beryllium springs are manufactured, they are heat treated to reduce distortion, re-inspected to ensure dimensional accuracy, and then finished by plating (Atlantic Precision Spring, 2012).

Coiling: Coil springs are manufactured by winding wire around a rod called an arbor or mandrel (Silberstein, 2007). Alternatively, the wire may be coiled without a mandrel using production machinery, such as a central navigation computer machine (Madehow.com, 2009). Automatic coiling machinery is typically used to manufacture large batch quantities of springs. For smaller quantities, springs can be produced manually using semi-automatic equipment, such as a lathe (an arbor is secured in the chuck of the lathe and the spring wire is coiled around the arbor). Copper-beryllium and other types of wire used in spring manufacturing are purchased from suppliers. Refer to Preliminary Economic Analysis, Section 8—Rolling, Drawing, and Extruding, for information on the firms that produce copper alloy wires.

Cold coiling of wire up to 0.75 inches in diameter consists of winding wire at room temperature around an arbor or mandrel. Winding is done on a dedicated, automatic spring-winding machine; a lathe; an electric hand drill with the mandrel secured in the chuck; a hand-cranked winding machine; or a computer numerically controlled machine (Madehow.com, 2009).

Hot coiling is done when thicker wire or bar stock is used for springs. The steel is heated to make it flexible and then wound around a mandrel while red hot. Standard industrial coiling machines are used for bar stock up to 3 inches in diameter. After coiling, the steel is removed from the coiling machine and immersed into oil to cool and harden it.

Hardening (heat treating): Coiling creates stress that must be relieved for the steel to maintain its resilience (Madehow.com, 2009). To relieve this stress, the spring must be tempered after coiling by heat treating it in an oven at the appropriate temperature for a predetermined time and then allowing it to cool slowly. Heat treating is required for all steel springs regardless of whether the steel has been coiled hot or cold.

An SMI representative stated that coil spring manufacturing typically does not require any machining, grinding, heat treating, or annealing; just cold forming (Wood, 2001). The available information suggests, however, that the manufacture of some coil springs can involve both heat treating and grinding. For example, steel alloy coiled springs may be coiled at room temperature (cold winding) or by heating the metal to make it flexible (hot winding). Whether the steel has been coiled hot or cold, the process creates stress within the material that must be relieved by heat treating (Madehow.com, 2009). For example, the guidelines for stress relief of copper-beryllium springs call for heating the springs at 600°F for 90 minutes.[271] Heat can cause compression springs to shorten; compression springs for high-temperature applications are heat-set so that shortening will not occur while the spring is in use (Silberstein, 2007). One-third of

[271] This temperature is associated with age-hardening heat treatment (< 950°F), which typically presents a low beryllium inhalation hazard (Brush Wellman Safety Fact 105, 2008).

the spring manufacturers contacted for this study reported heat treating copper-beryllium springs (Briere, 2001; Germain, 2001).

Finishing: Finishing steps include grinding (if specified by design), shot peening, setting, coating (electroplating or mechanical coating), and packaging. Shot peening (hammering the entire surface of the spring with tiny steel balls) strengthens the steel to resist metal fatigue and cracking during its lifetime of repeated flexings. Setting (fully compressing the spring so all the coils touch each other) permanently fixes the desired length and pitch of the spring. Coatings protect the surface of the spring from corrosion and include painting, dipping the spring in liquid rubber, electroplating with another metal such as chromium or zinc, and mechanical plating (tumbling with metallic powder, water, accelerant chemicals, and tiny glass beads that pound the powder onto the spring surface). When carbon steel springs are electroplated, they must be baked for several hours (at 325°F to 375°F) soon after plating to counteract embrittlement, which results from the plating process. Completed springs are individually bagged, enclosed in tubes, affixed to sticky paper, strung onto wires, or bulk-packaged in plastic bags or boxes (Madehow.com, 2009).

Grinding of copper-beryllium springs also occurs but, according to manufacturers' representatives, is limited. Only one of the six spring manufacturers contacted for this study reported grinding copper-beryllium springs, and this manufacturer indicated that his facility only performs grinding on about 10 percent of the copper-beryllium springs produced (Bollinger, 2001). A coil spring manufacturing manual indicates that grinding can occur during the manufacture of compression springs. For some applications, each end of the spring has to be ground square with respect to the body of the spring (Silberstein, 2007). If the design calls for flat ends, the ends are ground during the finishing steps. For coiled springs, the spring is mounted in a jig and held against a rotating abrasive wheel. Alternatively, if highly automated equipment is used, the spring is held in a sleeve while both ends are ground simultaneously. Grinding may be performed with water or an oil-based substance to cool the spring, carry away particles, and lubricate the grinding wheel (Madehow.com, 2009).

A review of the websites of several manufacturers of copper-beryllium springs indicates that some manufacturers perform grinding (and other machining) and heat treating in-house (MW Industries, 2012). Others perform machining-related activities in-house and utilize a network of approved vendors for surface modification and physical property alteration such as plating and heat treating (Atlantic Precision Spring, 2012; Dudek and Bock, 2012).

For all springs, the waste wire at the ends of the springs must be cut away. When highly automated spring manufacturing machines are used, the machine does the cutting. For small-scale production operations (fewer than 50 springs), springs may be cut with wire cutters, a cutoff wheel, or an acetylene torch (Silberstein, 2007).

Electronic Connectors and Other Stamped and Formed Metal Products

Beryllium alloys (typically copper-beryllium alloy) are stamped and formed to make a variety of parts, especially for electronic applications. These applications include connectors, terminals, switches, spring contacts, and electromagnetic interference (EMI) shielding gaskets (Battey, 2002; Page, 2002; Tech-Etch, 2006). Stamped alloy is also used to make a wide range of clips and card guides used to secure parts in electronic assemblies. Copper-beryllium clips are used to secure components, such as resisters, capacitors, fuses, relays, transistors, and other small cylindrical parts in electronic assemblies (Atlee Clips, 2012). Copper-beryllium card guides are used to hold printed circuit boards in place (Atlee Card Guides, 2012). Manufacturers also stamp copper-beryllium to produce parts for mechanical applications, including spring washers and retaining rings (Small Parts, 2006; Rotor Clip, 2008).

Electronic connectors are devices for mating and de-mating electrical power connections or communications media (NTIA, 1996). Copper-beryllium alloys are used in the manufacture of a variety of electronic connector components, including flat and leaf springs, pins, jacks, and bus bars. These components find use in computers, telecommunication equipment, audio and video components, medical monitors, and a range of other electronic equipment.

Number of Establishments and Employees

Establishments producing connectors or other stamped and formed metal products are classified in three NAICS industries. Facilities specializing in the production of electronic connectors and components are classified in NAICS 334417, Electronic Connector Manufacturing. Other establishments in the NAICS classification NAICS 332116, Metal Stamping, might produce stamped and formed products for use in the connector and electronics industries. Manufacturers producing electrical or electronic-related automotive parts might also directly use copper-beryllium alloys in the production of electronic equipment. These producers are included in the NAICS classification 336322, Other Motor Vehicle Electrical and Electronic Equipment Manufacturing.

Manufacturers of Stamped Products (NAICS 332116) Using Beryllium Alloys: Facilities in this industry produce stamped products for a range of applications, using a variety of metals. Based on information from industry representatives, copper-beryllium is used, at least occasionally, by most stampers that supply the electronics industry (Page, 2002; Tschool, 2002). Many such stampers produce parts to order and will use copper-beryllium alloys if called for in the customer's specifications (Battey, 2002; Becker, 2002; Tschool, 2002).

Copper-beryllium alloy stampings are believed to account for only a small percentage of the industry's total output, however. Though two stampers contacted said that copper-beryllium alloy stampings account for a substantial portion of their business (Laird, 2001; Yarborough, 2002), most industry sources stated that the alloy represented only a small percent of their overall output (Battey, 2002; Becker, 2002; Tschool, 2002; Volkert, 2001). One source estimated that no more than 5 percent of stamped parts intended for the electronics market are made of copper-beryllium alloys (Page, 2002).

Based on data from the 2007 Economic Census Product Summary, it is possible to identify the subset of companies that are likely to be stamping copper-beryllium parts for the electronics industry. These are the four product codes that OSHA has preliminarily determined comprise all copper-beryllium electronics applications in this NAICS industry code: NAICS 332116-1352: Radio and Phonographs; NAICS 332116-1354: Televisions; NAICS 332116-1421: Computers; and NAICS 332116-1441: Office Machines.

The 2007 Economic Census reports a total of 97 companies in these product classes. More recent information from the U.S. Census Bureau is not available to determine the number of affected establishments and employees. In order to estimate the number of affected establishments and employees, OSHA used historical information from the U.S Census Bureau. OSHA's arrival at an estimate of affected establishments is discussed below.

The 2002 Economic Census reports a total of 1,698 companies with 1,787 establishments in this NAICS code (with only a portion that manufacture products for the electronics industry). These numbers yield and average of 1.05 establishments per company. Thus, OSHA estimated a total number of establishments that manufacture products for the electronics industry by multiplying the 2007 Census number of companies likely to be producing stamped products for the electronics industry (97) by the 2002 Census total ratio of establishments per company in this NAICS code (1.05). This yields an estimate of 102 establishments. In order to obtain an estimate that reflect more recent data, OSHA multiplied this estimate by a ratio of 2010 Census total number of establishments to 2007 Census total number of establishments (102 * (1484/1528)). This results in a 2010 estimate of 99 establishments. Based on information from industry representatives, OSHA estimates that approximately 75 percent of these 99 stampers that produce parts for the electronics industry work with copper-beryllium alloys. OSHA's current estimate of affected establishments is 74 establishments.

OSHA has assumed that the number of employees per establishment in affected establishments is the same as that for all establishments in the NAICS group. Table IV-63 summarizes the number of affected establishments and employees in NAICS industry 332116.

Electronic Connector Manufacturers (NAICS 334417) Using Beryllium Alloys: According to the 2010 County Business Patterns, electronic connector industries (NAICS 334417) comprise 231 establishments. No data exist regarding the number of electronic connector manufacturers that use copper-beryllium alloys, nor could any of the industry sources contacted provide an estimate of the share of connector manufacturers that use such alloys. Because of copper-beryllium's cost, however, most sources believe that the number of copper-beryllium users is limited. This assumption is supported by an overall review of information on connector manufacturers in Thomas Register and on the Web (Thomas Register, 2002; Thomas Net, 2006). Based on these sources, OSHA estimates that 20 percent or fewer of electronic connector manufacturers likely use copper-beryllium alloys. Applying this percentage to the 231 establishments, OSHA estimates that 46 establishments (0.2 x 231) in this industry use copper-beryllium alloys. OSHA has assumed that the number of employees per establishment in affected establishments is the same as that for all establishments in the NAICS group. Table IV-63 summarizes the number of affected establishments and employees in NAICS industry 334417.

Automotive Parts Manufacturers (NAICS 336322) Using Copper-Beryllium Alloys: According to the 2010 County Business Patterns, 636 establishments produce automotive electrical and electronic equipment (NAICS 336322). Data describing the number of automotive parts manufacturers using copper-beryllium alloys are not available. Based on an earlier analysis of data from the 2002 Economic Census and the Brush Wellman customer database, OSHA estimated that about 25 percent of automotive parts manufacturers perform copper-beryllium alloy stamping, primarily for electronic applications (Kolanz, 2001). Applying this percentage to the establishment figures from the 2010 County Business Patterns, the Agency estimates that 159 establishments (636 x .25) in this industry use beryllium alloys. OSHA has assumed that the number of employees per establishment in affected establishments is the same as that for all establishments in the NAICS group. Table IV-63 summarizes the number of affected establishments and employees in NAICS industry 336322.

Table IV-63—Electronic Connector Manufacturing and Metal Stamping (2010)

NAICS Industry	Affected Establishments	Affected Employees
332116, Metal Stamping	*74*	*2,436*
334417, Electronic Connector Manufacturing	*46*	*3,908*
336322, Other Motor Vehicle Electronic and Electronic Equipment	*159*	*9,619*
Source: U.S. Census Bureau, 2002 ; U.S. Census Bureau 2010 ; OSHA Office of Regulatory Analysis		

Overview of Stamping Process Technology

Large and medium-size stamping operations are primarily automated and enclosed. Smaller shops still use manually operated presses, however, and larger shops may maintain manually operated equipment for smaller jobs. Stamping is often performed under a light flood coolant (Page, 2002). Copper-beryllium scrap resulting from stamping is generally returned to the supplier (Yarborough, 2002). According to industry representatives, limited grinding or other machining is performed on parts after stamping (Battey, 2002; Downing, 2002; Gabriel, 2002; Kramer, 2002; Laird, 2001; Mil-Max, 2001; Omastiak, 2002; Page, 2002; Trico, 2001; Yarborough, 2002). After stamping, parts may be degreased and, in some cases, heat treated (Yarborough, 2002). Stamped copper-beryllium parts are usually plated. Connectors typically receive a full plating of nickel and a selective plating of tin or gold (Downing, 2002). Several stampers reported that they send parts to an outside contractor for plating (Battey, 2002; Yarborough, 2002).

Stamping facilities are described as large, open spaces with very high ceilings and machinery spaced throughout. Work with copper-beryllium alloy may be performed on different automated stamping machines throughout the plant floor (OSHA-H005C-2006-0870-0345).

Connector manufacturers may either stamp copper-beryllium components in-house or purchase these components from a stamper. Industry representatives report that virtually no grinding or other machining of copper-beryllium occurs during connector manufacture. Connector assembly is reported to be largely automated. For example, Meiyu Automation Corporation manufactures automated systems that assemble and package connectors (Downing, 2002). Soldering of copper-beryllium components can occur during connector assembly, though one source reports the use of conductive adhesives instead (Richter, 2002).[272]

[272] Electrically conductive adhesives (ECAs) are an alternative for lead-based solder materials; however, limited impact resistance and long-term electrical and mechanical reliability issues prevent ECAs from becoming a general replacement for solders in electronic applications (Xu, 2002).

Affected Job Categories

The primary job categories with potential for beryllium exposure in the beryllium alloy products fabrication application group are summarized in Table IV-64. Other production jobs in this application group were found to have very low exposures (i.e., below an alternative PEL of 0.1 μg/m^3). The primary job categories with potential for beryllium exposure include machine operators, tool makers, welding operators, heat-treating operators, inspectors, and packers/shippers.

Table IV-64—Job Categories and Major Activities of Workers Potentially Exposed to Beryllium in the Fabrication Industry

Job Category	Major Activities
Chemical Processing Operators	*Operate and maintain one or more chemical cleaning and processing operations, such as pickling/cleaning, etching, and plating. Also includes wastewater treatment operators.*
Deburring Operators	*Set up and operate deburring, shot peening, or other mechanical/abrasive tumbling/grinding/finishing equipment used to clean (i.e., remove residue and imperfections) and increase the product life of fabricated parts.*
Assembly Operators	*Mechanically assemble finished product components when required, including operation of automated assembly lines. Assembly operations may include riveting, hardware insertion, tapping, threading, brazing, soldering, welding, and other operations.*

EXPOSURE PROFILE

To estimate the exposure profile for workers fabricating beryllium alloy products (i.e., springs, stampings, and connectors), OSHA used exposure information on stamping from five sources: a Brush Wellman case study conducted at four precision stamping companies; a National Institute for Occupational Safety and Health (NIOSH) report on a Michigan spring and stamping company; an Eastern Research Group (ERG) site visit to a precision stamping, forming, and plating establishment; and two presentations, one by Corbett and one by Miller, from the 2007 American Industrial Hygiene Conference and Exposition on follow-up exposure monitoring at one of the stamping facilities in the Brush Wellman case study (Brush Wellman Stamping, 2004; Corbett, 2007; ERG Beryllium Site 6, 2003; Miller, 2007; NIOSH EPHB 263-12a, 2004). These data are discussed in the subsection on Data Sources for this Fabrication of Beryllium Alloy Products section and represent the best available information for characterizing beryllium exposure in this application group. No data are available for spring manufacturing.

OSHA also reviewed unpublished exposure data from OSHA's Integrated Management Information System (IMIS) for beryllium. As noted in earlier sections of this report, IMIS data can be difficult to interpret because the database is not designed to capture information pertaining to worker activities, workplace conditions, engineering controls, personal protective equipment (PPE), and sampling limit of detection (LOD) values[273] (for nondetectable samples). Additionally, information on sampling durations was not available, and when evaluating job descriptions with potential beryllium exposure, it generally was not possible to determine whether beryllium was included in the sample analysis request because of potential workplace exposure to beryllium or because it was part of a routine metal screening. For these reasons, IMIS information was used as ancillary data in developing the exposure profile for beryllium alloy fabricators.

Data Sources

Brush Wellman—Precision Stamping Case Study

The Brush Wellman data are part of a case study that was conducted in 2000 at four precision stamping companies that use copper-beryllium alloy (2 percent beryllium). Exposure results for this study are summarized in the OSHA beryllium docket as Attachment 2.6–Stamping Facilities Processing Copper Beryllium (OSHA-H005C-2006-0870-0096). OSHA received the individual exposure results for this study from Brush Wellman and supplemented these data with information provided by industry consultants (Brush Wellman Stamping, 2004; Corbett, 2007; Miller, 2007). The individual total beryllium exposure results include 183 full-shift personal breathing zone (PBZ) samples collected on workers engaged in various fabrication jobs, including press operation, tool making and repair, chemical processing (e.g., parts washing, bright cleaning, photoetching, racking, plating, wastewater treatment), deburring, heat treating, welding, mechanical assembly, inspection, and packaging and shipping. Samples were analyzed by NIOSH Methods 7102 (Beryllium and Compounds, as Be) or 7300 (Elements by ICP). The limit of quantitation ranged from 0.02 to 0.005 micrograms (µg) per sample, depending on the laboratory that performed the analysis. Seventy-four percent of the results (136 samples of a total of 183 samples) were nondetectable for beryllium, with sampling LOD concentrations ranging from 0.004 µg/m^3 to 0.02 µg/m^3. A majority (35 of 47) of the positive results were obtained at one facility (Site 4) (Brush Wellman Stamping, 2004).

Fifty-two PBZ samples were obtained at Site 1, including 10 samples (19 percent) that were positive for beryllium (Brush Wellman Stamping, 2004). Results at Site 1 ranged from 0.0049 µg/m^3 to 0.024 µg/m^3. At Site 2, 43 PBZ samples were collected on fabrication workers and all the samples were nondetectable. Sampling LOD concentrations ranged from 0.005 µg/m^3 to 0.019 µg/m^3. Two of the 33 samples from Site 3 were positive for beryllium, with results of 0.0068 µg/m^3 and 0.014 µg/m^3. At Site 4, 55 PBZ samples were obtained. Thirty-five of these were positive for beryllium, with results ranging from 0.0058 µg/m^3 to 0.42 µg/m^3. Chemical handling and housekeeping practices were in need of significant improvement at this facility.

Although a survey report was not available for the Brush Wellman case study (Brush Wellman Stamping, 2004), OSHA obtained the following information on the stamping facilities through discussions with a beryllium industry consultant involved with the case study (Corbett, 2004):

[273] This refers to the set of variables necessary to determine exposure concentrations that are not reported (e.g., sampling flow rates and volume, and mass). These variables can be used to derive exposure concentrations (mass per volume units).

- Site 1 has state-of-the-art processes. Operations at Sites 1 and 4 include stamping, heat treating, and plating. No plating is conducted at Sites 2 and 3. At Site 1, copper, nickel, and gold plating is conducted with an automatic mass plating system.
- None of the facilities has beryllium intentional controls (i.e., there are no special work practices, engineering controls, or PPE specifically for beryllium). Investigators observed the use of compressed air for cleaning at all of these facilities, and advised against it.
- Assembly operations can vary by plant and may include soldering and welding. At Site 1, the parts are tiny (⅛ inch to ¼ inch) and assembly is automated. At Site 4, the parts are 25 to 500 feet long and assembly includes a coil-winding operation. A small metal roller guide is used to apply tension to the strip parts during coil winding. Investigators noted a visible metallic deposition on the equipment work surface and recommended that the metal roller guide be replaced with a nylon tension roller.
- Site 4 is the only facility with detectable beryllium levels in the plating area. Investigators observed the use of local exhaust ventilation (LEV) to control corrosive misting at pickling/cleaning, plating, and photoetching tanks and reported that containment, chemical handling, and housekeeping practices were poor and in need of improvement (Corbett, 2004 and 2007). Substantial quantities of crystalline materials (chemical residue) were observed on the floor and equipment due to spills and drag-out. Investigators recommended the following: 1) a thorough wall-to-wall cleaning; 2) a ventilation survey to determine the effectiveness of the exhaust ventilation and the need for modifications/enhancements; 3) no use of compressed air for cleaning; and 4) a re-evaluation of airborne beryllium levels after the first three recommendations have been completed.

Corbett Presentation—Follow-up Exposure Assessment at Site 4 of the Brush Wellman Case Study

The Corbett presentation reported on follow-up exposure data obtained in 2006 and 2007 during plating and associated support operations at one of the facilities included in Brush Wellman's case study of four precision stamping companies (Site 4) (Corbett, 2007). After the baseline exposure assessment in 2000, Site 4 made significant improvements in work practices and housekeeping. Follow-up PBZ samples were obtained in 2006 for pickling/cleaning (nine samples), photoetching (18 samples), plating (21 samples, tank and selective plating), racking (12 samples), deburring (five samples), and wastewater treatment operations (18 samples). Individual sample results were not provided.[274] The 2006 results indicated that the existing LEV with improved work practices and housekeeping were not sufficient to control beryllium exposures below the California OSHA (Cal/OSHA) permissible exposure limit (PEL) of 0.2 $\mu g/m^3$ for pickling/cleaning, photoetching, selective plating, and deburring. Tank plating, racking, and wastewater treatment were determined to be controlled, with nearly all sample results less than 0.10 $\mu g/m^3$. An engineering control evaluation and follow-up sampling were

[274] The 2006 sampling results were summarized in a bar chart. The "approximate" results (based on a visual evaluation of the bar chart) for the work groups considered to be uncontrolled are as follows: pickling/cleaning, 0.04 $\mu g/m^3$ to 0.39 $\mu g/m^3$; photoetching, 0.01 $\mu g/m^3$ to 0.28 $\mu g/m^3$; deburring, 0.005 $\mu g/m^3$ to 0.50 $\mu g/m^3$; and selective plating, 0.08 $\mu g/m^3$ to 0.5 $\mu g/m^3$.

conducted in 2007. A series of LEV improvements were made, including the addition of enclosures and improved ductwork and hood designs, and system maintenance.[275] PBZ results in 2007 showed that pickling/cleaning, photoetching, and selective plating were controlled, with all sampling results below 0.1 µg/m^3. Two deburring PBZ results of 0.29 µg/m^3 and 0.41 µg/m^3 exceeded the Cal/OSHA PEL and were attributed to corn cob deburring (i.e., polishing with dried, granulated corn cob finishing media). Corbett reported that corn cob deburring needed LEV during the six-hour cycle time and subsequent screening activities.

All of the follow-up samples were analyzed using NIOSH Method 7300 by a laboratory accredited by the American Industrial Hygiene Association (AIHA). The analytical reporting limit was not reported; however, Method 7300 lists the estimated analytical LOD as 0.005 µg per filter. Individual results were provided for the 2007 deburring samples only and ranged from 0.02 µg/m^3 to 0.41 µg/m^3.

Miller Presentation—Mechanical and Material Handling at the Four Plants in the Brush Wellman Case Study

The Miller presentation described the Brush Wellman case study of four precision stamping companies (Miller, 2007). Miller provided photographs of some of the manufacturing equipment and products at the stamping facilities and summarized the exposure results for press operators, tool makers, assembly operators, inspectors, and shipping technicians. As noted, these data were provided to OSHA by Brush Wellman and are incorporated into Attachment 2.6−Stamping Facilities Processing Copper Beryllium in the OSHA Beryllium Docket (OSHA-H005C-2006-0870-0096).

NIOSH—Strip Stamping Operation (Michigan Spring and Stamping)

The NIOSH data are from an August 21–22, 2003, study conducted at Michigan Spring and Stamping in Muskegon, Michigan (NIOSH EPHB 263-12a, 2004). NIOSH researchers collected two PBZ and 10 general area air samples for a copper-beryllium alloy (2 percent beryllium) strip stamping operation. The air samples were analyzed in accordance with NIOSH Method 7300 (Elements by ICP) modified for hot-block digestion. The analytical LOD and limits of quantitation were reported to be 0.004 µg and 0.01 µg of beryllium per sample, respectively.

The PBZ samples included one full-shift sample (450 minutes) with results of 0.021 µg/m^3 and one partial-shift (231 minutes) sample with results of 0.006 µg/m^3. OSHA used only the full-shift result in the exposure profile for this industry sector. The general area samples were collected in a variety of locations on and around the stamping machine with results ranging from 0.003 µg/m^{3}to 0.058 µg/m^3.

A Finzer–U.S. Baird stamping machine was used to stamp clips for a headlight assembly. Coiled 0.0150-inch thick by 0.3125-inch wide copper-beryllium strips were fed from a spool into the stamping machine at a rate of 10 feet per minute. The stamping machine cut, perforated, folded, and ejected each finished clip into a cardboard box using compressed air. A rag suspended by the machine operator across the inside of the collection box was used to catch small chips; process scrap dropped down a chute to another collection box on the floor. The finished clips

[275] System maintenance and filter change increased the flow rate by 30 percent from 633 cubic feet per minute (cfm) to 830 cfm (Corbett, 2007). No other details are provided.

were dumped into metal trays. When three trays were full, the machine operator transported the clips to a heat-treating oven where they were heated at 600°F for one hour. After the clips cooled, they were dumped into boxes, weighed, packaged, and shipped. The weighing operation was adjacent to the stamping machine.

At the time of the NIOSH survey, the headlight assembly clips were the only beryllium-containing part produced at Michigan Spring and Stamping, and only one stamping machine was used to produce these parts. No engineering controls were used with this process. During cold weather, tempered air is supplied to the area through a cloth duct suspended from the ceiling. In the summer months, the facility doors and windows are opened. Pedestal fans were observed in the production area, but the fan nearest the stamping machine was not operating during the NIOSH survey.

The machine operator is responsible for four other machine tools and spends only a portion of the workday at the stamping machine. The operator also has a desk in the production area where he completes administrative work.

ERG Beryllium Site 6—Copper-Beryllium Stamping, Forming, and Plating Facility

The ERG data are from an August 26–28, 2003, visit to a copper-beryllium stamping, forming, and plating facility (ERG Beryllium Site 6, 2003). ERG investigators collected five full-shift PBZ samples for beryllium, all with nondetectable results and sampling LOD concentrations ranging from 0.021 μg/m^3 to 0.024 μg/m^3. The air samples were analyzed by OSHA Method ID-125G (Metal and Metalloid Particulates in Workplace Atmospheres) using inductively coupled argon plasma-atomic emission spectroscopy (ICAP-AES); the laboratory analytical LOD was 0.02 μg per sample.

ERG Beryllium Site 6 operates one nine-hour shift per day, four and one-half days per week. The workforce at the site consists of 22 employees, of whom 20 are regarded by the facility as beryllium exposed. Exact production figures on the number of parts produced are not available because the work is piecework and changes continually; however, the company estimated that it was operating at 60 percent of maximum capacity at the time of the visit. Copper-beryllium parts are not produced on a daily basis for any given machine and might only be produced for a portion of a work shift (ERG Beryllium Site 6, 2003).

Raw materials are typically received as strips or plates of copper-beryllium and stored on site until needed. Machine operators retrieve the appropriate raw material from storage and load it into the stamping machines. The operations most commonly associated with stamping are performed with dedicated tooling known as hard tooling and include blanking, drawing, forming, and piercing. Hard tooling is used to make high-volume parts of a specific configuration. During production, a die is selected and, depending on the pattern required, may be placed into either the stamping machine or the forming machine, or both. The stamping machine is used to cut out patterns, whereas the forming machine is used to make bends and depressions in the stamped parts. Workers manually control the process and place the parts into containers as they are produced. These parts may then be heat-treated, cleaned, dried, and plated. Other steps that may be performed include assembly and quality control. Finished parts are packaged and shipped to customers. Maintenance of machine tools and dies is also performed on site, but these activities were not observed during the site survey (ERG Beryllium Site 6, 2003).

ERG investigators reported three operations at the site with potential beryllium exposure, including stamping, forming/assembly, and plating. During the site visit, the stamping operator was observed making 5-centimeter (cm) diameter spring rings at a rate of 80 per minute. The operator loaded a coil of copper-beryllium strip (1 millimeter thick and 5 cm wide) into the stamping machine and manually activated the stamp with a foot pedal. As the strip of copper-beryllium was fed into the machine a cutting die was pneumatically activated, causing the die to cut the material. Stamped parts dropped into a basket underneath the die and were subsequently dumped into a larger container as the basket filled up. About every 15 minutes the operator reached into the container with his hand and stirred the parts to keep the material level. During the site visit, only one worker was observed stamping parts, and he remained at the machine for the entire operation. Copper-beryllium parts were stamped for about two hours, and brass parts were stamped for the remainder of the work shift. No engineering controls (e.g., LEV) were associated with the stamping machine (ERG Beryllium Site 6, 2003).

Approximately five employees work as forming/assembly operators at ERG Beryllium Site 6. Parts for forming may be stamped on site from a coil of strip material or obtained from other sources. Forming/assembly operators obtain the appropriate parts, remove the parts individually from a container and place them into a die fixture, manually activate the press with a foot pedal, remove the parts from the die, check the clearance with a thumbnail, and place the formed parts into a cardboard box. ERG investigators generally observed careful and deliberate work practices and noted frequent hand washing by one worker. The forming/assembly operation is adjacent to the tooling operation, and compressed air was used for cleaning equipment, parts, and work surfaces (ERG Beryllium Site 6, 2003).

Electroplating takes place in a separate building from stamping and forming (see Figure IV-3). Beryllium exposure during the chemical processing, including electroplating, of small copper-beryllium parts is associated with 1) beryllium-containing aerosols that may be released from corrosive chemical solutions during processing and 2) beryllium-containing residue (from chemical solutions that have splashed outside process containers) that has dried and subsequently become airborne (Materion SF 104, 2011).

During the site survey, two employees were observed working in the plating area. Copper-beryllium parts produced in the stamping and forming operations are placed in a basket and lowered into a cadmium or nickel plating solution. When plating is complete, the basket is removed and placed in a spin dryer where the parts are rinsed and spun dry. The parts are removed from the basket, inspected, packaged, and then transferred to the stamping building for subsequent boxing and shipping. A complete cycle takes less than 30 minutes. The plating operator prepares the chemical plating solutions and was observed wearing nitrile gloves, protective outer garments, and work boots. Workers remained in the plating area for the majority of the work shift, except for the brief amount of time it took to move materials back and forth between buildings.

During the site visit, ERG investigators noted the following regarding baseline conditions (Corbett, 2004; ERG Beryllium Site 6, 2003):

- Production workers enter the facility at the start of the shift through a side entrance. Office workers enter through a front entrance that is also open to the public. No special precautions are used to enter production areas from the offices and vice versa (e.g., production workers entering the offices are not required to wear shoe covers while in the area).

- Respiratory protection is not worn in the plant and gloves are not required. Some workers (e.g., the plating workers) were observed using gloves during certain operations, but gloves generally are not worn in the plant. Plating operators wear protective outer garments to protect against chemical splashes. Workers do not shower or change clothes at the end of the shift on company premises.

- LEV is used at the metal plating tanks and by the machinists that maintain the tools and dies. The plating tanks are exhausted by slot-type hoods located at the rear of the tanks. The machinists have moveable LEV ducts at their workstations and are responsible for properly positioning them during tool and die maintenance.

With one notable exception, the facility's general appearance is that of a clean and well cared for operation. There was no apparent dust accumulation on work surfaces and no visible mist in the air from machining fluids. There was, however, room for improvement as small metallic chips were visible on the floor and some dry sweeping was observed during the survey. As the notable exception, plating area housekeeping was poor and in need of improvement; chemical residue was detected on the floor, process equipment, and supplies.

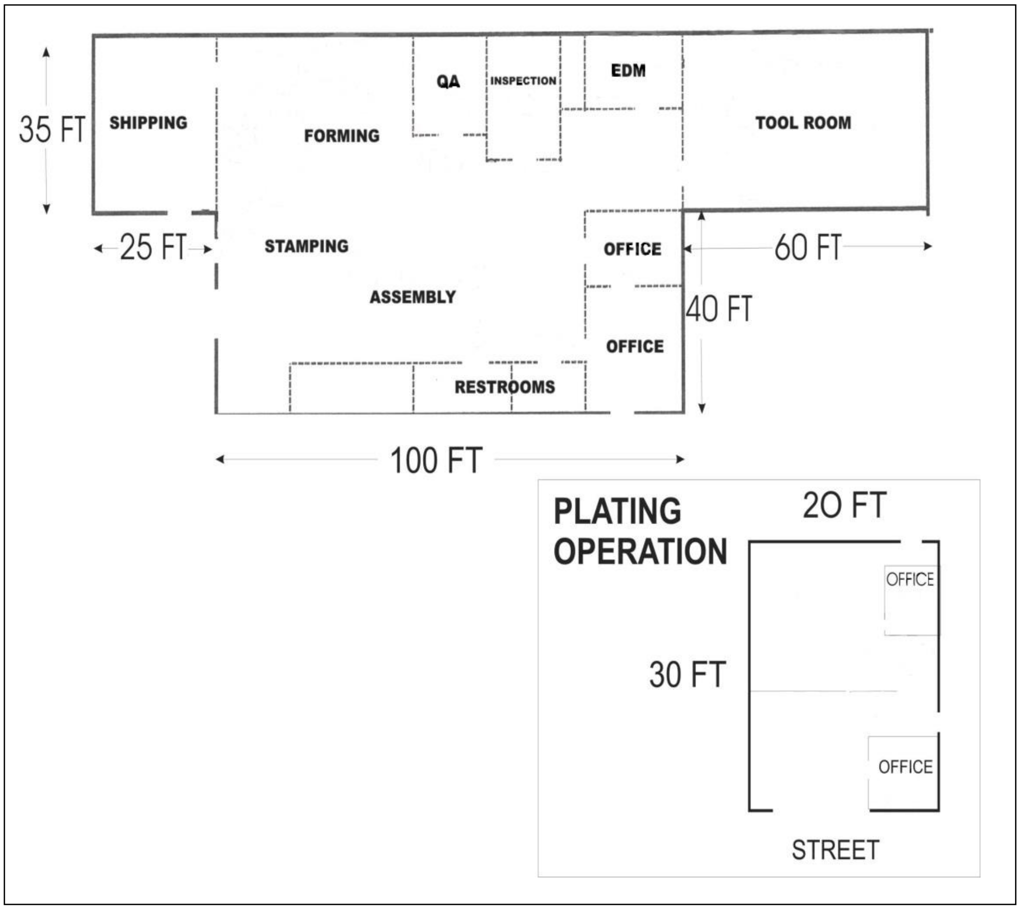

Figure IV-3. ERG Beryllium Site 6 plant layout. Note that the plating operation for this facility is located in a separate building.

IMIS Data

The IMIS database contains a total of 102 PBZ beryllium samples from June 1978 through September 2008 in the matching standard industrial classification (SIC) codes 3469 (Metal Stamping [NAICS 332116]), 3495 (Light Gauge Springs [NAICS 332612]), and 3678 (Electronic Connector Manufacturing [NAICS 334417]). These findings are summarized in Table IV-65 and include only two positive results for beryllium (i.e., 2 percent of the sample results are positive). The two positive results are both in SIC code 3469 and include values of 3.9 $\mu g/m^3$ for a painter in December 1995 and 0.01 $\mu g/m^3$ for a welder in July 2008. The available information suggests that the potential for higher exposure levels exists at some facilities, but most establishments fabricating beryllium alloy products have low beryllium exposures.

Table IV-65—OSHA IMIS PBZ Total Beryllium Air Sampling Results for Industries Fabricating Beryllium Alloy Products (SIC Codes 3469, 3495 and 3678)

SIC Code	SIC Description	No. PBZ Samples with Positive Results/ Total No. PBZ Samples[a]	Job Descriptions (as listed in the IMIS database)	Range[b] (μg/m³)	Mean[b] (μg/m³)	Median[b] (μg/m³)
3469	*Metal Stamping*	*2/72 (3% positive)*	*Assembler; Be-Cu line operator; brazing operator; grinder; melter mixed ingots; milling metal; molding machine operator; operator; packer; painter[c]; press operator; production; robot welder; shipping manager; supervisor; team leader; welder; welder and machine operator; welder-foreman; welder-union rep; welding[c]; and nine sample entries with no job descriptions.*	*0.01 - 3.9*	*1.96*	*1.96*
3495	*Light Gauge Springs*	*0/10 (0% positive)*	*Extruder operator; general labor; grinder; press operator; ram operator; and one sample entry with no job description.*	*None*	*None*	*None*
3678	*Electronic Connector Manufacturing*	*0/20 (0% positive)*	*Abrasive blaster; air arcing welder; assistant lead hard solder; band saw grinder; car body sander; CNC machine operator; finisher; grinder; machine operator; machine shop operator; melter/pourer; plate; pour; pourer/melter; spray painter; stocker/checker; supervisor; utility tool worker; W-G operator.*	*None*	*None*	*None*
Total		**2/102 (2% positive)**		**0.01 - 3.9**	**1.96**	**1.96**

[a] *Includes all positive PBZ samples by SIC code, regardless of the job description. Note that for each SIC code, other types of samples (in addition to PBZ samples) may have been obtained, such as area, screening, bulk, or wipe samples.*

[b] *The range, mean, and median results are based on positive sample results only. All positive results are included. Sampling limit of detection (LOD) concentrations for nondetectable samples are not available in the IMIS database.*

[c] *The positive PBZ beryllium air sampling results in the metal stamping industry include two workers with painter and welding job descriptions.*

PBZ: personal breathing zone.

Source: OSHA, 2009

Exposure Profile

OSHA produced an exposure profile for the establishments fabricating beryllium alloy products (i.e., springs, stampings, and connectors) based on full-shift PBZ total beryllium exposure samples available for workers in this industry. Tables IV-70 through IV-72 in Fabrication of Beryllium Alloy Products Appendix 1 show the exposure profile for all 201 samples and the breakdown of the nondetectable samples by job category and work group. Seventy percent of the exposure results are nondetectable for beryllium, and 90% are less than 0.1 μg/m^3, indicating that most workers in the beryllium alloy product fabrication industry have low exposures. OSHA evaluated the exposure data associated with the nine job categories for this industry. For six of the nine job categories (i.e., machine operators, tool makers, welders, heat treating operators, inspectors, and packers/shippers), all full-shift PBZ exposure results are less than the alternative PEL of 0.1 μg/m^3 for beryllium. Because their exposure levels are consistently low, OSHA anticipates that in the fabrication industry, the exposure levels of the vast majority of workers in these six job categories will not exceed the proposed PEL of 0.2 μg/m^3 or the alternative PEL of 0.1 μg/m^3.

There are 71 samples associated with three job categories that have a higher potential for beryllium exposure: chemical processing operators (primarily plating and bright cleaning), workers deburring fabricated parts (in this case, dry tumbling the parts with corn cob tumbling media), and assembly operators. The exposure profile for each of these job categories is summarized in Tables IV-66 and IV-67 and discussed below. These tables summarize the best available full-shift PBZ exposure results for the affected job categories in this industry sector (as discussed in the subsection on Data Sources, within this section on the Fabrication of Beryllium Alloy Products) and report the distribution of the results in relation to the proposed and current PELs for beryllium. Table IV-72 provides a breakdown of the nondetectable samples by affected job category.

Table IV-66—Personal Exposure Profile for Affected Job Categories in the Beryllium Alloy Products Fabrication Industry (NAICS 332612, 332116, 334417)[a,b]

Job Category	No. of Samples	No. of Samples <LOD	Range (μg/m^3)	Mean (μg/m^3)	Median (μg/m^3)
Chemical Processing Operators	*43*	*14*	*0.004 to 0.42*	*0.059*	*0.025*
Deburring Operators	*14*	*0*	*0.02 to 0.41*	*0.095*	*0.064*
Assembly Operators	*14*	*12*	*0.005 to 0.12*	*0.015*	*0.006*
TOTAL	**71**	**26**	**0.004 to 0.42**	**0.056**	**0.025**

[a] *Full-shift personal breathing zone (PBZ) lapel-type sample results are based on the actual sample duration. Full-shift means a sampling duration of 360 minutes or longer.*

[b] *Nondetectable results are reported as sampling limit of detection (LOD) concentrations.*

Source: Brush Wellman Stamping, 2004; Corbett, 2007; ERG Beryllium Site 6, 2003; NIOSH EPHB 263-12a, 2004

Table IV-67—Distribution of Full-Shift PBZ Exposure Results for Total Beryllium in the Beryllium Alloy Products Fabrication Industry (NAICS 332612, 332116, 334417)[a,b]

Job Category	Number of Results in Range (μg/m³)						Total
	< 0.1	≥ 0.1 to ≤ 0.2	> 0.2 to ≤ 0.5	> 0.5 to ≤ 1.0	> 1.0 to ≤ 2.0	> 2.0	
Chemical Processing Operators	*35 (81%)*	*6 (14%)*	*2 (5%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*43 (100%)*
Deburring Operators	*11 (79%)*	*1 (7%)*	*2 (14%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*14 (100%)*
Assembly Operators	*13 (93%)*	*1 (7%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*14 (100%)*
TOTAL	**59 (83%)**	**8 (11%)**	**4 (6%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**71 (100%)**

[a] *Full-shift personal breathing zone (PBZ) lapel-type sample results are based on the actual sample duration. Full-shift means a sampling duration of 360 minutes or longer.*

[b] *Nondetectable results are reported as sampling limit of detection (LOD) concentrations.*

Source: Brush Wellman Stamping, 2004; Corbett, 2007; ERG Beryllium Site 6, 2003; NIOSH EPHB 263-12a, 2004

Chemical Processing Operator

Table IV-66 shows that the exposure profile for chemical processing operators ranges from 0.004 μg/m³ to 0.42 μg/m³, with a mean of 0.059 μg/m³ and a median of 0.025 μg/m³. These values are based on 43 full-shift PBZ samples obtained on chemical processing operators at three precision stamping facilities.

Most worker exposures at these three facilities are well below 0.1 μg/m³; however, exposures exceeding the proposed PEL (0.2 μg/m³) can occur. Thirty-three percent of the results (14 of 43 PBZ samples) are nondetectable for beryllium, with sampling LOD concentrations ranging from 0.004 μg/m³ to 0.024 μg/m³. As shown in Table IV-67, 81 percent of the results (35 samples) are less than 0.1 μg/m³. The remainder (14 percent of the results, or six samples) range from 0.1 μg/m³ to 0.42 μg/m³; these results were obtained on chemical processing workers with job descriptions of plating operator and bright cleaning operator at one stamping facility (Site 4) (Brush Wellman Stamping, 2004).

Chemical processing of beryllium alloy parts does not occur at all fabrication facilities. Three of the six establishments (50 percent) for which exposure data are available have chemical processing operations (Brush Wellman Stamping, 2004; ERG Beryllium Site 6, 2003). One of the establishments (Site 1) electrochemically plates very small parts using a completely enclosed and automated plating system (Brush Wellman Stamping, 2004). Worker exposures associated with this technology are nondetectable, with sampling LOD concentrations of approximately 0.005 μg/m³ (0.0048 μg/m³ to 0.0054 μg/m³). At the other two establishments (Site 4 and ERG Beryllium Site 6) chemical processing takes place in classic open surface tanks equipped with LEV (Brush Wellman Stamping, 2004; ERG Beryllium Site 6, 2003). For both of these facilities, compressed air was used for cleaning, and poor housekeeping was observed in the chemical processing areas. At precision stamping Site 4, investigators observed significant amounts of crystallized material (dried chemical residue) on the floor and process equipment. Recommendations were made to 1) conduct a thorough wall-to-wall cleaning of the area; 2) eliminate the use of compressed air; 3) perform a ventilation survey to determine the effectiveness of the LEV, and enhance/modify as necessary; and 4) re-evaluate airborne beryllium levels after the first three recommendations have been completed.

To provide additional insight into the exposure profile for this job category, OSHA also reviewed the IMIS database for exposure information pertaining to the beryllium alloy fabricating industry.[276] However, the review identified only one entry with a job description representative of chemical processing. This sample was obtained in October 1985 on a plater at an electronic connector establishment (SIC 3678) and was nondetectable for beryllium. Although limited, this finding supports the exposure profile, which shows that most chemical processing operators experience minimal beryllium exposure, although exposures can occur at levels up to 0.42 μg/m^3.

Based on the conditions described for this job category in the data sources, OSHA has preliminarily determined that the range of exposures for chemical processing operators in the beryllium alloy products fabrication industry is represented by the range of results summarized in Tables IV-68 and IV-69 (the exposure profile). The median exposure level for this job category is 0.025 μg/m^3.

Deburring Operator

The deburring exposure profile, summarized in Tables IV-68 and IV-69, is based on 14 PBZ beryllium sample results reported for deburring operators at one precision stamping facility (Site 4)—the only source of full-shift exposure data available for this job category (Brush Wellman Stamping, 2004). As shown in Table IV-69, deburring is characterized by a median exposure level of 0.064 μg/m^3, a mean of 0.095 μg/m^3, and a range from 0.02 μg/m^3 to 0.41 μg/m^3. All of the results for deburring are positive for beryllium (see Table IV-72). Seventy-nine percent of the exposure results are less than 0.1 μg/m^3 (see Table IV-67). Seven percent (one result) are equal to 0.1 μg/m^3. Fourteen percent (two results) of the results fall between 0.2 μg/m^3 and 0.5 μg/m^3 and include values of 0.29 μg/m^3 and 0.41 μg/m^3. These two highest results are associated with follow-up exposure sampling conducted in 2007 after ventilation improvements were made in nearby wet chemical operations that were thought to be impacting deburring (i.e., a co-location exposure issue). The follow-up sampling showed that elevated deburring exposures were due to corn cob deburring (in an open tumbling mill) and not to co-location issues associated with the chemical operations. Industrial hygiene investigators concluded that corn cob deburring required work practice improvements and LEV to reduce exposures to below 0.2 μg/m^3 during the six-hour processing cycle and subsequent screening activities (Corbett, 2007). Other details are not available.

OSHA also examined the IMIS database for deburring exposure information in SIC codes 3469, 3495, and 3678. No entries with a job description of deburring were identified. However, since many techniques are used for deburring including blasting techniques and grinding machines, OSHA also reviewed the database for these job descriptions. For SIC code 3469, the database includes six PBZ results for workers with a job description of grinder. These samples were obtained at two establishments (May 1991 and February 2001) and are all nondetectable for

[276] SIC code 3469–Metal Stamping (NAICS 332116), SIC 3495–Light Gauge Springs (NAICS 332612), and SIC 3678–Electronic Connector Manufacturing (NAICS 334417).

beryllium. For SIC code 3495, there are three nondetectable results for grinders from three establishments (December 1984, October 1985, and June 1990). And for SIC code 3678, the database includes four nondetectable results for three grinders and one abrasive blasting operator from two establishments (August 1984 and November 1999). Together, these IMIS findings offer further evidence that exposures for deburring operators are typically low, supporting the exposure levels presented in the exposure profile for this job category.

Based on the descriptive information contained in the data sources, OSHA finds that the results presented in Table IV-67 offer the best available profile of deburring operator exposures in the beryllium alloy products fabrication industry. The median exposure level for this job category is 0.064 $\mu g/m^3$.

Assembly Operator

The exposure profile for assembly operators is summarized in Tables IV-68 and IV-69 and represents the best available exposure data for this job category. As shown in Table IV-69, the exposure levels for assembly operators range from 0.005 $\mu g/m^3$ to 0.12 $\mu g/m^3$, with a mean of 0.015 $\mu g/m^3$ and a median of 0.006 $\mu g/m^3$. These values represent 14 PBZ total beryllium results for assembly operators at two precision stamping facilities in the Brush Wellman case study (12 results from Site 1 and two results from Site 4) (Brush Wellman Stamping, 2004). Eighty-six percent of the results are nondetectable for beryllium (see Table IV-67), with sampling LOD concentrations ranging from 0.005 $\mu g/m^3$ to 0.02 $\mu g/m^3$. Only two of the 14 results are positive for beryllium, and of those, one result slightly exceeds 0.1 $\mu g/m^3$ (an assembly operator at precision stamping Site 4 had an exposure result of 0.12 $\mu g/m^3$). Assembly operations vary depending on the establishment and can include welding and soldering activities. At stamping Site 4, the assembly operations also include coil winding (i.e., running beryllium alloy strips across a steel roller to apply tension to the strips during winding). During coil winding, visible metallic dust was generated. The 0.12 $\mu g/m^3$ exposure level reported for an assembly operator at this site is likely associated with the coil-winding activity because investigators made a recommendation to substitute a less mechanically abrasive nylon roller for the steel roller (Corbett, 2004).

To provide additional insight into the exposure profile for this job category, OSHA also examined the IMIS database for relevant exposure information in SIC codes 3469, 3495, and 3678. From June 1978 to September 2008, the IMIS database contains a total of seven PBZ results for workers with a job description of assembler in the beryllium alloy product fabrication industry (SIC 3469 only). All the samples are nondetectable for beryllium and were obtained in April 1997 at a manufacturer of shielding equipment for electromagnetic (EMI) and radiofrequency interference (RFI). Because assembly operations can also include soldering and welding, OSHA reviewed the IMIS database for these job descriptions as well. For SIC 3469, the database contains 31 results (April 1987 to July 2008) from 16 different establishments. Relevant job descriptions include welder, welding, robot welder, and brazing operator. Ninety-seven percent of the sampling results for welding are nondetectable for beryllium; one welding sample was positive for beryllium, with a result of 0.01 $\mu g/m^3$. For SIC code 3678, the database contains two nondetectable welding results (August 1984 and June 1991) from two establishments. The job descriptions for these results are air arcing welder and assistant lead hard solder operator. No results with relevant welding job descriptions were identified for SIC

3495. These IMIS findings suggest that exposures for assembly operators are low and lend support to the exposure profile for this job category.

Based on the available information in the data sources, and supported by the IMIS findings from 19 additional facilities, OSHA assumes that the sample results provided by these sources reflect the experience of assembly operators throughout this industry. That is, the exposure profile for assembly operators is representative of assembly operator exposures in the beryllium alloy product fabrication industry. The median exposure level for this job category is 0.006 μg/m^3.

TECHNOLOGICAL FEASIBILITY

Most workers in the beryllium alloy product fabrication industry have low beryllium exposures, although the potential for occasional higher exposures exists for chemical processing, deburring, and assembly operators. These jobs are discussed in greater detail below. For all other fabrication workers, exposures are less than 0.1 μg/m^3 and additional exposure controls are not required to achieve exposures at or below the proposed PEL of 0.2 μg/m^3 or an alternative PEL of 0.1 μg/m^3.

Chemical Processing Operator

Chemical Processing Operator—Baseline Controls

Based on the information contained in the data sources described in the subsection on Data Sources for this section on Fabrication of Beryllium Alloy Products, OSHA finds that establishments fabricating beryllium alloy products typically do so without any exposure controls specific for beryllium. Most establishments do not isolate or segregate beryllium operations (OSHA-H005C-2006-0870-0345); no precautions are taken to enter or leave process areas of the facility; and no special work practice controls are in place. Workers also do not shower or change clothes on the company premises at the end of their shifts.

Housekeeping programs are in place, but production areas may not be cleaned on a daily basis and housekeeping in plating areas may be poor (Corbett, 2004; OSHA-H005C-2006-0870-0345). Compressed air and dry sweeping are used for cleaning in some establishments. In other establishments, employees use vacuums to clean machines at the end of the day or after a production run (OSHA-H005C-2006-0870-0345). Respiratory protection or Tyvek coveralls might be worn during cleaning activities (OSHA-H005C-2006-0870-0345).

The data source documents indicate that chemical processing areas are typically fitted with LEV, although this ventilation is likely designed to capture other chemical processing hazards (e.g., electroplating and wastewater contaminants rather than beryllium) and may not be well maintained (Brush Wellman Stamping, 2004; Corbett, 2007; Miller, 2007). Chemical processing operations (such as plating) described by Corbett (2007) use open chemical baths that are likely to have some form of LEV to control corrosive vapors and mists. The ventilation systems might not be effective, however, and could need improved ductwork and hood designs, as well as enhanced maintenance programs. This baseline condition was also found in the chromium plating and anodizing industries (analogous operations) where LEV was reported to be the primary exposure control in use for chemical process tanks. Upon investigation, however, most ventilation systems were found to be in need of repair, increased exhaust rates, enhanced maintenance programs, and other system improvements (OSHA-H054A-2006-0064-2527).

In addition to LEV, employees working with chemical processing operations are likely to wear PPE such as gloves, aprons, and safety glasses to protect against chemical contact and splashing. Although one facility (Site 1) has a state of the art automatic mass plating system, OSHA does not believe that the majority of establishments use this technology (Brush Wellman Stamping, 2004).

Chemical Processing Operator—Additional Controls

The exposure profile for chemical processing operators is representative of the beryllium alloy products fabrication industry. The median exposure level associated with this job category is 0.025 μg/m^3. Based on the exposure profile, 95 percent of the exposure results for these workers are less than 0.2 μg/m^3, and 80 percent are less than 0.1 μg/m^3. The 5 percent of chemical processing operators have exposures that exceed 0.2 μg/m^3 will require additional controls to further reduce exposures. These controls primarily include improvements in LEV, work practices, and housekeeping. An alternative to these controls, where possible, includes the use of automated self-contained chemical processing systems. Key benefits of this technology include reduced airborne contaminants and a clean working environment (no dripping and spillage) due to the self-contained design. One of the precision stamping establishments (Site 1) plated very small parts using a completely enclosed and automated plating system (Brush Wellman Stamping, 2004). Worker exposures associated with this technology were all nondetectable for beryllium, with a sampling LOD concentration of approximately 0.005 μg/m^3.

At sites without automated self-contained systems, chemical processing operators can be exposed to beryllium when drips and spills dry and leave dust, which is then disturbed. Control methods that minimize this source will reduce exposures originating from that dust because less dust will be available to become airborne. This point is demonstrated by a series of air samples obtained at Site 4 of the Brush Wellman case study series. At this precision stamping facility, compressed air was used for cleaning, and very poor housekeeping was observed in the chemical processing areas. Specifically, significant amounts of dried chemical residue were observed on the floor and process equipment surfaces. For several of the chemical processing operations at this facility (e.g., pickling/cleaning, photoetching, plating), workers experienced exposure levels greater than 0.1 μg/m^3. For pickling/cleaning, some PBZ exposures also exceeded 0.2 μg/m^3.

Follow-up PBZ sampling was conducted twice at stamping facility Site 4. The first follow-up sampling occurred in 2006 after the plant made significant work practice and housekeeping improvements (not otherwise specified) (Corbett, 2007). Three of nine follow-up PBZ results for pickling/cleaning were between 0.1 μg/m^3 and 0.2 μg/m^3, while four results exceeded 0.2 μg/m^3. Among 18 samples for photoetching, two of the results exceeded 0.2 μg/m^3. Maximum exposure levels of approximately 0.3 μg/m^3 and 0.4 μg/m^3 were obtained for photoetching and pickling/cleaning operations, respectively. Furthermore, in the "selective" plating area (not otherwise described), two of the sample results approaching 0.5 μg/m^3 (Corbett, 2007).

Based on the findings of the first (2006) follow-up sampling at stamping facility Site 4, investigators concluded that improved work practices and housekeeping in conjunction with the existing LEV were not sufficient to control exposures below 0.2 μg/m^3, and that exhaust ventilation improvements would also be required. After the facility implemented LEV improvements (consisting of improved ductwork and hood design/enclosures, additional exhaust airflow, system maintenance and filter change), additional air sampling was performed in 2007. During this second round of follow-up sampling the results were less than 0.1 µg/m^3 for all PBZ samples associated with chemical processing operators (Corbett, 2007). Table IV-68 summarizes the baseline exposure levels in 2000 (before controls) and the second follow-up air sampling results obtained in 2007 after housekeeping, work practice, and LEV controls were added at precision stamping Site 4 (individual exposure results for chemical processing are not available).[277]

Table IV-68—Precision Stamping Facility Site 4 Follow-Up PBZ Total Beryllium Results for Select Chemical Processing Operations after Work Practice, Housekeeping, and Ventilation Improvements

	BEFORE (baseline exposures)		AFTER (additional controls)	
Exposure Group	**No. Samples**	**Range (µg/m^3)**	**No. Samples**	**Range (µg/m^3)**
Pickling/Cleaning	*5*	*0.1 to 0.42*	*14*	*0.02 to 0.05*
Photoetching	*5*	*0.02 to 0.1*	*15*	*0.01 to 0.08*
Plating	*5*	*0.03 to 0.18*	*23*	*0.01 to 0.05*
Source: Brush Wellman Stamping, 2004; Corbett, 2007				

Based on the follow-up work conducted at Site 4, OSHA finds that exposure levels of less than 0.1 µg/m^3 can be achieved by 1) eliminating work practices that can generate airborne beryllium; 2) improving the frequency and quality of housekeeping (e.g., removing dried beryllium-containing chemical residue that can become airborne from work surfaces); and 3) enhancing existing LEV systems.

When consulting with facilities that use beryllium-containing materials, researchers from the National Jewish Health Division of Environmental and Occupational Health Sciences request that all compressed air lines be removed and that no dry sweeping be conducted in beryllium areas because both of these activities can result in significant worker exposure. In some cases, a worker's primary exposure to beryllium is due to cleaning his/her work clothes with compressed air. National Jewish researchers specify that only wet methods and HEPA filter vacuums should be used for cleaning in beryllium work areas (OSHA-H005C-2006-0870-0155).

OSHA consistently requires that compressed air not be used for cleaning work surfaces contaminated with hazardous metals (e.g., Lead, 29 CFR 1910.1025(h)(2)(i), Inorganic arsenic, 29 CFR 1910.1018(k)(2)) because it can disperse these materials into the workplace. In some cases, the use of compressed air for cleaning is allowed only when used in conjunction with a ventilation system designed to capture the dust cloud created by the compressed air (e.g., Cadmium, 29 CFR 1910.1027(k)(6), Hexavalent chromium, 29 CFR 1910.1026(j)(2)(iii)).

Yoshida et al. (1997) reported that workplace cleaning and ventilation improvements contributed to a significant reduction in general area beryllium levels in a copper-beryllium rolling and drawing establishment. Like beryllium alloy product fabrication plants, rolling and drawing

[277] Because the sample results are available only as a group, rather than as individual results, these values are not included in the exposure profile.

operations typically include chemical processing such as pickling. Airborne beryllium levels decreased 84 percent, from a geometric mean of 0.19 µg/m^3 to a geometric mean of 0.03 µg/m^3, through a combination of improved LEV and workplace cleaning to remove settled/deposited particulate matter.

A primary beryllium producer has developed recommended work practices and control measures for the chemical processing of small copper-beryllium alloy parts (Materion SF 104, 2011). These recommendations are summarized in Table IV-69 and include effective LEV, workplace cleanliness, safe work practices for servicing and maintaining LEV systems, and employee training and exposure monitoring.

Table IV-69—Safety Practices for Chemical Processing of Small Copper-Beryllium Parts
• *Install effective LEV to minimize the escape of mists and vapors associated with corrosive processes using acids and bases.*
• *Do not discharge the exhaust air from a recirculating air cleaning device into the workplace due to the potential for exposure if there is a failure of the filtration system.*
• *Contain chemical solutions used in the cleaning and processing of copper-beryllium to prevent splashing onto floor areas, external structures, and operators' clothing.*
• *Clean up chemical solutions that splash outside process containers as soon as possible and do not allow these solutions to dry, because they may carry beryllium-containing particulate that can later become airborne or attach to clothing or shoes.*
• *Thoroughly clean contaminated equipment prior to performing service and maintenance. Beryllium-containing residue can settle on the internal surfaces of ventilation enclosures and equipment structures and must be removed, kept wet, or otherwise be controlled during service and maintenance activities to minimize the generation of airborne particles.*
• *Develop detailed procedures for safely maintaining ventilation systems and process equipment. These procedures should provide detailed information regarding the use of wet methods, vacuuming, ventilation, and appropriate PPE to prevent exposure to beryllium.*
• *Train all process operators and maintenance personnel in the established procedures prior to performing service or maintenance activities.*
• *Characterize worker exposure, including the use of air monitoring, for those operations where a potential for beryllium exposure exists.*
Source: Materion SF 104, 2011

Both OSHA and the U.S. Environmental Protection Agency (EPA) recognize the importance of maintaining ventilation systems for plating operations. Poor maintenance can greatly diminish the effectiveness of the ventilation such that it operates at a fraction of its design specifications (OSHA-H054A-2006-0064-2527). Other factors for effective ventilation of plating operations include (OSHA-H054A-2006-0064-1364):

- Doubling the exhaust flow rate if the bath temperature is increased by 15° to 20°C.
- Limiting the height of the exhaust over the surface of the bath to 30 percent of the distance to the cathode rod.
- Using a lid that encompasses the bath and the exhaust to create a shorter distance between the source and the exhaust at a constant bath width.

- Isolating plating operations from door openings and transport paths where drafts can arise.
- Lifting and lowering product slowly through the exhaust zone.

Additionally, in a study of control technology for plating and cleaning operations in the metal plating industry, NIOSH concluded that covers are effective in limiting emissions from plating tanks (NIOSH 85-102, 1984). For example, around one tank normally uncovered and located in a region of strong cross-drafts, the average tank concentration of hexavalent chromium was substantially reduced (20-fold drop) when a cover was placed over the tank. For operations involving smaller tanks and pieces, the use of partial covers can increase the effectiveness of the exhaust ventilation while allowing viewing of and access to the pieces being plated (NIOSH 85-102, 1984).

Chemical Processing Operator—Conclusion

Based on the best available data described in the exposure profile, the median exposure level associated with this job category is 0.025 $\mu g/m^3$, and beryllium exposure levels of 0.2 $\mu g/m^3$ or less have already been achieved for the vast majority (95 percent) of the chemical processing operators in this industry. This control level has been achieved through the use of LEV, work procedures that minimize spillage, and housekeeping methods that minimize the opportunity for beryllium dust to become airborne. OSHA estimates that the remaining workers in this job category (the 5 percent that are not already protected by these methods) will require additional controls to reach this level. Additional controls could include upgrading or installing and maintaining ventilation systems, eliminating the use of compressed air, and improving housekeeping.

These additional controls have proven effective in the past. A 2007 follow-up industrial hygiene study at a precision stamping facility showed that the beryllium exposure of chemical processing operators was reduced to less than 0.1 $\mu g/m^3$ by the combined use of several control measures (Corbett, 2007). These measures included improved work practices (such as eliminating the use of compressed air), thorough and frequent housekeeping, and enhanced LEV for chemical processing tanks (those that initially did not meet the established performance criteria specified for the operation). Previously, in 2000, before the control measures were put in place, chemical processing operators performing the same jobs experienced beryllium exposure levels up to 0.42 $\mu g/m^3$.

In the event that further control measures are required, employers can protect chemical processing operators by installing completely enclosed and automated chemical processing systems (such as for plating), which will also reduce operator exposures. At one precision stamping facility (Site 1), workers plating copper-beryllium parts with an automated mass plating system had nondetectable beryllium exposures, with sampling LOD concentrations of approximately 0.005 $\mu g/m^3$ (Brush Wellman Stamping, 2004). Based on the available information, OSHA preliminarily concludes that an alternative PEL of 0.1 $\mu g/m^3$ and proposed PEL of 0.2 $\mu g/m^3$ are feasible for chemical processing operators.

Deburring Operator

Deburring Operator—Baseline Controls

Deburring operators in this industry use the same range of deburring processes for product finishing tasks used by other metal product fabrication industries, including manual filing, brushing with wire or other stiff material, abrasive action, and vibratory and media barrel finishing (Corbett, 2007; Fennel et al., 2006). Data source documents suggest that these processes are ventilated with LEV, but air flow rates might not meet ACGIH recommendations (ACGIH, 2010; Corbett, 2007).

Deburring Operator—Additional Controls

The exposure profile for deburring operators is based on 14 full-shift PBZ samples obtained at one precision stamping facility (Site 4) (Brush Wellman Stamping, 2004). The median exposure level for this job category is 0.064 $\mu g/m^3$. Based on the exposure profile presented in Tables IV-68 and IV-69, 86 percent of the samples are less than 0.2 $\mu g/m^3$, and 79 percent are below the alternative PEL of 0.1 $\mu g/m^3$. The 14 percent of deburring operator exposures (2 samples) that exceed 0.2 $\mu g/m^3$ would require additional controls to further reduce exposures. In the exposure profile, the elevated exposures for this job category (0.29 $\mu g/m^3$ and 0.41 $\mu g/m^3$) are associated with a precision stamping facility (Site 4) deburring operation, which involves dry tumbling small copper-beryllium alloy products with corn cob media in an small open tumbling mill (less than 24-inch diameter barrel) (Corbett, 2007). During a follow-up industrial hygiene survey at Site 4, the investigators, who were highly experienced with beryllium process controls, concluded that to reduce exposures, this deburring operation required 1) work practice improvements and 2) the addition of LEV during both the six-hour cycle time and subsequent screening activities. The case study does not include an update on this operation, however, and OSHA does not have access to exposure data to support the effectiveness of these recommended additional controls for deburring.

In the absence of additional information on the effectiveness of the recommended controls, OSHA considered evidence that well-designed and properly maintained LEV can control exposures of other mechanical surface finishing operations to levels of less than 0.1 $\mu g/m^3$. OSHA also considered options for using more fully enclosed or wet deburring process equipment as well as reducing the need for deburring (Dayton Progress Corporation, 2003; Hedrick, 2004). For the former (LEV), OSHA reviewed the exposure reduction associated with LEV improvements for a related finishing operation (buffing) at the same facility (Site 4), where mechanical buffing is one of the steps in the selective plating operation (Brush Wellman Stamping, 2004; Corbett, 2007).

Buffing and deburring are two forms of mechanical surface finishing work (Fennell et al., 2006). Both are capable of removing oxides and small imperfections from metal alloy products through mild abrasion or friction applied to the product surface. Although not identical processes, both buffing (at Site 4, a bench-mounted electric buffing machine with buffing/polishing wheels) and deburring (in a small, open tumbling mill with plant-based media such as corn husks) involve gentle, moderate-to-high-energy action on the product surfaces; therefore, for both processes, the source and nature of the beryllium particles is also similar. Additionally, at Site 4, before exposure control upgrades, both buffing and deburring were associated with similar levels of worker exposure (0.5 µg/m^3 in the buffing area, compared to up to 0.41 µg/m^3 for deburring, as noted above) (Corbett, 2007). Both buffing machines and small tumbling mills (up to 24 inches in diameter) have recommended ventilation design specifications provided by ACGIH (2010).

Initially, investigators conducting an industrial hygiene survey in the Site 4 selective plating/buffing area determined that elevated PBZ sampling results of approximately 0.5 µg/m^3 were associated with the operation. Further investigation led them to focus their attention specifically on buffing as a source of exposure requiring control. Improved ductwork and hood designs were implemented following the ACGIH industrial ventilation manual guidelines for buffing and polishing operations (ACGIH, 2010 [Figure VS-80-30]). Design improvements coupled with ventilation filter changes and LEV system maintenance increased the exhaust flow rate by 31 percent, from 633 cubic feet per minute (cfm) to 830 cfm. After the improvements were implemented, seven follow-up PBZ samples for beryllium were all less than 0.10 µg/m^3 (Corbett, 2007). This case demonstrates that a well-maintained exhaust ventilation system designed to ACGIH's recommended specifications can effectively control beryllium exposure during mechanical surface finishing.

ACGIH (2010) provides air exhaust specifications for nine different sizes in each of two tumbling mill shape configurations. OSHA preliminarily finds that, because tumbling/vibrating media mills are typically more automated (largely an unattended process) and can be more fully enclosed (Royson, 2011; Vibra Finish, 2011; ACGIH, 2010 [Figure VS-80-03]) than manual buffing wheels, the ACGIH ventilation design guidelines for tumbling mills will be at least as effective (and likely more so) for preventing the release of beryllium particles as the ventilation design for the buffing ventilation system. In some cases (e.g., low speed, low-energy tumbling), shop-built housing connected to an appropriate ventilation system will be sufficient.

The tumbling equipment used at Site 4 was uncontrolled and involved a final screening step (Corbett, 2007). Tumbling equipment is commercially available with various levels of control options (Gibson, 2011; Royson, 2011; Vibra Finish, 2011). The more aggressive the anticipated media, the more tightly enclosed the tumbler and its housing must be to achieve good exposure control. Some tumbling mills (e.g., those that incorporate an abrasive blast feature) are already designed with sealed external housing, pneumatic locking doors, and exhaust ventilation (Gibson, 2011). These principles of enclosure design can be applied to any tumbling mill. OSHA believes well-designed housing and exhaust ventilation that meet ACGIH specifications will substantially reduce exposures compared to the open unventilated process.

Some deburring operators perform a final screening step, which involves dumping batches of beryllium alloy shapes into receptacles and separating items from particulate matter. This final screening step generates airborne dust (Kent, 2012; Russell Finex, 2009). Where beryllium alloy workers also perform sieving to separate alloy product from tumbler media, the ventilated housing will need to enclose the sieving screen(s) as well, or the screening process will require separate ventilation. Housing fitted for exhaust ventilation is commercially available for media mills and associated separating/drying equipment (Royson, 2011) and for tumble blasting equipment with media-separating capability (Gibson, 2011). Additionally, the pharmaceutical industry uses screening equipment and certain commercially available, enclosed, ventilated pharmaceutical screening equipment (e.g., designed for separating pills from extremely high-potency dust) that has been proven to limit dust concentrations to less than 1 µg/m^3 (Russell

Finex, 2009). At Site 4, screen separation of beryllium alloy product from tumbling media occurs for just a moment or two at the end of a six-hour cycle (360 minutes). Using such equipment, even if the screening process were performed for a full five minutes during each 360-minute tumbling cycle, the time-weighted average dust emission from the screening process would be less than 0.014 μg/m^3 over the cycle.

Tumbling mills designed to be watertight for wet deburring processes are also a commercially available option (Royson, 2011). In this case, media is separated from the product by rinsing, and dust release is prevented by work practices that minimize splashing and dripping of dust-laden process water and that require spills to be cleaned up immediately while still wet.

Another option involves minimizing the need for deburring processes by adjusting stamping machinery to optimize punch-to-die clearance to decrease burr height while increasing tool life (Dayton Progress Corporation, 2003; Hedrick, 2004).

Deburring Operator—Conclusion

The median exposure level for deburring operators is 0.064 μg/m^3. Based on the exposure profile for this group of workers, exposure levels at or below the proposed PEL of 0.2 μg/m^3 have already been achieved for 86 percent of the deburring operators (79 percent are also already below the alternative PEL of 0.1 μg/m^3). For those workers who experience higher exposures (14 percent), additional controls include work practice and LEV improvements (Corbett, 2007). For a related mechanical surface finishing operation at Site 4 (manual buffing), initial exposure levels of 0.5 μg/m^3 were reduced to less than 0.1 μg/m^3 after the LEV system was upgraded to meet ACGIH recommendations. OSHA observes that the deburring operation, which is an automated activity in open equipment with exposure levels up to 0.41 μg/m^3, will be at least as effectively controlled by LEV that meets the ACGIH recommendations for tumbling mills (ACGIH, 2010 [Figure VS-80-03]). Using these methods, OSHA preliminarily concludes that the exposure of all deburring operators can be reduced to levels of less than or equal to the proposed PEL of 0.2 μg/m^3 and also less than an alternative PEL of 0.1 μg/m^3. In the event that deburring operator exposures continue to exceed the proposed PEL of 0.2 μg/m^3, enclosed and ventilated deburring equipment, fully enclosed screening equipment, and wet process deburring equipment are also available. OSHA therefore preliminarily concludes that an alternative PEL of 0.1 μg/m^3 and the proposed PEL of 0.2 μg/m^3 are feasible for this job category.

Assembly Operator

Assembly Operator—Baseline Controls

Assembly operators perform a wide range of activities, including soldering and welding, forming equipment, manual processes, and automated processes (Brush Wellman Stamping, 2004; Corbett, 2007; Miller, 2007). Little evidence suggests that these activities contribute to the beryllium exposure of assembly operators. Although exposures exceeding 0.1 μg/m^3 can occur where the process abrades the beryllium alloy (Corbett, 2004), 13 of the 14 samples for this job category were lower than 0.1 μg/m^3, indicating that this is not a typical concern. Compressed air is used for clearing work pieces and work areas (ERG Beryllium Site 6, 2003; Corbett, 2004).

Assembly Operator—Additional Controls

Fourteen PBZ samples were obtained for assembly operators at two precision stamping facilities (12 at Site 1 and two at Site 4) (Brush Wellman Stamping, 2004). Of these, none exceeded 0.2 $\mu g/m^3$ and only one sample (7 percent) resulted in an exposure that was 0.1 $\mu g/m^3$ or greater (an assembly operator at precision stamping facility Site 4 experienced an exposure level of 0.12 $\mu g/m^3$).

Assembly operations vary depending on the establishment and can include welding and soldering activities. At stamping facility Site 4, the assembly operations also include coil winding (i.e., running beryllium alloy strips across a steel roller to apply tension to the strips during winding). During coil winding, friction is generated from the metal strip sliding over the roller. This activity results in the generation of a small amount of metallic dust that gets deposited on the equipment surface. The 0.12 $\mu g/m^3$ exposure level reported for an assembly operator at this site is likely associated with the coil-winding activity. As a result of this observation, investigators made a recommendation to substitute a less mechanically abrasive nylon roller for the steel roller (i.e., to eliminate the metal-to-metal abrasion from occurring). OSHA does not have access to exposure data to support the effectiveness of this additional control. OSHA estimates that exposure levels of less than 0.1 $\mu g/m^3$ can be achieved by an engineering change to the coil-winding activity if the change reduces the generation of visible metallic dust. Therefore, OSHA concurs with the investigators' determination that this source of exposure will be eliminated by switching to a nylon roller. Nylon is softer than beryllium alloy and will not abrade the alloy metal. Additionally, although the number of variables involved with resuspension of dust is large (Caplan, 1993), routine cleaning of equipment surfaces (with wet methods or vacuums equipped with HEPA filtration) to remove deposited dust may help to further reduce worker exposures, because deposited dust can be a secondary source of worker exposure if it gets resuspended in the air. Variables that affect dust resuspension include the dust and surface properties and the resuspension action, such as air velocity, vibration, foot traffic, and powered and nonpowered wheel traffic (Caplan, 1993).

Yoshida et al. (1997) reported that workplace cleaning to remove settled dust, in conjunction with LEV improvements (not otherwise specified), reduced ambient (general area) levels of beryllium by 84 percent in a copper-beryllium rolling and drawing facility, reducing the total beryllium geometric mean from 0.19 $\mu g/m^3$ to 0.03 $\mu g/m^3$. These data show that improved engineering controls and a thorough cleaning contribute to reduced ambient levels of beryllium in a manufacturing environment. Although this establishment is not a fabrication facility, the sources of beryllium dust were similar to those associated with a fabrication facility (i.e., both use mechanical processes to shape beryllium alloys). Similarly, at a primary beryllium production plant, ambient air samples collected in an area noted to be "very dirty" were reduced by 93 and 89 percent, respectively, after the areas were cleaned (Couch, 2006). Prior to cleaning, the results of two general area samples obtained in the powder ball mill area of the plant were 12.7 $\mu g/m^3$ and 14 $\mu g/m^3$. After cleaning, two follow-up ambient air samples from the same areas were 0.9 $\mu g/m^3$ and 1.5 $\mu g/m^3$, respectively. Although some source(s) of exposure remained, this study demonstrates the extent to which poor versus improved housekeeping can influence worker exposure. Depending on the plant area, primary beryllium production can involve materials containing 2 to 50 times more beryllium in the metal than is present in the beryllium alloys used in fabricating plants. The dust generated (and exposure levels created by this dust) would be correspondingly lower in a fabrication facility. If poor housekeeping contributed to assembly operator exposure results, even a modest 20-percent reduction in exposure due to improved housekeeping would bring the highest assembly operator exposure level (0.12 μg/m^3) down to a level less than 0.1 μg/m^3 (0.096 μg/m^3).

Assembly Operator—Conclusion

The median exposure level for this job category is 0.006 μg/m^3. No results exceeded 0.2 μg/m^3 and OSHA preliminarily concludes that no additional controls are required to achieve the proposed PEL of 0.2 μg/m^3 for assembly operators. This conclusion is supported by the exposure profile for this job category, which shows that 93 percent of the measurements on assembly operators are less than 0.1 μg/m^3. The remaining workers in this job category (7 percent) can experience exposure levels between 0.1 μg/m^3 and 0.2 μg/m^3.

In the event that elevated exposures do arise, additional controls are available. For example, at precision stamping Site 4, a simple, straightforward engineering modification to an assembly coil-winding operation (i.e., substituting a steel roller with a nylon roller that will not abrade the beryllium alloy) will eliminate the source of exposure. Furthermore, routine cleaning of equipment surfaces to remove deposited dust (i.e., housekeeping) will help to further reduce worker exposures, because deposited dust can be a secondary source of worker exposure if it gets resuspended in the air. Any required engineering modifications together with routine cleaning are estimated to reduce the exposures of all assembly operators to below 0.1 μg/m^3.

The available exposure data show that all assembly operators are exposed below the proposed PEL of 0.2 μg/m^3, with the highest exposure being slightly above 0.1 μg/m^3. This information suggests that implementation of additional controls can reduce exposures below 0.1 μg/m^3. Therefore, OSHA preliminarily concludes that an alternative PEL of 0.1 μg/m^3 and the proposed PEL of 0.2 μg/m^3 are feasible for assembly operators.

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SECTION 9—FABRICATION OF BERYLLIUM ALLOY PRODUCTS, APPENDIX 1—PERSONAL EXPOSURE PROFILE AND DISTRIBUTION OF RESULTS IN THE BERYLLIUM ALLOY PRODUCTS FABRICATION INDUSTRY

Table IV-70—Personal Exposure Profile in the Beryllium Alloy Products Fabrication Industry (NAICS 332612, 332116, 334417)[a,b]

Job Category and Work Groups	No. of Samples	Range (μg/m³)	Mean (μg/m³)	Median (μg/m³)
MACHINE OPERATORS	**49**	**0.005 to 0.021**	**0.007**	**0.005**
TOOL MAKERS	**29**	**0.004 to 0.007**	**0.005**	**0.005**
Die Set-Up Machinist	*4*	*0.005 to 0.006*	*0.005*	*0.005*
Die Repair	*25*	*0.004 to 0.007*	*0.005*	*0.005*
CHEMICAL PROCESSING OPERATORS	**43**	**0.004 to 0.42**	**0.059**	**0.025**
Plating Racker	*5*	*0.026 to 0.084*	*0.052*	*0.051*
Plating Operator	*11*	*0.005 to 0.18*	*0.053*	*0.024*
Bright Cleaning Operator	*5*	*0.099 to 0.42*	*0.22*	*0.14*
Parts Washing Technician	*8*	*0.004 to 0.024*	*0.008*	*0.005*
Photo Etching Operator	*5*	*0.022 to 0.10*	*0.042*	*0.025*
Wastewater Treatment Operator	*9*	*0.004 to 0.096*	*0.038*	*0.007*
DEBURRING OPERATORS	**14**	**0.02 to 0.41**	**0.095**	**0.064**
WELDING OPERATORS	**7**	**0.005 to 0.006**	**0.005**	**0.005**
HEAT TREATING OPERATORS	**6**	**0.011 to 0.032**	**0.020**	**0.019**
ASSEMBLY OPERATORS	**14**	**0.005 to 0.12**	**0.015**	**0.006**
INSPECTORS	**23**	**0.005 to 0.02**	**0.007**	**0.005**
PACKERS/SHIPPERS	**16**	**0.005 to 0.006**	**0.005**	**0.005**
Shipping	*4*	*0.005 to 0.005*	*0.005*	*0.005*
Packaging	*12*	*0.005 to 0.006*	*0.005*	*0.005*
TOTAL	**201**	**0.004 to 0.42**	**0.025**	**0.005**

[a] *Full-shift personal breathing zone (PBZ) lapel-type sample results are based on the actual sample duration. Full-shift means a sampling duration of 360 minutes or longer.*

[b] *Nondetectable results are reported as sampling limit of detection (LOD) concentrations.*

Source: Brush Wellman Stamping, 2004; Corbett, 2007; ERG Beryllium Site 6, 2003; NIOSH EPHB 263-12a, 2004

Table IV-71—Distribution of Full-Shift PBZ Exposure Results for Total Beryllium in the Beryllium Alloy Products Fabrication Industry (NAICS 332612, 332116, 334417)[a,b]

Job Category and Work Groups	Number of Results in Range (μg/m³)						
	< 0.1	≥ 0.1 to ≤ 0.2	> 0.2 to ≤ 0.5	> 0.5 to ≤ 1.0	> 1.0 to ≤ 2.0	> 2.0	Total
MACHINE OPERATORS	**49 (100%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**49 (100%)**
TOOL MAKERS	**29 (100%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**29 (100%)**
Die Set-Up Machinist	*4 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*4 (100%)*
Die Repair	*25 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*25 (100%)*
CHEMICAL PROCESSING OPERATORS	**38 (88%)**	**3 (7%)**	**2 (5%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**43 (100%)**
Plating Racker	*5 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*5 (100%)*
Plating Operator	*8 (73%)*	*3 (27%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*11 (100%)*
Bright Cleaning Operator	*1 (20%)*	*2 (40%)*	*2 (40%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*5 (100%)*
Parts Washing Technician	*8 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*8 (100%)*
Photo Etching Operator	*4 (80%)*	*1 (20%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*5 (100%)*
Wastewater Treatment	*9 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*9 (100%)*
DEBURRING OPERATORS	**11 (79%)**	**1 (7%)**	**2 (14%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**14 (100%)**
WELDING OPERATORS	**7 (100%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**7 (100%)**
HEAT TREATING	**6 (100%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**6 (100%)**
ASSEMBLY OPERATORS	**13 (93%)**	**1 (7%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**14 (100%)**
INSPECTORS	**23 (100%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**23 (100%)**
PACKERS/SHIPPERS	**16 (100%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**16 (100%)**
Shipping	*4 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*4 (100%)*
Packaging	*12 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*12 (100%)*
TOTAL	**189 (94%)**	**8 (4%)**	**4 (2%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**201 (100%)**

[a] *Full-shift personal breathing zone (PBZ) lapel-type sample results are based on the actual sample duration. Full-shift means a sampling duration of 360 minutes or longer.*

[b] *Nondetectable results are reported as sampling limit of detection (LOD) concentrations.*

Source: Brush Wellman Stamping, 2004; Corbett, 2007; ERG Beryllium Site 6, 2003; NIOSH EPHB 263-12a, 2004

Table IV-72—Number of Nondetectable Sample Results in the Personal Exposure Profile for the Beryllium Alloy Products Fabrication Industry (NAICS 332612, 332116, 334417)

Job Category and Work Groups	Total No. of PBZ Samples	Total No. of Nondetectable PBZ Samples
MACHINE OPERATORS	**49**	**40 (82%)**
TOOL MAKERS	**29**	**28 (97%)**
Die Set-Up Machinist	*4*	*4 (100%)*
Die Repair	*25*	*24 (96%)*
CHEMICAL PROCESSING OPERATORS	**43**	**14 (33%)**
Plating Racker	*5*	*0 (0%)*
Plating Operator	*11*	*6 (54%)*
Bright Cleaning Operator	*5*	*0 (0%)*
Parts Washing Technician	*8*	*3 (38%)*
Photo Etching Operator	*5*	*0 (0%)*
Wastewater Treatment Operator	*9*	*5 (56%)*
DEBURRING OPERATORS	**14**	**0 (0%)**
WELDING OPERATORS	**7**	**7 (100%)**
HEAT TREATING OPERATORS	**6**	**1 (17%)**
ASSEMBLY OPERATORS	**14**	**12 (86%)**
INSPECTORS	**23**	**23 (100%)**
PACKERS/SHIPPERS	**16**	**16 (100%)**
Shipping	*4*	*4 (100%)*
Packaging	*12*	*12 (100%)*
TOTAL	**201**	**141 (70%)**

PBZ: personal breathing zone lapel-type samples. Nondetectable results are reported as sampling limit of detection (LOD) concentrations.

Source: Brush Wellman Stamping, 2004; Corbett, 2007; ERG Beryllium Site 6, 2003; NIOSH EPHB 263-12a, 2004

SECTION 10—WELDING

INDUSTRY PROFILE

Welding is the process of joining materials (metals or thermoplastics) by applying heat, pressure, or both. Fumes are generated in welding operations when metals and oxides vaporize at the point of operation where the materials are joined, and rapid condensation of the vapors occurs to form particles. This vaporization can occur by the direct application of heat (e.g., arc welding) or pressure (e.g., the pressure between surfaces being welded generates heat and releases fumes). The extremely high temperature at the point of operation (above 6,000°F) is above the boiling points of most metals commonly encountered in welding operations, and can cause the release of welding fumes composed of the same materials as the base metals, the welding electrode or filler material, the shielding gas, and any fluxes or coatings (Slavin, 1984). A range of gases and vapors (e.g., carbon monoxide, nitrogen dioxide, ozone) can also be generated, depending on the welding process (Burgess, 1991).

Worker exposure to beryllium can result from welding operations utilizing beryllium-containing materials, including beryllium-containing base materials, Class 3 or Class 4 electrodes, wires, or filler materials. Such welding operations are common throughout the general industry sector both for manufacturing and maintenance operations. Beryllium-containing materials may be welded using common resistance and arc welding techniques as well as less conventional welding methods such as electron beam welding (Brush Wellman 2009a, 2009b, 2009c). For the purposes of this discussion, OSHA has classified welding exposures into two main groups based on the welding process: (1) gas and arc welding, and (2) resistance welding. All of the NAICS codes affected by these operations are listed in Tables III.9 and III.10 of Chapter III, Industrial Profile, of this Preliminary Economic Analysis (PEA).

To estimate the number of at risk workers from gas and arc welding operations, OSHA used information from Materion’s 2001 customer survey. It indicated that 235 facilities (evenly split between strip and bulk product customers) perform gas and arc welding on beryllium-containing materials (Kolanz, 2001). Assuming that the Materion survey covered virtually all domestic customers for beryllium alloy materials, this estimate can be used as the national total of firms with gas and arc welding operations involving these materials. Materion further estimated that 2,029 employees are engaged in gas and arc welding at its customer facilities (1,697 in strip customer facilities and 332 in bulk product customer facilities). The welding operations performed by Materion are covered in Section 3—Beryllium Production, of the Preliminary Economic Analysis.

To estimate the number of workers exposed to beryllium from resistance welding, OSHA looked at multiple sources that indicate the use of electrodes for resistance welding. These sources indicate that copper-beryllium resistance welding electrodes might be used in any industry where spot, projection, or seam welding occurs; however, these types of electrodes are used primarily in the Motor Vehicle Manufacturing Industry (NAICS 3361). A number of sources also identified the commercial and household appliance industries (Air-Conditioning and Warm Air Heating Equipment and Commercial and Industrial Refrigeration Equipment Manufacturing—

NAICS 333415 and Household Appliance Manufacturing—NAICS 3352) as the other major consumers (Burnett, 2001; Foley; 2001; Green, 2001; Mitchell, 2001; Pelkey, 2001). One supplier estimates that these three industries account for approximately 90 percent of the market for copper-beryllium electrodes (Burnett, 2001). Data from the BLS Occupational Statistics Survey (BLS, 2010) show that between 5 and 7 percent of establishments in these industries, or about 400, employ a total of approximately 6,100 resistance welders.

WELDING OVERVIEW

Arc and Gas Welding

Although more than 80 different arc and gas welding techniques and allied processes have been developed, four welding techniques comprise most (80 to 90 percent) types of manufacturing and maintenance welding overall (AIHA, 1984; Burgess, 1991). These techniques include shielded metal arc welding; gas metal arc welding; gas tungsten arc welding; and oxygen-fuel gas welding. All arc welding processes create an electric arc (current) between the welding electrode (stick, rod, or wire filler metals) and the surface of the work piece.[278] The heat of the arc melts the electrode, or the filler metal if a nonconsumable electrode is used, and the work pieces to be joined. To prevent the formation of metal oxides and nitrides and weakening of the weld, the arc must be shielded, or protected.

In arc welding, the major sources of fumes are the electrode (electrode metal and the covering or flux material) and the base metal (AIHA, 1984; AWS, 1987). The type and quantity of fumes produced depend on the welding process. For a given welding process on the same base metal, fume generation can vary substantially depending primarily on the type of electrode used. Other factors affecting the type and quantity of fumes generated include electrode diameter, welding current, arc voltage/arc length, electrode polarity, shielding gas, contact-tube-to-work distance, and method for transferring metal from the electrode to the base metal (AIHA, 1984; Slavin, 1984).

Shielded Metal Arc Welding: Shielded metal arc welding (also called stick or manual metal arc welding) uses a consumable electrode coated in flux (a chemical that prevents oxidation of the base and filler metals) to lay the weld and a welding power supply (direct or alternating current) to form an electric arc between the metals to be joined and the electrode. Shielding is provided by the flux coating of the electrode; as the weld is laid, the flux coating decomposes and shields the weld area from atmospheric contamination. Stick welding is manually controlled and can be used on a wide variety of ferrous and nonferrous metals and alloys.

Gas Metal Arc Welding: In gas metal arc welding (also called metal inert gas, or MIG, welding), the electrode is a spool of consumable wire continuously fed through the electrode holder that forms the arc and provides the filler metal (Slavin, 1984). Shielding is provided by shielding gas (such as argon, helium, nitrogen, carbon dioxide, or a mixture of these gases) that

[278] In arc welding, an electrode is used to conduct a current through a work piece to fuse two pieces together. Electrodes are either consumable or nonconsumable (depending on the process) and are classified into three types: solid (bare metal electrode with no covering), covered (composite electrode with metal core and a covering), and flux-cored (composite electrode with a metal tube containing flux material) (AIHA, 1984).

flows through the electrode holder. MIG welding is typically used for production or automated welding operations and can be used to join all types of base metals, such as aluminum, copper, nickel alloys, magnesium, steel alloys, and titanium (Burgess, 1991; Slavin, 1984). The electrode wire is usually composed of the same material as the base metal; however, for carbon-steel welding, bare or copper-coated steel wire may be used for the electrode.

Gas Tungsten Arc Welding: In gas tungsten arc welding (also called tungsten inert gas, TIG, or Heliarc welding), filler metal (rod or wire) is usually fed into the arc created between the base metal and a nonconsumable tungsten electrode (Slavin, 1984). The process also uses a shielding gas such as argon or helium (or a mixture of such gases) around the electrode to maintain an inert environment. Small amounts of other gases (such as hydrogen or oxygen) are occasionally added to the principal shielding gas. TIG welding is routinely used to make welds on thinner materials or on reactive metals such as aluminum and magnesium (Slavin, 1984; Burgess, 1991). It is also commonly used on a number of alloys, such as low-alloy steels, stainless steel, copper-nickel, nickel alloys, brasses, bronze, and silver.

Gas Welding: Gas welding uses an oxygen-fuel gas flame to melt the workpiece and a manually fed rod to fill the weld joint (Burgess, 1991). Commonly used fuel gases include acetylene, methylacetylene propadiene (MAPP), butane, propane, and hydrogen. The filler rods are usually of the same composition as the metal being welded.[279] Depending on the base metal, various fluxes are applied to the filler rod prior to welding. Gas welding can be used to weld a variety of metals, such as aluminum, magnesium, cast iron, and steel and nonferrous alloys (Burgess, 1991).

Resistance Welding

Resistance welding refers to a group of welding processes that apply electric current and mechanical pressure to create a weld between two pieces of metal. Welding electrodes conduct the electric current to the two pieces of metal as they are forged together. In resistance welding, exposures may occur from beryllium in the base metal or in electrodes.

Resistance welding is generally divided into two groups of welds: lap welds and butt welds. Note that lap and butt welds are broad categories that characterize the point of contact in the weld area can apply to resistance, arc and gas welding, or any of the other less conventional methods. Lap welding is performed by overlapping two materials and joined by the application of heat and/or pressure. Spot, seam, high frequency and projection welding are referred to as lap welds. Butt welding is performed by joining two materials at their ends (cross-sectional areas) by applying heat and/or pressure. Butt welds include upset, percussion, and flash butt welds.

Materion Corporation describes resistance welding of beryllium alloys in the following terms:

> *Electric resistance welding (RW) is a reliable, low cost, efficient method of permanently joining two or more thin pieces of metal. Although RW is a true welding process, no filler metal or protective gases are required. There is no excess metal to remove after*

[279] However, if iron is the base metal, a bronze filler rod is utilized.

> *welding. The process is suited to high volume production. The welds are strong and almost invisible.* (Materion_ResistanceWeld, 2011).

Most resistance welding is done using fixed welding machines or robotic spot welding guns, though portable, manually operated resistance welding guns are available (Davis, 2001; Foley, 2001; Kelly, 2001; Mitchell, 2001). Some resistance welding machines require the operator to position the work piece during welding. However, the cycle of operation of most modern welding machines is completely automatic once the work piece has been loaded and the foot or hand control is pressed (Davies, 1989). Many resistance welding machines are part of highly automated assembly lines and require little or no human intervention during operation, though, like other welding machines, they require periodic maintenance and adjustment (Kelly, 2001).

Various materials can be used for resistance welding electrodes, depending on the application. Common electrode materials include (MTI MicroWelding, 2012):

- Copper/chromium (Class 2)
- Copper/chromium/zirconium (Class 2)
- Copper/chromium/nickel/silicon (Class 3)
- Copper/nickel/beryllium (Class 3)
- Copper/beryllium (Class 4)
- Copper/tungsten (Class 10-12)
- Tungsten (Class 13)
- Molybdenum (Class 14)

Copper-beryllium resistance welding electrodes are primarily used to weld materials having high electrical resistance, such as stainless steel, or in situations where there is concern of high pressure density and severe wear but heating is not excessive (Tuffaloy, 2012). Copper-beryllium electrodes are designated as either Class 3 or Class 4 electrodes, depending on their beryllium content. Class 3 alloy is recommended for flash and butt welding electrodes, projection welding electrodes, electrode shanks, heavy-duty electrode holders and other highly-stressed current-carrying parts. Class 4 is frequently used in seam welder bushings, tooling facings, and inserts (Tuffaloy, 2012).

Welding Beryllium-Containing Base Materials

Beryllium-containing materials can be welded using common gas and arc, and resistance welding techniques (see the Industry Profile subsection for this Welding section), as well as less common welding methods, such as diffusion welding, which is a solid state pressure welding technique, and electron beam welding, which is done in a vacuum chamber with an electron beam (Davies, 1989; Materion_WeldCuBe, 2011; Materion_ResistanceWeld, 2011; Materion_AlBeWeld, 2012; WHO, 1990). Oxygen-fuel gas and flux-cored arc welding (flux is located in the center of the welding rods), two types of gas and arc welding, are reportedly inappropriate for copper-beryllium due to the lack of suitable fluxes to prevent the formation of metal oxides from oxidation of the base and filler materials that can weaken the weld (Materion_WeldCuBe, 2011). However, these two welding techniques may be employed on a base metal that may contain beryllium in it, such as aluminum.

When beryllium-containing welding materials are used, the highest beryllium air concentrations are reportedly associated with argon-arc welding (Bobrischev-Pushkin et al., 1975, cited in WHO, 1990). Although OSHA does not specifically know whether this argon-arc welding refers to MIG welding, TIG welding, or both, OSHA believes that to the extent that the consumable material used in MIG welding has beryllium, exposures during MIG welding may be higher than during TIG welding.

Both MIG and TIG welding are well suited for welding copper-beryllium. When copper-beryllium is welded to itself or other metals, copper-beryllium rod is typically used as the filler metal. Aluminum-bronze filler can also be used for welding copper-beryllium to steel. The resistance welding processes commonly used for copper-beryllium include spot and projection welding. Resistance welding is frequently used to attach electrical contacts to copper-beryllium flat springs. Flash and seam welding are not typically used with copper-beryllium alloys. During less conventional welding methods such as diffusion and electron beam welding, beryllium exposure can occur when the welded objects are removed from the welding chambers or cleaned (Materion_AlBeWeld, 2012).

Aluminum as a Base Metal

Beryllium is found in other metals, including some aluminum alloys, and welding these products can result in beryllium exposures. OSHA estimates that there are over 500 grades of aluminum alloys, but only a few of them contain more than 0.1 percent beryllium by weight. However, Cole et al. (2007) found that welding on aluminum alloys with beryllium content as low as 0.008 percent (80 parts per million [ppm]) can produce beryllium exposures well in excess of 2.0 $\mu g/m^3$.

Cole (1997) summarized four laboratory studies from the 1980s and 1990s on beryllium emissions during welding trials using aluminum alloys. These studies used a mannequin fitted with a standard welding helmet to simulate manual welding with various combinations of aluminum base and filler metals.[280,281] Samples of air contaminants were collected

[280] Filler alloy selection criteria depend primarily on the application (end use) of the welded part and its desired performance. Many alloys and alloy combinations can be joined using any of several filler alloys, but only one filler may be optimal for a specific application. The major factors considered when choosing a welding filler alloy include 1) ease of welding, 2) tensile or shear strength of the weld, 3) weld ductility, 4) service temperature, 5) corrosion resistance, 6) color match between the weld and the base alloy after anodizing, and 7) sensitivity to weld cracking (KeyToMetals.com, 2009). Filler alloy selection charts list the recommended filler metals for various aluminum alloys and should be consulted before making a decision. Filler alloy 5356 was used in several of the laboratory welding studies discussed by Cole (1997). This filler alloy is an aluminum filler alloy with 5 percent magnesium added. Alloy 5356 might be used as a filler alloy because it provides a closer color match after anodizing or is a more rigid alloy, so feasibility is less of an issue when MIG welding.

simultaneously inside and outside the helmet. For at least the first of the four studies, testing involved about 100 minutes of arc time, which the researchers estimated as the typical cumulative amount of time that a welder has an arc struck over the course of an 8-hour shift.[282] A companion publication provides additional details about the first welding study (Cole et al., 2007).

Table IV-77 in Welding Appendix 3 summarizes the results from these studies. As shown, four positive beryllium results ranging from 9.3 µg/m^3 to 45.8 µg/m^3 are associated with MIG welding on four different aluminum base alloys containing 0.008 to 0.33 percent beryllium. In all four cases, only the base metal contains beryllium; the filler alloys do not contain beryllium. Cole et al. (2007) conducted numerous additional tests with other combinations of base and filler metals. Although the high levels of detection make the results difficult to interpret relative to the proposed PEL value (0.2 µg/m^3), all the emission levels from the other tests are lower than 1.0 µg/m^3, indicating that the emissions from the other combinations are at least 9 to 45 times lower than those associated with the MIG welding trials on beryllium alloy base metal.[283] When the base metal contained no beryllium, emission concentrations associated with filler alloy up to 0.0007 percent (7 ppm) beryllium were all less than 0.2 µg/m^3.

The results from these laboratory welding studies show that welding some aluminum alloys can generate beryllium concentrations significantly greater than 2.0 µg/m^3. Welding with aluminum filler alloys might also be associated with beryllium exposures, but together, the welding studies show that these concentrations are reliably less than 0.5 µg/m^3. In addition, the welding studies suggest that the beryllium content of the base metal has greater influence on potential beryllium exposures than the small amount of beryllium associated with typical aluminum filler alloys.

It should be noted, however, that the concentrations of airborne contaminants reported by Cole et al. (2007) are uncontrolled simulations and represent airborne emission concentrations only during the times when the electrode was struck. These values, therefore, represent a worst-case situation (i.e., uncontrolled continuous welding without breaks for repositioning or other purposes) and overestimate the exposure that would be experienced by a welder during normal operations, when sample results are typically time-weighted for 8 hours. For example, if the arc was struck only for the 100 minutes (out of 480 minutes) reflected by the samples, and air

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[281] Although the filler metals used in these studies did not contain beryllium, a limited review of aluminum filler metals shows that some filler metals contain beryllium concentrations ranging from less than 0.0003 percent to 0.0008 percent (AlcoTec, 2009; All-State, 2013; Aufhauser_Alum, 2009; Cole et al., 2007; Washington, 2009).

[282] The first of four studies was conducted at Martin Marietta laboratories, where sampling was performed during 100 minutes of arc time. The remaining three studies were conducted at Alcoa laboratories; however, the details of the sampling protocols were not specified (Cole et al., 2007).

[283] For MIG welding (with non-beryllium-containing filler alloys) on aluminum base alloys containing lower levels of beryllium (0.002 to 0.006 percent beryllium), the results are nondetectable for beryllium. However, the findings have higher reporting limits (0.63 µg/m^3 and 0.99 µg/m^3), so it is not clear how these results compare to the proposed PEL and action level. OSHA cannot be certain whether "reporting "limits" refer to LOD or LOQ in this case as it was not specified. For both MIG and TIG welding, testing was conducted with a filler alloy containing 0.0007 percent beryllium and two beryllium-free base alloys. In these instances, nondetectable beryllium results (0.2 µg/m^3 and 0.5 µg/m^3) are reported. A nondetectable result of 0.2 µg/m^3 is reported for MIG welding with beryllium-free base and filler metal, and a nondetectable result of 0.5 µg/m^3 is reported for plasma arc cutting on beryllium-free base metal. Finally, for three of the laboratory tests, low levels of beryllium (0.0001 to 0.0004 percent) were present in both the base and filler alloys. The results for these tests are nondetectable for beryllium and are reported as less than 1.0 µg/m^3 (Cole et al., 2007).

movement from general ventilation was sufficient to quickly diminish fume exposure between rounds of welding, the worker would experience 8-hour TWA concentrations just 21 percent of the values reported by Cole et al. (2007).[284] Still, these findings suggest there is a potential for significant beryllium exposures while welding some aluminum alloys.

The OSHA IMIS data provide additional evidence that beryllium exposures are low among welders working with aluminum in general industry. Eleven IMIS results specifically indicate that the welder was working on aluminum (e.g., alum welder, welding-aluminum, aluminum welder). Of these, 10 samples are nondetectable for beryllium and one is positive, with a result of 0.1 μg/m^3.

Information on beryllium exposure levels during aluminum welding is available from other industries. Table IV-78 in Welding Appendix 3 summarizes 17 sample results for aluminum welding and cutting operations in U.S. shipyards and Navy facilities (OSHA Shipyards, 2005; U.S. Navy, 2003). These data are characterized by a median of 0.04 μg/m^3 and a mean of 0.2 μg/m^3. Fourteen of these samples (82 percent) are nondetectable for beryllium and are assigned the analytical limit of detection (LOD) values, which are less than 0.1 μg/m^3 in every case. Only three results (18 percent) are positive for beryllium, with concentrations of 0.76 μg/m^3 (523 minutes), 0.77 μg/m^3 (533 minutes), and 1.34 μg/m^3 (534 minutes).

The laboratory welding studies described by Cole et al. (2007) demonstrate the potential for significant beryllium exposures (i.e., 9.3 μg/m^3 to 45.8 μg/m^3 for 100 minutes of arc time) among welders working with aluminum base metals.[285] However, the beryllium emissions measured in these studies are inconsistent with the PBZ exposure values in IMIS and U.S. Navy and shipyard data for workers welding on aluminum, which are typically well below 0.1 μg/m^3, with even the most elevated remaining below the current PEL of 2.0 μg/m^3.[286]

Beryllium is also added in small amounts to magnesium alloys to improve the quality of the melt and the castings (Houska, 1988). Concentrations in magnesium alloys typically range from 0.001 to 0.01 percent (Houska, 1988). Welding on such materials can result in beryllium exposures. Further, certain classes or grades of magnesium filler metal (e.g., welding wire) contain beryllium, creating another potential source of exposure. In magnesium-based filler metals, beryllium can be present in concentrations ranging from 0.0002 to 0.0008 percent (Aufhauser_Mag, 2013; Stoody, 2009; U.S. Welding, 2008; Uniweld, 2009).

[284] This calculation is based on 100 minutes of welding over an 8-hour shift, which is described as typical by the study author (Cole et al., 2007). Assuming no additional exposure during the day, and using OSHA's standard equation $(C_1)(T_1)/480$ = 8-hour TWA from 29 CFR 1910.1000, OSHA calculates that the hypothetical worker welding under the conditions experienced by the mannequin would have an 8-hour TWA exposure of: (C_1)(100 minutes)/480 minutes = 20.8 percent of the initial concentration. Here, C_1 is the concentration of beryllium in air during T_1, the period monitored.

[285] When these study findings are time-weighted for 8 hours, the 8-hour TWA results range from 1.94 μg/m^3 to 9.5 μg/m^3.

[286] Data contained in Appendix C of this chapter show that the highest exposures in U.S. Navy and shipyard data for welders working on beryllium are 0.76 μg/m^3, 0.77 μg/m^3, and 1.34 μg/m^3 (OSHA Shipyards, 2005; U.S. Navy, 2003).

EXPOSURE PROFILE

To estimate the exposure profile for welders in general industry, OSHA used unpublished personal breathing zone (PBZ) sampling results from several Materion facilities (previously Brush-Wellman) and a precision stamping case study (Brush Wellman Elmore, 2004; Brush Wellman Service, 2004; Brush Wellman Stamping, 2004). These data represent 44 full-shift total beryllium sampling results and are the primary information available to OSHA to characterize welding exposures in general industry. The findings are supplemented with a discussion of the relevant unpublished exposure data from the Integrated Management Information System (IMIS) and the specifically targeted beryllium exposures (not part of a metal screening) that occur when welding aluminum base metals.

Data Sources

Materion Operations: The Materion data include 37 full-shift PBZ samples representing TIG welding operations at three Materion facilities. Fifteen of the results were obtained during 1999 baseline exposure sampling at the company's Elmore, Ohio, facility, where beryllium alloy strip coils were butt-welded together on an automated weld line. These results range from 0.15 μg/m^3 to 2.21 μg/m^3. The welding operator stood near the operation to monitor the process. Exposure controls included local exhaust ventilation (LEV) at the welding point of operation and wet methods to contain loose beryllium-containing surface oxides on the hot-milled coils during handling. The remaining 22 samples were obtained between 1994 and 2001 at two of the company's alloy strip distribution centers, with results ranging from 0.01 μg/m^3 to 0.17 μg/m^3. At the strip distribution centers, coiled strips of copper-beryllium metal are smoothed and straightened using tension leveling and then are slit to customer-specified widths (Stanton et al., 2006). After slitting, lengths of copper-beryllium strip may be TIG welded end to end to create customer-specified lengths. The strip welding operations are enclosed and ventilated with a recirculating HEPA-filtered[287] LEV system.

The Materion samples (part of a larger dataset covering several industries) were analyzed using National Institute for Occupational Safety and Health (NIOSH) Methods 7102 (Beryllium and compounds, as Be) or 7300 (Elements by ICP), and the LOD was reported to be 0.1 µg per sample. For results less than the analytical LOD, a sample weight of 0.05 µg (one half the LOD) was used to calculate the sampling LOD concentration (Kent, 2005). Information indicating which sample results are below the analytical LOD is not available, however, so it is not readily apparent which, if any, of the Materion welding results are nondetectable.

Precision Stamping Case Study: The precision stamping case study includes seven full-shift PBZ samples obtained in 2000 for a resistance welding operation at a precision stamping facility. These data are part of a larger study that investigated airborne beryllium exposure during stamping of copper-beryllium alloy strip with high-speed punch presses (Brush Wellman Stamping, 2004; Materion PSCS 101, 2011). At this facility, the welding operator oversaw the spot welding machines and the stamping presses. In the welding process, a small single or double contact of silver was spot welded onto the copper-beryllium strip before final stamping of

[287] HEPA-filtered means filtered with a High Efficiency Particulate Air (HEPA) filter.

the part. The process was automated and enclosed, but not ventilated. No visible fume was produced.

Samples from the precision stamping facility were analyzed by NIOSH Method 7102 (Beryllium and compounds, as Be) and the laboratory limit of quantitation was 0.005 µg per sample. All seven resistance welding results were nondetectable for beryllium, with sampling LOD ranging from 0.005 $\mu g/m^3$ to 0.006 $\mu g/m^3$.

IMIS Data for Welding: The IMIS database includes results for approximately 4,148 samples that were analyzed for beryllium (and other metals), with job descriptions representative of welders in the general industry Standard Industrial Classification (SIC) codes (i.e., all industries except for agriculture, construction, maritime, and mining other than coal and gas extraction) (OSHA, 2009). These data are summarized in Tables IV-75 and IV-76 in Welding Appendix 1. While the circumstances of these results are not known, most exposures are nondetectable. Only 8 percent of the general industry welding results are positive for beryllium, and of these, the median exposure level (for the positive results) for nearly all manufacturing sectors is 0.1 $\mu g/m^3$ or less. As shown in Table IV-76, 88 percent (282 of 322 samples) of the positive results are less than or equal to 0.2 $\mu g/m^3$ and another 8 percent (25 samples) fall between 0.2 $\mu g/m^3$ and 1.0 $\mu g/m^3$. Five samples (1.6 percent) range between 1.0 $\mu g/m^3$ and 2.0 $\mu g/m^3$ and the remaining 10 samples (3.1 percent) exceed 2.0 $\mu g/m^3$.

Values exceeding the current Permissible Exposure Limit (PEL) of 2.0 $\mu g/m^3$ were noted in SIC 2531 (Public Building and Related Furniture), SIC 3443 (Fabricated Plate Work—Boiler Shops), SIC 3444 (Sheet Metal Work), SIC 3465 (Automotive Stampings), and SIC 3498 (Fabricated Pipe and Pipe Fittings).[288] Additionally, several samples obtained through OSHA's On-site Consultation Services Program also exceed the current PEL, with values ranging from 11 $\mu g/m^3$ to 32 $\mu g/m^3$; however, the data documentation does not indicate the types of industries associated with these results.

OSHA acknowledges that several factors limit the value of the IMIS dataset. First, no beryllium was detected in the vast majority of samples analyzed for beryllium (reported as "ND", or not detected); however, most of the IMIS beryllium samples likely were the result of general metal emissions screening (i.e., beryllium was not necessarily present in the sampled workplace but rather, was automatically included as part of the standard 10-metal analytical screening panel performed by the laboratory). Further, sample results in the IMIS database do not include the sampling LOD for nondetectable samples. It is not possible to tell whether the nondetectable samples were analyzed with a LOD below the proposed PEL and action level. Nevertheless, the IMIS sample results provide limited evidence that 1) general purpose welding can, on occasion, generate notable beryllium exposures and 2) unless workers are welding on or with beryllium-containing materials, beryllium exposures are rare.

The same trends have been observed among exposure results for welders at U.S. naval facilities, shipyards, construction industry worksites, and welding schools. In every case, the vast majority (or sometimes all) of the welding sample results are well below 0.1 $\mu g/m^3$; however, at least half

[288] The vast majority (283 samples) of the positive IMIS results were obtained at manufacturing facilities in SIC major groups 24 through 39 (encompassing the manufacture of wood, chemical, and metal products; industrial machinery; electronics; transportation equipment; instruments; and miscellaneous goods).

of these data sources indicate that a small percentage of the beryllium sample results exceed the proposed PEL of 0.2 μg/m^3 (up to 0.74 μg/m^3).[289] Because the exposure values from these sources are not from general industry establishments, and because some results are from area or less-than-full-shift samples, OSHA did not include them in the exposure profile. Instead, a discussion of these sources appears in Welding Appendix 2. In some cases, these data sources offer additional insight into the relationship between exposures and the type of welding, base metal, and welding materials associated with the samples.

IMIS Data for Resistance Welding: Several sources suggest that welders who perform resistance welding (e.g., spot welding machine operators) tend to have lower exposures to beryllium than other welders.[290] For example, IMIS provides supplemental exposure information regarding resistance welding in general industry (the sources of exposure information for resistance welding are discussed under Resistance Welding in the next section of this chapter).

Resistance welding can include welding with beryllium-containing electrodes as well as welding on beryllium-containing base materials. To identify resistance welding results in IMIS, OSHA reviewed job descriptions most representative of employees performing resistance welding, such as resistance welder, spot welder, butt welder, projection welder, seam welder, and others.[291] In all, 70 results with job descriptions representative of resistance welding were identified in the database. Fifty-eight (83 percent) of the results are nondetectable for beryllium (sampling LOD concentrations not reported for nondetectable results) and 12 are positive, with results ranging from 0.01 μg/m^3 to 0.2 μg/m^3. Eleven of the positive results have a value of 0.01 μg/m^3 for both spot and robotic welding. The twelfth positive result (0.2 μg/m^3) is reported for a butt welder. These data indicate that the beryllium exposures experienced by resistance welders are quite low. It is unknown whether the samples reflect the use of beryllium-containing materials such as copper-beryllium resistance welding electrodes.

IMIS Data for Arc and Gas Welding: IMIS also provides supplemental exposure information regarding arc welding, which reportedly is associated with the highest beryllium exposures. Of the approximately 4,148 results with job descriptions representative of welders, the vast majority (94 percent) do not specify the type of welding performed. As with resistance welding, OSHA reviewed the job descriptions and identified those most representative of arc welding, such as MIG, TIG, stick, flux-cored, and other arc welding. One hundred sixty-six arc welding results were identified, of which 78 percent (129 samples) are nondetectable for beryllium. The positive results (37 samples) range from 0.01 μg/m^3 to 2.0 μg/m^3, with a mean of 0.17 μg/m^3 and a median of 0.01 μg/m^3. Twenty-seven results are less than 0.1 μg/m^3; the remainder includes six results of 0.1 μg/m^3, one result of 0.4 μg/m^3, and three results ranging from 1.0 μg/m^3 to 2.0

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[289] Sources of exposure data from the U.S. Navy, the construction industry, and welding schools include: OSHA Shipyards, 2005; U.S. Navy, 2003; NEHC_Jan24, 2005; NIOSH HETA 82-106-1366, 1983; NIOSH ECTB 214-13a, 1997; and Wallace et al., 1997.

[290] Sources regarding variations in exposure with different types of welding and materials include OSHA, 2009; Brush Wellman Stamping, 2004; and Materion PSCS 101, 2011.

[291] To identify resistance welding job descriptions, OSHA searched the general industry IMIS data using the following search terms: resistance, lap, spot, projection, seam, butt, flash, upset, percussion, high frequency, and robot.

μg/m³. Although limited, these data show that arc welding is associated with higher beryllium exposures than resistance welding.

Exposure Profile for Welders

The exposure profile for welders in general industry is shown in Tables IV-73 and IV-74. This profile is based on the unpublished sample results from three Materion facilities and one precision stamping facility (as discussed in the Data Sources subsection of this Welding section) and reports the distribution of the results in relation to the current and proposed beryllium exposure limits. Although other exposure data sources exist, they provide only partial-shift or aggregated results (as opposed to individual results) and are excluded from the exposure profile. This profile is based on the best available exposure data for general industry.

Table IV-73—Personal Exposure Profile for Welders in General Industry[a]

Job Category	Number of Samples	Range (μg/m³)	Mean (μg/m³)	Median (μg/m³)
Welding: Beryllium alloy base materials	*44*	*0.005 to 2.21*	*0.19*	*0.02*
TIG Welding (beryllium alloy strip)	*37*	*0.01 to 2.21*	*0.23*	*0.05*
Resistance Welding[b] (copper-beryllium parts)	*7*	*0.005 to 0.006*	*0.005*	*0.005*

[a] General industry refers to all industries not included in agriculture, construction, maritime and mining except for oil and gas extraction.

[b] All results for resistance welding are nondetectable. Nondetectable results, where apparent, are incorporated into the exposure profile by using the sampling limit of detection (LOD) concentration for each result reported as nondetectable or less than the analytical LOD.

Source: Brush Wellman Elmore, 2004; Brush Wellman Service, 2004; Brush Wellman Stamping, 2004; Materion PSCS 101, 2011

Table IV-74—Distribution of Full-Shift PBZ Total Beryllium Exposure Results for Welders in General Industry[a]

Job Category	Number of Results in Range (μg/m³)						Total
	< 0.1	≥ 0.1 to ≤ 0.2	> 0.2 to ≤ 0.5	> 0.5 to ≤ 1.0	> 1.0 to ≤ 2.0	> 2.0	
Welding: Beryllium alloy base materials	*28 (64%)*	*5 (11%)*	*6 (14%)*	*4 (9%)*	*0 (0%)*	*1 (2%)*	*44 (100%)*
TIG Welding (beryllium alloy strip)	*21 (57%)*	*5 (13%)*	*6 (16%)*	*4 (11%)*	*0 (0%)*	*1 (3%)*	*37 (100%)*
Resistance Welding[b] (copper-beryllium parts)	*7 (100%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*0 (0%)*	*7 (100%)*

[a] General industry refers to all industries not included in agriculture, construction, maritime and mining except for oil and gas extraction.

[b] All results for resistance welding are nondetectable. Nondetectable results, where apparent, are incorporated into the exposure profile by using the sampling limit of detection (LOD) concentration for each result reported as nondetectable or less than the analytical LOD.

PBZ: personal breathing zone

Source: Brush Wellman Elmore, 2004; Brush Wellman Service, 2004; Brush Wellman Stamping, 2004; Materion PSCS 101, 2011

As shown in Table IV-73, the exposure profile for workers welding beryllium-containing base materials is characterized by a mean of 0.19 μg/m^3, a median of 0.02 μg/m^3, and a range from 0.005 μg/m^3 to 2.21 μg/m^3. These values represent 44 full-shift PBZ total beryllium sample results reported for general industry workers welding beryllium alloys.[292] Seven of the welding results (16 percent) are nondetectable for beryllium. Table IV-74 shows that 64 percent of the sample results are less than 0.1 μg/m^3, with an additional 11 percent between 0.1 μg/m^3 and 0.2 μg/m^3. Most of the remaining 11 sample results (25 percent) are below 1.0 μg/m^3, but one sample result (2 percent) of 2.21 μg/m^3 exceeds the current PEL of 2.0 μg/m^3.

The more elevated arc welding exposures (14 sample results ranging from 0.15 μg/m^3 to 0.88 μg/m^3 and the result of 2.21 μg/m^3, which is the highest in the exposure profile) occurred in Materion's primary beryllium production facility and reportedly are associated more with loose beryllium oxide scale (formed during hot rolling) than with the actual welding fume (Materion Information Meeting, 2012). Beryllium alloy products that are hot worked can develop a surface oxide composed of beryllium. The oxide scale can flake off and become airborne when workers manipulate the coils (i.e., while flexing the metal as they unroll and roll the coil before and after welding). The oxide film varies in thickness and composition depending on the alloy, the amount of surface area, and the processing technique (elevated temperature and the presence of moisture accelerates oxide formation) (Materion Information Meeting, 2012). Health and safety professionals who work frequently with beryllium welders estimate that airborne beryllium from flaking oxide may account for up to 90 percent of the exposure to welding operators who work with base metal when loose oxide is present (Corbett, 2006; Kent, 2005).

Overall, a distinct majority (75 percent) of the welding results included in the industry profile (Table IV-74) are less than or equal to 0.2 μg/m^3. These welders are known to be working with beryllium-containing materials. New exposure data OSHA received from Materion subsequent to the development of the welding exposure profile also support this finding and are consistent with the results of the exposure profile. These data include nine full-shift PBZ samples obtained during a TIG welding operation at a facility that fabricates plastic blow molds using copper-beryllium inserts (MC Pkg I-D, 2010). The operation is performed at a ventilated workstation and is used to repair molds by creating a buildup of metal on the wear surfaces of the molds that is subsequently machined to specifications. The nine results range from 0.008 μg/m^3 to 0.29 μg/m^3, with a mean of 0.05 μg/m^3 and a median of 0.02 μg/m^3. Eighty-nine percent of the results (eight of nine samples) are less than 0.1 μg/m^3. Of these, two are nondetectable for beryllium, both with sampling LOD concentrations of 0.008 μg/m^3. The highest result (0.29 μg/m^3) is associated with a 423-minute sample that included 3 hours of copper-beryllium welding. Comments included with the survey report suggest that a majority of the samples (i.e., six of the nine samples) do not reflect a full shift of welding on copper-beryllium alloys.

Similar results are evident among OSHA's IMIS data (profiled in Table IV-76 in Welding Appendix 1), which represent a wider group of welders for whom beryllium was detected in the breathing zone (signaling some source of exposure), but who might or might not have been working directly with beryllium alloys. Approximately 88 percent of the positive IMIS welding

[292] The industry profile data sources include Brush Wellman Elmore, 2004; Brush Wellman Service, 2004; Brush Wellman Stamping, 2004; and Materion PSCS 101, 2011.

results occurred at levels of 0.2 µg/m^3 or less, while nearly 8 percent of the results fell between 0.2 µg/m^3 and 1.0 µg/m^3, and 3 percent exceed 2.0 µg/m^3. These IMIS data support OSHA's preliminary conclusion that the welder exposure profile is representative of the exposure levels for all welders in general industry who work on materials that contain beryllium, regardless of the source of the beryllium (including beryllium alloy base material and other welding materials such as electrode/filler that contain lower amounts of beryllium).

A more detailed analysis of the exposure profile indicates that, compared to the industry average, certain types of welding can be associated with beryllium exposures that are greater or less than the industry average. The following discussion shows that some forms of arc welding (e.g., TIG welding) and welding on oxidized beryllium alloys are associated with greater exposure levels, while lower exposures result when workers perform resistance welding, particularly on clean, oxide-free alloys.

As noted in the exposure profile (Tables IV-73 and IV-74), the exposures for workers who are involved with arc welding beryllium alloy strip coils range from 0.01 µg/m^3 to 2.21 µg/m^3, while the resistance welding results for workers in a stamping facility that produces parts from beryllium alloy strip are all nondetectable for beryllium (0.005 µg/m^3 to 0.006 µg/m^3). OSHA concludes that this effect is likely due in part to the decreased weld time during resistance spot welding and increased distance between the welder and the mechanical resistance welding machines compared to workers who manually weld across the width of alloy strips or products (i.e., the resistance welding operation at the precision stamping facility was automated and enclosed). Other factors also contribute to these differences in exposure level, however. Three important differences are 1) the scale and extent of operations, 2) the presence or absence of heat treating at a facility, and 3) the extent to which beryllium surface oxide is present on the metal.

Among arc welders, the strip-welding exposure results for workers at the Materion service (or distribution) centers are lower (typically 0.01 µg/m^3 to 0.05 µg/m^3) than for workers at the Elmore primary beryllium production facility. This might be attributable to the scale of the service operation (i.e., cycled, noncontinuous welding process with small-scale product) as well as to a lack of heat treatment prior to welding at the service centers, which use alloy strip with surfaces treated to minimize oxidation. The service centers perform work on oxide-free copper-beryllium alloy strip products, including limited processing, with the main production activities including slitting, welding, and material handling. They avoid heating the strip, thereby preventing surface oxides from forming. Additionally, the strip welding operations are enclosed and ventilated. Under these conditions, only one of 22 results (5 percent) for the service centers exceeded 0.1 µg/m^3.

Stanton et al. (2006) reported that workers in the beryllium service centers would be expected to have lower exposures than those in primary production because work at the distribution centers does not require large-scale heat treatment or manipulation of materials that are known to generate higher levels of beryllium air contaminants—mainly from the generation and release of beryllium oxide from the metal surface.[293] Stanton et al. (2006) also examined Materion records

[293] Stanton et al. (2006) do not specifically state that Materion Corporation is the subject of their investigation. OSHA reached this conclusion after Stanton et al. (2006) noted that the subject of their paper was the leading global producer and supplier of beryllium, which operated three copper-beryllium alloy distribution centers in the United States.

of full-shift PBZ samples from 1996 to 2004. For strip metal welding, a total of 44 samples were analyzed.[294] The 44 samples ranged from 0.01 μg/m^3 (nondetectable) to 0.17 μg/m^3, with a median of 0.01 μg/m^3.

The available exposure data for resistance welding (seven full-shift nondetectable PBZ results), although limited, are also supported by the findings in IMIS. As noted in on Data Sources for this Welding section, 83 percent of the 70 results representing resistance welding in the IMIS database are nondetectable for beryllium. These findings are also consistent with the primary beryllium producer determination that properly controlled copper-beryllium resistance welding operations do not present any special hazards because the weld pool (e.g., the area of the weld where the metal has reached its melting point) is small and is not exposed (Materion_ResistanceWeld, 2011). Additionally, an OSHA beryllium consultant determined that during resistance welding, the beryllium-containing electrode does not melt; therefore, the generation of airborne beryllium fume is not anticipated (Corbett, 2004). If beryllium is contained in filler material and/or in the base metal, the potential exists to generate airborne levels of beryllium, and LEV might be necessary to control exposures. Reconditioning or dressing resistance welding electrode tips (e.g., grinding) to remove surface oxidation can, however, generate significant airborne beryllium particles and should only be performed with LEV.

Limited data from other industries also suggests that beryllium exposures associated with resistance welding are low. Six PBZ samples obtained on U.S. Navy welders using resistance welding methods were all nondetectable for beryllium, with sampling LOD concentrations ranging from 0.01 μg/m^3 to 0.08 μg/m^3 (8-hour time-weighted averages) (U.S. Navy, 2003). Sampling durations ranged from 28 to 321 minutes. It is not known whether these results reflect the use of copper-beryllium resistance welding electrodes, and there is no indication that the base metals contained beryllium.[295]

Generalized reports in the published literature provide additional support for the available exposure information for resistance welding. Slavin (1984) notes that metal fumes associated with resistance welding processes are minimal compared to arc welding due to the short weld cycle time. Lee et al. (1990) also report that the metal fume hazards associated with resistance (spot) welding are considered low compared to other types of welding. Area samples collected in a factory during a spot-welding operation were nondetectable for cadmium (< 1 μg/m^3), chromium (< 8 μg/m^3), cobalt (< 2 μg/m^3), and nickel (< 6 μg/m^3), despite the fact that each of these elements was known to be present in the metal. Mild steel wires containing about 0.2 percent each of chromium, cobalt, and nickel were fed into the spot-welding machine and welded together to form a cross-linked wire mesh. The welding electrode was copper and contained approximately 0.4 percent chromium.

[294] The time frame covered differs from that of the date provided by Materion to OSHA, but the information in Stanton et al. (2006) is not sufficient to identify individual differences in the data.
[295] The base metals reported included steel, stainless steel, and painted metal; in two instances the base metal was not specified (U.S. Navy, 2003).

TECHNOLOGICAL FEASIBILITY

Welding—Baseline Controls

Based on the available information, OSHA finds that baseline exposure controls for welders typically include the use of LEV and/or enclosures when the base metal is a beryllium alloy. For example, at Materion's Elmore facility, sheets of alloy strip were TIG-welded together to produce longer length coils using LEV, with a slot-type exhaust hood at the welding point-of-operation.[296] For other beryllium alloy welding operations included in this analysis, the welding processes were either enclosed (workers overseeing resistance welding) or enclosed and ventilated (Materion beryllium service centers).[297]

OSHA's welding and cutting standard for general industry (29 CFR 1910.252) lists minimum controls that employers must put in place for beryllium alloy welding. Paragraph (c)(8) of that standard requires LEV and airline respirators for all welding or cutting operations involving beryllium-containing base or filler metals, unless air sampling under the most adverse conditions has established that the worker's exposure is at or below the PEL as defined by 29 CFR 1910.1000.[298] These requirements apply indoors, outdoors or in confined spaces. In all cases, workers in the immediate vicinity of the welding or cutting must be protected by LEV or airline respirators.

All the sample results included in the exposure profile for this industry were obtained under conditions that complied with the welding and cutting standard requirements.[299] Therefore, the

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[296] As a supplemental control, the coils were also wetted with process water to help contain loose beryllium-containing surface oxides during handling, a substantial source of exposure during the welding process; however, this was not found to be an effective control, as the water dried quickly (Materion Information Meeting, 2012).

[297] When the base metal does not contain beryllium, welding is typically conducted without the use of LEV. Based on the best available information, OSHA estimates that LEV is used less than 20 percent of the time when the base metal welded is aluminum or another non-beryllium alloy such as stainless steel or iron (OSHA Shipyards, 2005; U.S. Navy, 2003). OSHA made this determination using U.S. shipyard and Navy facility data and the findings of arc welding studies (Donoghue et al., 1994; Fishwick et al., 1997; Korczynski, 2000; Nelson et al., 2009). OSHA examined 60 arc welding results (MIG, TIG, and stick welding) from shipyard and Navy facilities and determined that LEV was used in about 18 percent of the results (11 samples); natural ventilation (i.e., an open window) was present for another 8 percent (five samples); and for 30 percent of the results (18 samples), no engineering controls were used. For the remaining 26 samples (43 percent), no information on controls was provided.
Nelson et al. (2009) characterized shipyard welders' exposure to total welding fume and its metal components under different conditions and environments and found that only 2 percent of the welders used LEV, occurring only in shop environments. When welding occurred in enclosed or confined spaces, only dilution ventilation was observed. This observation is consistent with the available information from shipyards and Navy facilities. For example, three shipyard samples with positive beryllium results of 0.76 $\mu g/m^3$, 0.77 $\mu g/m^3$, and 1.34 $\mu g/m^3$ were collected on workers welding aluminum in confined or semi-confined spaces with only ship ventilation (general dilution ventilation). Two other welding studies reported that 10 percent (Korczynski, 2000) and 16 percent (Fishwick et al., 1997) of welders welded with functioning LEV systems. In another study, investigators noted the complete absence of LEV while welders performed arc welding in large workshops (Donoghue et al., 1994).

[298] For construction and shipyard environments, OSHA welding and cutting standards require LEV for all work in enclosed spaces (29 CFR 1926.353 and 29 CFR 1915.51).

[299] Three of the four facilities used LEV (or LEV and enclosure), while the stamping facility that performed resistance welding used enclosure only, because air sampling had established that worker exposure was at or below the PEL (Brush Wellman Stamping, 2004; Materion PSCS 101, 2011).

median exposure level for the exposure profile for workers welding beryllium-containing alloys (0.02 μg/m^3) also represents the median exposure level for these baseline conditions. The available information, however, is not sufficient to confirm that all ventilation systems used to comply with the OSHA welding and cutting standard are designed and maintained for optimal beryllium control.

Welding—Additional Controls

The exposure profile for welders is based on 44 full-shift samples from four establishments. The median exposure level for this job category is 0.02 μg/m^3, and 75 percent of the results are less than or equal to 0.2 μg/m^3. Additional controls will be required to reduce the exposures of the remaining 25 percent of welders who work on beryllium alloys to 0.2 μg/m^3. Control options for this industry include taking steps to minimize the presence and release of beryllium oxide that can flake off the surface of the metal work piece when the welder handles it (applicable only to facilities and operations where beryllium alloy has not been treated to prevent loose oxide from forming) and/or enhancing exhaust ventilation.[300]

As noted in the previous section, welding fumes could account for just 10 percent of welders' beryllium exposure when welding on beryllium coated with surface oxide. Flaking oxide may account for 90 percent of the beryllium exposure experienced by a welder and has been implicated in the exposure levels recorded at the Materion Elmore facility (Corbett, 2006; Kent, 2005). Accordingly, reducing the oxide as a source of contaminant could have a dramatic effect (90-percent reduction) on the 14 most elevated exposure results in the industry profile (ranging from 0.15 μg/m^3 to 0.88 μg/m^3, plus one value of 2.21 μg/m^3), which are reportedly due to loose beryllium oxide scale. Under this theory, completely eliminating the release of loosely adhered oxide would bring these 14 most highly exposed workers down to levels of between 0.015 μg/m^3 to 0.088 μg/m^3, plus one value of 0.221 μg/m^3. Employers might be able to eliminate the release of loosely adhered oxide by chemically stripping and pickling the beryllium alloy work piece prior to welding on it. These procedures remove the loose surface oxides and stabilize the surface to prevent additional loosely adhered beryllium oxides from forming (Materion Information Meeting, 2012). Although supporting data are not available, safety and health professionals at Materion's Elmore facility report that the beryllium exposure of welders on their strip welding line decreased substantially when welding was performed only on pre-cleaned/pickled alloy strip (Kent, Michael S., 2012). An alternative method for eliminating loose oxides from the surface involves employing a wet method with an amending agent that does not dry or interfere with or create a hazard during hot work. Although not yet incorporated into the overall production process, such an amending agent is currently undergoing testing (Materion Information Meeting, 2012).

Where welding fume is the primary source of beryllium exposure, LEV will be needed as an additional control measure. Where existing LEV is not adequate to reduce exposures to or below

[300] Based on knowledge of their customers from direct sales, Materion Corporation reports that welding is commonly performed on alloy bulk products whereas few (e.g., one to five) of their alloy strip customers currently perform welding. Most customers of alloy bulk products perform cold forming, which does not generate substantial loose oxide. A number of these customers, however, also perform some hot processes, as either forming or heat treating steps, which can cause loose surface oxides to form on the alloy (Kent, Michael S., 2012).

the PEL, employers must enhance the existing ventilation controls to improve placement of the exhaust pickup or hood, the work piece, or both. The ventilation hood needs to be well placed to avoid interference with the welding process while optimizing exposure reduction. Ideally, the LEV hood or exhaust pick-up should be positioned close to and above the welding arc at an angle of approximately 45 degrees (Fiore, 2006). Additionally, it is critical that the hood be repositioned regularly during the course of the welding (Fiore, 2006). Furthermore, freely suspended hoods, cross-draft and down-draft tables, enclosing hoods, open hoods, and fume extracting welding guns (gun-mounted exhaust) are among possible technical approaches to reducing exposures (see Group 13.40 in ACGIH, 2010; AIHA, 1984). For temporary or mobile operations, movable LEV systems need to be employed and used carefully to ensure that toxic dust and fumes are not dispersed.

Various studies have been performed to assess the likely effectiveness of LEV systems (including portable LEV) in controlling welding fumes. Welding studies specific to beryllium exposures are limited to one study by Materion Corporation, which reports that ventilated welding enclosures used to weld other metals are effective for welding copper-beryllium alloys (Materion SF1, 2011). As an internal standard, this company judges the effectiveness of a control against its ability to reliably maintain 8-hour PBZ exposures to a recommended exposure guideline of 0.2 µg/m^3 (Knudson and Kolanz, 2009). A process is considered controlled when the recommended exposure guideline is achieved with a degree of statistical confidence that demonstrates that all worker exposures are held at this level or lower the vast majority of the time.[301] To further reduce the exposures, OSHA believes that this ventilated welding enclosure method can be implemented in many situations, including the operation that resulted in the highest exposure for welders (Table IV-74). Currently, this exposure remains slightly above 0.2 µg/m^3 (0.221 µg/m^3) even after accounting for loose oxide control.

Materion Corporation's recent information shows that effective capture is possible with carefully designed LEV systems intended to control fumes, and beryllium fumes in particular. This welding ventilation study, specific to beryllium, occurred at a facility that manufacturers blow molds using copper-beryllium inserts (MC Pkg I-D, 2010). At this facility, TIG welding is used to repair the molds by building up metal on wear surfaces and pinch edges that are subsequently machined to specifications.[302] The employer was able to reduce welder beryllium exposure levels substantially by adding enclosures and improving exhaust ventilation. When the study began, the existing TIG welding workstation was equipped with a nonenclosing backdraft slot hood connected to a wall-mounted exhaust fan. The average slot velocity was approximately 909 feet per minute (fpm); however, at the edge of the work table (24 inches from the hood slots), where most of the welding occurred, the average capture velocity was less than 5 fpm. With the existing welding ventilation system, one full-shift PBZ sample obtained on a worker whose activities included 3 hours of copper-beryllium welding resulted in a beryllium exposure level of 0.29 µg/m^3. Based on this finding (which was higher than the employer's occupational exposure limit of 0.2 µg/m^3), the welding hood was subsequently enclosed on three sides and the

[301] The company follows statistical guidelines published by the American Industrial Hygiene Association, including as Appendix VI—Exposure Control Charts in *A Strategy for Assessing and Managing Occupational Exposures* (Hewett, 2006).
[302] Although not specifically stated, the nature of the parts being welded suggest that the primary source of airborne beryllium is fume generated by the welding process itself (in contrast to recently heat-treated alloy strip, because the mold insert being repaired in this case is unlikely to have a significant amount of loose oxide on its surface).

exhaust system was redesigned to draw an average flow rate of 100 cubic feet per minute (cfm) per square foot of hood face area and 2,000 fpm ductwork transport velocity. These engineering enhancements increased the hood capture velocity from 5 fpm to 50 fpm. After the ventilation system improvements, a full-shift PBZ sample for a worker who welded on copper-beryllium for approximately 2 hours was nondetectable for beryllium, with a sampling LOD concentration of 0.008 $\mu g/m^3$. The enhanced LEV system, together with improved work practices (i.e., proper placement of hood during welding) and materials storage (so as not to interfere with the hood performance), resulted in a 97 percent reduction in beryllium exposure during copper-beryllium TIG welding. This experience demonstrates that a welding ventilation system intended to provide benefit at low exposure levels can offer great improvement over typical existing ventilation systems, such as exhaust trunks.

Correct use of portable ventilation systems can greatly improve system effectiveness. A second relatively recent study focused on reducing welder exposures to another highly toxic metal (in this case hexavalent chromium (chromium VI)). This study, conducted by the Center for Construction Research and Training (formerly The Center to Protect Workers' Rights) (CPWR) at a training center for pipefitters and plumbers measured chromium VI exposures with LEV with and without instruction on correct placement of the LEV hood and found a dramatic difference in exposure levels before and after instruction (CPWR, 2008; Susi and Meeker, 2008; TAPS Grant U54 OH008307-05 Year 3, 2007). For welders using LEV while working on carbon steel, the mean chromium VI sample result dropped by 99.6 percent, from 40.6 $\mu g/m^3$ before instruction to 0.16 $\mu g/m^3$ after the welders were instructed on the correct use of LEV (exposure levels ranged from less than 0.04 $\mu g/m^3$ to 0.38 $\mu g/m^3$). The difference was less extreme, but still considerable, with an 85.7 percent reduction when welders worked on stainless steel. The study investigators suggested that differences in the welding material gauge and percent time spent welding might account for the differences in results for welders working on different base metals.

In its review of the literature, OSHA finds that most studies on LEV for welding evaluate the extent to which welding fume is controlled by an exhaust system compared to uncontrolled welding (no exhaust system or general dilution ventilation only). Although equally relevant for beryllium fume as for any other metal fume, these studies do not define the level of benefit derived from improved LEV compared to poorly functioning LEV. Additionally, many focus on welding ventilation systems that are not intended to control fumes to exposure levels that approach the levels of interest for beryllium (0.2 or less $\mu g/m^3$). For example, Flynn and Susi (2012) conducted an extensive review of the literature on LEV systems for welding with relevance to the construction industry (much of it on systems more mobile than are available in general industry beryllium facilities). Flynn and Susi (2012) evaluated more than two dozen studies conducted in the construction, shipyard, and general industry over several decades, concluding that "45–50 percent or more reduction in exposure is possible with portable or fixed LEV systems relative to natural ventilation, but that correct positioning of the hood and adequate exhaust flow rates are essential." All these studies, however, either compared exposures with and without the ventilation system or were qualitative—providing specifications for LEV suitable for welding, rather than evaluating effectiveness numerically.

OSHA independently reviewed several evaluations of non-beryllium welding ventilation systems and drew a similar conclusion to that of Flynn and Susi (2012): Compared to no system, LEV systems designed for capturing general welding fumes and other emissions (with higher PELS) typically offer exposure reductions in the range of 50 percent, although findings vary widely. See Welding Appendix 4 for a discussion of several such articles. One of those articles, by AWS, shows that dramatic exposure reduction (96 percent) can occur when the worker uses a movable exhaust system as intended (OSHA-H054A-2006-0064-2527). Although OSHA concluded that this exposure reduction represents a best case scenario, the results support the findings from Susi and Meeker (2008), who reported similar results in a larger study (described above).

Based on the findings presented by Materion (in MC Pkg I-D, 2010) and Susi and Meeker (2008), OSHA preliminarily concludes that improvements in existing ventilation design, position, and operator usage techniques will reduce worker beryllium exposure levels up to 97 percent. Each of these methods has been demonstrated to reduce metal fume exposures of welders by 97 percent or better. A 97-percent additional reduction in the 0.221 μg/m^3 value (achieved by eliminating loosely adhered oxide as a source) will bring it down to well below 0.1 μg/m^3 (i.e., 0.007 μg/m^3). In those cases where loose beryllium oxide is not the major source of welders' beryllium exposure, a 97-percent reduction in exposure due to enhanced LEV will likewise reduce exposures below 0.1 μg/m^3. For example, at one of the Materion service centers (where oxide-free strip products are processed), the highest exposure associated with a copper-beryllium alloy strip TIG welding operation was 0.17 μg/m^3. Reducing this value by 97 percent will result in an exposure level of 0.005 μg/m^3. Acknowledging that other welding studies have reported lower exposure reductions, OSHA notes that an improvement from enhanced LEV as low as 55 percent would reduce the highest exposure to below 0.1 μg/m^3.

Other control methods are also available, including design and work practice controls. As one option, employers can isolate welding operations on beryllium-containing materials from other operations to avoid cross contamination or secondary exposures. Additionally, employers can install ventilated enclosures that capture and control potential emissions. For fixed welding operations, work locations can be designed so that welders can remain as removed from welding fumes as possible.

Automated welding processes (where operators can be farther away from the fume source) should also be considered. Automated processes generally can be effectively controlled with tight enclosures and LEV. In contrast to manual operations, LEV hoods can be positioned very close to the operation without interfering with visibility or worker movement (Slavin, 1984). Summary statistics for a laser welding operation at a primary beryllium producer's alloy thin gauge strip and wire products manufacturing facility suggest that beryllium exposures are low when welding operations are well controlled.[303] The welding operation at this facility takes place in an enclosed booth. Twelve full-shift PBZ sample results for the laser welder operator range from 0.010 μg/m^3 to 0.023 μg/m^3, with a mean of 0.02 μg/m^3 (OSHA-H005C-2006-0870-0093).[304]

A change in welding methods might present another opportunity for exposure reduction at some facilities. As noted in the Beryllium Exposures from Welding section, welding emissions are

[303] The alloy products produced contain 0.1 to 2.0 percent beryllium.
[304] Individual exposure results are not available, therefore, these sample results are not included in the exposure profile for welders.

influenced by a number of variables, including the welding process, electrode, current, arc voltage/arc length, electrode polarity, shielding gas, contact-tube-to-work distance, and metal transfer mode (AIHA, 1984). Facilities should consider fume production when choosing a welding process, shielding gases, and welding parameters. Processes such as TIG and submerged arc welding (welding conducted in water medium) generate fewer fumes than the other traditional arc and gas welding methods discussed (Fiore, 2006). Stick and flux-cored arc welding tend to produce more fumes, especially in terms of the amount of fume generated per unit length of weld (Fiore, 2006). For example, OSHA understands that flux cored arc welding reportedly requires personal protective equipment for skin and mucous membrane protection because the process liberates water-soluble beryllium salts. If it is not possible or practical to change to a different welding process to minimize exposure to beryllium, it might be possible to modify the welding process. For example, argon-rich shielding gases produce fewer total fumes than carbon dioxide and helium-rich shielding gases (Fiore, 2006). Another option involves reducing the amount of total fumes generated by modifying the welding parameters. In general, reducing the current and voltage reduces the fume generation rate (Fiore, 2006). Additionally, the metal transfer mode used with MIG welding affects the total amount of fumes generated. Studies have shown that MIG welding with pulse[305] transfer produces fewer total fumes than MIG welding with spray transfer (Fiore, 2006). Significantly reducing the amount of total welding fumes generated helps reduce the potential exposure to beryllium.

Welding—Conclusion

The median exposure level for welders working with beryllium-containing materials is 0.02 μg/m^3. Based on the exposure profile, most welders (75 percent) have exposures significantly below 0.2 μg/m^3 and will not require additional controls to reduce exposures to or below the proposed PEL. These welders are generally working with oxide-free base materials, and the level of control has been achieved through exhaust ventilation used in accordance with 29 CFR 1910.252, and/or by using automated resistance welding methods with process enclosures. For the 25 percent of welders that experience beryllium exposures exceeding this level (in all cases due to the presence of loose oxides), additional controls include two methods: first, eliminating surface oxide release while handling beryllium alloys, then implementing or improving exhaust ventilation to manage beryllium fume emissions from the welding process.

All of the sample results included in the exposure profile with the exception of the one highest result (i.e., values up to 0.88 μg/m^3) would be reduced by 90 percent to a level of 0.088 μg/m^3 or less by eliminating surface oxide release (Corbett, 2006; Kent, 2005). This can be accomplished by using only chemically treated alloys (e.g., by pickling) or by treating the alloy surface with an amended wetting agent that provides long-lasting benefits (Materion Information Meeting, 2012). Strip alloy that is free of loose oxides is readily available; Materion Corporation currently provides it no other way (Materion Information Meeting, 2012; Kent, Michael S., 2012). The highest value in the exposure profile (2.21 μg/m^3) would be reduced to 0.221 μg/m^3 using this method. Using the results of the available welding studies, OSHA further estimates that improvements to LEV system design, positioning, and use can reduce beryllium exposures by up to an additional 97 percent, reducing the 0.221 μg/m^3 value to 0.007μg/m^3. The available

[305] A pulse transfer delivers the electrode or filler material intermittently to the point of operation.

information suggests that implementing additional controls can reduce exposures to below 0.1 μg/m^3. OSHA therefore preliminarily concludes that the proposed PEL of 0.2 is feasible for most welders working with beryllium-containing materials, and believes that the controls can also reduce exposures to an alternative PEL of 0.1 μg/m^3.

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SECTION 10—WELDING, APPENDIX 1—OSHA IMIS PBZ TOTAL BERYLLIUM AIR SAMPLING RESULTS FOR WELDING OPERATIONS IN GENERAL INDUSTRY

Table IV-75—OSHA IMIS PBZ Total Beryllium Air Sampling Results for Welding Operations in General Industry[a]

SIC Group	SIC Description	No. PBZ Samples With Positive Results/Total No. PBZ Samples[b]	Example Welding-Related Job Descriptions (as listed in the IMIS database)	Range[c] (µg/m³)	Mean[c] (µg/m³)	Median[c] (µg/m³)
13	*Mining: Oil and gas extraction*	*0/8 (0% positive)*	*Welder; welder helper*	*None*	*None*	*None*
20-23	*Manufacturing: Food, tobacco, textile mill and apparel products*	*0/14 (0% positive)*	*Welder; welder helper; A grade welder*	*None*	*None*	*None*
24-27	*Manufacturing: Lumber/wood products; furniture/fixtures; paper/allied products; printing/publishing/allied industries*	*7/158 (4% positive)*	*Welder; welder maintenance; welder foreman; welder-frame shop; beam welder; welder 5; welder/building 1; welder building 2; manual welder; robot welder operator; production welder*	*0.01–5.2*	*0.76*	*0.03*
28-32	*Manufacturing: Chemicals/allied products; petroleum refining/related industries; rubber/miscellaneous plastics products; leather/leather products; stone/clay/glass/concrete products*	*7/66 (11% positive)*	*Maintenance welder; welder; MIG/TIG welder/maintenance; millwright welder; stick welder maintenance; TIG welder maintenance; welder assistant*	*0.1–0.11*	*0.1*	*0.1*
33	*Manufacturing: Primary metal industries*	*28/183 (15% positive)*	*Welder(s); A1-welder; weld trim; production welder; welder/arc/air; MIG welder; MIG welder/plasma cutter; apprentice welder; pipefitter/welder; weld mill operator 4; welder grinder; welding; maintenance welder; welder/pourer*	*0.002–1.0*	*0.11*	*0.1*

Table IV-75—OSHA IMIS PBZ Total Beryllium Air Sampling Results for Welding Operations in General Industry[a]						
SIC Group	**SIC Description**	**No. PBZ Samples With Positive Results/Total No. PBZ Samples[b]**	**Example Welding-Related Job Descriptions (as listed in the IMIS database)**	**Range[c] (μg/m³)**	**Mean[c] (μg/m³)**	**Median[c] (μg/m³)**
34	*Manufacturing: Fabricated metal products*	*124/1,374 (9% positive)*	*Welder; welding; butt welder; taper welder; MIG welder; MIG welding; foreman and welder; welder/fabricator; welder finish; TIG welder; TIG welding; panel welder; spot welder; welder, robotic; maintenance welder; welder, SS workcell*	*0.004–4,800*	*43.4*	*0.03*
35	*Manufacturing: Industrial and commercial machinery and computer equipment*	*70/1,135 (6% positive)*	*Welder; welding; TIG welding; welder (MIG); fitter welder; welding buckets; MIG, TIG welder; MIG welder*	*0.01–0.8*	*0.11*	*0.05*
36	*Manufacturing: Electronic and other electrical equipment/components*	*1/79 (1% positive)*	*Welder; welding; welder fabrication; welder/welding facility; welder/forklift driver; welds transformers; welder/grinder; spot weld(er); galvanized welding; steel welder; cell welder; air arcing welder; welder/MIG; heat sealer/welder; TIG welder*	*0.01–0.01*	*0.01*	*0.01*
37	*Manufacturing: Transportation equipment*	*41/771 (5% positive)*	*Welder; line welder; automatic welder; MIG welder; production welder; station #3 welder; subassemble/spot weld; welder-flux; aluminum welder; TIG welder; brass welder; flux core welder; welder/stick; ring welder helper*	*0.01–2.0*	*0.23*	*0.1*
38-39	*Manufacturing: Instruments, photographic/medical/optical goods; watches/clocks and miscellaneous manufacturing industries*	*5/83 (6% positive)*	*Welder; repair welding; TIG/MIG welder(ing); welder/grinder; lead welder; welder #2, #5, #7, #8, or #9 station; lead arc welder; mechanic welder; MIG weld aluminum and steel; stick weld steel; welder/fitter; welding aluminum; S-Y bottom welder; welder S-Y bancroft; welder/old S-Y bottom*	*0.1–0.11*	*0.11*	*0.11*

Table IV-75—OSHA IMIS PBZ Total Beryllium Air Sampling Results for Welding Operations in General Industry[a]

SIC Group	SIC Description	No. PBZ Samples With Positive Results/Total No. PBZ Samples[b]	Example Welding-Related Job Descriptions (as listed in the IMIS database)	Range[c] (µg/m^3)	Mean[c] (µg/m^3)	Median[c] (µg/m^3)
40-49	*Transportation, communications, electric, gas, and sanitary services*	*4/47 (9% positive)*	*Mechanic welder; welder; car man welder; arc welding and cutting; welder cutter*	*0.01–0.01*	*0.01*	*0.01*
50-67	*Wholesale and retail trade; finance, insurance, and real estate*	*0/41 (0% positive)*	*Welder; welding; iron worker/welder; maintenance welder; MIG steel welder; sheet metal welder; welder/fabricator; machinist welder; head welder; welding technician*	*None*	*None*	*None*
70-89	*Services*	*28/152 (18% positive)*	*Welder(s); welder/metal finisher; welder supervisor; drive shaft welder; F/T welder; machinist welder; P/T welder; welder/cutter; welder/fabricator; welder laborer; welding head leather*	*0.01–0.4*	*0.06*	*0.04*
91-99	*Public administration*	*0/18 (0% positive)*	*Welder, welder-student; apprentice welder*	*None*	*None*	*None*
N/A	*OSHA On-Site Consultation Services*	*7/19 (37% positive)*	*Welder*	*0.05–32.0*	*16.8*	*11.0*
Total		*322/4,148 (8% positive)*		*0.002–4,800*	*17.2*	*0.05*

[a] *OSHA uses the term "general industry" to refer to all industries not included in agriculture, construction, or maritime.*

[b] *Includes all welding-related PBZ samples by SIC code.*

[c] *The range, mean, and median results are based on positive sample results only. All positive results are included. Note that sampling limits of detection for nondetectable samples are not available in the IMIS database.*

PBZ: personal breathing zone
N/A: not available

Source: OSHA, 2009

Table IV-76—Distribution of Positive OSHA IMIS PBZ Total Beryllium Air Sampling Results for Welding Operations in General Industry

Job Category	Number of Results in Range (µg/m^3)						Total
	<0.1	≥0.1 to ≤ 0.2	> 0.2 to ≤ 0.5	> 0.5 to ≤ 1.0	> 1.0 to ≤ 2.0	> 2.0	
Welders	*204 (63.4%)*	*78 (24.2%)*	*14 (4.3%)*	*11 (3.4%)*	*5 (1.6%)*	*10 (3.1%)*	*322 (100%)*

Source: OSHA, 2009 (see Table IV-75)

SECTION 10—WELDING, APPENDIX 2—FULL-SHIFT EXPOSURE RESULTS FOR WELDERS AT U.S. NAVAL FACILITIES, SHIPYARDS, CONSTRUCTION INDUSTRY WORKSITES, AND WELDING SCHOOLS

U.S. NAVAL FACILITIES AND SHIPYARDS: One hundred twenty-seven PBZ samples collected on welders welding non-specified or non-beryllium-containing materials in U.S. shipyards and Navy facilities range from 0.02 $\mu g/m^3$ to 0.74 $\mu g/m^3$, with a mean of 0.13 $\mu g/m^3$ and a median of 0.08 $\mu g/m^3$ (OSHA Shipyards, 2005; U.S. Navy, 2003). Of the 127 samples, 123 samples (97 percent) are nondetectable for beryllium. This pattern was also confirmed in an observation by the Navy Environmental Health Center, which indicated that beryllium has not generally been found in welding fumes (NEHC_Jan24, 2005). The four positive results include values of 0.1 $\mu g/m^3$, 0.15 $\mu g/m^3$, 0.66 $\mu g/m^3$, and 0.74 $\mu g/m^3$. For three of the results (0.1 $\mu g/m^3$, 0.15 $\mu g/m^3$, and 0.66 $\mu g/m^3$) the base material welded was not mentioned; for the remaining value, which is also the highest result (0.74 $\mu g/m^3$), a shipyard employee was working with scrap metal.

CONSTRUCTION INDUSTRY: In the construction industry, NIOSH evaluated employee exposures to particulates from arc welding operations at the site of the Honda Motor Company of America plant in Marysville, Ohio (NIOSH HETA 82-106-1366, 1983). NIOSH investigators collected 47 PBZ and general area air samples for total particulates and metals inside the building at the construction site. The investigators analyzed 28 of the samples for iron, lead, nickel, zinc, beryllium, and copper. Of the metals, only iron was detected, in concentrations ranging from 20 $\mu g/m^3$ to 2,580 $\mu g/m^3$. All results for beryllium, copper, lead, nickel, and zinc were nondetectable (sampling LOD concentrations not provided). Engineering controls consisted of several ceiling exhaust fans specifically installed to reduce the levels of air contaminants associated with welding and diesel vehicular traffic. No information was provided about the type of arc welding performed, the base metals welded, or the sampling and analytical methods employed.

WELDING SCHOOLS: Studies in welding schools also show that beryllium exposures are limited when workers are not welding with beryllium-containing materials. During a simulation study (NIOSH ECTB 214-13a, 1997) of arc welding (shielded metal arc welding) on stainless steel at the boilermaker's National Apprenticeship Training School in Kansas City, Kansas, beryllium was not detected in 45 short-term (15-minutes) PBZ samples and six full-shift general area samples collected under various study conditions (e.g., with and without LEV, indoors, outdoors in a semi-enclosed tank). Investigators collected the general area samples at a flow rate of 3 liters per minute to determine the background level of air contaminants on each day of the study. They collected PBZ samples at a flow rate of 13 liters per minute, by using a length of tubing to connect the filter on the welder to a high-volume air sampling pump placed on the floor. Samples were analyzed for total welding fume and elements according to NIOSH Methods 0500 and 7300, respectively. The laboratory analytical detection and quantitation limits for beryllium varied depending on the analysis date of the filters. The sampling LOD concentrations were 0.01 µg or 0.03 µg per sample and the limits of quantitation were either 0.035 µg or 0.075 µg.

In another study, NIOSH investigators evaluated student exposures in the welding shop of a vocational school located in the Midwest (Wallace et al., 1997). During the study, most students performed stick welding on mild steel, and one student performed MIG welding. In addition to welding, students also performed cutting and grinding operations. Investigators collected 12 air samples (10 PBZ and two general area samples) in the welding shop to determine total welding fumes (NIOSH Method 0500) and perform elemental analysis (NIOSH Method 7300). Sampling durations ranged from 80 to 109 minutes for PBZ samples and 264 and 268 minutes for the general area samples. Beryllium was detected in one sample at a concentration of 0.48 µg/m^3 for the only student who was MIG welding. The remaining 11 samples were all nondetectable for beryllium (sampling LOD concentrations not provided). No information was provided to indicate the potential source of beryllium. Although mild steel was used during the study, the students also learned to weld aluminum (a potential source of beryllium exposure during welding) and stainless steel during the year. Investigators noted that the ventilation system in the welding shop was not functioning properly during the study. An inspection of the fans on the roof revealed that two of the three exhaust fans servicing the welding shop were not operational. Additionally, no preventive maintenance program for the fans was in place at the school.

SECTION 10—WELDING, APPENDIX 3—BERYLLIUM EXPOSURES WHILE WELDING ALUMINUM ALLOYS

Table IV-77—Beryllium Emissions During Experimental Uncontrolled Aluminum Arc Welding and Cutting Using Base and Filler (Electrode) Alloy of Varying Beryllium Content[a]

ALUMINUM BASE ALLOY		ALUMINUM FILLER ALLOY (electrode)		Beryllium Emissions (µg/m^3)
Designation	Be Content (%)	Designation	Be Content (%)	
MIG Welding				
¼" 2219	*0.00*	*1/16" 4145*	*0.00*	*< 0.2*
¼" 5456	*0.0002*	*1/16" 5556*	*0.0001*	*< 1.0*
½" 5456 (with high current)	*0.0004*	*3/32" 5556*	*0.0001*	*< 1.0*
5456 (with argon shield gas)[c]	*0.00*	*5356*	*0.0007*	*< 0.2[B]*
5456 (with helium-argon shield gas)[c]	*0.00*	*5356*	*0.0007*	*< 0.2[B]*
6061 (with argon shield gas)[c]	*0.00*	*5356*	*0.0007*	*< 0.2[B]*
¼" 7039	*0.0001*	*1/16" 5039*	*0.0001*	*< 1.0*
A356.0	*0.002*	*4043*	*0.00*	*< 0.63*
A356.0	*0.006*	*4043*	*0.00*	*< 0.99*
A356.0	*0.008*	*4043*	*0.00*	*9.3*
¼" A357.0	*0.054*	*1/16" 4047*	*0.00*	*16.0*
¼" 358.0	*0.33*	*1/16" 4047*	*0.00*	*31.9*
½" 358.0 (with high current)	*0.25*	*3/32" 4047*	*0.00*	*45.8*
TIG Welding				
6061 (with argon shield gas)[c]	*0.00*	*5356*	*0.0007*	*< 0.2[b]*
5456 (with argon shield gas)[c]	*0.00*	*5356*	*0.0007*	*< 0.2[b]*
5456 (with helium-argon shield gas)[c]	*0.00*	*5356*	*0.0007*	*< 0.5*
Plasma Arc Cutting				
2090	*0.00*	*NA*	*NA*	*< 0.5*

[a] *Based on four laboratory investigations designed to estimate worst case emissions during the welding of aluminum alloys. One study was conducted at the Martin Marietta laboratories and three studies were completed at Alcoa laboratories.*

[b] *Result is the geometric mean of five tests.*

[c] *Tests were conducted in a high-bay production welding facility with natural ventilation. Welding areas of about 10 feet by 12 feet (with large open spaces overhead) were enclosed using flexible welding curtains. Cross-draft air movement was minimal, and the welding enclosures were designed to allow updraft convection currents. Sampling was conducted for 100 minutes of arc time, the estimated time a welder has an arc struck during an 8-hour shift at this type of facility.*

Be = beryllium
<: means less than (i.e., the result is nondetectable)
NA: means "not applicable"

Source: Cole, 1997; Cole et al., 2007

Table IV-78—PBZ Total Beryllium Results for Aluminum Welding and Cutting Operations in U.S. Shipyards and Navy Facilities[a]

Base Metal	Task	Sample Time (minutes)	8-Hour TWA Concentration (µg/m^3)
Aluminum	*Welding, plasma arc and cutting*	*19*	*0.02[b]*
Aluminum	*Thermal flame spraying*	*30*	*0.01[b]*
Aluminum	*Thermal flame spraying*	*39*	*0.03[b]*
Aluminum	*Welding, gas tungsten arc*	*108*	*0.06[b]*
Aluminum/steel	*Welding, not otherwise classified*	*124*	*0.06[b]*
Aluminum	*Welding, shielded metal arc*	*135*	*0.02[b]*
Aluminum	*Welding, gas tungsten arc*	*153*	*0.04[b]*
Aluminum	*Welding, shielded metal arc*	*200*	*0.02[b]*
Aluminum and steel plates	*Hot work helper/Fire watch (Burning steel/plasma arc aluminum)*	*206*	*0.03[b]*
Aluminum	*Welding, gas tungsten arc*	*209*	*0.03[b]*
Aluminum and steel plates	*Oxygen cutting/plasma arc welding*	*299*	*0.06[b]*
Aluminum and steel plates	*Oxygen and plasma cutting*	*301*	*0.06[b]*
Aluminum	*Welding, not otherwise classified*	*390*	*0.03[b]*
Aluminum	*Welding, not otherwise classified*	*401*	*0.06[b]*
Aluminum	*Welding, not otherwise classified*	*523*	*0.76*
Aluminum	*Welding, not otherwise classified*	*533*	*0.77*
Aluminum	*Welding, not otherwise classified*	*534*	*1.34*

[a] *These data are characterized by a median of 0.04 µg/m^3, a mean of 0.2 µg/m^3, and a range from 0.01 µg/m^3 to 1.34 µg/m^3. Eighty-two percent (14 samples) of the sample results are less than 0.1 µg/m^3 and are also nondetectable for beryllium.*

[b] *Sampling limit of detection (LOD) concentration (i.e., the sample result is nondetectable or less than the analytical detection limit).*

PBZ: means personal breathing zone
TWA: means time-weighted average

Source: OSHA Shipyards, 2005; U.S. Navy, 2003

SECTION 10—WELDING, APPENDIX 4—WELDING STUDIES INDICATING THE EFFECTIVENESS OF LOCAL EXHAUST VENTILATION SYSTEMS

OSHA reviewed several studies submitted to the chromium VI rulemaking docket. These studies discuss the effectiveness of various LEV for controlling general welding fumes or other (non-beryllium) components of welding fumes.

A 1982 study by AWS showed that a welding fume reduction of 96 percent could be achieved with the use of a movable exhaust hood during steel welding (OSHA-H054A-2006-0064-2527). As with the work conducted by Susi and Meeker (2008), that AWS study showed that great exposure reductions can be achieved when ventilation systems are well designed and the workers using them are attentive to using the systems properly. Other studies also reviewed by OSHA have found the effectiveness of moveable exhaust hoods for controlling hexavalent chromium exposures to range from a 5 to 33 percent reduction, or 4 to 54 percent, depending on the type of welding performed (Kura, 1998). Hexavalent chromium is a potential occupational carcinogen with a PEL of 5 $\mu g/m^3$ (8-hour TWA). The use of chromium alloy electrodes during arc welding could lead to exposure to hexavalent chromium, which is also a component of stainless steel welding fumes. Recent OSHA research on the control of hexavalent chromium estimated the effectiveness of well-positioned, flexible LEV systems for welding, such as the Neiderman Filterbox (a portable exhaust blower with a flexible welding fume collection duct), at 50 percent (OSHA-H054A-2006-0064-2527).

OSHA also reviewed additional studies on the same topic:

- The Center for Construction Research and Training (formerly the Center for the Protection of Workers' Rights) (CPWR) investigated welders' exposure to hexavalent chromium with and without the use of LEV in a controlled setting (union training facility) and during two large coal-fired power plant rehabilitation projects (BCTD_CPWR, 2009). In the controlled setting, the use of LEV was associated with a 55-percent reduction in hexavalent chromium levels in trials involving TIG and stick welding. During the power plant rehabilitation projects, use of a portable LEV system for stick welding at one plant resulted in hexavalent chromium exposures 76 percent lower than when no LEV was used. The second power plant survey involved the use of a large central LEV unit with up to eight main branches and smaller terminal bifurcating ducts with hoods. Samples collected at this site when the central LEV system was in use during MIG or stick welding had 79 percent lower hexavalent chromium concentrations than when the system was not used.

- NIOSH performed a controlled study of welding fume exposures in which it was demonstrated that correctly used ventilation could substantially reduce exposures to welding fumes. In this 1996 study, NIOSH examined two portable LEV systems and found that total welding fume concentrations with the use of LEV could be reduced by 80 percent, from a maximum of 60 mg/m^3 to a maximum of 13 mg/m^3 (CPWR, 1997). PBZ hexavalent chromium exposures were reduced from a maximum of 2,615 $\mu g/m^3$ to a maximum of 1,077 $\mu g/m^3$, an exposure reduction of about 59 percent (NIOSH ECTB 214-13a, 1997).

- In another study of 20 MIG welders in a Tennessee plant, a new general ventilation system combined with portable LEV units (exhausting 740 cubic feet per minute and positioned to pull the fumes out of the welder's breathing zone) reduced the amount of welding fume exposure by 51 percent (Ashby, 2002). Individual sample results were not provided.

SECTION 11—DENTAL LABORATORIES

INDUSTRY PROFILE

Dental laboratory technicians cast and form the metal framework for prosthetic devices. These technicians and other dental workers may be exposed to beryllium, primarily while performing induction casting and finishing beryllium-containing metal alloys used in some dental prostheses, specifically crowns, bridges, and cast partial dentures. Beryllium is added to some dental alloys (typically in quantities of 0.5 to 2.0 percent) to improve strength, corrosion resistance, and elasticity, and is considered a less expensive alternative to silver and gold (Kotloff et al., 1993; Rom et al., 1984; Materion MSDS A11, 2011; ERG Beryllium Site 5, 2003).

According to the 2010 County Business Patterns, there are 6,995 establishments in the NAICS industry classification 339116, Dental Laboratories (U.S. Census Bureau, 2010). These establishments employ a total of 44,030 people. Of these, OSHA estimates that 1,749 establishments and 11,008 employees will be affected by beryllium exposures. Refer to Preliminary Economic Analysis (PEA) Chapter IV.III, Industrial Profile, for details of OSHA's methodology in obtaining this estimate.

Occasionally, a dentist office (NAICS 621200, Offices of Dentists) may contain a captive dental laboratory that performs the activities of dental laboratories in NAICS 339116. The 2010 County Business Patterns reports 129,830 establishments and 846,092 employees in NAICS 621200. While no data exist on the number dentist offices that contain captive dental laboratories, a representative of the National Association of Dental Laboratories estimates that 950 dental practices include a captive dental laboratory (Napier, 2004). OSHA estimates that approximately 25% of these dental practices (238) use beryllium alloys. Refer to PEA Chapter IV.III, Industrial Profile, for details of OSHA's methodology in obtaining this estimate.

Table IV-79 shows the number of affected establishments and affected employees by NAICS code.

Table IV-79—Dental Laboratories

NAICS	Industry	Affected Establishments	Affected Employees
339116	*Dental Laboratories*	*1,749*	*11,008*
621210	*Dentists Offices with "captive" dental labs*	*238*	*1,548*
	Total	**1,986**	**12,555**

Sources: U.S. Census Bureau, 2010; BLS 2008; OSHA Office of Regulatory Analysis

PROCESS DESCRIPTION

Dental laboratory technicians produce custom dental appliances (a device to repair teeth or replace missing teeth), first by constructing plaster models of dental impressions, and then using the models as templates to make metal castings. Dental laboratory technicians manually handle and work in close proximity to the dental appliances (within about 8 inches) (Kim et al., 2002). Beryllium exposure can occur during the melting and casting of beryllium-containing alloys and during abrasive blasting, cutting, grinding, or polishing of the resulting casting. As noted, not all dental laboratories use beryllium alloys. Precious metal alloys and beryllium-free non-precious metal alloys are both widely used.

Most dental laboratories include some form of local exhaust ventilation (LEV); typically a recirculating filtration unit is used with the grinding tools. LEV is not, however, present in all dental laboratories. For example, Koltoff et al. (1993) described a laboratory where a dental technician produced dental appliances using beryllium alloy in a 10-foot by 12-foot room with one window, which remained closed, and no ventilation hoods. The dental technician developed chronic beryllium disease. Other reports suggest that the few laboratories without adequate exhaust ventilation are "mom and pop" operators who are unaware of the safety and health regulations (OSHA-H005C-2006-0870-0345).

The process description presented below is based primarily on observations made by ERG during a site visit to a dental laboratory conducted as part of an analysis of crystalline silica exposure, as well as interviews with dental laboratory staff regarding the handling of beryllium alloys (ERG Dental Lab A, 2000; Dental Laboratory A, 2004; ERG Beryllium Site 5, 2004).

The steps in dental product manufacture include:

Plaster Model and Mold Production: The technician produces plaster by mixing dry ingredients and water in a small container. He then pours the plaster into an impression of the patient’s mouth or teeth taken by a dentist. After the plaster has set, the technician removes the model from the impression, grinds it to the proper shape, and uses it to form a wax pattern of the dental appliance. Although the modeling and mold production steps are not associated with beryllium alloy handling or exposures, these steps can influence a potential source of exposure during later production phases. By using extra care to produce a precise pattern, technicians can minimize excess metal and blemishes that must be removed using grinding equipment during subsequent finishing processes. Because beryllium alloy is a hard metal and difficult to grind, dental technicians have an incentive to produce quality patterns rather than spend extra time grinding (Dental Laboratory A, 2004).

Casting: To cast metal portions of dental appliances, including those made of beryllium alloy, the technician constructs a high-temperature mold by mixing ceramic material and applying it to the wax pattern to form the mold. The piece is placed in a furnace, and after the wax is burned off, the technician melts the dental alloy and pours molten metal into the mold. Technicians can melt alloy using a small burner (heating until metal appears melted) or specialized, temperature-controlled equipment.

Beryllium alloy releases beryllium fumes during heating and casting. Castings often involve less than an ounce of metal, and the casting process can be completed in a few minutes. Once the casting cools, the technician cracks the mold and manually removes the casting. Due to the small volume of metal and short task duration, OSHA considers the melting and casting process to be a relatively modest source of exposure compared to the subsequent finishing process.

Finishing: The technician grinds, polishes, or abrasively blasts the casting to remove any remaining mold material, sprues (metal left in the channels through which alloy was poured into the mold), or blemishes, and to achieve the required finish. Technicians can be exposed to beryllium when the resulting dust becomes airborne. This dust is also the primary source of surface and hand contamination.

Blasting is typically performed using silica sand or aluminum oxide inside an enclosed, ventilated glove-box-type blasting cabinet. Grinding, polishing and abrasive blasting all remove fine particles of beryllium alloy from the casting.

Another finishing step involves heat treating the casting to improve durability of the resulting dental appliance. The technician "fires" the casting in a temperature-controlled oven for a prescribed period of time before applying the coatings that form the white teeth on the appliance. Heating can induce the formation of an oxide (with a higher concentration of beryllium than the base metal) on the surface of beryllium alloys (Covington et al., 1985). A technical representative of a beryllium dental alloy manufacturer indicated, however, that oxide formation is minimal when dental alloys are handled properly (Pentron, 2004). The MSDS for this dental alloy specifies that the alloy should not be handled or stored with oxidizing agents. This would reduce the amount of beryllium oxide formed on the surface of the alloy.

Coating: The technician may manually apply a coating (often porcelain) to the casting, which is then oven-fired again to set the coating. The technician also uses a hand-held grinder and abrasive blasting technique to achieve the desired shape and finish. Finally, the metal portion of the appliance is polished with a soft brush fitting on the grinding tool.

Depending on the size and configuration of the facility, a single dental laboratory technician may perform all the steps in dental product manufacture or just one particular activity repeatedly, such as abrasive finishing or applying coatings (ERG Dental Lab A, 2000; Dental Laboratory C, 2004). The layout of one of the dental laboratories visited by ERG is illustrated in Figure IV-4 below.

Dental technicians in laboratories that use beryllium-free alloys for casting can still experience limited beryllium exposure if the laboratory performs repair work on dental appliances that were produced using beryllium-containing alloys. This could include any non-precious metal appliance that may have been made by another laboratory or by the same laboratory using another alloy. It is not possible for dental technicians to tell (visually or by a simple test) whether a non-precious metal alloy contains beryllium (Cardinal Dental Laboratory, 2004).

Two laboratories that consider themselves typical of the industry in this respect report that about 1 percent of the crowns and bridges they handle are items sent to the laboratory for repair (Dental Laboratory A, 2004; Cardinal Dental Laboratory, 2004). Technicians typically spend less than 10 minutes per week grinding (to prepare the metal surface) and polishing these items, usually with a hand-piece grinder (i.e., hand-held), and beryllium exposure can occur during these steps (Hinman et al., 1975; Rom et al., 1984; Materion MSDS A11, 2011). It is important to note, however, that the amount of metal removed during surface preparation of repaired items (usually lightly roughing an area a few millimeters square) is substantially less than the amount removed during production of a new casting (when casting sprues must be removed and the whole casting must be polished). OSHA assumes that a technician exposed only to beryllium during surface preparation associated with appliance repair is likely to have substantially lower beryllium exposure than a technician who grinds newly cast beryllium alloy appliances to remove excess metal from the casting process and shape the appliance.

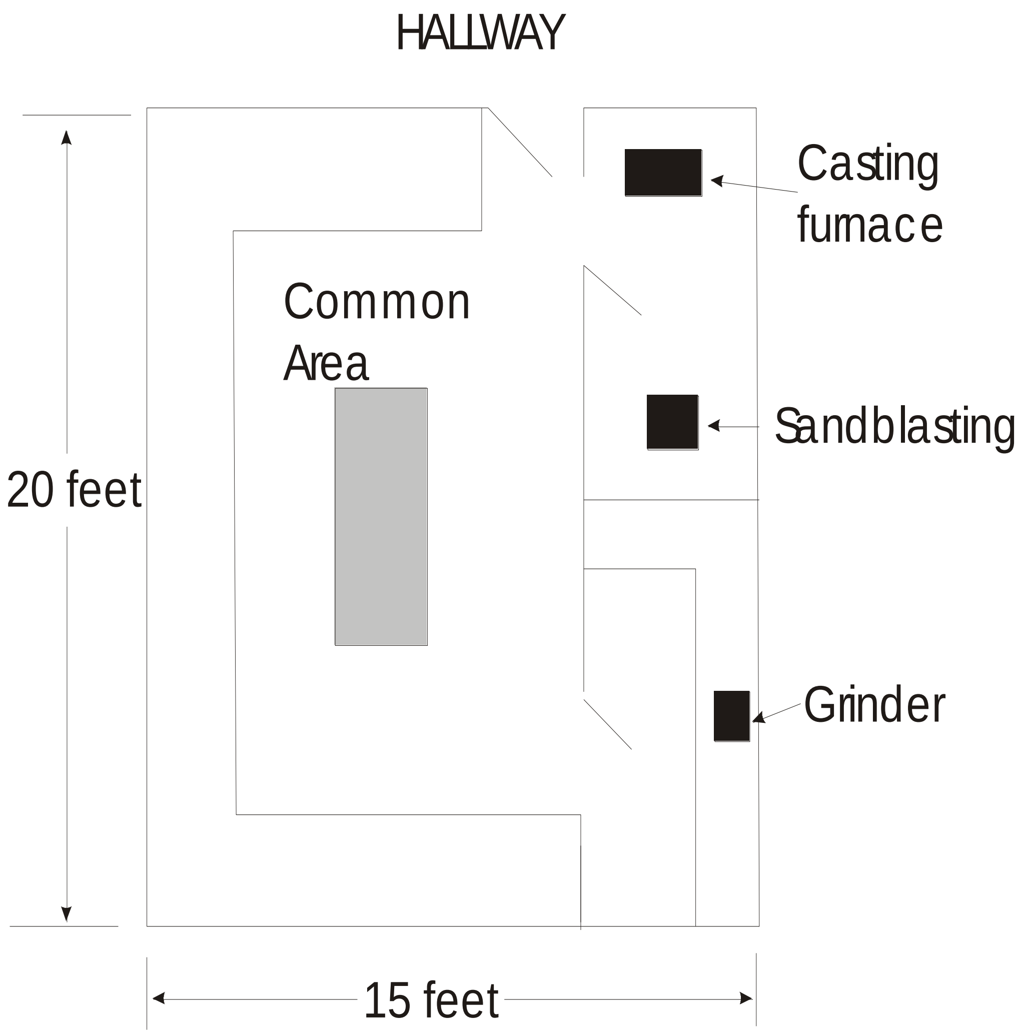

Figure IV-4. ERG Beryllium Site visit 5.

ERG Beryllium Site 5, a university-associated dental laboratory with one employee during the day shift. Layout shows grinder and casting oven where the technician worked. Approximate size of the laboratory is 15 feet wide by 20 feet long. The common laboratory area has a work bench (shown in gray) in the center. The grinder is on a laboratory bench, and the technician sits on a chair to do the grinding and polishing. Most of the technician's time is spent in the grinding room. Occasionally, several other technicians work in the common laboratory area (i.e., area where no beryllium work is done). No physical separation exists between the rooms, and they share the same ventilation system. (Source: ERG Beryllium Site 5, 2003)

EXPOSURE PROFILE

Data Sources

Several sources report workplace beryllium exposure results for technicians working in dental laboratories. The five sources OSHA identified include a site visit conducted by ERG (ERG Beryllium Site 5, 2003), a published article by Rom et al. (1984), two datasets submitted to the OSHA Beryllium Docket,[306] and OSHA's Integrated Management Information System (IMIS) (OSHA, 2009). These sources are discussed below:

- ERG obtained two full-shift personal breathing zone (PBZ) total beryllium air samples (as well as surface and hand wipe samples) during a 2003 site visit to a dental laboratory (ERG Beryllium Site 5, 2003). At this facility, a technician used 0.5 percent beryllium alloy to produce partial dentures. The laboratory was fitted with a canopy hood over the casting area and a recirculating high-efficiency particulate air (HEPA)-filtered ventilation system at the grinding bench. Other technicians at this laboratory worked in other rooms and did not handle beryllium alloy. Both air sampling results from this source are included in the dental technician exposure profile; one result is positive for beryllium (0.59 $\mu g/m^3$) and one is nondetectable (0.02 $\mu g/m^3$). The samples were analyzed by OSHA Method ID-125G (Metal and Metalloid Particulates in Workplace Atmospheres) using inductively coupled argon plasma-atomic emission spectroscopy (ICAP-AES). The laboratory analytical reporting limit was 0.02 µg per sample.

- Rom et al. (1984) obtained seven full-shift (all results were obtained from sampling times greater than seven hours[307]) PBZ total beryllium air samples in six dental laboratories in Utah that used non-precious metal alloys containing beryllium. Samples were collected on mixed cellulose ester filters (0.8-micrometer diameter pore size) and analyzed by atomic absorption spectroscopy. The analytical limit of detection (LOD) was not reported; however, for other methods using this technique, such as National Institute for Occupational Safety and Health (NIOSH) Method 7102, the estimated LOD is 0.005 µg per sample. The Rom et al. data are included in the dental laboratory technician exposure profile and contain three positive results of 1.5 $\mu g/m^3$, 2.7 $\mu g/m^3$, and 4.4 $\mu g/m^3$ and four nondetectable results with sampling LOD concentrations of 0.23 $\mu g/m^3$, 0.29 $\mu g/m^3$, 0.34 $\mu g/m^3$, and 0.72 $\mu g/m^3$. General information on exposure controls is limited to the two positive results with values

[306] The two datasets submitted to OSHA's Beryllium Docket include: 1) OSHA-H0005C-2006-0870-0144 (U.S. Navy Response to Occupational Safety and Health Administration's Occupational Exposure to Beryllium Request for Information) and H005C-2006-0870-0145 (Attachment 1. U.S. Navy Occupational Exposure Database [NOED] Query Report. Personal Breathing Zone Air Sampling Results for Beryllium), and 2) OSHA-H005C-2006-0870-0346 (EHS Services letter report dated May 15, 2002, regarding industrial hygiene air sampling for beryllium in a large Ticonium laboratory. Letter report in: Report of the Small Business Advocacy Review Panel on the OSHA Draft Proposed Standard for Occupational Exposure to Beryllium, January 15, 2008).

[307] Note that for the purpose of this analysis, OSHA considers a full shift sample to be that obtained from a sampling time equal or greater than 360 minutes. Refer to Chapter IV, Section 2—Methodology, of this Preliminary Economic Analysis for a more detailed discussion.

exceeding the current Permissible Exposure Limit (PEL) of 2.0 μg/m^3. In both cases, the beryllium overexposures were primarily associated with grinding tasks, inadequate LEV, and improper use of available LEV (no other details are available). Rom et al. also commented on a dental laboratory technician diagnosed with acute berylliosis (and not affiliated with the six laboratories investigated). This technician ground beryllium-containing metal alloys four to six hours a week for three months with only a dust mask and no LEV on his grinder. In an effort to estimate the dental worker's beryllium exposure, Rom et al. recreated the grinding task in the actual laboratory in which the technician worked and measured 2.6 μg/m^3 of beryllium during a 30-minute grinding task.

- The U.S. Navy submitted a large beryllium dataset to OSHA's Beryllium Docket (OSHA-H005C-2006-0870-0145). The dataset includes 134 PBZ results, obtained from 1987 to 2001, for dental technicians primarily grinding dental prosthetics or castings that have been time-weighted for eight hours (TWA); however, only 12 of the results are regarded as full-shift samples (approximately 360 minutes in duration or greater) and are included in the dental laboratory technician exposure profile. The full-shift samples range from 0.02 μg/m^3 to 3.0 μg/m^3, and five of the 12 results (42 percent) are nondetectable for beryllium. The Navy samples were analyzed by either NIOSH Method 7102 (Beryllium and Compounds, as Be) or Method 7300 (Elements by ICP), and analysis was performed by one of the Navy's three consolidated industrial hygiene laboratories, which are accredited by the American Industrial Hygiene Association (AIHA). Although it was not reported, the estimated LOD for Method 7102 and Method 7300 is 0.005 µg per sample. These data represent an unknown number of naval facilities; location identifiers were not included in the docket submission (the data were drawn from a central database that consolidates exposure results from a number of naval installations). The Navy also reported that "Dental prosthetics operations are enclosed (glove box) and ventilated as much as possible with grinding and polishing operations requiring dust collecting systems or vacuums fitted with high efficiency particulate air (HEPA) filters" (OSHA-H005C-2006-0870-0144).

- A second docket submission from CMP Industries (OSHA-H005C-2006-0870-0346) provided two nondetectable (0.2 µg/m^3) PBZ results for dental technicians in a commercial dental laboratory that was described as a large user of nickel-beryllium alloy (Ticonium) for cast partials. CMP Industries obtained these samples in 2002 and provided them to OSHA in 2007. The associated report describes the results as "representative of the highest exposures expected for the processes being performed. Local exhaust ventilation was present and running during the sampling." The samples were analyzed using modified NIOSH Method 7300, and the level of quantitation was reported as 0.15 µg per sample. The documentation does not indicate whether the results are full-shift samples; however, the air volumes listed in the laboratory analysis report (931.4 liters and 952.3 liters) are consistent with full-shift samples obtained using NIOSH Method 7300, and the results were compared to the current eight-hour TWA PEL for beryllium. Therefore, both samples from this source are included in the dental technician exposure profile.

- OSHA's IMIS entries for the years 1978 to 2008 contain 41 PBZ samples associated with dental technicians, of which 23 (56 percent) are positive for beryllium. Table IV-82 (in Dental Laboratories Appendix 1) summarizes the results for dental technicians working either in dental laboratories or in other facilities that include dental laboratory operations. The means, medians, and distribution of results represent positive IMIS samples. Only positive IMIS results are used because the sampling LOD concentrations (i.e., analytical LOD/air volume sampled) for the nondetectable results are not included in the IMIS database.[308] As shown in Table IV-82, the IMIS contains three results (all nondetectable) for standard industrial classification (SIC) code 8071 (Medical Laboratories) and 32 results for SIC code 8072 (Dental Laboratories). Nineteen of the 32 samples (59 percent) for SIC code 8072 are positive for beryllium. Six of the positive results are coded as ceiling samples, with results ranging from 0.1 µg/m^3 to 0.2 µg/m^3. Another four of the positive results are coded as short-term exposure limit (STEL) samples, each with a value of 0.1 µg/m^3. The remaining nine positive samples are coded as TWA (eight-hour time-weighted average) samples, with results ranging from 0.03 µg/m^3 to 0.2 µg/m^3.

  In addition to dental and medical laboratories, the IMIS data include sample entries for dental technicians in four other industries, including SIC code 3843 (Dental Equipment and Supplies), SIC code 5160 (Chemicals and Allied Products), SIC code 8049 (Offices and Clinics of Health Practitioners, not elsewhere classified); and SIC code 8062 (General Medical and Surgical Hospitals). Two of the four entries are positive for beryllium, with results of 0.01 µg/m^3 (SIC 3843) and 3.0 µg/m^3 (SIC 8049). The IMIS data also include two positive samples obtained through OSHA's On-site Consultation Services Program that are consistent with dental technician job descriptions (e.g., crown grinder); however, the industries associated with these results are not available. The consultation program results include values of 0.02 µg/m^3 and 0.03 µg/m^3.

  Overall, the IMIS results with detectable levels of beryllium are characterized by a mean of 0.22 µg/m^3, a median of 0.10 µg/m^3, and a range from 0.01 µg/m^3 to 3.0 µg/m^3. Thirty percent of the positive results (7 of the 23 samples) are less than 0.1 µg/m^3, and 96 percent are less than or equal to 0.2 µg/m^3. These results include all positive IMIS results regardless of the exposure type (i.e., ceiling, STEL, or TWA). If the positive TWA samples are analyzed separately, the 11 results range from 0.02 µg/m^3 to 0.2 µg/m^3, with a mean of 0.08 µg/m^3 and a median of 0.09 µg/m^3. Fifty-five percent of the TWA results (6 of the 11 samples) are less than 0.1 µg/m^3, and 100 percent are less than or equal to 0.2 µg/m^3. Refer to Table IV-82 for details.

[308] As a general comment on IMIS limitations, OSHA acknowledges that several factors limit the value of the IMIS dataset. No beryllium was detected in the vast majority of samples analyzed for beryllium in all industries (reported as "ND", or not detected); however, most of the IMIS beryllium samples likely were the result of general metal emissions screening (i.e., beryllium was not necessarily present in the sampled workplace, but rather, beryllium was automatically included as part of the standard 10-metal analytical screening panel performed by the laboratory). Further, sample results in the IMIS database do not include the sampling LOD concentrations for nondetectable samples. It is not possible to tell whether the nondetectable samples had LOD concentrations below the proposed PEL and alternative PEL.

The sample analysis methods for these samples are not included in the IMIS database; however, OSHA's laboratory analyzes compliance samples using the OSHA method in effect at the time the sample was collected (e.g., OSHA Method 125G—Metal and Metalloid Particulates in Workplace Atmospheres). The LOQ for this method is 0.043 µg per sample, and the analysis is by ICAP-AES. Beyond the short job description, no supporting information, such as the actual sampling duration, the exposure controls in use, or whether the dental technician was actually working with beryllium-containing alloys, is available for the IMIS results. The IMIS data are therefore used in a supporting role to provide additional insight into the dental laboratory technician exposure profile.

Exposure Profile for Dental Technicians

Tables IV-80 and IV-81 summarize the exposure profile for workers in dental laboratories and report the distribution of the results relative to the current and proposed OSHA PELs for beryllium. These tables summarize all of the available full-shift eight-hour TWA PBZ total beryllium sample results for dental technicians.

As shown in Table IV-80, the exposure profile for dental technicians is based on 23 PBZ samples and is characterized by a median of 0.20 µg/m^3, a mean of 0.74 µg/m^3, and a range from 0.02 µg/m^3 to 4.4 µg/m^3. Table IV-81 shows that 13 percent of the results are less than 0.1, 52 percent are less than or equal to 0.2 µg/m^3, 70 percent are in the range from 0.1 µg/m^3 to 1.0 µg/m^3, and 17 percent (four values) exceed 1.0 µg/m^3.

Twelve of the 23 samples (52 percent) are nondetectable for beryllium and suggest that the exposure profile may be overestimating exposures for this group of workers. This finding is supported by the positive IMIS results for dental technicians discussed in the subsection on Data Sources, above in this Dental Laboratories section. As noted, 30 percent of positive-value IMIS results are less than 0.1 µg/m^3, and 96 percent are less than or equal to 0.2 µg/m^3. Note that the IMIS values may underestimate the population of workers experiencing levels below 0.1 µg/m^3 since only positive values were considered.

Table IV-80—Personal Exposure Profile for Workers in Dental Laboratories (NAICS 339116)[a,b]

Job Category	No. of Samples	Range (µg/m^3)	Mean (µg/m^3)	Median (µg/m^3)
Dental Technician	*23*	*0.02 to 4.4*	*0.74*	*0.20*

[a] Samples represent eight-hour time-weighted average (TWA) personal breathing zone (PBZ) total beryllium exposure results.

[b] Nondetectable results are reported as sampling limit of detection (LOD) concentrations. Twelve of the 23 samples (52 percent) are nondetectable for beryllium. Eight of those 12 have reported sampling limits of detection of 0.2 µg/m^3 or less, while the remaining four samples were nondetectable at sampling limits of detection of 0.23 µg/m^3, 0.29 µg/m^3, 0.34 µg/m^3, and 0.72 µg/m^3.

Source: ERG Beryllium Site 5, 2003; OSHA-H005C-2006-0870-0145; OSHA-H0005C-2006-0870-0346; Rom et al., 1984

Table IV-81—Distribution of Full-Shift PBZ Total Beryllium Exposure Results for Workers in Dental Laboratories (NAICS 339116)[a,b]

Job Category	Number of Results in Range (μg/m³)						Total
	< 0.1	≥ 0.1 to ≤ 0.2	> 0.2 to ≤ 0.5	> 0.5 to ≤ 1.0	> 1.0 to ≤ 2.0	> 2.0	
Dental Technician	*3 (13%)*	*9 (39%)*	*3 (13%)*	*4 (18%)*	*1 (4%)*	*3 (13%)*	*23 (100%)*

[a] *Samples represent eight-hour time-weighted average (TWA) personal breathing zone (PBZ) total beryllium exposure results.*

[b] *Nondetectable results are reported as sampling limit of detection (LOD) concentrations. Twelve of the 23 samples (52 percent) are nondetectable for beryllium. Eight of those 12 have reported sampling limits of detection of 0.2 μg/m³ or less, while the remaining four samples were nondetectable at sampling limits of detection of 0.23 μg/m³, 0.29 μg/m³, 0.34 μg/m³, and 0.72 μg/m³.*

Source: ERG Beryllium Site 5, 2003; OSHA-H005C-2006-0870-0145; OSHA-H0005C-2006-0870-0346; Rom et al., 1984

Three positive results in the exposure profile exceed the current OSHA PEL of 2.0 μg/m³. Two of these results (2.7 μg/m³ and 4.4 μg/m³) are also the oldest samples and occurred during grinding operations with inadequate LEV (Rom et al., 1984). The study investigators reported that improper use of available LEV may have contributed to the exposure levels. Full-shift PBZ results for cobalt sampled at this dental laboratory also exceeded the OSHA PEL and were attributed to inadequate LEV during grinding. The third result (3.0 μg/m³) exceeding the current beryllium PEL is a 1988 Navy sample obtained during casting operations in a prosthetics laboratory. However, no information is available about the nature of this exposure. In general, few details are available for the Navy results. As noted, the Navy reports that dental prosthetics operations are enclosed and ventilated and that engineering controls such as glove boxes are used. Grinding and polishing operations require dust collection systems or vacuums equipped with HEPA filters (OSHA-H005C-2006-0870-0144).

One of the lowest results in the exposure profile (nondetectable at 0.02 μg/m³) is one of two results (the other being 0.6 μg/m³) obtained on consecutive dates for a dental technician at ERG Beryllium Site 5. The technician's typical work activities include casting frames for partial dentures using 0.5 percent beryllium alloy, sandblasting the frames after casting to remove powdered investment material, and deburring and polishing the frames. The first two activities are performed for two to three minutes each, while the final activity consumes most of the technician's time (ERG Beryllium Site 5, 2003). These were the technician's activities on the first sampling date, during which this worker completed four frames and experienced the higher of the two exposure levels in the 469-minute sampling period. On the second date, however, when the lower, nondetectable result was obtained, the technician completed just two frames and performed paper work during the latter half of the 511-minute sampling period, indicating that only part of the shift was spent handling beryllium alloy. The difference in exposure levels on the two dates (0.6 μg/m³ versus 0.02 μg/m³) is greater than might be expected based strictly on the amount of work performed (four frames compared to two frames). Additional information is not available to explain the difference, but a basic facility description is provided: The casting furnace is equipped with an overhead canopy hood, and the grinding equipment is ventilated with a HEPA-filtered recirculating ventilation system. Sandblasting is conducted in a small, enclosed sandblasting booth within the same room as the casting furnace (ERG Beryllium Site 5, 2003).

As noted previously, over half (52 percent) of the full-shift PBZ sample results incorporated into the exposure profile for dental laboratory technicians are nondetectable for beryllium.[309] Because these values have been assigned the LOD level—the most protective option for handling nondetectable samples—the true values are likely lower than the reported levels (i.e., somewhere between zero and the reported level). OSHA's conservative approach to assigning values to nondetectable results leads to an exposure profile that might overestimate the exposures for this group of workers.[310] The data in the IMIS, summarized in Table IV-82 (in Dental Laboratories Appendix 1), supports this conclusion. The IMIS data for this industry contain a lower percentage of results that exceed 0.2 μg/m^3 (one of 23 positive samples) compared to the exposure profile. This could be a consequence of the way the IMIS samples were obtained (i.e., a metal scan involving beryllium as a standard analyte might have been performed during metal work regardless of whether a beryllium alloy was used on that date). It could also signal that the exposure profile somewhat overestimates the typical daily beryllium exposure of dental technicians.

TECHNOLOGICAL FEASIBILITY

Dental Laboratory Technician—Baseline Controls

The primary baseline control in dental laboratories is exhaust ventilation during grinding operations (OSHA-H005C-2006-0870-0345). One manufacturer of dental laboratory materials and equipment reports that all of its clients (dental laboratories) that grind beryllium-containing partial denture alloy use an exhaust system to remove dust (OSHA-H005C-2006-0870-0345). Common exposure control in dental laboratories involves bench-top recirculating ventilation (not HEPA-filtered) with conical hoods that are positioned by workers during hand grinding (with a hand-piece) (ERG Dental Lab A, 2000; Dental Laboratory A, 2004). Bench-top grinders or lathes (for larger items and to remove larger amounts of metal—such as casting sprues) are often fitted with basic recirculating dust collection units, primarily intended to capture medium and large particles (ERG Beryllium Site 5, 2004). The grinding wheels are partially enclosed (perhaps less than a 50-percent enclosure), and exhaust air is filtered and recirculated, but usually not HEPA-filtered. HEPA filtration and ventilation exhausted directly outdoors are rare in dental laboratories (ERG Dental Lab A, 2000; Dental Laboratory C, 2004).

Dental laboratory technicians also perform beryllium alloy metal casting using unvented furnaces, although a canopy hood is likely to be present; when a hood is present, the worker can typically stand under it next to the casting operation, which could cause contaminated air to be ventilated away from the worker's breathing zone (ERG Dental Lab A, 2000; ERG Beryllium Site 5, 2004). Technicians perform abrasive blasting of the castings in enclosed and exhaust-ventilated blasting cabinets; however, at Dental Laboratory A, ERG investigators noted that the

[309] Data sources for the exposure profile are: ERG Beryllium Site 5, 2003; OSHA-H005C-2006-0870-0145; OSHA-H0005C-2006-0870-0346; and Rom et al., 1984.
[310] If the true values of the nondetectable samples were known, they would be lower than the LOD values, and the exposure profile would reflect that difference.

glove box used had an opening on the side (perhaps originally intended as a pass-through) and was therefore poorly sealed (ERG Dental Lab A, 2000). Exhaust air from blasting cabinets is typically filtered (not HEPA) and released into the laboratory. Other baseline practices include a minimal level of housekeeping, involving occasional cleaning of visible debris from surfaces, dry sweeping, wet mopping, and vacuuming (again, without HEPA filtration) (ERG Dental Lab A, 2000; ERG Beryllium Site 5, 2003).

Dental Laboratory Technician—Additional Controls

The median exposure level associated with dental laboratory technicians is 0.2 μg/m^3. Fifty-two percent of the available exposure results are less than or equal to 0.2 μg/m^3. Based on the current exposure profile, 48 percent of dental laboratory technicians have exposures that can exceed 0.2 μg/m^3 and require additional controls. Some dental laboratories may choose to eliminate all beryllium exposure by not repairing dental appliances that contain beryllium and by substituting beryllium-free alloys for beryllium-containing alloys. Beryllium-free alternatives for casting dental appliances are readily available from commercial sources and some alloy suppliers have stopped carrying alloys that contain beryllium (Dental Alloy Manufacturer A, 2006; Dental Alloy Distributor A, 2006). For crowns and bridges, alternatives include all precious metal alloys and certain non-precious metal alloys (Pentron Rex 4 MSDS, 2004; Dental Laboratory A, 2004; Dental Laboratory D, 2006; Dental Laboratory F, 2006; Dental Alloy Distributor A, 2006).

For those dental laboratories that continue to use beryllium alloys, the primary control options include 1) properly designed, installed, and maintained LEV systems (equipped with HEPA filters) and enclosures, 2) work practices that optimize LEV system effectiveness, and 3) housekeeping methods that prevent contamination from building up. These controls work together to limit beryllium release and keep it from spreading (Thomas et al., 2009).[311]

Appropriate LEV for dental laboratories grinding beryllium alloy dental appliances includes booth-type enclosures for both grinding wheels (see Figure VS-80-17 in ACGIH, 2010) and hand-held grinding tools. To use this style of enclosure, the worker reaches into the ventilated booth interior to operate tools and manipulate the work piece while his breathing zone remains outside the booth.

For manual grinding tasks, regardless of the nature of the industry, the primary beryllium producer suggests a booth designed with both backdraft and downdraft exhaust ventilation inside the enclosure (Materion Information Meeting, 2012). For example, such a booth would include a front opening and rear exhaust, as is available for abrasive cut-off saws (Figure VS-80-17 in ACGIH, 2010), and the downdraft table ventilation of a hand-grinding bench (Figure VS-80-18 in ACGIH, 2010). An adaptation to provide a rear-slot exhaust (rather than plain rear takeoff) is preferable for hand grinding, which might not occur at a single fixed spot inside the booth. The

[311] Thomas et al. reports that in June of 2000, the Brush Wellman Reading facility launched an enhanced multi-faceted beryllium exposure control program that included "improved workplace orderliness and cleanliness, enhanced dermal protection in the form of polymer gloves and long-sleeve uniforms, dust migration control measures (e.g., tacky mats at entrances/exits and company clothing and boots that do not leave the facility), administrative controls (e.g., routine decontamination procedures in work areas), limiting airborne beryllium concentrations through engineering upgrades, such as enclosure and ventilation of high-risk processes to reduce airborne exposures to predominantly less than 0.2 μg/m^3, and extensive training and involvement of workers."

booth exhaust should be fitted with a HEPA air filter, and special precautions must be used when servicing the booth or blower and changing the filter (respiratory protection needed for these tasks). The booth should also be equipped with alarms to indicate when filter performance falls outside an effective range.

The primary beryllium producer advocates grinding booths of this general backdraft-plus-downdraft design, paired with work practices and careful housekeeping methods, as an effective method for reducing exposure levels for workers performing manual grinding (and related tasks using powered or rotary tools, such as polishing and buffing) to concentrations of 0.2 μg/m^3 or less (Materion Information Meeting, 2012). These control measures (i.e., engineering controls, work practices, and housekeeping) must be used together to ensure that exposure levels are reliably maintained below 0.2 μg/m^3 for most workers most of the time (Thomas et al., 2009). The primary beryllium producer's exposure reduction guidelines are generic and applicable to any industry where beryllium-containing particles are generated using powered or rotary hand tools. Thus, these guidelines pertain equally to foundries and machining facilities as they do to dental laboratories.

Although no study specifically demonstrates the effectiveness of these controls for dental laboratories, several studies provide evidence that ventilation systems can reduce technician exposure levels substantially. Two of the full-shift PBZ results included in the dental laboratory technician exposure profile are nondetectable (LOD 0.2 μg/m^3) for beryllium (OSHA-H005C-2006-0870-0346). Both samples were obtained from a commercial laboratory known to use large quantities of nickel-beryllium alloy (Ticonium) for cast partials. The associated study report contains limited information and states that LEV was operating during the sampling and that the samples are representative of the highest exposures expected for the processes performed. No information is available regarding the workers' activities, however. Two full-shift area samples obtained in the denture and plaster rooms were also nondetectable (0.2 μg/m^3) for beryllium. Although no other details are available, these results suggest that low beryllium exposures are associated with effective ventilation controls.

Other available supporting information on the benefits of LEV in dental laboratories is discussed below. Although these studies lend support to the value of LEV, they are hampered by various issues, such as the high LOD in effect at the time of the studies.

In the early 1970s, NIOSH and the Dental Research Section of the United States Public Health Service Hospital in San Francisco, California, studied beryllium exposures from handling non-precious alloys in a large commercial laboratory (Pacific Dental Laboratory, San Francisco, California) (Moffa et al., 1973). The alloy used in the laboratory (Ultratek) contained 1.6 percent beryllium (approaching the typical upper range for alloys used in dental laboratories). Investigators collected a total of 15 PBZ and six area samples over a two-day period during casting, finishing, and polishing operations. Finishing operations included the use of dental lathes (with interchangeable grinding and polishing points and discs) ventilated by a LEV system equipped with a rooftop baghouse for dust collection. Sampling times ranged from 12 to 120 minutes and the ventilation controls were reported to be operating normally. Three PBZ samples were collected on the worker operating the casting machine, six PBZ samples were obtained on one worker performing finishing activities during an entire workday, and two additional PBZ samples were collected on a worker polishing beryllium-containing materials. All PBZ samples, including two general area samples, were reported to be nondetectable for beryllium (individual sampling LOD concentrations were not provided). Although no beryllium was detected during the casting and finishing operations when the LEV was functioning normally on the first sampling day, Kimball (1983) reported that the sampling LOD concentrations for beryllium (on the first sampling day) were all greater than the current PEL of 2.0 µg/m^3.[312]

During the second day of the investigation, Moffa et al. (1973) evaluated the effectiveness of the finishing LEV system. With the LEV system blocked (no other details are available), the investigators collected four general area samples and four PBZ samples on the same finishing employee who had been evaluated on the first day of sampling. During this testing, the worker wore a respirator while grinding and polishing. Sampling times were short, ranging from 34 to 68 minutes. Beryllium was detected in three of the four PBZ samples, with positive values of 0.6 µg/m^3, 1.2 µg/m^3, and 1.6 µg/m^3. Three of the four general area samples (collected within two feet of the worker) were also positive for beryllium, with results of 1.4 µg/m^3, 3.2 µg/m^3, and 5.6 µg/m^3. Sampling LOD concentrations were not provided for the two nondetectable results. Based on the results of the study, Moffa et al. concluded that beryllium-containing alloys can be used safely in dental laboratories that are equipped with adequate LEV control measures. OSHA observes that although Moffa et al. base their conclusion on a PEL of 2.0 µg/m^3, the results of this study do show that LEV can have a large impact on dental technician exposure levels during peak periods of exposure.

In a study simulating the work of dental laboratory technicians finishing and polishing beryllium-containing dental alloy (Ticonium Premium 100, with an assayed beryllium content of 0.470 percent), Hinman et al. (1975) of the Naval Graduate Dental School in Bethesda, Maryland, evaluated airborne beryllium levels while an operator used a high-speed grinding and polishing lathe with and without LEV. Samples were collected at four different locations (one PBZ and three area samples) in two different rooms. At each location, three 10-minute air samples were collected during separate finishing and polishing operations. With the lathe connected to a vacuum dust collector, PBZ results were below the sampling LOD concentrations (0.5 µg/m^3 for the 10-minute test periods). By contrast, when the vacuum was disconnected, the mean PBZ values for two sets of three 10-minute samples were 22.0 µg/m^3 and 23.9 µg/m^3. This represents at least a 98-percent reduction in the short-term exposure level due to the use of LEV.

In the Moffa and Hinman investigations, the sampling results are limited by either very high LODs (Moffa et al., 1973) or very short sampling periods that are not under actual work conditions (Hinman et al., 1975). Despite these shortcomings, however, both studies clearly show the importance of adequate LEV in reducing beryllium exposures in dental laboratories.

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[312] Kimball (1983) reported that the sampling LOD concentrations for beryllium discussed by Moffa et al. (1973) for casting and finishing operations were quite high, "ranging from 2.1 to 7.1 µg/m^3 for the personal finishing and polishing samples and from 2.2 to 3.6 µg/m^3 for the area finishing samples. The limit of detection for the personal casting samples was 20.8 µg/m^3." Kimball is presumed to have calculated the sampling LOD concentrations using information in the Moffa et al. (1973) publication. Moffa et al. reported the air volumes (liters) for the samples collected and that the analytical methodology was atomic absorption spectroscopy. Although not specifically stated in the Moffa et al. publication, the analytical LOD for beryllium at the time of the study was 0.5 µg per sample. Kimball's nondetectable sampling LOD concentrations are confirmed by using an LOD mass of 0.5 µg and the individual sample volumes reported in the Moffa et al. publication.

In 1980, NIOSH evaluated a large dental laboratory (Walter Reed Army Medical Center, Washington, DC) using beryllium-containing dental alloy (Ticonium Premium 100) where all but one exhaust hood met or exceeded a minimum capture velocity of 100 feet per minute (fpm), with an average capture velocity of 500 fpm for operator-positioned scoop hoods on bench tops (NIOSH TA 80-60-756, 1980). Additionally, windows and doors were open, and supplemental fans were used to help control heat. Under these conditions, 12 PBZ air samples for laboratory technicians and six area samples indicated that beryllium, nickel, chromium, and molybdenum concentrations were all below the LODs (sampling LOD concentrations were not reported). NIOSH noted that most metal grinding was performed at the benchtop hood scoops and that an average capture velocity of 500 fpm was considered adequate for removal of fine dusts.

At a dental laboratory in Norway, investigators evaluated another toxic metal that laboratory technicians might be exposed to in addition to beryllium. Brune and Beltesbrekke (1980) determined that the cobalt exposure levels of dental technicians cutting, grinding, and polishing cobalt-containing dental alloys (Vitallium and Wironium brands) were at least 12 times higher (approximately 1.0 to 1.2 mg/m^3—10 times the allowable level in Norway at that time) when work was performed without LEV compared to the exposure levels measured with ventilation present (less than 0.1 mg/m^3 in this case). These findings indicate that LEV during abrasive activities can achieve at least a 90-percent reduction (i.e., % reduction = (1.0 mg/m^3 -0.1 mg/m^3)/(1.0 mg/m^3)) in the cobalt exposure level. Although not specific to beryllium, these results show that significant exposure reduction is possible with effective LEV, which is consistent with the findings of other studies that have evaluated beryllium. Thus, this investigation further supports the effectiveness of LEV to lower dental laboratory technician exposures.

In addition to improving LEV, employee training should be augmented to ensure that all employees use engineering controls properly and routinely. Housekeeping in laboratories that use beryllium alloys should be performed routinely and thoroughly to prevent the accumulation of dust that can be spread to other work areas or become airborne if disturbed. Cleaning should be performed with HEPA vacuums instead of traditional vacuums, and the use of compressed air and dry sweeping should be avoided.

In this standard group of controls described above, the downdraft-plus-backdraft grinding bench will control the exposures of dental laboratory technicians while they manually grind dental appliances, but work practice and administrative controls are necessary to ensure that the bench ventilation is maintained in working order, kept clean, and that beryllium particles are not released when the ventilation system is serviced and the filter is changed.

In the event that exposures continued to remain elevated with the standard group of controls, additional control options are also available, such as providing improved exhaust ventilation for both the furnace and abrasive blasting units. Furnaces should be fitted with close-capture hoods attached to the furnace whenever possible.[313] Abrasive blasting units should be upgraded to meet the specifications presented in ACGIH (2010) (see Figure VS-80-02, abrasive blasting

[313] OSHA notes that the kitchen-type canopy-style ventilation hoods typically present in dental laboratory furnace areas are primarily intended to control heat and are not effective for toxic air contaminants (see Sections 13.27 [Hot Process Ventilation] and 13.30 [Kitchen Equipment] in ACGIH, 2010).

cabinet, adapted to the scale of the benchtop blasting units typically used in dental laboratories). The blasting media must be changed frequently—using dust control precautions and respiratory protection—to prevent buildup of beryllium in the sand or other medium. Ventilation systems must be discharged outdoors, or fit with HEPA or equivalent filtration.[314] The same precautions and alarms are required for this ventilation equipment as for the grinding booth.

Dental Laboratory Technician—Conclusion

The median exposure level for dental laboratory technicians is 0.2 μg/m^3 (see Table IV-80). Based on the findings of the exposure profile presented in Table IV-81, the proposed PEL of 0.2 μg/m^3 has already been achieved for 52 percent of dental technicians. Additionally, 13 percent of dental laboratory technicians currently have exposures below an alternative PEL of 0.1 μg/m^3. Roughly 48 percent of these workers will require additional controls to reduce exposures to or below the proposed PEL of 0.2 μg/m^3. For those laboratories that continue to use beryllium alloys, the exposure of dental laboratory technicians can be substantially reduced through the combined use of appropriate enclosures and LEV systems; administrative and work practice controls to ensure that the ventilation systems are maintained and used so that they function effectively; and housekeeping to ensure that beryllium contamination is not spread should it occur. A study simulating the work of dental laboratory technicians found that the proper use of adequate LEV was associated with exposure reductions of at least 98 percent (Hinman et al., 1975). Other studies also show substantial exposure reductions associated with LEV. Enclosed and ventilated cabinets or booths would be expected to further reduce exposure. By using these control methods in conjunction with effective work practices and housekeeping methods, nearly all dental laboratory technicians will achieve beryllium exposure levels below 0.1 μg/m^3 (Hinman et al., 1975; Thomas et al., 2009). OSHA therefore preliminarily concludes that both an alternative PEL of 0.1 μg/m^3 and the proposed PEL of 0.2 μg/m^3 are feasible for dental laboratory technicians.

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SECTION 11—DENTAL LABORATORIES, APPENDIX 1—OSHA IMIS PBZ TOTAL BERYLLIUM AIR SAMPLING RESULTS FOR DENTAL TECHNICIANS

Table IV-82—OSHA IMIS PBZ Total Beryllium Air Sampling Results for Dental Technicians[a]

SIC Code	SIC Description	No. PBZ samples with Positive Results / Total No. of PBZ Samples[b]	Example Job Descriptions (as listed in IMIS)	Range[c] ($\mu g/m^3$)	Mean[c] ($\mu g/m^3$)	Median[c] ($\mu g/m^3$)
3843	*Dental Equipment and Supplies*	*1/1 (100% positive)*	*Dental lab technician*	*0.01[d]*	*0.01*	*0.01*
5160	*Chemicals and Allied Products*	*0/1 (0% positive)*	*Dental tech*	*None*	*None*	*None*
8049	*Offices and Clinics of Health Practitioners, NEC*	*1/1 (100% positive)*	*Denture metal alloys*	*3.0[e]*	*3.0*	*3.0*
8062	*General Medical and Surgical Hospitals*	*0/1 (0% positive)*	*Dental tech*	*None*	*None*	*None*
8071	*Medical Laboratories*	*0/3 (0% positive)*	*Dental lab tech*	*None*	*None*	*None*
8072	*Dental Laboratories*	*19/32 (59% positive)*	*Dental tech; dental technician; frame grinder; grinding partials; lab technician; metal fabricator; metal finisher; tech/denture polisher; metals grind etc.*	*0.03 to 0.20[f]*	*0.10*	*0.10*
N/A[e]	*OSHA On-site Consultation Services*	*2/2 (100% positive)*	*Dental tech metal; crown grinder*	*0.02 to 0.03[g]*	*0.025*	*0.025*
Total		*23/41 (56% positive)*		*0.01 to 3.0*	*0.22*	*0.10*

[a] *Information regarding worker activities, the engineering controls in place, personal protective equipment (PPE) worn during sampling, nondetectable limit of detection (LOD) sample concentrations, and sample duration is not available.*

[b] *Includes all PBZ samples by SIC code.*

[c] *The range, mean, and median results are based on positive sample results only. All positive results are included.*

[d] *Coded as a ceiling sample.*

[e] *Coded as a STEL (short-term exposure limit) sample.*

[f] *Includes six samples coded as ceiling samples; four samples coded as STEL samples; and nine samples coded as time-weighted average (TWA) samples.*

[g] *Coded as TWA samples.*

[e] *N/A: not available*

Table IV-82—OSHA IMIS PBZ Total Beryllium Air Sampling Results for Dental Technicians[a]
Source: OSHA, 2009

SECTION 12—SHORT-TERM EXPOSURES

INTRODUCTION

This section of the Preliminary Economic Analysis (PEA) identifies the tasks or jobs and the industries in which elevated short-term exposures have been documented, describes the influence that short-term exposures have on daily full-shift exposure levels, and discusses the technological feasibility of reducing short-term exposures.

DEFINING SHORT-TERM EXPOSURES AND IDENTIFYING SAMPLES

Short-term exposure means the worker exposure level averaged over a 15-minute sampling period. A 15-minute averaging period for short-term exposure limits (STELs) has been a standard in OSHA's previous rulemakings for air contaminants, such as 1, 3-Butadiene (29 CFR 1910.1051) and Methylene chloride (29 CFR 1910.1052). Elevated short-term exposures occur when tasks lasting 15 minutes or less, or short bursts of activity within longer tasks, result in peaks in airborne concentrations that significantly exceed background levels. Thus, one or more intermittent peaks during a 15-minute sampling period can contribute to an elevated short-term exposure.

OSHA's current acceptable ceiling limit for beryllium is defined in Table Z-2 of 29 CFR 1910.1000 as airborne concentrations of beryllium no greater than 5 µg/m^3 during an 8-hour shift, except that exposures may be as high as 25 µg/m^3 for one 30-minute period during an 8-hour shift. For compliance purposes, exposure levels can exceed an acceptable ceiling value of 5 µg/m^3 only once for not more than one thirty-minute interval during which exposures cannot exceed an acceptable maximum peak of 25 µg/m^3. In order to assess compliance with OSHA's ceiling concentrations, employers have the option of assessing the beryllium ceiling concentration as a 15-minute time-weighted average (TWA) (FR 40 202, 1975).

With this proposed beryllium standard, OSHA intends to replace the current acceptable ceiling limit of 5.0 µg/m^3 with a short-term exposure limit (STEL) of 2.0 µg/m^3 based on a 15-minutes averaging period. OSHA is also considering an alternative STEL of 1.0 µg/m^3. To evaluate the feasibility of these proposed STELs, OSHA gathered samples for short-term tasks sampled over 15 minutes. To supplement these data, OSHA also considered samples collected over a somewhat shorter or longer period of time (e.g., 5 minutes and 30 minutes). OSHA has used this time range because it allows the Agency to build a more comprehensive exposure profile, and the short-term tasks that may expose workers to beryllium are typically conducted within this time frame. The 15- and 30-minute samples are equally prevalent within the data provided by the United States Navy (NEHC, 2003). Among samples collected by OSHA personnel, however, the 15-minute sampling period has been the most common short-term sampling period for evaluating beryllium exposure (OSHA, 2009).[315]

[315] Of the 58 shorter-term samples provided by the U.S. Navy for industries covered in Sections 2 through 11, nearly three-fifths (33 samples) were obtained over 15-minutes and two-fifths (24 samples) were obtained over 16 to 30

In some cases, such as with OSHA's IMIS dataset for beryllium, sample durations are not specified for the reported exposure levels; however, OSHA considered the sample relevant to this analysis if the data indicate that the compliance officer compared the result to OSHA's current ceiling or peak exposure limits, presented in 29 CFR 1910.1000 Table Z-2. OSHA considered this to be sufficient evidence that the investigator limited the sampling time to a relevant short period. However, due to the limited nature of the available information OSHA could not discern exactly what the worker was doing during the sampling period.

SOURCES OF INFORMATION

OSHA searched for relevant job categories and short-term beryllium sampling data in the sources of exposure information described in Sections 3 through 11, Beryllium Production through Dental Laboratories, of the PEA.[316] In general, short-term samples were less prevalent than full-shift samples. For example, all available personal breathing zone (PBZ) beryllium samples from Brush Wellman and the National Institute for Safety and Health (NIOSH) exceed 30 minutes, and most are reported as full-shift. However, two sources—OSHA's IMIS database and the United States Navy's Naval Environmental Health Center (NEHC) database—included short-term samples (OSHA, 2009; NEHC, 2003).

<u>IMIS Short-Term Exposure Data</u>

ERG reviewed IMIS data from June 1978 to September 2008 to identify all PBZ samples reported as ceiling (C), short-term (L), or peak exposures (P).[317] Collectively, these three exposure types in the IMIS dataset are representative of exposures that occur during short-term tasks for this analysis.

The IMIS database presents information by SIC code classification. OSHA analyzed the short-term IMIS data by SIC codes corresponding to the industries and job titles included in this technological feasibility analysis. The IMIS data include 593 PBZ air samples positive for total beryllium and representative of exposures that result from short-term tasks ("C" samples, "L" samples, and "P" samples) in the application groups addressed by this feasibility analysis (Beryllium Production through Dental Laboratories, Sections 3 through 11 of this PEA).[318]

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minutes. One sample was obtained over a period of 10 minutes (NEHC, 2003). Among the 593 personal breathing zone (PBZ) positive IMIS peak, ceiling, or STEL beryllium records used in this analysis, 69 percent (411 samples) were associated with ceiling or STEL exposure limits (both are evaluated over 15-minute periods) (OSHA, 2009). The remaining 31 percent of the shorter term IMIS data were designated as peak samples (30 minutes).

[316] Reviewed sources are: Brush Wellman, 2004; NEHC, 2003; NIOSH EPHB 263-12a, 2004; NIOSH EPHB 326-12a, 2008; NIOSH EPHB 326-15a, 2008; NIOSH EPHB 326-17a, 2009, MC Pkg I-A though I-F, various dates; Kent et al., 2007; Materion PSCS 102, 2011; Materion PSCS 103, 2011; Materion PSCS 104, 2011; Materion SF 201, 2011; MBC-A through MBC-R, various dates.

[317] The IMIS data available to ERG are categorized by sample type (i.e., area, bulk, personal, screening, or wipe); exposure type (i.e., ceiling, STEL, peak, TWA, or not detected); and exposure level (exposure value) in the units specified.

[318] Prior to analysis, 119 values were eliminated from the IMIS data because the results appeared to be invalid. Three of the samples were removed because the listed PELs and/or concentration units did not correspond to OSHA's beryllium PELs. These values include 260 $\mu g/m^3$ (SIC 3324), 280 $\mu g/m^3$ (SIC 3465), and 57 parts per million (SIC 3519). The remaining 116 values were eliminated because the samples have no job description and the

However, the database does not provide details of the activities that the workers were performing during the time they were monitored. As in Beryllium Production through Dental Laboratories, Sections 3 through 11 of this PEA, the nondetectable (ND) short-term samples have been excluded; thus, all the IMIS short-term sample results discussed here are positive for beryllium.[319]

<u>Other Short-Term Exposure Data</u>

ERG also compiled and reviewed PBZ total beryllium air samples shorter than or equal to 30 minutes in duration that were submitted by the U.S. Navy in response to OSHA's request for information pertaining to occupational exposure to beryllium (NEHC, 2003). Fifty-eight short-term PBZ samples from the Navy docket submittal were utilized in this analysis. These samples represent the most relevant jobs/tasks with positive beryllium results or possible beryllium exposure. [320] The majority of these samples are associated with the following jobs or tasks: maintaining ventilation equipment (air-cleaning devices) that support beryllium operations; machining beryllium-containing materials (e.g., turning copper-beryllium bushings); and welding and cutting involving base materials (e.g., aluminum) or electrodes (e.g., resistance welding) that could contain beryllium. [321]

OPERATIONS DURING WHICH SHORT-TERM EXPOSURES OCCUR

Elevated exposures can occur during intermittent or periodic activities that involve a brief period of increased potential for beryllium exposure. Activities that can cause intermittent increased exposure are concentrated within high-energy tasks that release beryllium particles (e.g., certain machining jobs, such as grinding); jobs that involve creating a substantial amount of fume for a short period of time (e.g., removing dross during furnace operations, pouring/casting beryllium

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exposure, PEL, and severity are all listed as zero. Subsequently, the dataset was refined to include only sample results associated with the SIC covered in Sections 3 through 11, resulting in 593 short-term IMIS samples.

[319] OSHA acknowledges that several factors limit the value of the IMIS dataset. First, no beryllium was detected in the vast majority of samples analyzed for beryllium (reported as "ND", or not detected); however, most of the IMIS beryllium samples were likely the result of general metal emissions screening (i.e., beryllium was not necessarily present in the sampled workplace but rather, was automatically included as part of the standard 10-metal analytical screening panel performed by the laboratory). Overall, beryllium was not detected in 84 percent of the samples reviewed for this analysis; however, the actual percentage of samples in which beryllium was not detected is likely to be even higher. Only data for IMIS samples positive for beryllium were provided for the period 2003 to 2008. From 1978 to 2003, on average beryllium was detected in just 12 percent of the IMIS samples analyzed for beryllium (none detected in 88 percent). As an additional limitation, sample results in the IMIS database do not include the sampling limit of detection (LOD) for nondetectable samples. It is not possible to tell whether the nondetectable samples were analyzed with a LOD below the proposed PEL and action level. Despite these limitations, the positive IMIS sample results provide limited supplemental evidence of trends in short-term beryllium exposure levels.

[320] OSHA originally considered 149 sample results from the U.S. Navy's docket submission. However, 91 of the samples were associated with LODs above the range of interest (2.0 $\mu g/m^3$) or activities that are not included in this technological feasibility analysis (e.g., abrasive blasting, military-only tasks).

[321] As noted above, OSHA also reviewed data from other sources, including NIOSH and Materion (Brush Wellman). However, these data were not used in this analysis because sampling durations exceeded 30 minutes and/or there was no reasonable indication that beryllium might be present, based on the description of the tasks involved (such as machining non-beryllium-containing metals, welding with no other descriptors, and abrasive blasting with glass bead).

alloys); jobs that require workers to handle beryllium products on which loose, friable oxides of beryllium are present (e.g., tasks involving containers of foundry dross or powdered beryllium oxide); and housekeeping or maintenance tasks that cause beryllium dusts or mists to become airborne (e.g., sweeping, maintaining exhaust ventilation systems used to capture beryllium).

Based on the IMIS and Navy samples, results exceeding 2.0 µg/m^3 appear to be associated with the following types of operations and job categories:

- Beryllium production: Furnace operations (melting and casting); powdering/pebble plant operations.
- Copper and aluminum foundries: Furnace operations (melting and casting).
- Secondary smelting, refining, and alloying, including handling of scrap and recycled materials: Furnace operations (furnace charging, melting and casting, calcining); mechanical processing; machining; housekeeping (sweeping).
- Welding: Welding and cutting.
- Jobs similar to those listed above (furnace operations, machining, housekeeping), which are occasionally listed in association with other related industries (e.g., manufacturing of fabricated metal products).

RELATIONSHIP BETWEEN STEL AND PEL EXPOSURES

Elevated short-term exposures are included in calculations of a worker's daily 8-hour TWA. Although brief, the higher concentration of a short-term exposure can influence the 8-hour TWA. A short-term exposure exceeding the proposed STEL of 2.0 µg/m^3 can influence whether the proposed PEL of 0.2 µg/m^3 can be achieved for a worker. For example, the typical average daily exposure of 0.1 µg/m^3 for a worker will increase to 0.225 µg/m^3 (exceeding the proposed PEL of 0.2 µg/m^3) if that worker is assigned a new task that adds two 15-minute periods at an exposure level of 2.1 µg/m^3 (slightly exceeding the proposed STEL of 2.0 µg/m^3).[322]

Even when the worker has no other source of beryllium exposure during the work shift, that worker's 8-hour TWA will exceed the proposed PEL if the STEL is exceeded during more than three 15-minute periods over the course of a work shift. For example, in the absence of any other exposure, a concentration of 2.1 µg/m^3 for 48 minutes will cause the 8-hour TWA for that worker to exceed the proposed PEL of 0.2 µg/m^3. Similarly, even with no other source of beryllium exposure, a single 15-minute exposure of 6.4 µg/m^3 or greater will cause the worker's 8-hour TWA to exceed the PEL of 0.2 µg/m^3. These values represent the short-term threshold above which the PEL cannot be achieved.[323]

[322] OSHA's equation from 29 CFR 1910.1000(d)(1)(i) is used for determining an 8-hour TWA exposure when the beryllium concentration varies over time:

$$(\text{Concentration}_1 \text{ X Time}_1 + \text{Concentration}_2 \text{ X Time}_2 + \text{Concentration}_n \text{ X Time}_n)/480 \text{ minutes}).$$

[323] Situations exist in which it is mathematically possible to have four–15 minutes exposures of 2.0 µg/m^3 (compliant with the STEL) with zero exposure for the remainder of the work shift, and yet have a resulting 8-hour TWA of 0.25 µg/m^3 (noncompliant with the PEL). Additionally, with a background exposure of 0.1 µg/m^3, the

Table IV-83 demonstrates how various elevated short-term beryllium concentrations can cause the daily exposure level to exceed the PEL.

Table IV-83—Influence of Short-Term Beryllium Exposure Levels on a Worker's 8-hour TWA Exposure

Number of Short (15 minute) Periods During the Shift	Short-Term Concentration for Cumulative Time	Concentration During Remainder of Shift	8-hour TWA Concentration
Short-Term Exposure, With No Other Exposure			
One	*2.1 µg/m³ for 15 minutes*	*0 µg/m³ for 465 minutes*	*0.07 µg/m³*
Two	*2.1 µg/m³ for 30 minutes*	*0 µg/m³ for 450 minutes*	*0.13 µg/m³ Exceeds Proposed AL*
Three	*2.1 µg/m³ for 45 minutes*	*0 µg/m³ for 435 minutes*	*0.2 µg/m³ Exceeds Proposed AL*
Four	*2.1 µg/m³ for 60 minutes*	*0 µg/m³ for 420 minutes*	*0.26 µg/m³* ***Exceeds Proposed PEL***
Short-Term Exposure and Constant Background Exposure at the Action Level (AL) of 0.1 µg/m³			
One	*2.1 µg/m³ for 15 minutes*	*0.1 µg/m³ for 465 minutes*	*0.16 µg/m³ Exceeds Proposed AL*
Two	*2.1 µg/m³ for 30 minutes*	*0.1 µg/m³ for 450 minutes*	*0.23 µg/m³* ***Exceeds Proposed PEL***
Three	*2.1 µg/m³ for 45 minutes*	*0.1 µg/m³ for 435 minutes*	*0.29µg/m³* ***Exceeds Proposed PEL***
Increasing Short-Term Exposure Level, With No Other Exposure			
One	*4 µg/m³ for 15 minutes*	*0 µg/m³ for 465 minutes*	*0.13 µg/m³ Exceeds Proposed AL*
One	*8 µg/m³ for 15 minutes*	*0 µg/m³ for 465 minutes*	*0.25 µg/m³* ***Exceeds Proposed PEL***
One	*12 µg/m³ for 15 minutes*	*0 µg/m³ for 465 minutes*	*0.38 µg/m³* ***Exceeds Proposed PEL***
Increasing Short-Term Exposure Level and Constant Background Exposure of 0.1 µg/m³			
One	*4 µg/m³ for 15 minutes*	*0.1 µg/m³ for 465 minutes*	*0.22 µg/m³* ***Exceeds Proposed PEL***

Notes:
8 hours = 480 minutes.
8-hour TWAs calculated using OSHA's equation from 29 CFR 1910.1000(d)(1)(i) for determining an 8-hour TWA exposure:
($Concentration_1$ X $Time_1$ + $Concentration_2$ X $Time_2$ + $Concentration_n$ X $Time_n$)/480 minutes).
In the absence of any other beryllium exposures, the short-term threshold above which the proposed PEL of 0.2 µg/m³ cannot be achieved is 48 minutes at 2.1 µg/m³, or 15 minutes at 6.4 µg/m³.

Table IV-83 also indicates the relatively narrow range of short-term and background exposure conditions under which the STEL could be exceeded without also exceeding the PEL.

proposed PEL of 0.2 µg/m³ will be exceeded with two or more 15-minute exposures of 2.0 µg/m³ during the work shift.

EVIDENCE THAT STEL EXPOSURES CAN OCCUR

OSHA considered the available information for samples designated as short-term with results exceeding 2.0 μg/m^3 (OSHA, 2009; NEHC, 2003). OSHA also examined results exceeding 6.4 μg/m^3, the short-term (15-minute) threshold above which the PEL cannot be achieved. Among a total of 651 short-term samples, 117 (18 percent) exceeded the proposed STEL of 2.0 μg/m^3, and 39 (6 percent) exceeded 6.4 μg/m^3. These details provide evidence that short-term exposures do occur and can exceed the proposed STEL.

In reviewing the short-term exposure data by decade, OSHA observed a trend toward a lower percentage of sample results exceeding 2.0 μg/m^3 in more recent decades. However, as shown in Table IV-84, excessive short-term exposures continue to occur. During the most recent time period analyzed (2000 to 2008), only 5 of 82 positive short-term samples (6 percent) exceeded 2.0 μg/m^3, while the other 94 percent were all less than or equal to 1.0 μg/m^3. In total, only 6% of the 623 positive short term measurements were greater than 1.0 μg/m^3 and less than or equal to 2.0 μg/m^3.

Table IV-84—Distribution of Short-term Beryllium Exposure Levels, Over Three Decades

Time Period	Number of Positive Short-Term Sample Results[a] (μg/m^3)					
	0 to ≤ 1	**> 1 to ≤ 1.5**	**> 1.5 to ≤ 2**	**> 2 to ≤ 6.4**	**> 6.4**	**Total**
Total 1980-2008	*468 (75.1%)*	*21 (3.4%)*	*17 (2.7%)*	*78 (12.5%)*	*39 (6.3%)*	*623 (100%)*
Decade						
1980 through 1989	*74 (50.7%)*	*7 (4.8%)*	*14 (9.6%)*	*38 (26.0%)*	*13 (8.9%)*	*146 (100%)*
1990 through 1999	*317 (80.3%)*	*14 (3.5%)*	*3 (0.8%)*	*38 (9.6%)*	*23 (5.8%)*	*395 (100%)*
2000 and later [2008]	*77 (93.9%)*	*0 (0%)*	*0 (0%)*	*2 (2.4%)*	*3 (3.7%)*	*82 (100%)*

[a] *Short-term sample results associated with industries addressed in Methodology through Dental Laboratories, Sections 2 through 11 of this PEA (593 positive short-term sample results reported in IMIS and 30 short-term results reported by the U.S. Navy, a total of 623 samples). OSHA removed 28 non-detectable U.S. Navy samples that had reporting limits between 1.0 μg/m^3 and 2.0 μg/m^3 (i.e., greater than 1.0 μg/m^3 and less than 2.0 μg/m^3). Before those 28 U.S. Navy samples were removed, the data set included 593 IMIS and 58 U.S. Navy samples (a total of 651 STEL samples).*

Source: OSHA, 2009; NEHC, 2003

AFFECTED INDUSTRIES AND JOB CATEGORIES

OSHA analyzed the short-term IMIS data by industry. As for all analysis in Section 12—Short-Term Exposures, OSHA restricted the data to only those samples associated with the application groups described earlier in Beryllium Production through Dental Laboratories, Sections 3 through 11 of this PEA. The analysis shows that short-term tasks or jobs involving elevated exposures are most often associated with beryllium production and the secondary smelting, refining, and alloying industries, although elevated short-term exposures do occasionally occur in other major beryllium industries as well.

Overall, 82 percent (494 samples) of the 606 short-term IMIS sample results for all beryllium industries analyzed in this section (12—Short-Term Exposures) were 2.0 $\mu g/m^3$ or less (range 0.005 $\mu g/m^3$ to 7.1 $\mu g/m^3$). The individual industry sectors analyzed by median short-term exposure levels, presented in Table IV-85 (details by job category in Table IV-88 in Short-Term Exposures Appendix 2), include beryllium production (0.7 $\mu g/m^3$); beryllium oxide (0.4 $\mu g/m^3$); aluminum and copper foundries (0.17 $\mu g/m^3$); secondary smelting, refining, and alloying, including handling of scrap and recycled materials (0.6 $\mu g/m^3$); copper rolling, drawing, and extruding (0.08 $\mu g/m^3$); welding and cutting (0.07 $\mu g/m^3$); and dental laboratories (0.1 $\mu g/m^3$). The data for each of these sectors are well supported, with at least 10 short-term samples for each industry, except for the beryllium oxide industry, with seven samples.[324, 325] OSHA observes that the median short-term sample result for each of these industries is less than one-half the proposed STEL (medians range from 20 to 35 percent of the proposed STEL for beryllium production; beryllium oxide; and secondary smelting, refining, and alloying (including handling of scrap and recycled materials) and just 4 percent to 9 percent of the proposed STEL for the remaining industries). These findings suggest that elevated short-term exposures are infrequent in the industries covered by the proposed standard.

Table IV-87 in Short-Term Exposures Appendix 1 confirms this observation, using 149 PBZ exposure results from the Navy to demonstrate that task-based short-term samples typically are less than or equal to 2.0 $\mu g/m^3$. In this dataset, 87 percent (130 samples) of the 149 short-term sample results were 2.0 $\mu g/m^3$ or less (conversely only 13 percent, or 19 samples exceed 2.0 $\mu g/m^3$).[326]

[324] Although it is a job category, rather than an entire industry, the furnace (melting and casting) job category stands out with 27 samples for which the median is above 2.6 $\mu g/m^3$. Due to the elevated full-shift exposures associated with this job category, it is also identified as a job category of concern in the section on Nonferrous Foundries (Chapter IV, Section 5, of the PEA).

[325] Table IV-85 summarizes the more detailed information presented in Appendix B (Table IV-88), which, to be complete, presents 13 welder samples both under the appropriate beryllium industry sector SIC and under the consolidated Welding heading. See Notes section in Table IV-88 for additional information. The number of samples (607) summarized in Table IV-85 includes those 13 welder results under both the specific beryllium sector and the Welding sector. Overall, Table IV-85 represents (606-13=593 individual IMIS sample results. This is consistent with the number of IMIS samples considered in Table IV-84.

[326] A substantial portion (83 percent) of the total short-term sample results in this dataset were below the limit of detection. Although only 9 of these non-detected samples had results above 2.0 $\mu g/m^3$, they represent 47 percent of the 19 samples that exceed 2.0 $\mu g/m^3$. This means that actual concentrations were likely less than 2.0 $\mu g/m^3$ during the periods when some of these samples were obtained and therefore the concentration was 2.0 $\mu g/m^3$ or less at least 87 of the time, and possibly as much as 93 percent of the time.

Table IV-85—Summary of OSHA IMIS PBZ Short-Term Air Sampling Results Positive for Total Beryllium by Industry Sector

Beryllium Industry Sector	IMIS Job Titles	Short-Term Exposure Sources	No. Samples	Beryllium Concentration (μg/m³)				Sample Distribution	
				Mean	Median	Minimum	Maximum	≤ 2.0 μg/m³ (Percent)	> 2.0 μg/m³ (Percent)
Beryllium Production (Section 3)	*Foundry (mold and core preparation, shakeout, melting and casting); machining; pebble plant operator; pelletizing; powdering; sheet operator; welding and cutting*	*Transition activities (transferring)*	*96*	*4.4*	*0.7*	*0.01*	*99*	*63 (65%)*	*33 (35%)*
Beryllium Oxide (Section 4)	*Welding and cutting; engine manufacturing*	*Transition activities (transferring), breaching enclosed processes*	*7*	*0.7*	*0.4*	*0.1*	*2.0*	*7 (100%)*	*0 (0%)*
Nonferrous Foundries (Section 5)	*Furnace - melting and casting; shakeout; mold and core preparation; machining; welding and cutting*	*Hot processes that generate fumes; dross handling; tasks that disturb dust*	*80*	*1.0*	*0.17*	*0.01*	*8.8*	*65 (81%)*	*15 (19%)*
Secondary Smelting, Refining, Alloying (Section 6)	*Electrical - engineering; foundry; mold and core; pressing; calcining; furnace charging; incinerator; kiln; laboratory technician; material handling; heavy equipment operations; mechanical processing; scrap operations; sweeping; tool-making; laundry operator; repair and maintenance*	*Hot processes that generate fumes; high-energy activities; tasks that disturb dust (including housekeeping and maintenance)*	*194 (substantial legacy exposure data)*	*2.1*	*0.6*	*0.02*	*18*	*135 (70%)*	*59 (30%)*
Precision Turned Products (Section 7)	*No short-term exposure data*	*Potential for breaching enclosed processes; uncontrolled cutting fluid mist*	*0*	*n/a*	*n/a*	*n/a*	*n/a*	*0 (0%)*	*0 (0%)*

Table IV-85—Summary of OSHA IMIS PBZ Short-Term Air Sampling Results Positive for Total Beryllium by Industry Sector

Beryllium Industry Sector	IMIS Job Titles	Short-Term Exposure Sources	No. Samples	Beryllium Concentration (µg/m³)				Sample Distribution	
				Mean	Median	Minimum	Maximum	≤ 2.0 µg/m³ (Percent)	> 2.0 µg/m³ (Percent)
Copper Rolling, Drawing, Extruding (Section 8)	*Furnace - melting and casting; mechanical processing; forging; powdering*	*Friable beryllium oxide on surfaces being worked*	*10*	*0.28*	*0.08*	*0.01*	*0.9*	*10 (100%)*	*0 (0%)*
Fabrication of Beryllium Alloy Products (Section 9)	*No short-term exposure data*	*none*	*0*	*n/a*	*n/a*	*n/a*	*n/a*	*0 (0%)*	*0 (0%)*
Welding (Section 10)	*Welding and cutting*	*Friable beryllium oxide on surfaces being worked*	*209*	*0.21*	*0.07*	*0.005*	*7.1*	*204 (98%)*	*5 (2%)*
Dental Laboratories (Section 11)	*Dental laboratory*	*Grinding and polishing; abrasive blasting (on beryllium alloy)*	*10*	*0.11*	*0.1*	*0.1*	*0.2*	*10 (100%)*	*0 (0%)*
TOTAL			**606**			**0.005**	**99**	**494 (82%)**	**112 (18%)**

Note:
n/a: not applicable

Source: OSHA Integrated Management Information System (IMIS) Database, 1978 -2008 (OSHA, 2009)

RELATIONSHIP OF CONTROL METHODS FOR STEL AND PEL EXPOSURES

As discussed earlier, only a relatively narrow range of short-term and background exposure conditions exists under which the proposed STEL (2.0 µg/m^3) could be exceeded without also exceeding the proposed PEL of 0.2 µg/m^3. Additionally, with a background exposure at the proposed action level (0.1 µg/m^3), the proposed PEL will be exceeded with two or more short term exposures of at least 2.0 µg/m^3. There are a larger number of scenarios in which an alternative STEL of 1.0 µg/m^3 could be exceeded and still comply with the proposed PEL of 0.2 µg/m^3. Using the same methodology from Table IV-83, OSHA estimates that with a background exposure of 0.1 µg/m^3, it would take four or more short-term exposures of 1.1 µg/m^3 to exceed the proposed PEL.

Effective controls for reducing short-term exposure levels are required to maintain exposure levels at the proposed PEL or lower. To achieve the proposed PEL, employers should be aware of the impact that short-term exposures have on the 8-hour TWA and thus make efforts to reduce short-term exposures as part of their overall exposure-reduction strategy. However, as discussed below the controls that OSHA has recommended to reduce the workers' 8-hr TWA would also be applicable to reduce short term exposures.

Information presented in Table IV-84 (623 short-term beryllium samples from IMIS and the U.S. Navy) suggests that 81 percent of workers' short-term exposures are already at or below 2.0 µg/m^3. However, OSHA does not have sufficient detail in the activities of the workers to know if these samples were in operations that are most likely to produce exposures above the STEL. Therefore the estimate could underestimate the percentage of workers in activities that are most likely be affected by high short term exposures that are already below the proposed STEL. However, based on relationship between the STEL to the 8 hour TWA as described in Table IV-84 and the controls OSHA has recommended to reduce worker's exposure to below the 8 hr TWA, OSHA preliminarily concludes that the proposed STEL of 2.0 µg/m^3 is achievable in most operations most of the time. OSHA believes that the control measures identified in the technological feasibility analysis to reduce exposures to the proposed PEL will similarly reduce exposures to the proposed STEL or below. In many situations, these controls will have reduced short-term exposures as a necessary condition of reducing the full-shift exposure. For example, in material handling operations, modifying the process by ensuring enclosure of drums and preventing leakage reduces the highest short-term exposures and the 8-hour TWA, which is influenced by the short-term exposures. Refer to Beryllium Production through Dental Laboratories, Sections 3 through 11 of this PEA, for details on how these additional controls affect exposures above the proposed PEL.

Many of the engineering control measures described in this technological feasibility analysis and listed in Appendix B of the proposed rule are recommended for operations with the potential for highest short term exposures. In most cases, reducing peak exposures during short term tasks will be necessary to reduce the TWA exposures to workers who are currently exposed above the proposed PEL.

OSHA has been able to obtain only limited information regarding work shifts where both a short-term exposure and an 8-hour TWA exposure were obtained. Table IV-86 presents the limited dataset containing eight samples with both short-term and 8-hour TWA values. OSHA is unable to use this information to characterize the nature of STEL and PEL exposures for all the affected job categories, as these data represent only a few operations. As previously discussed, however, these data show how it is possible to have instances where the short-term exposures are above the proposed STEL when the 8-hour TWA exposures are below the proposed PEL.

These data indicate that high mechanical energy operations, such as grinding, can produce peak exposures that exceed the proposed STEL and PEL, as is the case with the 10 µg/m^3 short-term exposure associated with the 1.0 µg/m^3 8-hour TWA (NEHC, 2003). This phenomenon is common to all operations with elevated peak exposures. OSHA assumes that the engineering controls listed in Appendix B can be implemented to reduce elevated short-term exposures, as well as background exposure levels. For example, partial enclosures, automation, and improved material handling systems all address potential peak exposures in those problematic operations such as furnace operations and mechanical processing operations identified in Beryllium Production through Secondary Smelting, Refining, and Alloying, Including Handling of Scrap and Recycled Materials, Sections 3 through 6 of this PEA. Lacking the comparative data of short-term and 8-hour TWA exposures for the vast majority of operations, OSHA cannot determine to what extent the remaining 18 percent of the population exposed over the proposed STEL will shift toward maintaining short-term exposures at or below 2.0 µg/m^3. OSHA requests additional information that may help in identifying the conditions under which the proposed STEL can and cannot be achieved, including correlated short-term and 8-hour TWA exposures.

The data in Table IV-86 help to demonstrate the importance of reducing peak exposures for operations in which peak exposures contribute to both elevated short-term and full-shift TWA exposures. The engineering controls identified in Secondary Smelting, Refining, and Alloying, Including Handling of Scrap and Recycled Materials, Sections 3 through 11 of this PEA that reduce the highest full-shift exposures also reduce peak exposures. Reduction of peak exposures will in turn result in lower short-term exposures in these operations. In these situations, if after implementing all feasible control options, short term exposures continue to exceed the proposed STEL, the employer will have to employ respiratory protection to reduce short-term exposures, while also characterizing the associated 8-hour TWA exposures in order to develop a comprehensive exposure-control program that satisfies the provisions of the proposed standard. In some cases, respiratory protection might only be necessary for short-term exposures if the background exposure is minimal, or respiratory protection might be needed to control both short-term and 8-hour TWA exposures. The type of respiratory protection should be determined in accordance with the Respiratory Protection standard (29 CFR 1910.134).

ADDITIONAL CONTROL MEASURES

As mentioned previously in this section of the PEA (12—Short-Term Exposures), control measures are similar (often identical) for short-term activities and longer processes. Additionally, to be effective, the controls that manage daily exposures must reduce short-term exposures as part of the effort. The following controls represent examples that reduce both short-term and full-shift exposures. The controls are described in Beryllium Production through Dental Laboratories, Sections 3 through 11 of this PEA, and many of them are listed in Appendix B of OSHA's proposed rule. These measures are mentioned here as examples of how controls are applicable to short-term exposure, both as part of a general exposure control strategy and in the event that efforts need to be targeted at short-term exposures.

Control Measures for Transition Activities Involving Material Handling and Transfers

Material handlers may experience elevated exposures when entering production areas. For example, workers in foundries and smelters that deliver furnace charge materials (i.e., materials to be put in the furnace for melting) may be exposed from ongoing furnace operations. To reduce exposures, this material delivery might be timed so that workers making the deliveries approach the furnace between periods of degassing, sparging, and dross skimming, thus avoiding periods when airborne contaminant levels in that area are highest. In another example, material handlers may be exposed from shakeout operations in foundries, as they are present in this operation when they deliver the cast to the shakeout area. Workers who usually work in the area but are not specifically involved in the shakeout process should move out of the area before vibrating equipment is activated. Until such time as all beryllium operations are reduced to the proposed PEL and STEL, workers should not linger in areas where exposure is not adequately controlled.

Control Measures for Machining Activities

Emissions from short- and long-term machining activities can expose workers to beryllium if these activities are not properly controlled. Many machining operations use metalworking fluid to regulate the temperature at the point of operation. Free beryllium particles in air and beryllium particles suspended in metalworking fluid mist are potential sources of exposure, and both can be controlled using enclosures and ventilation.

Hands et al. (1996) concluded that machining equipment with LEV and total enclosures designed by the original equipment manufacturer provides the most effective control of metalworking fluid mist exposure. Additionally, NIOSH investigators determined that entry, or even partial entry, into a machine tool enclosure led to higher operator exposures. The investigators used an aerosol photometer and video exposure monitoring to identify the peak metalworking fluid exposures of machine operators in the course of their work. One worker had his highest metalworking fluid exposure (0.93 mg/m^3) when he was inside a machining center cleaning; another worker had his highest exposures (0.45 mg/m^3 and 0.63 mg/m^3) when he was at the open doors of partially enclosed machining centers, sometimes with his arm inside (NIOSH ECTB 218-12a, 1997).

OSHA compared exposures at a facility that had fully enclosed and ventilated operations to another facility that did not have these control measures fully implemented. At ERG Beryllium Site 1, all machining operations were fully enclosed and ventilated, and full-shift PBZ exposure results were characterized by a median of 0.02 μg/m^3 and a mean of 0.035 μg/m^3 (range of 0.02 μg/m^3 to 0.11 μg/m^3). In contrast, control measures were not as fully implemented at ERG Beryllium Site 4 (also referred to as Site 9), some machining operations were not enclosed (i.e., open machining), and some enclosures and/or LEV systems were in need of upgrades to ensure that sufficient exhaust flow and containment were always available. The beryllium samples were collected over two shifts and are characterized by a mean of 1.48 μg/m^3, a median of 0.29 μg/m^3, and a range from 0.03 μg/m^3 to 41.48 μg/m^3. During the site surveys, ERG investigators noted that workers improperly positioned several exhaust ducts by a few centimeters, resulting in less than optimal exhaust flow around the parts being machined, or positioned themselves too close to the point of operation (ERG Beryllium Site 4, 2003; ERG Beryllium Site 9, 2004). Local exhaust ventilation (LEV) was applied to open machining operations through the use of moveable exhaust ducts manually positioned close to the point of operation. These operations relying on worker-positioned LEV and/or partial enclosure resulted in sample levels notably higher than those found at Site 1, where all operations were fully enclosed and ventilated.

Work practices can also play an important role in worker exposures. Opening or entering an enclosed process can lead to increased short-term exposures. If an operator opens the enclosure while particles remain suspended or if he reaches into the enclosure, the operator's breathing zone exposure is influenced by the enclosure contents. At ERG Beryllium Site 4, the highest total beryllium exposure level of 6.6 $\mu g/m^3$ was obtained on a machinist operating a fully enclosed and ventilated double-sided lapper. During the lapping cycle, it was noted that the worker opened the machine enclosure four to five times to check on the progress of the parts. It is likely that this work practice increased the machinist's exposure to beryllium (ERG Beryllium Site 4, 2003). Eliminating or minimizing this work practice will help significantly reduce machinists' exposures. Alternatively, the doors of the fully enclosed and ventilated machine enclosure could be interlocked with the machining cycle such that the enclosure cannot be opened during the machining cycle and the operator has to wait a designated period of time at the completion of the cycle (e.g., 1 to 2 minutes) before the door can be opened to retrieve the machined part. Materion Corporation advocates a similar approach and recommends that enclosure doors and ventilation systems be interlocked to the machine controls in a manner that requires the ventilation to be operating before startup, and stops the machine automatically if the doors are opened (Materion SF 201, 2011).

Another work practice that can help reduce exposures is the adjustment of equipment and materials so they are close to the door (which remains sealed during operation) to reduce the extent to which the worker must reach inside. Handles, trays, and tongs extend the reach without causing the worker to lean toward the open door.

As discussed in the opening paragraphs of the Additional Control Measures subsection of this Short-Term Exposure section, exposure reductions demonstrated for 8-hour TWA sample results likely translate into exposure reductions for short-term samples too. For additional information, see the discussion on additional controls for machinists (those turning both pure beryllium and beryllium alloy products in Section 7—Precision Turned Products of this PEA).

Control Measures for Hot Processes That Generate Fumes

Furnaces typically generate beryllium fumes over an extended period of time (depending on the amount of metal being melted), but worker exposures can be intermittent if workers approach the furnace only occasionally to check the melt or make additions. Pouring molten beryllium alloys also constitutes an intermittent activity that is sometimes associated with elevated short-term exposures.

Foundries will also need to upgrade LEV on furnaces to improve fume and dust capture and reduce the influence of cross-drafts (CCMA, 2000). A foundry casting copper-based alloy

(CCMA Case History Foundry C) used a horseshoe-shaped slotted hood at the top of the furnace (CCMA, 2000). This design allows ready access to the molten metal for treatment and dross skimming. An auxiliary ventilation system would be required to ensure that skimmed dross and the associated scoop would be continually held under exhaust ventilation as they passed between the furnace mouth, the dross receptacle, and the scoop storage area. At a beryllium alloy foundry where NIOSH found beryllium exposures for nearly all foundry workers to be below 0.5 $\mu g/m^3$ (NIOSH EPHB 326-16a), the employer had installed a slotted hood above the furnace in the green sand foundry and a slotted hood with flexible hoses connected to a Hawley Trav-L-Vent system over the crucible to remove fumes during pouring and transport. In the ingot foundry, the furnace was equipped with both a slotted hood over the furnace pot and a canopy hood with canvas side extensions. Visual observations indicated that dust and smoke from the melting and casting operations were effectively captured at the LEV openings. Controls for foundry furnaces are discussed in this PEA at Section 5—Nonferrous Foundries.

Control Measures for Dross Handling

Dross handling is a short-term intermittent activity performed routinely in facilities that melt beryllium alloys. Dross skimming takes several minutes, during which workers are exposed to beryllium fume (from the furnace and hot tools coated with molten metal) and flaking beryllium oxide (develops as the molten dross cools). Dross receptacles can be fitted with LEV. A beryllium producer designed and installed a ventilated dross collection tray that integrates fume control with furnace-mounted slot hood exhaust ventilation. The tray extends down to the edge of the furnace slot hood opening; using a skimming tool, the operator places several scoops of dross from the furnace onto the tray. Dross fumes are collected by both the furnace slot hood and the dross hood. When the tray is full, the operator activates a control that retracts the dross tray into a ventilated enclosure and dumps the tray contents into a barrel (also under exhaust ventilation) (Corbett, 2005).

A related source of exposure is furnace tools that have come into contact with the molten metal. Dross skimming rakes, furnace lining rub bars, thermal couples, and degassing wands, used as part of dross handling operations, release fumes as they are removed from the furnace after tasks that bring them in contact with molten metal. At Materion Corporation's beryllium production facility, furnace operators place the furnace tools in ventilated tool holders after use to capture residual beryllium fumes. This control method should work equally well for capturing beryllium fumes from furnace tools at beryllium alloy foundries. Since dross handling and work with the associated tools are short-term tasks, these controls are specifically intended to reduce exposures during these brief activities and prevent an increase in background exposure levels due to beryllium release. These controls benefit 8-hour TWA exposures and short-term exposures equally when the majority of the worker's daily exposure occurs during short-term activities.[327] These and other controls for dross handling are discussed in this PEA at Section 5—Nonferrous Foundries.

[327] When contamination (e.g., beryllium-containing dust that accumulates on surfaces) or other uncontrolled activities also contribute to the worker's daily exposure level, the 8-hour TWA might not be reduced to the same extent as the short-term sample results until those other beryllium sources are also controlled.

Control Measures for Dust-Disturbing Tasks

Dry sweeping and use of compressed air to clean surfaces can contribute to higher beryllium exposures. The Materion Worker Protection Model calls for rigorous housekeeping (see Methodology Appendix 1 in Section 2 of this PEA for a detailed discussion of the Materion Worker Protection Model). In facilities with airborne beryllium exposures, housekeeping should be performed routinely and thoroughly to prevent the accumulation of dust that can be spread to other work areas or become airborne if disturbed. Cleaning should be performed with HEPA vacuums instead of traditional vacuums, and the use of compressed air and dry sweeping should be avoided, as these intermittent activities can all result in high short-term exposures. Eliminating these sources of elevated short-term exposures by switching to HEPA vacuums will reduce workers' short-term exposures. Wet methods may also be used to clean beryllium contamination instead of dry methods or compressed air.

Control Measures for Friable Beryllium Oxide on Surfaces Being Worked

Loosely adhered oxides of beryllium have also been implicated in overexposures during tasks, such as welding, that otherwise are rarely associated with excessive exposure. Workers who move materials into position and then work on them can experience short-term exposures during direct handling of these oxide-coated materials. According to representatives of Materion Corporation, welding fumes could account for just 10 percent of welders' beryllium exposure when welding on beryllium coated with surface oxide. Flaking oxide may account for 90 percent of the beryllium exposure experienced by a welder and has been implicated in the exposure levels recorded at the Materion Elmore facility (Corbett, 2006; Kent, 2005). Employers might be able to eliminate the release of loosely adhered oxide by chemically stripping and pickling the beryllium alloy work piece prior to welding on it. These procedures remove the loose surface oxides and stabilize the surface to prevent additional loosely adhered beryllium oxides from forming (Materion Information Meeting, 2012). Eliminating the loosely adhered oxides would eliminate this source of exposure for tasks such as handling or transporting materials. For additional information, see Section 10 of this PEA—Welding.

Control Measures for Grinding and Polishing

While some workers might grind and polish beryllium-containing materials for a substantial portion of their shift, for many others (including dental technicians), grinding and polishing are intermittent short-term activities, interspersed with other activities. For manual grinding tasks, regardless of the nature of the industry, the primary beryllium producer suggests a booth designed with both backdraft and downdraft exhaust ventilation inside the enclosure (Materion Information Meeting, 2012). For example, such a booth would include a front opening and rear exhaust, as is available for abrasive cut-off saws (Figure VS-80-17 in ACGIH, 2010), and the downdraft table ventilation of a hand-grinding bench (Figure VS-80-18 in ACGIH, 2010). An adaptation to provide a rear-slot exhaust (rather than plain rear takeoff) is preferable for hand grinding, which might not occur at a single fixed spot inside the booth. The booth exhaust should be fitted with a HEPA filter, and special precautions must be used when servicing the booth or blower and changing the filter (e.g., respiratory protection is needed for these tasks).

The booth should also be equipped with alarms to indicate when filter performance falls outside an effective range. These controls are equally effective for short-term intermittent activity and steady-state activity conducted over most of the shift. Controls for grinding and polishing are discussed in this PEA at Section 5—Nonferrous Foundries and Section 11—Dental Laboratories.

FEASIBILITY CONCLUSION

As presented in Table IV-84, 81 percent of the 623 short-term samples measured beryllium levels less than or equal to 2.0 µg/m^3, and 75 percent were less than or equal to 1.0 µg/m^3. In the most recent time period (2000 to 2008), 77 percent of short-term exposure measurements were less than or equal to 1.0 µg/m^3. Due to limitations in the available sampling data and the higher detection limits for short term measurements, OSHA could not determine the percentage of the STEL measurements that are less than or equal to 0.5 µg/m^3, and therefore has not reached a preliminary conclusion regarding the technological feasibility of an alternative STEL of 0.5 µg/m^3. OSHA preliminarily concludes that the proposed STEL of 2.0 µg/m^3 can be achieved for most operations most of the time, but respiratory protection may be required for a small number of operations for which peak exposures cannot be maintained at or below 2.0 µg/m^3. However, it is more difficult based on the currently available evidence to determine whether the alternative STEL of 1.0 µg/m^3 would also be feasible in most operations based on lack of detail in the activities of the workers presented in the data. OSHA expects additional use of respiratory protection would be required for tasks in which peak exposures can be reduced to less than 2.0 µg/m^3 but not less than 1.0 µg/m^3.

Where short-term exposures do remain elevated, even after the proposed PEL has been achieved, a number of control measures are available to reduce short-term worker exposures. The appropriate method depends on the exposure source and generally involves more intensive application of the control measures listed in Appendix B of OSHA's proposed rule and already reported in this analysis.

Until such time as effective controls can be installed, short-term exposure levels (along with the corresponding 8-hour TWA exposure levels) might remain elevated during a few activities, such as powder activities related to the beryllium oxide industry (see Beryllium Oxide Ceramics and Composites Section, 4 of this PEA) and dross handling in the foundry industry (see Section 5—Nonferrous Foundries of this PEA).

OSHA believes that there may be some instances in which engineering controls may reduce short-term exposures during these few activities to below the proposed STEL of 2.0 µg/m^3, but not necessarily to below an alternative STEL of 1.0 µg/m^3. Due to limitations in sample descriptions, as well as the higher detection limit for shorter samples, OSHA cannot characterized the specific conditions under which this may occur.

However, OSHA notes that most of the activities in which short-term exposures may be controlled between 1.0 µg/m^3 and 2.0 µg/m^3 are also the same activities that may occasionally produce short-term exposures above 2.0 µg/m^3 and 8-hour TWA exposures above the proposed PEL. As such, OSHA estimates that firms that require respirators to control short-term exposures to the proposed STEL can also use these respirators to control exposures to an alternative lower STEL. This means that the additional costs of compliance when comparing the proposed STEL with an alternative STEL of 1.0 μg/m^3 will be minimal. Refer to Chapter VIII of the PEA for estimated costs of the regulatory alternatives.

Table IV-85 summarizes short-term exposure levels from OSHA's IMIS database and indicates that, except in the beryllium production industry, short-term exposure levels do not exceed 20 μg/m^3 (10 times the proposed STEL of 2.0 μg/m^3). Therefore, a respirator with a maximum use concentration (MUC) of 20 μg/m^3 will offer sufficient protection during these short-term activities. A respirator with an assigned protection factor (APF) of 10 such as a half-facepiece respirator fitted with P-100 filters will provide this level of protection, although other models, such as a powered air purifying respirator with a loose-fitting hood (APF of 25), or any respirator offering a higher level of protection, will also be suitable. In some cases, as in the beryllium production industry, workers involved with furnace melting and casting, according to Table IV-88, may continue to experience short-term exposures that require a higher level of protection—for example, a full facepiece respirator (APF 50, MUC 100 μg/m^3) or a powered air-purifying respirator with an APF of 1,000 (MUC 2,000 μg/m^3). OSHA notes that employers must evaluate both the short-term and 8-hour TWA exposure levels and select respiratory protection that will protect workers from the hazards they might encounter during the work shift.

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SECTION 12—SHORT-TERM EXPOSURES, APPENDIX 1—

SUPPLEMENTAL ANALYSIS OF NAVY EXPOSURE DATA

Table IV-86—Short-Term Beryllium Samples Greater Than 2.0 μg/m³ and Associated 8-hour TWA Exposure Levels

Year	Job Description	Job Category	Short-Term		8-Hour TWA*		Note
			Minutes Sampled	μg/m³	Minutes Sampled	μg/m³	
1988	*Casting*	*Dental appliance, melting/casting*	*30*	*3.0*	*357*	*3.0*	*a*
1993	*Lathing beryllium*	*Machining*	*15*	*3.1*	*231*	*0.1*	*a, b*
1995	*Grinding Partial [Dental Appliance]*	*Dental appliance, grinding*	*15*	*2.8*	*375*	*0.1*	*b*
2000	*Grind and polish ticonium [Alloy]*	*Dental appliance, grinding*	*15*	*10*	*368*	*1.0*	
2000	*Grind and polish ticonium [alloy]*	*Dental appliance, grinding*	*15*	*2.8*	*368*	*1.0*	
2000	*Grinding ticonium [alloy]*	*Dental appliance, grinding*	*15*	*2.8*	*147*	*0.07*	*a, b*
2001	*Empty grinder dust bag*	*Equipment repair & maintenance, HVAC*	*15*	*4.0*	*260*	*0.4*	*a*

* *As reported, based on one or more samples. May have been rounded in source document. One 26-minute result of 5.78 μg/m³ excluded as invalid because the reported 0.17 μg/m³ 8-hour TWA is not mathematically possible for a shift less than 15 hours.*

[a] *Reported 8-hour TWA based on less than 360 minutes total cumulative sample duration.*

[b] *The 8-hour TWA is less than the proposed PEL of 0.2 μg/m³, although the short-term sample result exceeds the proposed STEL of 2.0 μg/m³.*

Source: NEHC, 2003

Table IV-87. Short-Term Beryllium PBZ Exposure Levels Obtained by the U.S. Navy During Various Tasks

Job or activity	Total Count	Nondetected Count (Percent)		PBZ Beryllium Concentration (μg/m³)				Total Sample Distribution	
		Total ND	ND > 2.0 μg/m³	Mean	Median	Min	Max	≤ 2.0 μg/m³	> 2.0 μg/m³
Dental (primarily grinding)	*79*	*70 (87%)*	*8 (10%)*	*1.5*	*1.7*	*0.1*	*10.0*	*66 (84%)*	*13 (16%)*
Equipment repair and maintenance	*27*	*16 (59%)*	*0 (0%)*	*0.9*	*0.3*	*0.1*	*5.8*	*25 (93%)*	*2 (7%)*
Machining	*14*	*13 (93%)*	*0 (0%)*	*0.3*	*0.8*	*0.2*	*3.1*	*13 (93%)*	*1 (7%)*
Aircraft brake work (related to machining)	*9*	*5 (56%)*	*0 (0%)*	*1.3*	*1.4*	*0.17*	*3.8*	*7 (78%)*	*2 (22%)*
Welding/cutting	*20*	*20 (100%)*	*1 (5%)*	*1.4*	*1.0*	*0.2*	*3.7*	*19 (95%)*	*1 (5%)*
Total	*149*	*124 (83%)*	*9 (6%)*	*1.3*	*1.4*	*0.1*	*10.0*	*130 (87%)*	*19 (13%)*

Notes: Beryllium concentrations and distributions presented here are the maximum possible (e.g., the limit of detection value was used for all sample results below the limit of detection); actual values are likely lower because a notable portion of the total short-term sample results are below the limit of detection; however, very few of these exceed 2.0 μg/m³ and therefore do not unduly influence the results in the range of the proposed STEL.

Source: NEHC, 2003

SECTION 12—SHORT-TERM EXPOSURES, APPENDIX 2—IMIS SAMPLE RESULTS BY INDUSTRY SECTOR AND JOB CATEGORIES

Table IV-88—OSHA IMIS PBZ Total Positive Beryllium Short-Term Air Sampling Results by Industry Sector or SIC Description

Application Group	Corresponding SIC Code(s)	Job Title	No. Samples	No. Positive Samples	Beryllium Concentration (μg/m^3)			
					Mean	Median	Min	Max
Beryllium Production	*3369*	*Foundry, mold and core preparation*	*2*	*2 (100%)*	*0.75*	*0.75*	*0.5*	*1.0*
(Section 3)		*Foundry, shakeout*	*2*	*2 (100%)*	*0.4*	*0.4*	*0.4*	*0.4*
		Furnace, melting and casting	*27*	*27 (100%)*	*10.4*	*2.6*	*0.01*	*99*
		Generic, laborer	*10*	*10 (100%)*	*2.8*	*0.7*	*0.3*	*7.4*
		Generic, lead man/lead operator	*16*	*16 (100%)*	*4.7*	*2.3*	*0.7*	*14*
		Generic, operator	*18*	*18 (100%)*	*0.49*	*0.5*	*0.1*	*1.1*
		Generic, other	*2*	*2 (100%)*	*0.95*	*0.95*	*0.7*	*1.2*
		Machining, nos	*3*	*3 (100%)*	*0.43*	*0.1*	*0.1*	*1.1*
		Pebble plant operator, Be production	*6*	*6 (100%)*	*1.7*	*0.7*	*0.2*	*4.3*
		Pelletizing, Be production	*2*	*2 (100%)*	*0.3*	*0.3*	*0.3*	*0.3*
		Powdering	*2*	*2 (100%)*	*2.6*	*2.6*	*2.6*	*2.6*
		Sheet operator	*2*	*2 (100%)*	*0.3*	*0.3*	*0.3*	*0.3*
		Welding and cutting	*4*	*4 (100%)*	*1.4*	*1.4*	*1.2*	*1.5*
		TOTAL	**96**	**96 (100%)**	**4.4**	**0.7**	**0.01**	**99**
Beryllium Oxide Ceramics and Composites	*3264*	*No short-term exposure data*	*0*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
(Section 4)	*3651*	*No short-term exposure data*	*0*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
	3663	*No short-term exposure data*	*0*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
	3671	*No short-term exposure data*	*0*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
	3674	*No short-term exposure data*	*0*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
	3676	*No short-term exposure data*	*0*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
	3679	*Welding and cutting*	*3*	*3 (100%)*	*0.5*	*0.4*	*0.1*	*1.0*
	3694	*No short-term exposure data*	*0*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*

Table IV-88—OSHA IMIS PBZ Total Positive Beryllium Short-Term Air Sampling Results by Industry Sector or SIC Description								
Application Group	Corresponding SIC Code(s)	Job Title	No. Samples	No. Positive Samples	Beryllium Concentration (μg/m³)			
					Mean	Median	Min	Max
	3714	*Racing engine manufacturing*	*1*	*1 (100%)*	*0.26*	*0.26*	*0.26*	*0.26*
		Welding and cutting	*3*	*3 (100%)*	*1.0*	*1.0*	*0.1*	*2.0*
	3845	*No short-term exposure data*	*0*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
		TOTAL	**7**	**7** *(100%)*	**0.7**	**0.4**	**0.1**	**2.0**
Nonferrous Foundries	*3363*	*Generic, laborer*	*2*	*2 (100%)*	*0.2*	*0.2*	*0.2*	*0.2*
(Section 5)	*3364*	*Furnace, melting and casting*	*6*	*6 (100%)*	*0.03*	*0.02*	*0.01*	*0.06*
		Machining	*2*	*2 (100%)*	*0.05*	*0.05*	*0.05*	*0.05*
	3365	*Foundry, mold and core preparation*	*2*	*2 (100%)*	*1.3*	*1.3*	*0.9*	*1.7*
		Foundry, worker	*10*	*10 (100%)*	*2.5*	*2.4*	*0.5*	*4.3*
		Furnace, melting and casting	*9*	*9 (100%)*	*2.6*	*0.3*	*0.1*	*8.8*
		Machining	*4*	*4 (100%)*	*0.6*	*0.6*	*0.1*	*1.1*
		Welding and cutting	*1*	*1 (100%)*	*0.2*	*0.2*	*0.2*	*0.2*
	3366	*Foundry, shakeout*	*4*	*4 (100%)*	*0.28*	*0.28*	*0.05*	*0.5*
		Furnace, melting and casting	*24*	*24 (100%)*	*0.96*	*0.13*	*0.03*	*6.1*
		Generic, foreman	*1*	*1 (100%)*	*0.22*	*0.22*	*0.22*	*0.22*
		Machining	*8*	*8 (100%)*	*0.16*	*0.045*	*0.03*	*0.5*
		Metal working, metal chasing	*1*	*1 (100%)*	*0.2*	*0.2*	*0.2*	*0.2*
		Unknown tasks, copper foundry	*4*	*4 (100%)*	*0.22*	*0.1*	*0.1*	*0.6*
		Welding and cutting	*2*	*2 (100%)*	*0.1*	*0.1*	*0.1*	*0.1*
		TOTAL	**80**	**80 (100%)**	**1.0**	**0.17**	**0.01**	**8.8**
Secondary Smelting, Refining, Alloying	*3341*	*Electrical*	*2*	*2 (100%)*	*0.07*	*0.07*	*0.07*	*0.07*
(Section 6)		*Engineering*	*1*	*1 (100%)*	*0.4*	*0.4*	*0.4*	*0.4*
		Foundry, foreman	*2*	*2 (100%)*	*0.02*	*0.02*	*0.02*	*0.02*
		Foundry, laborer	*2*	*2 (100%)*	*0.11*	*0.11*	*0.11*	*0.11*
		Foundry, mold and core preparation	*2*	*2 (100%)*	*0.6*	*0.6*	*0.6*	*0.6*
		Foundry, pressing	*2*	*2 (100%)*	*0.5*	*0.5*	*0.5*	*0.5*
		Foundry, utility	*2*	*2 (100%)*	*0.02*	*0.02*	*0.02*	*0.02*

Table IV-88—OSHA IMIS PBZ Total Positive Beryllium Short-Term Air Sampling Results by Industry Sector or SIC Description								
Application Group	**Corresponding SIC Code(s)**	**Job Title**	**No. Samples**	**No. Positive Samples**	**Beryllium Concentration (μg/m³)**			
					Mean	**Median**	**Min**	**Max**
		Furnace, calcining	*1*	*1 (100%)*	*3.5*	*3.5*	*3.5*	*3.5*
		Furnace, charge preparation/charging	*9*	*9 (100%)*	*0.66*	*0.7*	*0.1*	*1.2*
		Furnace, incinerator	*2*	*2 (100%)*	*0.08*	*0.08*	*0.08*	*0.08*
		Furnace, kiln	*2*	*2 (100%)*	*0.06*	*0.06*	*0.06*	*0.06*
		Furnace, melting and casting	*67*	*67 (100%)*	*3.3*	*1.8*	*0.03*	*18*
		Furnace, repair and maintenance	*4*	*4 (100%)*	*1.8*	*1.8*	*1.8*	*1.9*
		Generic, assistant operator	*2*	*2 (100%)*	*4.2*	*4.2*	*4.2*	*4.2*
		Generic, crew leader	*2*	*2 (100%)*	*1.7*	*1.7*	*1.7*	*1.7*
		Generic, helper	*5*	*5 (100%)*	*3.8*	*1.6*	*1.3*	*7.5*
		Generic, laborer	*4*	*4 (100%)*	*0.08*	*0.08*	*0.06*	*0.1*
		Generic, lead operator	*2*	*2 (100%)*	*0.08*	*0.08*	*0.07*	*0.08*
		Generic, operator	*10*	*10 (100%)*	*2.4*	*3.0*	*0.07*	*5.9*
		Industrial hygiene technician	*1*	*1 (100%)*	*2.3*	*2.3*	*2.3*	*2.3*
		Laboratory technician	*1*	*1 (100%)*	*0.6*	*0.6*	*0.6*	*0.6*
	3341	*Machining*	*7*	*7 (100%)*	*1.0*	*0.2*	*0.1*	*5.1*
		Maintenance operations	*2*	*2 (100%)*	*3.1*	*3.1*	*0.6*	*5.5*
		Material handling	*2*	*2 (100%)*	*0.11*	*0.11*	*0.02*	*0.2*
		Mechanical processing	*24*	*24 (100%)*	*0.64*	*0.08*	*0.05*	*10*
		Operating equipment, heavy	*4*	*4 (100%)*	*0.15*	*0.15*	*0.1*	*0.2*
		Scrap operations	*1*	*1 (100%)*	*1.7*	*1.7*	*1.7*	*1.7*
		Shipping/receiving	*1*	*1 (100%)*	*0.5*	*0.5*	*0.5*	*0.5*
		Sorting	*2*	*2 (100%)*	*0.1*	*0.1*	*0.1*	*0.1*
		Sweeping	*1*	*1 (100%)*	*14.3*	*14.3*	*14.3*	*14.3*
		Tool making/grinding	*5*	*5 (100%)*	*0.34*	*0.2*	*0.1*	*1.0*
	3399	*Coiling*	*2*	*2 (100%)*	*0.1*	*0.1*	*0.1*	*0.1*
		Furnace, charge preparation/charging	*2*	*2 (100%)*	*2.3*	*2.3*	*2.3*	*2.3*
		Furnace, melting and casting	*2*	*2 (100%)*	*0.7*	*0.7*	*0.7*	*0.7*

Table IV-88—OSHA IMIS PBZ Total Positive Beryllium Short-Term Air Sampling Results by Industry Sector or SIC Description

Application Group	Corresponding SIC Code(s)	Job Title	No. Samples	No. Positive Samples	Beryllium Concentration (μg/m³)			
					Mean	Median	Min	Max
		Generic, lead operator	*6*	*6 (100%)*	*3.8*	*4.6*	*0.6*	*7.4*
		Generic, trainee	*2*	*2 (100%)*	*9.3*	*9.3*	*9.3*	*9.3*
		Laundry operator	*2*	*2 (100%)*	*0.1*	*0.1*	*0.1*	*0.1*
		Machining	*2*	*2 (100%)*	*2.5*	*2.5*	*2.5*	*2.5*
		Unknown task, primary metals	*2*	*2 (100%)*	*0.4*	*0.4*	*0.1*	*0.7*
	4953	*Unknown task, waste processing/disposal*	*1*	*1 (100%)*	*12*	*12*	*12*	*12*
		TOTAL	**194**	**194 (100%)**	**2.1**	**0.6**	**0.02**	**18**
Precision Turned Products	*3451*	*No short-term exposure data*	*0*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
(Section 7)	*3452*	*No short-term exposure data*	*0*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
		TOTAL	**0**	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**
Copper Rolling, Drawing, Extruding	*3351*	*Furnace, melting and casting*	*5*	*5 (100%)*	*0.38*	*0.06*	*0.01*	*0.9*
(Section 8)		*Mechanical processing*	*2*	*2 (100%)*	*0.09*	*0.09*	*0.09*	*0.09*
	3356	*Forging*	*1*	*1 (100%)*	*0.6*	*0.6*	*0.6*	*0.6*
		Powdering	*2*	*2 (100%)*	*0.05*	*0.05*	*0.05*	*0.05*
	3357	*No short-term exposure data*	*0*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
		TOTAL	**10**	**10 (100%)**	**0.28**	**0.08**	**0.01**	**0.9**
Fabrication of Beryllium Alloy Products	*3469*	*No short-term exposure data*	*0*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
(Section 9)	*3495*	*No short-term exposure data*	*0*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
	3678	*No short-term exposure data*	*0*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
		TOTAL	**0**	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**
Welding	*3089*	*Welding and cutting*	*2*	*2 (100%)*	*0.01*	*0.01*	*0.01*	*0.01*
(Section 10)	*3229*	*Welding and cutting*	*4*	*4 (100%)*	*0.1*	*0.1*	*0.1*	*0.1*
	3312	*Welding and cutting*	*6*	*6 (100%)*	*0.04*	*0.05*	*0.005*	*0.06*
	3325	*Welding and cutting*	*5*	*5 (100%)*	*0.28*	*0.1*	*0.1*	*1.0*

Table IV-88—OSHA IMIS PBZ Total Positive Beryllium Short-Term Air Sampling Results by Industry Sector or SIC Description								
Application Group	**Corresponding SIC Code(s)**	**Job Title**	**No. Samples**	**No. Positive Samples**	**Beryllium Concentration (µg/m³)**			
					Mean	**Median**	**Min**	**Max**
	3365	*Welding and cutting*	*1*	*1 (100%)*	*0.2*	*0.2*	*0.2*	*0.2*
	3366	*Welding and cutting*	*2*	*2 (100%)*	*0.1*	*0.1*	*0.1*	*0.1*
	3369	*Welding and cutting*	*4*	*4 (100%)*	*1.4*	*1.4*	*1.2*	*1.5*
	3433	*Welding and cutting*	*2*	*2 (100%)*	*0.6*	*0.6*	*0.6*	*0.6*
	3441	*Welding and cutting*	*6*	*6 (100%)*	*0.25*	*0.18*	*0.06*	*0.7*
	3443	*Welding and cutting*	*23*	*23 (100%)*	*0.11*	*0.1*	*0.01*	*0.28*
	3444	*Welding and cutting*	*24*	*24 (100%)*	*0.03*	*0.01*	*0.01*	*0.2*
	3446	*Welding and cutting*	*5*	*5 (100%)*	*0.05*	*0.01*	*0.01*	*0.1*
	3448	*Welding and cutting*	*3*	*3 (100%)*	*0.01*	*0.01*	*0.01*	*0.01*
	3449	*Welding and cutting*	*4*	*4 (100%)*	*0.01*	*0.01*	*0.01*	*0.01*
	3465	*Welding and cutting*	*4*	*4 (100%)*	*0.01*	*0.01*	*0.01*	*0.01*
	3483	*Welding and cutting*	*2*	*2 (100%)*	*0.1*	*0.1*	*0.1*	*0.1*
	3499	*Welding and cutting*	*4*	*4 (100%)*	*0.26*	*0.26*	*0.05*	*0.47*
	3511	*Welding and cutting*	*4*	*4 (100%)*	*0.06*	*0.06*	*0.03*	*0.1*
	3523	*Welding and cutting*	*6*	*6 (100%)*	*0.06*	*0.05*	*0.04*	*0.1*
	3535	*Welding and cutting*	*2*	*2 (100%)*	*0.01*	*0.01*	*0.01*	*0.01*
	3536	*Welding and cutting*	*2*	*2 (100%)*	*0.1*	*0.1*	*0.1*	*0.1*
	3541	*Welding and cutting*	*2*	*2 (100%)*	*0.2*	*0.2*	*0.2*	*0.2*
	3544	*Welding and cutting*	*4*	*4 (100%)*	*0.2*	*0.2*	*0.2*	*0.2*
	3552	*Welding and cutting*	*2*	*2 (100%)*	*0.02*	*0.02*	*0.02*	*0.02*
	3559	*Welding and cutting*	*4*	*4 (100%)*	*0.05*	*0.05*	*0.05*	*0.05*
	3561	*Welding and cutting*	*2*	*2 (100%)*	*0.02*	*0.02*	*0.02*	*0.02*
	3564	*Welding and cutting*	*4*	*4 (100%)*	*0.03*	*0.03*	*0.02*	*0.04*
	3569	*Welding and cutting*	*6*	*6 (100%)*	*0.31*	*0.08*	*0.05*	*0.8*
	3585	*Welding and cutting*	*2*	*2 (100%)*	*0.08*	*0.08*	*0.08*	*0.08*
	3679	*Welding and cutting*	*3*	*3 (100%)*	*0.5*	*0.4*	*0.1*	*1.0*

Table IV-88—OSHA IMIS PBZ Total Positive Beryllium Short-Term Air Sampling Results by Industry Sector or SIC Description

Application Group	Corresponding SIC Code(s)	Job Title	No. Samples	No. Positive Samples	Beryllium Concentration (μg/m³)			
					Mean	Median	Min	Max
	3713	*Welding and cutting*	*3*	*3 (100%)*	*0.2*	*0.05*	*0.05*	*0.5*
	3714	*Welding and cutting*	*3*	*3 (100%)*	*1.0*	*1.0*	*0.1*	*2.0*
	3724	*Welding and cutting*	*2*	*2 (100%)*	*0.04*	*0.04*	*0.04*	*0.04*
	3731	*Welding and cutting*	*16*	*16 (100%)*	*0.15*	*0.15*	*0.06*	*0.3*
	3743	*Welding and cutting*	*5*	*5 (100%)*	*0.14*	*0.1*	*0.1*	*0.2*
	3799	*Welding and cutting*	*6*	*6 (100%)*	*0.09*	*0.1*	*0.07*	*0.1*
	3823	*Welding and cutting*	*2*	*2 (100%)*	*0.04*	*0.04*	*0.04*	*0.04*
	3942	*Welding and cutting*	*2*	*2 (100%)*	*0.11*	*0.11*	*0.11*	*0.11*
	3993	*Welding and cutting*	*2*	*2 (100%)*	*0.1*	*0.1*	*0.1*	*0.1*
	5051	*Welding and cutting*	*2*	*2 (100%)*	*7.1*	*7.1*	*7.1*	*7.1*
	5093	*Welding and cutting*	*4*	*4 (100%)*	*0.08*	*0.08*	*0.08*	*0.09*
	7312	*Welding and cutting*	*2*	*2 (100%)*	*0.01*	*0.01*	*0.01*	*0.01*
	7538	*Welding and cutting*	*2*	*2 (100%)*	*0.01*	*0.01*	*0.01*	*0.01*
	7692	*Welding and cutting*	*2*	*2 (100%)*	*0.1*	*0.1*	*0.1*	*0.1*
	7699	*Welding and cutting*	*8*	*8 (100%)*	*0.05*	*0.05*	*0.02*	*0.1*
		TOTAL	**209**	**209 (100%)**	**0.21**	**0.07**	**0.005**	**7.1**
Dental Laboratories	*8071*	*No short-term exposure data*	*0*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*
(Section 11)	*8072*	*Dental, laboratories*	*10*	*10 (100%)*	*0.11*	*0.1*	*0.1*	*0.2*
		TOTAL	**10**	**10 (100%)**	**0.11**	**0.1**	**0.1**	**0.2**
OVERALL TOTAL FOR ALL INDUSTRIES LISTED			**606**	**606 (100%)**			**0**	**99**

Notes:
Job categories preceded by the word "unknown" mean there is no job/task description for the sample result or the available information is indiscernible.
There are no SIC codes specific to welding and abrasive blasting; welding and abrasive blasting operations are common throughout the construction and general industry sectors.
Welding exposure data consists of 196 welding sample results that represent welders from general industry SIC that would not otherwise be included in this analysis, plus 13 welding sample results that represent welders from SIC that are in one of the industries addressed in Sections 3 through 11, Beryllium Production through Dental Laboratories, of this PEA (196+13=209). For completeness, those 13 welding samples also appear in this table under the SIC in which those welders actually work. OSHA recognizes that presenting these 13 welding sample under both the welding heading and the individual SIC heading means that the 13 results appear twice in Table IV-88 (the repeat welder samples appear under the headings for SIC 3369, 3679, 3714, and

Table IV-88—OSHA IMIS PBZ Total Positive Beryllium Short-Term Air Sampling Results by Industry Sector or SIC Description								
Application Group	Corresponding SIC Code(s)	Job Title	No. Samples	No. Positive Samples	Beryllium Concentration (μg/m³)			
					Mean	Median	Min	Max

3366). OSHA believes that the benefit of showing welders in both contexts out ways any minor inconvenience the repetition might cause. The number of individual data points represented in Table IV-88 is 593. Repeating the 13 welder results brings the total number of beryllium exposure results presented in this table to 606.

SIC: Standard Industrial Classification
Be: beryllium
n/a: not applicable
Al/Cu: aluminum/copper
cont: continued
nos: not otherwise specified

Source: OSHA Integrated Management Information System (IMIS) Database, June 1978 through September 2008 (OSHA, 2009). Positive short-term samples (designated as personal breathing zone air samples; STEL, ceiling, or peak)

Chapter IV Appendix A: Primary Aluminum Production

INTRODUCTION

Exposure to beryllium can occur during primary aluminum production due to the beryllium content of the crude aluminum ore (bauxite). Beryllium is found as a naturally occurring impurity in bauxite in varying amounts depending on the source (Taiwo et al., 2008). The average beryllium concentration of bauxite is estimated to be 5 parts per billion (or 0.0000007 percent by weight) (Taylor et al., 2003). During the refining of bauxite into smelting grade alumina, the beryllium contained in bauxite is concentrated in the alumina. Sources of bauxite with higher levels of beryllium may result in alumina with 1 to 6 parts per million (or 0.0001 percent by weight) of beryllium (Lindsay and Dobbs, 2007).

PROCESS DESCRIPTION

Primary aluminum production begins with the mining of bauxite ore, a heterogeneous material consisting of aluminum hydroxide minerals, aluminosilicates, iron oxide, silica, titanium dioxide and other materials in trace amounts (USGS, 2004). The crude bauxite ore is refined into alumina (aluminum oxide) and then shipped to primary aluminum production establishments for processing into aluminum.

Primary aluminum is produced by the electrolytic reduction of alumina to metallic aluminum (Atkins, 1985). Alumina is added to an electrolytic bath composed of natural or synthetic cryolite and fluoride compounds. The bath is contained in aluminum reduction pots that are 3 to 4 meters (10 to 13 feet) wide and 10 to 12 meters (33 to 40 feet) long and connected in electrical series to form a bank of pots called a potline (Atkins, 1985).

The reduction pots are shallow rectangular steel shells lined with a carbon material. The carbon lining serves as the cathode and consumable carbon electrodes extending into the pot bath serve as the anodes. Electricity is passed from the consumable carbon anodes through the bath causing the alumina to break down or dissociate into aluminum metal and free oxygen (Atkins, 1985). The oxygen reacts with carbon from the anodes to form carbon monoxide and carbon dioxide. Aluminum is deposited at the cathode and remains below the surface of the cryolite bath as molten metal. The temperatures generated by the electric current passing through the pot keeps the bath and precipitated aluminum molten (Karsten, 1982). Additional alumina and bath ingredients are added as needed and molten aluminum is periodically withdrawn (siphoned off) from the pots into tapping crucibles. The molten aluminum is transferred to the casting department where it is cast into aluminum products (alloyed and unalloyed). Some metal may be transported to customers in molten form.

Primary aluminum operations are classified into two types of processes known as prebake and Soderberg. These processes are distinguished by the type of carbon anode used, the method used to introduce the anode into the cell, and the manner in which the pot is worked. In prebake plants, the pots use multiple anodes that are formed and baked in a separate operation prior to consumption in the pots. Soderberg plants use a single, continuous anode that is shaped and baked in place directly in the pot. Most of the primary aluminum produced in United States is made using the prebake process. The prebake process is preferred over the Soderberg process because it generally results in lower ambient emissions (McCawley, 2009).

AFFECTED JOB CATEGORIES

Beryllium exposure in primary aluminum production is principally associated with pot emissions and potroom support activities (Alcan, 2002, 2003, 2004; Alcoa, 2003; Dion et al., 2005; Labreche et al., 2005; McCawley, 2009; McSherry and Demers, 2004; Noranda, 2004; Thomassen et al., 2005).

The job categories with potential exposures to beryllium include:

- **Pot tending:** During this activity, workers check and adjust the pots to ensure they are running properly. These workers sample the bath and check alumina additions, bath temperatures, electrolyte levels, and anode effects[328] which may cause pot emissions to increase several fold (Atkins, 1985; Sim and Benke, 2003; NIOSH, 1983). These workers are responsible for maintaining optimal conditions in all the pots on the line. Pots are typically serviced on a daily basis (Atkins, 1985).

- **Tapping:** To tap the pots, workers remove pure aluminum or electrolytic bath from the pots. Tapping is typically conducted at the pot by breaking the crust on top of the bath and vacuum siphoning the molten metal or liquid bath into large crucibles. These crucibles are transported between pots either by crane or specialty vehicles. Typically, every pot is tapped about every 24 hours (Slaugenhaupt and Bruggeman, 2006).

- **Anode Changing/Setting:** Workers break the crust that forms on top of the molten bath, remove spent anodes from the potlines and replace them with new anodes, and adjust the anode bus bar to compensate for the effects of tapping (Sim and Benke, 2003; NIOSH, 1995). Anodes are replaced about once every three weeks (NIOSH, 1983).

- **Equipment and Material Transport:** Typically, workers transport equipment and material by operating overhead cranes. These workers move heavy objects such as crucibles, spent and new anodes, jacking frames, and ore buckets (NIOSH, 1995; Seixas et al., 2000). The removal of spent anodes from pots and the replacement of new anodes is a continually ongoing effort each shift (McCawley, 2009). Other workers operate mobile equipment, such as forklifts and vacuum sweepers, on the potroom floor (McCawley, 2009).

- **Pot Repair/Lining:** Another activity that may expose workers to beryllium is the repair and lining of pots. During the production of aluminum, the pots are filled with

[328] When the alumina concentration of the bath drops to about 2 percent, the electrical resistance of the pot increases (due to a gas film that envelops the anode) and the voltage drop across the pot increases. This is called the anode effect and the net result is that it raises the temperature of the pot bath and increases pot emissions and potential exposure to the pot emissions. As soon as it occurs, the bath crust must be broken and more alumina added to return the pot to normal operating condition (EPA, 1996).

a bath of alumina and molten salts. Over the three to seven year life span of the pot bath, salts migrate into the carbon pot liner, resulting in the deterioration and eventual failure of the utility of the pot as a cathode (e.g., electricity does not flow well enough to maintain necessary production temperatures) (Barnett and Mezner, 1999). When a pot is taken out of service for pot relining, the pot superstructure (steel shell) is dismantled, the solidified pot contents and spent pot liner are broken up to facilitate subsequent handling and disposal, and the pot lining and superstructure are rebuilt (Karsten, 1982; Sim and Benke, 2003). Pots may be relined in place, or by removing the superstructure and relining the pot outside the potroom (NIOSH, 1983).

- **Production/Facility Maintenance:** Workers also perform regular maintenance on the systems that deliver alumina to the pots, and mechanical and electrical systems (Sim and Benke, 2003). Other jobs and/or work tasks identified with potential beryllium exposure include sweeping or shoveling loose or spilled bath material near or beneath the pots; removal of solidified electrolyte from used/spent anodes with jack hammers and crow bars (butt cleaning); recycling activities associated with spent pot liner material; and air pollution equipment maintenance (Alcoa, 2003; Dion et al., 2005; McCawley, 2009; McSherry and Demers, 2004).

EXPOSURE DATA

Air monitoring to assess exposure to beryllium was conducted at four primary aluminum smelters (one in the U.S., two in Canada, and one in Italy) between 2000 and 2005 (Taiwo et al., 2008). The results of the air samples are presented in Table IV.A-1. The geometric mean exposure at the four smelters ranged from 0.03 to 0.10 µg/m^3, indicating that the majority of exposures are below 0.1 µg/m^3. For all four smelters combined, 75% of the measurements were less than 0.16 µg/m^3.

Table IV.A-1—Distribution of Beryllium Exposures at Four Aluminum Smelters

	Exposure Summary (µg/m^3)					Distribution of Be Exposure by Percentile (µg/m^3)				
Smelter	N	AM	SD	GM	GSD	25%	50%	75%	95%	Max-imum
US Smelter	*346*	*0.26*	*0.85*	*0.04*	*5.66*	*0.02*	*0.03*	*0.09*	*1.50*	*12.00*
Canadian Smelter 1	*246*	*0.09*	*0.21*	*0.03*	*3.62*	*0.01*	*0.03*	*0.07*	*0.33*	*2.02*
Canadian Smelter 2	*329*	*0.29*	*0.82*	*0.08*	*5.87*	*0.05*	*0.11*	*0.26*	*1.70*	*13.00*
Italian Smelter	*44*	*0.14*	*0.10*	*0.10*	*2.55*	*0.06*	*0.12*	*0.19*	*0.31*	*0.44*
All 4 combined	*965*	*0.22*	*0.71*	*0.05*	*4.67*	*0.02*	*0.05*	*0.16*	*1.20*	*13.00*
Source: Taiwo et al., 2008										

The results of air monitoring conducted to assess exposures to beryllium at six Norwegian aluminum smelters were reported by Skaugset et al (2012). Table IV.A-2 provides the results of sampling conducted in 2003 and 2004. The geometric mean of the air samples taken to assess exposure to respirable beryllium was very low (0.005 µg/m^3); however, the maximum values exceeded 0.2 µg/m^3. At one of the smelters, air sampling was conducted both before and after installation of an "enforced cell ventilation system" in the potroom. The sampling results indicate that the geometric mean exposure to inhalable beryllium in the potroom was reduced following installation of the ventilation system from 0.112 μg/m^3 to 0.041 μg/m^3, a reduction of 63%.

Table IV.A-2—Beryllium Air Sampling Results at Six Norwegian Smelters

No. of Samples	Geometric Mean (μg/m^3)	Range (μg/m^3)
247	*0.005*	*<0.005-0.236*
Source: Skaugset et al., 2012		

Based on the sampling data presented in Table IV.A-1, which represents the largest data pool for exposures in US primary aluminum smelters, OSHA estimates that less than 30 percent of the potroom workers in primary aluminum production may be exposed to beryllium levels at or above 0.1 μg/m^3, and that less than 20% of potroom workers may be exposed to levels above the proposed PEL of 0.2 μg/m^3. OSHA notes that the maximum values reported exceeded the proposed PEL.

OSHA obtained unpublished data from McCawley, 2009. with individual PBZ air sampling results for prebake and Soderberg operations at an Alcoa Canadian smelter. This is the only information available to OSHA regarding exposure results associated with specific job tasks at aluminum smelters. Table IV.A-3 indicates that workers in potrooms and those engaged in maintenance activities could be exposed to beryllium exposures above the proposed PEL. To the extent that exposures exceed the proposed PEL, OSHA has identified engineering controls that can minimize exposures to these workers.

Table IV.A-3—Full-Shift PBZ Total Beryllium Air Sampling Results at a Canadian Smelter

Process	Job	Task	Total Be Concentration (μg/m^3)
Prebake	*Crane Operator*	*Anode changing*	*0.19*
Prebake	*Line Attendant*	*Operating mobile equipment on potroom floor*	*0.28*
Prebake	*Butt cleaner*	*Cleaning spent anodes*	*ND*
Prebake	*Pot Tender (process control)*	*Sampling metal, bath, and temperature*	*0.37*
Prebake	*Bagger*	*Bagging powder (ground spent bath material)*	*ND*
Soderberg	*Tapper*	*Cleaning tapping equipment*	*0.17*
Soderberg	*Tapper*	*Tapping metal on potroom floor*	*0.20*
Soderberg	*Line Attendant*	*Operating mobile equipment on potroom floor*	*ND*
Soderberg	*Pot Tender (process control)*	*Pulverizing a sample*	*ND*
Soderberg	*Services Operator (near pots)*	*Sweeping/shoveling loose/spilled bath material*	*0.10*
Soderberg	*Services Operator (beneath pots)*	*Cleaning the basement*	*0.39*
ND: non-detectable. Beryllium less than the limit of quantitation (0.1 micrograms of beryllium per filter). *Source: McCawley, 2009*			

DESCRIPTION OF ENGINEERING CONTROLS

Baseline Controls

All primary aluminum production facilities in the United States capture and control process emissions at the source (EPA, 1996). While these controls are not specific to the control of beryllium exposures, they are relevant because they are applied at the same sources of beryllium exposure. Potroom buildings are typically ventilated by general dilution. Pot emissions are controlled by totally enclosing, sealing, and exhausting the pot to a central emission collection and treatment system. Periodically, the pots are opened to add raw materials, replace anodes, correct anode effects, and to remove molten aluminum. These tasks require personnel to remove some of the hooding (anode covers) and be in close proximity to the pot emissions.

OSHA believes that some of the cranes and forklifts used for material and equipment transport are equipped with air-conditioned and air-filtered cabs. NIOSH (1983) reported that operators of manned equipment sit in enclosed, conditioned, and filtered-air cabs that can provide significant protection from process-related emissions.

Additionally, establishments may use automated processes to make aluminum. OSHA believes that some establishments may use computer-controlled equipment and systems that automatically perform crust breaking and ore additions, and eliminate anode effects.

Some of the primary aluminum producers in the United States may employ personal protective equipment (PPE). Information from smelters in Canada and Norway state that workers at those plants use PPE such as work uniforms, respirators, and head, eye and foot protection (AIHABC, 2004; Dion et al., 2005; Labreche, 2005; McSherry and Demers, 2004; McSherry, 2005; Noranda, 2000; Thomassen et al., 2005). Other U.S. aluminum producing establishments may not use PPE (Labreche, 2005).

Other Engineering Controls

High short-term exposures to pot emissions may be a hazard for workers when the pot hooding (individual removable shields or doors that comprise the pot local exhaust ventilation (LEV) system) is periodically removed to add raw materials, replace anodes, correct anode effects and remove molten aluminum (Sim and Benke, 2003). Opening the pot hooding reduces the velocity of the exhaust ventilation allowing beryllium and other air contaminants to escape into the workplace.

Local Exhaust Ventilation

OSHA estimates that all potrooms employ LEV at individual production pots. Available information suggests that LEV can be improved to reduce process emissions (EPA, 1996). Enhanced ventilation designed for production pots will reduce exposures during pot tending and tapping, and during anode changing and setting.

The ventilated enclosure for pots consists of a structure with side shields and end doors. Many plants can increase the exhaust rate on a pot when one or more of the side shields are removed; thus reducing the amount of process emissions escaping into the workplace. Typical exhaust rates for larger pots are reported to range from 3,000 to 4,900 cubic feet per minute (cfm) per pot. When needed, most plants with larger pots can increase the exhaust rate up to 50 percent over the normal rate. The exhaust rates for smaller and older pots range from 2,000 to 2,250 cfm per pot and there might be very limited ability to increase this rate, perhaps only by as much as 15 percent maximum when feasible (EPA, 1996).

Regardless of how well the pots are enclosed and sealed, workers may need to open and/or remove side shields or end doors to work the pots, replace anodes, correct anode effects, make inspections, measure the depth of aluminum, and tap metal. To control process emissions and potential worker exposure, potline hooding must be carefully designed, constructed, and maintained; and potroom operators must not open or remove shields more frequently than is absolutely necessary. The number of hoods or shields that are open, the extent to which they are open, and the duration affect the efficiency of the hooding and the release of process emissions into the workplace. To control the escape of process emissions, many plants limit the number of side shields and end doors that can be open at any one time. Other potline exposure control measures practiced at some plants include increasing the exhaust rate on open pots and exhausting tapping emissions back into the primary hooding (EPA, 1996).

LEV may also be used during pot repair and demolition. These activities are typically conducted with the use of jackhammers, which can be equipped with LEV to reduce the concentration of airborne particles. To illustrate the capacity of LEV to reduce exposures, OSHA notes that NIOSH tested two tool-mounted LEV shrouds: one custom built, the other a commercially available model during work with chipping hammers (intended for chipping vertical concrete surfaces). Comparing multiple short–term samples, NIOSH found that the shrouds reduced respirable dust by 48 to 60 percent (Echt et al., 2003; NIOSH EPHB 282-11a, 2003). In a separate evaluation, NIOSH evaluated short-term activities in which workers used 25- or 30-pound jackhammers to chip concrete from inside concrete mixer truck drums. During 90- to 120-minute periods of active chipping, mean silica levels decreased 69 percent when the workers used a tool-mounted LEV shroud in these enclosed spaces (NIOSH EPHB 247-19, 2001). Based on these studies, OSHA believes that similar reductions can be achieved during pot demolition as the LEV would control total dust generated, which would include beryllium dust.

Process Automation

Automating (mechanization and computer control) crust breaking and pot feeding results in lower pot temperatures, fewer and shorter anode effects, and reduced pot emissions when compared to manual operation because pot operators have more time to closely monitor the pots and maintain temperature within narrow ranges. Automation of the process also reduces the need to open hooding components (e.g., to add chemicals, correct overfeeding problems or anode effects) which reduces the amount of emissions that escape into the workplace and potential worker exposure to beryllium and other air contaminants in these emissions. Automation in the potroom will reduce overall exposures, especially during pot tending and tapping, and anode changing and setting (EPA, 1996).

When a potline is completely automated, the operating parameters of each pot are monitored on a regular basis and any variation from the normal set operating parameters is automatically corrected. Additionally, with complete automation, all pots in a potline can be operated at the lowest possible temperature, with fewer process upsets, and essentially none of the variability associated with operator work practices (EPA, 1996).

Some examples of process automation in the potroom include the use of specially designed equipment (e.g., cranes and pot tending machines) for changing anodes and tapping metal. Manned cranes can be equipped with a pneumatically operated punch for breaking the crust around the anode to be removed, an arm for anode removal and placement, a dual-wrench for anode-to-bus connections, and a feed spout and storage bin for the alumina used to cover a newly placed anode. Other cranes are computer controlled and automatically make ore additions, do crust breaking, and eliminate anode effects (EPA, 1996).

Enclosed Cabs for Material and Equipment Transport

Enclosed operator cabs on forklifts and cranes can help reduce beryllium exposure for material handlers. As mentioned in Chapter IV, Technological Feasibility, of the Preliminary Economic Flexibility Analysis (PEA), enclosed cabs can substantially reduce exposures to beryllium dust and fumes. OSHA estimates that enclosed cabs can achieve a 90 percent reduction in beryllium exposures. See Chapter IV.5 of the PEA (Nonferrous Foundries) for details on some of the studies that discuss beryllium particle sizes in smelting environments and the reductions achieved with enclosed cabs.

Since workers engaged in material and equipment transport do not work directly at the main source of exposure (i.e., pots), OSHA believes that enclosed cabs will maintain exposures to these workers below the proposed PEL during transport. To the extent that these workers are not working on transport, LEV at the pots will also help maintain their exposures at a minimum.

Wet methods

During pot repair and demolition, OSHA believes that jackhammers equipped with water delivery systems would effectively suppress dust generated and thus control exposures to beryllium.

NIOSH completed several studies evaluating water spray devices to suppress dust created while workers use chipping and breaking equipment (NIOSH EPHB 282-11a, 2003). NIOSH investigated water spray dust control used by workers breaking concrete with 60- and 90-pound jackhammers. Using both a direct reading instrument and a high-flow cyclone and filter, NIOSH collected 10-minute respirable dust readings with and without the spray activated. Compared with concentrations during uncontrolled pavement breaking, respirable dust results were between 72 and 90 percent lower when the water spray was used. A follow-up NIOSH study reported a similar 77 percent reduction in silica concentration during 60-minute trials (NIOSH EPHB 282-11c-2, 2004).

OSHA believes that wet methods may also be used during removal of solidified electrolyte from used/spent anodes. OSHA expects that the grinders used for this task, when equipped with water delivery systems, can achieve significant dust reductions as mentioned by the NIOSH studies above. Additionally, shoveling loose or spilled bath material around pots should be conducted with a dust suppression method such as water to minimize the amount of dust that may become airborne.

The available information about the aluminum production process indicates that peak exposures can occur during short term tasks. When LEV or wet methods are not sufficient to control exposures during pot repair and dismantling, respirators would further protect workers. Respirators may also be necessary to protect workers during tapping and anode changing and setting. Employers should be especially cautious about minimizing anode effects as these increase process emissions and exposures to beryllium. Also, as workers tend the pots, LEV hooding is lifted, and the exhaust system loses capture efficiency. Respirators would also further protect workers during maintenance activities such as regular maintenance on the systems that deliver alumina to the pots, and mechanical and electrical systems, and during recycling activities associated with spent pot liner material and air pollution equipment maintenance.

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Chapter IV—Appendix B: Coal-Fired Electric Power Generation

INTRODUCTION

The potential for exposure to beryllium at coal-fired electric power plants is associated with the naturally occurring beryllium content of coal and fly ash. In a 1987 public health assessment document for beryllium, the average beryllium concentration in coal was reported to vary between 1.8 and 2.2 micrograms per gram of coal (µg/g) (EPA, 1987).[329] Clarke and Sloss (1992) report that the typical beryllium concentration of coal is 2 µg/g and ranges from 0.1 to 15 µg/g. The West Virginia Geological and Economic Survey reports that beryllium concentrations in West Virginia coal based on 851 analyses range from 0.007 ppm to 24.72 ppm with an average of 2.57 ppm (WVGES, 2002). In a review of beryllium in the environment, Taylor et al. (2003) report that the beryllium concentration in U.S. coal typically ranges from 1.46 to 1.52 ppm. Beryllium concentrations in the coals of 28 U.S. states range from 0.18 to 3.17 ppm.

Fly ash is fine particulate formed by the combustion of coal. The composition of coal fly ash varies depending on the type of coal, preparation techniques (such as cleaning and crushing) prior to burning, and boiler operating conditions. Fly ash is primarily comprised of silicon, aluminum, iron, and calcium oxides with magnesium, potassium, sodium, titanium, and a wide range of trace elements (including beryllium). One source reports that in the United States fly ash contains on average 46 milligrams of beryllium per kilogram of ash (Stadnichenko et al., 1961).[330] More recent investigations at coal-fired power plants report beryllium concentrations in fly ash and settled dust ranging from 0.4 ppm to 10 ppm depending on sample location (NIOSH, 1996, 1997). Bulk samples of fly ash, bottom ash, and lignite coal collected during a National Institute for Occupational Safety and Health (NIOSH) health hazard evaluation (HHE) at one large coal-fired power plant contained 4 ppm, 2 ppm, and nondetectable levels of beryllium, respectively (NIOSH, 1996a).[331,332]

Fly ash also consists of other heavy metals which are regulated by OSHA. Most notably arsenic (29 CFR 1910.1018) in which arsenic is often in concentrations 10 to 1000 times greater than beryllium. OSHA currently regulates exposures to arsenic in power plants due to the fact that arsenic is contained in fly ash (see OSHA-H054A-2006-0064-1972).

PROCESS DESCRIPTION

The electric power generation industry includes facilities that use coal, petroleum, gas or other fossil fuels (as opposed to solar, thermal, hydro, or nuclear energy) to generate electricity. Approximately 80 percent of the coal produced annually in United States is used to generate

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[329] The scope of the proposed rule includes only operations in which the beryllium content of any materials handled is greater than or equal to 0.1 percent by weight, which is equivalent to 1000 micrograms per gram (µg/g), or 1000 parts per million (ppm).

[330] A milligram per kilogram (mg/kg) is equivalent to a ppm.

[331] Bottom ash is large agglomerated ash particles (formed in pulverized-coal boilers) that adhere to boiler walls or fall through open grates to an ash hopper at the bottom of the boiler (U.S. Geological Survey, 2001).

[332] Bulk samples were prepared and analyzed according to methods developed by the U.S. EPA. The beryllium limit of detection was not provided in the NIOSH report.

electric power and nearly half of the nation's electricity comes from coal (Kim and Kazonich, 1999; EEI, 2010).

Coal-fired steam turbine generation includes 1) a heating system, 2) a boiler and steam delivery system, 3) a steam turbine, and 4) a condenser for condensation of used steam. Pulverized or crushed coal (fuel) is pumped into the boiler’s furnace and combusted. Heat from the combustion process generates steam. High temperature, high pressure steam from the boiler enters the steam turbine, drives the turbine blades, and powers the electric generator. Low-pressure steam exits the turbine, enters the condenser where it is cooled to condensate, and then is transported (by the boiler feedwater system) back to the boiler where it is reused.

Coal is transported to the plants by rail, truck, or barge and is unloaded to live storage, dead storage, or directly to the hopper or stoker. Coal unloading techniques vary depending on the type and size of plant. Live storage refers to an enclosed bunker or silo that is adjacent to conveyors leading to the pulverizer. Dead storage is the backup supply of coal and is stored outdoors in the open. From the coal bunker or silo, coal is transported to pulverizers, cyclones, or stokers to crush, grind, and dry the coal.

To control the dust associated with coal handling (e.g., unloading, storage, and processing), dust suppression may be required, especially in dry climates and during warmer weather. Water, oil, and calcium chloride ($CaCl_2$) are typically used for dust suppression. During the winter months, antifreeze chemicals are applied to coal. Coal may also be cleaned to reduce dust emissions and coal impurities such as metals, ash, silica, and sulfur. Coal cleaning is typically performed at the mine using a variety of methods. Some utility plants purchase pre-cleaned coal that significantly reduces the amount of dust generated during coal unloading. After the coal is ground and dried, it is transported to the boiler for combustion.

Waste from the combustion process includes fly ash (fine airborne particles that result from the burning of coal), bottom ash, boiler slag, and exhaust gases. Fly ash and exhaust gases typically pass through air cleaning devices before exiting the exhaust stack. Bottom ash consists of large agglomerated ash particles that adhere to the boiler walls or fall through open grates to an ash hopper at the bottom of the boiler. Boiler slag is molten ash that is quenched with water and breaks into black, angular particles with a smooth, glassy appearance. Boiler slag is collected at the base of slag tap and cyclone boilers. The main components of coal fly ash are oxides of silicon, aluminum, iron, and calcium, with lesser amounts of magnesium, sulfur, sodium, and potassium. Other metals can be found in trace quantities: arsenic, cadmium, beryllium, thallium, nickel, lead, manganese, chromium, selenium, zinc, and other metals.

AFFECTED JOB CATEGORIES

Workers in coal-fired electric power plants with potential exposure to airborne contaminants may be broadly categorized as operations workers and maintenance workers (including baghouse cleaners and coal handling personnel) (NIOSH, 1981). Table IV.B-1 summarizes the tasks and/or job titles associated with these work categories.

Table IV.B-1—Workers in Coal-Fired Power Plants with Potential Exposure to Airborne Contaminants (NAICS 221112)

Job Category	Description
Operations	*Operations workers operate, control, and monitor the routine production of electric power. Work tasks may include operating, testing, and inspecting equipment and processes, observing and recording equipment operation parameters, and others. Most of the work shift may be spent inside an air-conditioned control room under positive pressure. Several times a shift these workers conduct walk-through surveys of the entire facility to monitor the operation. Job titles include control and auxiliary (equipment) operator, boiler and assistant boiler turbine operator, fireman, tender, helper and auxiliary helper, and others.*
Maintenance	*Maintenance workers are responsible for the routine upkeep of the facility as well as emergency repairs. Examples of routine maintenance include regular inspection and maintenance of pulverizers, soot blowers, fans, and meters/gauges. Examples of scheduled outage (shut downs) maintenance include boiler inspection and repair and hopper maintenance. Job titles include maintenance mechanic, maintenance worker, mechanic, apprentice mechanic, instrument technician, instrument and control repair worker, electrician, apprentice electrician, electric technician, welder, custodian, janitor, and others.*
Baghouse/ESP cleaners	*Baghouse/ESP cleaners service and maintain air cleaning devices during scheduled outages (e.g., baghouse changeout or high efficiency cleaning; ESP inspection, cleanout, and wash; shoveling fly ash dust from ESP shelves). Some power plants hire traveling contract work crews to perform baghouse/ESP service and maintenance.*
Coal Handlers	*Coal handlers are involved with coal handling activities in the coal yard as well as inside the power plant. Job titles include coal handler, coal equipment operator, switchman/sampler, unloader, train or locomotive operator, tractor operator, car runner, conveyor man, tripper deck operator, and others.*

ESP: Electrostatic precipitator

Source: NIOSH, 1981, 1988; Bird et al., 2004; Beaulieu et al., 2006

Coal-fired electric power plants might operate under routine conditions about 60 to 70 percent of the time (Bird et al., 2004). The remaining time is associated with scheduled and unscheduled (e.g., unforeseen equipment failures) shut downs or outages. Scheduled outages typically involve some form of preventive maintenance and include disassembly, inspection, repair/rebuilding, and reassembly of plant equipment such as boilers and steam turbines. Baghouse maintenance has been associated with high levels of exposure to fly ash.

EXPOSURE DATA

Beryllium exposure to workers at coal-fired electric power plant was monitored during three NIOSH HHEs (NIOSH 1988, 1996, 1997).

NIOSH—City of Ames Municipal Power Plant (NIOSH, 1988)

On July 21–23, 1986 and January 12–14, 1987, a NIOSH health hazard evaluation was conducted at the City of Ames, Iowa, municipally-owned coal and refuse derived fuel (RDF) power plant during what are described as routine, non-outage work activities. NIOSH investigators conducted an initial walkthrough survey of the process on July 21–23 and collected bulk samples of settled dust and insulation at various locations throughout the plant to use in developing a follow-up monitoring protocol. The bulk samples were analyzed for trace or minute amounts (e.g., 0.1 percent or less) of metals using NIOSH Method 7300 (ICP/AES)[333] and the sample limit of detection (LOD) for beryllium was reported to be 1.0 microgram per gram of sample (0.0001 percent). NIOSH investigators reported that beryllium and other toxic metals were present in 50 percent or more of the bulk settled dust samples.[334]

During the follow-up survey on January 12–14, personal breathing zone (PBZ) monitoring was conducted for various air contaminants including trace metals identified in the bulk samples of settled dust. A total of 15 PBZ samples for trace metals were collected on operations and maintenance workers during presumed routine, non-outage work activities. All samples were full-shift except for one shorter duration sample (collected on a maintenance worker present for a partial shift). The samples were analyzed using NIOSH Method 7300 with a limit of quantitation (LOQ) for beryllium of 1.0 µg/sample. Worker exposures to all metals including beryllium were nondetectable. Based on the reported LOQ, these samples indicate that beryllium exposures were below 1.0 µg/m^3. However, the beryllium content of the dust at this facility was less than 0.01%, and respirable dust samples collected on operations workers at this facility ranged from 0.3 to 3.6 mg/m^3. When multiplied by the detection limit of 0.01%, OSHA estimates that beryllium exposures were most likely less than 0.03 to 0.36 µg/m^3.

NIOSH—Bruce Mansfield Power Station

On January 10 and 11, 1995, NIOSH investigators collected bulk, hand wipe, and PBZ samples from 27 plumbers and steam fitters for metals, respirable dust, and silica during the scheduled rebuilding of coal-fired boiler unit #2 at the Bruce Mansfield Power Station in Shippingport, Pennsylvania (NIOSH, 1996). Forty-five full-shift PBZ samples for metals were collected on plumbers and steamfitters who removed boiler drains and retractable soot blowers on the exterior of the boiler.[335] The samples were analyzed using NIOSH Method 7300 and the beryllium analytical limits of detection and quantitation were reported as 0.02 µg/sample and 0.12 µg/sample, respectively. The PBZ total beryllium sample results ranged from nondetectable to 0.39 µg/m^3. Thirty-two (74 percent) of the samples were nondetectable for beryllium (less than 0.02 µg/m^3); eight samples (19 percent) had a trace[336] amount of beryllium present; and three samples were positive with results of 0.11 µg/m^3, 0.14 µg/m^3 and 0.39 µg/m^3. Approximately 42 percent (18 of 43) of the full-shift PBZ metal samples contained arsenic concentrations above the detection limit of 0.3 µg/m^3. The arsenic concentrations ranged from trace levels to 31 µg/m^3, and three of the air samples measured arsenic exposures above the OSHA PEL. NIOSH associated the higher results with poor housekeeping and work practices.

[333] ICP/AES: Inductively Coupled Plasma/Atomic Emission Spectroscopy.

[334] The NIOSH report states that metals of greater toxicologic interest such as beryllium, cadmium, chromium, nickel, and lead were present in at least 50 percent or more of the bulk settled dust samples. However, a table with the bulk sample results does not include the beryllium content of the bulk samples. A footnote to the table states that metals not listed in the table were all below the analytical limits of detection or quantitation, or interferences prevented an accurate determination.

[335] NIOSH investigators eliminated two PBZ samples from the survey results because of possible tampering.

[336] Samples reported as trace had a quantity between the LOD and the LOQ.

NIOSH—Clinch River Power Plant

On September 25–28, 1995, NIOSH investigators collected bulk fly ash samples, hand wipe samples, and PBZ samples for metals, respirable dust, and silica during the scheduled rebuilding of a coal-fired boiler at the Clinch River Power Plant near Cleveland, Virginia (NIOSH, 1997). A total of 12 bulk fly ash samples were collected inside and outside the boiler. Bulk samples were analyzed for selected metals using NIOSH Method 7300 and the analytical limits of detection and quantitation for beryllium were reported as 0.08 µg/g and 0.26 µg/g, respectively. Five bulk samples collected *inside* the boiler had beryllium levels that ranged from 0.4 µg/g to 10 µg/g. Three of these samples were boiler scale/slag that was obtained by scraping material from boiler elements; the other two interior samples were obtained near refractory brick removal areas. Seven bulk samples of settled dust collected *outside* the boiler had beryllium levels that ranged from 3 µg/g to 6 µg/g. These samples were collected from various locations including on or near access portholes, on a nearby I-beam, on the exterior wall of the boiler, and on a soot blower.

A total of 42 PBZ samples for metals were collected on boilermakers and laborers. Samples were analyzed for 28 elements using NIOSH Method 7300. The beryllium analytical limits of detection and quantitation were reported as 0.02 µg/sample and 0.06 µg/sample, respectively. All PBZ samples were six hours or greater in duration except two; the shorter duration samples were collected on boilermakers moving elements on the outside of the boiler and had sampling durations of 121 minutes and 280 minutes. Seven of the PBZ samples were collected on boilermakers working inside the boiler; 31 samples were collected on boilermakers working outside the boiler; and four PBZ samples were collected on laborers maintaining walkways and work areas by dry sweeping and vacuuming.

The results for boilermakers working inside the boiler ranged from nondetectable to a trace amount (five nondetectable sample results and two trace concentration results). For boilermakers working outside the boiler, total beryllium results ranged from nondetectable to 0.37 µg/m^3. The worker associated with the highest sample result of 0.37 g/m^3 was also exposed to arsenic above the OSHA PEL. All other samples were reported as trace or non-detectable. Beryllium sample results for the laborers ranged from nondetectable to a trace amount (two nondetectable sample results and two trace concentration results). Samples with a trace of beryllium had a quantity between 0.02 to 0.06 µg/sample.

OSHA IMIS Data

OSHA also reviewed exposure data from OSHA's Integrated Management Information System (IMIS) for beryllium (OSHA, 2009). The IMIS data includes information on industry and job descriptions, but does not include information on worker activities, workplace conditions, engineering controls, use of personal protective equipment, nondetectable concentrations, and sampling durations. In addition, it is not possible to determine whether beryllium was included in the sample analysis request because there is known potential workplace exposure to beryllium, or because it was part of a routine metal screening. For this application group, there are two corresponding SIC[337] classifications: 4911 (Electric Services) and 4931 (Electric and Other Services Combined) with beryllium exposures in the IMIS database.

For the time period June 1978 to September 2003, the IMIS database includes 10 PBZ sample entries for beryllium in SIC classification 4911. SIC classification 4911 includes hydroelectric, fossil fuel, nuclear electric, and other electric power generation; electric power transmission and control; and electric power distribution. Thus, the PBZ entries in the IMIS database for SIC code 4911 might represent establishments other than coal-fired electric power generation plants. Four of the sample entries are reported as nondetectable and six sample entries have positive beryllium results ranging from 0.01 µg/m^3 to 8.6 µg/m^3. The nondetectable results are reported for workers with job descriptions of mechanic welder (two samples, March 1994), operator (one sample, August 1986), and technician (one sample, April 2006). Three positive sample results of 0.01 µg/m^3 (February 1996) are reported for workers with a job description of fuel handler. Two sample results of 0.05 µg/m^3 (March 2002) are reported for workers with a job description of pipe fitter; the highest sample result (8.6 µg/m^3, May 1987) is reported for a worker with a job description of electrician.

For SIC code 4911, the IMIS database also includes one area sample (March 1994), one screening sample with no job description (April 1991), one wipe sample (March 1994) for a job description of mechanic, and one bulk sample (March 1989) for a job description of fly ash loader. OSHA assumes all of these samples were nondetectable because the result for each is listed as zero.

Table IV.B-2 summarizes the available PBZ beryllium exposure data discussed above. Results reported as less than the LOD or LOQ are incorporated into the exposure profile as volume-adjusted LOD or LOQ concentrations.

Table IV.B-2—Exposure to Beryllium in the Coal-Fired Electric Power Generation Industry (NAICS 221112)

Job Category	No. of Samples	Range (µg/m^3)	Mean (µg/m^3)	Median (µg/m^3)
Operations	*4*	*<1.0*	*<1.0*	*<1.0*
Maintenance	*96*	*0.01 to 0.39*	*0.05*	*0.02*
Routine Maintenance	*10*	*0.17-0.17*	*0.17*	*0.17*
Scheduled Outage Maintenance	*83*	*0.02 to 0.39*	*0.04*	*0.02*
Coal Handling	*3*	*0.01*	*0.01*	*0.01*
TOTAL	*100*	*0.01 to 0.39*	*0.06*	*0.02*
Source: NIOSH, 1988, 1996, 1997; OSHA, 2004, 2009				

Operations Worker: Operations workers typically would be expected to have only limited exposures to fly ash in coal-fired power plants due to the nature of their work. Four full-shift PBZ total beryllium exposure results reported for operations workers during a NIOSH HHE at the City of Ames, Iowa, municipal coal and RDF power plant (NIOSH, 1988) were nondetectable for beryllium. Two of the samples were collected on the power plant auxiliary operator and two were collected on a fireworker (fireman). The auxiliary operator assists the

[337] OSHA IMIS data after 2002 are coded using NAICS codes, while data prior to 2002 are coded using SIC codes.

plant operator in the operation of power plant equipment; operates, lubricates, and inspects auxiliary power plant equipment; observes and records equipment operation parameters; tests various process water qualities; and operates the boiler bottom ash and fly ash removal equipment. The power plant fireman operates control equipment in firing high pressure boilers; uses stoker and pulverized coal burning equipment and observes burning conditions of burners when firing coal, gas, oil, RDF, or combination fuels; operates soot blowers, fly ash removal equipment, boiler feed pumps, fans, pulverizers, and other boiler-related auxiliary equipment. During a NIOSH HHE conducted in 1991 at a coal-fired power plant in Healy, Alaska, beryllium was detected in two settled dust samples, but not in 15 full-shift air samples (12 area and 3 PBZ) collected and analyzed for elemental metals according to NIOSH Method 7300 (NIOSH, 1998).[338,339] In a follow-up survey at this plant in 1993, 30 full-shift area samples were collected throughout all seven floors of the plant and analyzed for elemental compounds (NIOSH, 1998). Results of that analysis indicated only trace quantities of metals present. Area sampling locations included the control room, basement, coal pulverizer, burner deck, baghouse (various levels), turbine deck, coal tunnel (various levels), air intakes (various levels), boiler (various levels), and others. These findings suggest that under routine operating conditions beryllium exposures for most power plant workers are low.

NIOSH investigators also noted that employees at the Healy power plant use compressed air and brooms to clean settled fly ash from plant surfaces (also called "blow down") and that the individuals doing the cleaning might expose themselves and other personnel throughout the plant to excessive dust. Since there is the potential for exposure to arsenic, these procedures are prohibited unless other means have been tried and found not to be effective (29 CFR 1910.1018(k)(2)). At least three operations jobs at the Healy plant have job duties that include some form of cleaning. *Relief control room engineers* are responsible for general cleaning and assisting maintenance mechanics when not providing relief for other operators. *Auxiliary operators* are responsible for monitoring equipment in the basement of the plant and operating the automatic ash removal equipment. Other duties include cleanup of the first three floors and helping the assistant control room engineer during abnormal operating conditions. The *relief assistant's* duties are the same as the relief control room engineer, except that this worker relieves the assistant and auxiliary positions only. Since a total of 45 full-shift air samples collected throughout the Healy power plant were either nondetectable for beryllium or had trace levels, these findings suggest that elevated airborne dust levels associated with cleaning activities, some of which might be performed by operations workers, are not necessarily associated with elevated beryllium exposures.

Maintenance Worker: Maintenance workers have the highest potential exposure to fly ash and beryllium (NIOSH, 1988, 1996, 1997). The available exposure measurements for maintenance workers are summarized in Table IV.B-2. The exposure profile is described by a median of 0.02 $\mu g/m^3$, a mean of 0.05 $\mu g/m^3$, and range from 0.01 to 0.39 $\mu g/m^3$. These results are based on 96 full-shift PBZ total beryllium results for all workers classified in the maintenance category. This category includes routine, emergency, and planned outage maintenance as well as other production-related work such as coal handling. Job titles in this category for which exposure data are available include: maintenance worker, maintenance mechanic, electrical technician,

[338] Individual sample results are not available and the limit of detection for beryllium was not specified.
[339] One PBZ sample was obtained on a mechanic/welder; the other two workers monitored were not specified.

boilermaker, laborer, and coal handler. Although a majority of the data was obtained during scheduled outage maintenance activities, beryllium exposures associated with scheduled outage and other maintenance may be similar. The operations manager at one coal-fired power plant reports that emergency tube leak repairs produce fly ash levels that are visually comparable to those of scheduled outage activities (Coal-Fired Power Plant A, 2006).

Routine Maintenance: Ten of the sample results in the exposure profile were obtained on workers engaged in routine maintenance activities during a NIOSH HHE at the City of Ames, Iowa, municipal coal and refuse derived fuel power plant (NIOSH, 1988). All 10 of the sample results for routine maintenance work are nondetectable for beryllium. However, the LOD for beryllium was 0.5 micrograms at the time of the NIOSH survey. Two of the routine maintenance samples were collected on an electrical technician, four of the samples were collected on maintenance mechanics, and the remaining four samples were obtained on maintenance workers. The electrical technician installs, maintains, trouble shoots and tests a wide variety of electrical and electronic systems. Maintenance mechanics perform skilled and difficult tasks involving the maintenance and repair of mechanical equipment. This work includes machine work, steam fitting, plumbing, and welding; turbine, boiler, and auxiliary equipment repair; and inspection and repair of ash handling equipment. Plant maintenance workers perform manual labor and semi-skilled work tasks. These workers repack valves and assist with basic machine work, steam fitting, plumbing, cutting and welding; and turbine, boiler, and auxiliary equipment repair.

As noted, during subsequent HHEs at the Bruce Mansfield and Clinch River coal-fired power plants, the LOD for trace metals analysis was 0.02 micrograms per sample and the LOQ ranged from 0.06 to 0.12 micrograms per sample (NIOSH 1996, 1997). If the nondetectable results for routine maintenance were based on the lower reporting limits, the results would be less 0.2 $\mu g/m^3$.

Scheduled Outage Maintenance: A majority (87 percent) of the sample results in the maintenance worker exposure profile were obtained while boilers were rebuilt during scheduled outages at the Bruce Mansfield and Clinch River coal-fired power plants (NIOSH, 1996, 1997). Eighty-three full-shift PBZ samples were collected on plumbers, steamfitters, boilermakers, and laborers. Fifty-one of the sample results were nondetectable for beryllium (0.02 µg/sample LOD), 28 samples had trace[340] amounts of beryllium, and four samples had beryllium concentrations of 0.11 $\mu g/m^3$, 0.14 $\mu g/m^3$, 0.37 $\mu g/m^3$, and 0.39 $\mu g/m^3$. To incorporate the trace results into the maintenance worker exposure profile, OSHA conservatively estimated the airborne concentrations of these samples by using the analytical limits of quantitation (0.06 µg/sample or 0.12 µg/sample) to quantify the trace airborne beryllium concentrations. Although this approach might slightly overestimate the exposure profile for this job category, the resulting mean and median are less than the lowest PEL option (0.1 $\mu g/m^3$) being considered by OSHA.

The four positive sample results that ranged from 0.11 $\mu g/m^3$ to 0.39 $\mu g/m^3$ were collected on workers that removed and replaced soot blowers (0.11 $\mu g/m^3$, 0.14 $\mu g/m^3$) and boiler drains (0.39 $\mu g/m^3$), and torch cut a rear exterior boiler wall casing (0.37 $\mu g/m^3$). During the boiler rebuilding activities, NIOSH investigators observed that workers were exposed to fly ash, metal

[340] Sample results reported as "trace" contained a quantity of beryllium between the analytical limits of detection (0.02 µg/sample for both surveys) and quantitation (0.06 µg/sample or 0.12 µg/sample, depending on the survey).

fumes from hot work, and settled dust from fly ash and/or coal. In some cases, the settled dust was five to six inches deep on work surfaces. When workers removed boiler parts such as soot blowers and boiler drains, the settled dust became airborne. NIOSH investigators also observed poor work practices, such as using compressed air to clean settled dust from surfaces, that created airborne dust (NIOSH, 1996, 1997).

One scheduled outage maintenance operation that is associated with higher beryllium exposures is maintenance of air pollution control equipment (Beaulieu et al., 2006; Beaulieu and Siert, 1997). Beaulieu et al. (2006) conducted a 10-year exposure assessment of maintenance worker exposures to air contaminants (particulate matter, crystalline silica, and metals) at eight Colorado coal-fired power plants (four bituminous coal; four sub-bituminous coal). Maintenance and cleaning of baghouse systems was evaluated at six of the plants and cleaning of electrostatic precipitators (ESPs) was evaluated at another plant with two ESP units. For baghouse maintenance, worker exposures were evaluated during filter bag replacement and cleanup. For ESP maintenance, worker exposures were assessed while shoveling fly ash from shelves for one type of ESP and erection of scaffolding and wash down for the other ESP. Cleaning these air pollution control devices was reported to be extremely dusty. The average respirable dust concentration measured during the baghouse cleaning was 9.5 mg/m^3 for the bituminous and 11.2 mg/m^3 for sub-bituminous coal, well above the OSHA PEL. Beryllium exposures varied by the type of coal. For baghouse bag changing in plants that burn bituminous coal, the mean of 15 full-shift PBZ samples was 0.2 µg/m^3 with a maximum of 1.2 µg/m^3. Ninety-three percent of the results were less than or equal to 0.1 µg/m^3; 7 percent of the results were greater than 0.1 µg/m^3 and less than 2.0 µg/m^3. However, for bag changing in facilities that burn sub-bituminous coal, the concentration of beryllium was higher, with a mean of 14 full-shift PBZ samples of 2.4 µg/m^3 and a maximum of 13 µg/m^3. Fifty percent of the beryllium results were less than or equal to 0.1 µg/m^3, 14 percent of the results were greater than 0.1 µg/m^3 and less than 2.0 µg/m^3, and 36 percent exceeded the current PEL of 2.0 µg/m^3.

To provide additional insight into the exposure profile for maintenance workers, OSHA also examined IMIS data for relevant supporting information. For SIC groups 4911 and 4931, the IMIS data contains five PBZ entries with job descriptions representative of maintenance workers (see the beginning of this subsection on OSHA IMIS Data). These job descriptions include mechanic welder (two samples collected in March 1994), pipe fitter (two samples collected in March 2002) and electrician (one sample collected in May 1987). Both sample results for the mechanic welder are nondetectable (no volume-adjusted minimum detectable concentration available); the pipe fitter sample results are both 0.05 µg/m^3; and the electrician sample result is 8.6 µg/m^3. Although the IMIS data contain limited exposure information for maintenance workers, four out of the five sample results are nondetectable (< 0.05 µg/m^3) which indicates that typical beryllium exposures for maintenance workers are low. Thus, the baseline exposure level for maintenance workers is estimated to be less than 0.02 µg/m^3. As previously discussed, during a HHE at the Healy coal-fired power plant in Healy, Alaska, 45 full-shift air area samples collected throughout the power plant were either nondetectable for beryllium or had trace levels, suggesting that beryllium exposures for most power plant workers are low at least under routine operating conditions (NIOSH, 1998). Elevated exposures (exceeding the PEL) can occur for workers involved in air pollution equipment maintenance.

NIOSH investigators also noted that employees at the Healy plant use compressed air and brooms to clean settled fly ash from plant surfaces (also called blow down) and that these activities might expose the employees performing them, as well as other personnel throughout the plant, to excessive dust. The clothing of maintenance workers becomes visibly soiled from cleaning settled dust or entering the baghouse to remove and/or clean filters. These findings suggest that workers were exposed to excessive airborne dust levels due to maintenance activities which may be the root cause of the elevated beryllium exposures. NIOSH investigators did not report PBZ total dust exposure levels for workers cleaning fly ash with compressed air and brooms during the Healy power plant health hazard evaluation.

Coal Handler: As shown in Table IV.B-2, the exposure data for coal handlers is based on three PBZ samples, each with results of 0.01 $\mu g/m^3$. The published literature reviewed by OSHA contained no beryllium exposure data for coal handlers. PBZ exposure data for air contaminants is available for coal handlers, but it is limited to respirable crystalline silica and coal dust results (NIOSH, 1981, 1984, 1988). To estimate beryllium exposure for coal handling, OSHA used the only available PBZ exposure data—three unpublished exposure results from the OSHA IMIS database. These samples were obtained in February 1996 on workers with a job description of fuel handler at a coal-fired power plant. Information pertaining to actual sample duration is not available; however, the sample results are listed as time-weighted averages and presumed to be representative of full-shift samples.

DESCRIPTION OF ENGINEERING CONTROLS

Operations Worker: Operations workers are responsible for operating, controlling, and monitoring the routine production of electric power. Most of the work shift may be spent inside an air-conditioned control room under positive pressure. Several times a shift, operations workers conduct walk-through surveys of the entire facility to monitor and inspect the operation. Potential exposure to beryllium can result when workers are outside the control room (e.g., when conducting walk-through surveys and inspecting equipment and processes) from worker movement or motion in areas where fly ash/coal dust has settled on exposed surfaces as well as airborne levels of fly ash/coal dust associated with boiler and process equipment leaks. Other baseline conditions include some level of protective clothing and respiratory protection (depending on work activity or area) and routine housekeeping. Some plants might use housekeeping techniques that generate considerable airborne dust such as dry sweeping and shoveling and the use of compressed air.

Operations workers have less exposure to fly ash and/or coal dust than maintenance workers and coal handlers. The median exposure levels for scheduled outage maintenance and coal handling are both less than 0.1 $\mu g/m^3$, thus, the actual baseline exposure level for operations workers is also likely less than 0.1 $\mu g/m^3$. Coal-fired power plants must ensure that they are in compliance with OSHA's arsenic standard which includes a provision on housekeeping.

Maintenance Worker: Potential maintenance worker exposure to beryllium is associated with worker movement or motion in areas where fly ash/coal dust has settled on exposed surfaces, as well as airborne levels of fly ash/coal dust associated with boiler and process equipment leaks.

Baseline conditions for maintenance include enclosed and ventilated boilers and process equipment. During boiler rebuilding, exposure controls might include cleaning the interior surfaces of the boiler with high-pressure water; local exhaust ventilation (LEV); operating induced draft fans to ventilate the boiler (if available); and opening the stack dampers to create a natural draft. Other baseline conditions include some level of protective clothing and respiratory protection (depending on work activity or area) and housekeeping (although housekeeping might include cleaning techniques that generate considerable airborne dust such as dry sweeping/shoveling and the use of compressed air). Some plants might require good personal hygiene including the use of showers and on-site laundering of work clothes.

The median exposure level for all maintenance work is 0.02 $\mu g/m^3$. Based on the available information, this value is also the best estimate of the typical exposure level for this job category. Thus, the preliminary baseline exposure level for maintenance workers is estimated to be 0.02 $\mu g/m^3$. Some maintenance tasks are associated with higher beryllium exposures. To reduce these exposures, the following controls options could minimize the overall level of airborne dust:

- Housekeeping procedures should be implemented and/or improved. Fly ash/coal dust on working surfaces should be removed before work begins using wet methods and/or HEPA-filtered vacuums to minimize the suspension of settled dust. Compressed air and the use of dry methods (such as sweeping and shoveling) should be prohibited.

- Engineering controls such as LEV, operating induced draft fans and/or opening stack dampers should be used to reduce worker exposures to settled dust and fly ash during boiler rebuilding.

- Good work practices to minimize exposure to dust should be implemented such as applying a water mist to exterior boiler panels and carefully placing them down after removal.

- Boiler and process equipment leaks should be located and repaired to reduce in-plant airborne levels of fly ash/coal dust.

For workers involved in maintenance of baghouse systems, additional controls includeusing a pulley system to break up the ash cake and remove the bags, and inspecting the bags more frequently and promptly replacing them when leaks are detected (Beaulieu et al., 2006). For ESP maintenance, additional exposure reductions can be achieved by increasing the cleaning frequency where possible during outages.

Fly ash contains other toxic metals, including arsenic and cadmium, for which OSHA has established substance specific standards. Therefore, precautions to avoid exposure are routinely used during bag house maintenance and cleaning operations.

In sum, workers at coal-fired power plants can be exposed to beryllium due to trace amounts of beryllium in the fly ash in addition to other heavy metals. The beryllium content of the fly ash is low (i.e., less than 0.01%), and exposures to beryllium during routine operations appear to be below 0.2 $\mu g/m^3$. However, workers may be exposed to higher levels during very dusty maintenance operations such as cleaning the air pollution control devices.

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Chapter IV—Appendix C: Abrasive Blasting

INTRODUCTION

Abrasive blasting involves the use of hand-held or automatic equipment to direct a stream of abrasive material at high speed against a surface to clean, abrade, etch or otherwise change the original appearance or condition of the surface (WorkSafe, 2000). Surfaces commonly treated by abrasive blasting techniques include iron, steel, aluminum, brass, copper, glass, masonry (brick, concrete, stone, etc.), sand castings, plastic, and wood (NIOSH, 1976). Abrasive blasting is used for a variety of purposes, including but not limited to:

- Cleaning surfaces by removing unwanted paint, rust, scale, dirt, salts, grease, and flux in preparation for painting, anodizing, welding, or other processes requiring a clean surface.
- Deburring, removing tooling marks, or otherwise finishing a crude product.
- Producing a desired matte or decorative finish.
- Cutting or inscribing of partially masked parts such as tombstones.
- Removing "flashing" (excess material) from molded plastic or rubber.
- Changing metallurgical properties or stress relieving parts by the peening action of multiple impactions.

A number of possible blasting media can be used depending on the application. The blasting media used as well as the surface being blasted can contribute to potential beryllium exposures. When beryllium is considered, several blasting media appear to be the most problematic, including coal slag and copper slag. Coal slag is the processed residue produced by coal-burning electric power plants. “Black Beauty,” a trade name for a coal slag abrasive product, accounts for about two-thirds of the market for coal slag (Greskevitch, 2000). A NIOSH sponsored study of alternative media for use in shipyard blasting operations found that the level of beryllium in coal slag varies from one product to another. However, all nine bulk samples of coal slag products analyzed in the study contained detectable levels of beryllium at concentrations ranging from 0.28 to 6.3 micrograms per gram of sample (µg/gm), suggesting that coal slag typically contains beryllium. Copper slag produced as by-product at copper smelters can also be used as an abrasive. The bulk analysis of 10 copper slag samples showed beryllium concentrations from 0.448 to 1.45 µg/gm (NIOSH/KTA-Tator, 1999).

Abrasive blasting can generate large quantities of dust that can contain high levels of toxic air contaminants. The source of the air contaminants includes the base material being blasted, the surface coating(s) being removed, the abrasive being used, and any abrasive contamination from previous blasting operations (Burgess, 1991). This means workers can have exposures to multiple air contaminants from both the abrasive and the surface being blasted. Potential air contaminants that might be associated with abrasive blasting and their sources are listed in Table IV.C-1.

Table IV.C-1—Potential Air Contaminants Associated with Abrasive Blasting	
Source	**Potential Air Contaminants**
Base Material (e.g., steel, aluminum, stainless steel, galvanized steel, copper-nickel and other copper alloys)	*Aluminum, chromium, copper, iron, lead, manganese, nickel, and zinc*
Surface Coatings (e.g., pre-construction primers, anticorrosive and antifouling paints)	*Copper, barium, cadmium, chromium, lead, tributyl tin compounds, zinc*
Abrasive Blasting Media (e.g., coal slag, copper slag, nickel slag, steel grit, garnet, silica sand)	*Arsenic, beryllium, cadmium, chromium, cobalt, crystalline silica, lead, manganese, nickel, silver, titanium, and vanadium*
Source: EPA, 1997b; EPA, 2000; NFESC, 1996; NIOSH/KTA-Tator, 1999	

PROCESS DESCRIPTION

Abrasive blasting systems generally include an abrasive container or blasting pot, a propelling device, and an abrasive blasting nozzle. The three propelling methods include air pressure, water pressure, and centrifugal wheels. Air blasting systems use compressed air to propel the abrasive, water blasting systems use either compressed air or high pressure water, and centrifugal wheel systems use centrifugal and inertial forces (EPA, 1997a).

Air blasting systems include compressed air suction, compressed air pressure, and wet abrasive blasting systems (EPA, 1997a). In compressed air suction systems, hoses are connected to a blasting gun or nozzle from the bottom of the abrasive blasting pot and the compressed air supply. The abrasive blasting gun consists of a jet of high velocity air that creates a partial vacuum as it expands inside a larger outer nozzle. This suction draws the abrasive into the outer nozzle and expels it through the discharge opening of the gun (EPA, 1997a). Compressed air pressure systems include a pressure tank or pot that contains the abrasive. The compressed air supply is connected to the top and the bottom of the abrasive pot. This configuration forces the abrasive through the blast hose without loss of pressure.

Wet blasting techniques include wet abrasive blasting, air and water abrasive blasting, high-pressure water blasting, and high-pressure water and abrasive blasting (EPA, 1997a). Wet abrasive blasting systems use a specially designed pressure pot to propel the water and abrasive with compressed air. An alternative system uses a pressure pot and an adapter nozzle on the blasting gun to convert the system from a dry blasting unit to a wet blasting unit (EPA, 1997a).

In air and water abrasive blasting systems, the use of air, water, and the abrasive are varied. High-pressure water blasting systems include a high-pressure water pump and hose and a blasting nozzle. To provide high-pressure water and abrasive blasting, abrasives are added to high-pressure water blasting systems.

Centrifugal blasters use high speed rotating blades (spinning wheel) to propel metallic shot or grit to the surface to be prepared and provide for easy recovery of abrasive materials for reuse and recycling (Burgess, 1991; EPA, 1997b; Queensland Government, 1999). Centrifugal blasters are typically used for large, flat surfaces such as ship decks, hulls, and storage tanks. Small hand-held units are available for use on bridges and similar structures (EPA, 1997a).

Abrasives: The most commonly used abrasives in the construction industry (e.g., to etch the surfaces of outdoor structures, such as bridges, prior to painting) currently include coal slag and steel grit (Meeker et al., 2006). Shipyards are large users of mineral slag abrasives. In a recent survey conducted for the Navy, the use of coal slag abrasives accounted for 68 percent and copper slag accounted for 20 percent of abrasive media usage as reported by 26 U.S. shipyards and boatyards (NSRP, 1999).

Workers who blast with coal slag abrasives are potentially exposed to beryllium, according to a NIOSH-sponsored study of substitutes for silica sand in abrasive blasting (NIOSH/KTA-Tator, 1999). In addition to coal slag abrasives, the use of copper slag abrasives may also produce beryllium exposures, and the NIOSH study also found significant airborne concentrations of beryllium when this material was used for abrasive blasting. Coal slag, however, is more commonly used (Greskevitch, 2000).

The use of coal and copper slag abrasives has increased in recent years as industries have sought substitutes for silica sand blasting abrasives to avoid health risks associated with respirable crystalline silica. There has been limited published information regarding the potential for and health risks of beryllium exposure associated with the use of coal slag for blasting. The potential for beryllium exposure during abrasive blasting appears to be widespread.

AFFECTED JOB CATEGORIES

Abrasive blasting is used in general industry, construction and maritime operations by painting contractors, welders, shipyards, aircraft manufacturers, foundries, steel mills and fabrication plants, structural steel supply yards, memorial monument markers, plating and anodizing shops, special purpose job and machine shops, building cleaners, gas transmission stations, canneries, breweries, wineries, rubber and plastic manufacturers, electronic manufacturers, petrochemical companies, wood shops and furniture manufacturers, and many others (NIOSH, 1976).

In general industry, most abrasive blasting for the purposes of cleaning or finishing metal parts is typically conducted in blasting cabinets or similar enclosures. Some open blasting is performed in the concrete products and cut stone industries, but no significant beryllium exposures have been documented for these operations. Open blasting of large objects (e.g., airplanes) might also be performed in other industries, but, again, any resultant beryllium exposures have not been documented. Abrasive blasting of copper-beryllium alloy castings is described in Section 5 of Chapter IV of this PEA, Nonferrous Foundries.

For construction applications, abrasive blasting is done in blasting yards or rooms, or inside temporary enclosures constructed on-site. For maritime applications, abrasive blasting may be conducted within a blast house, a building dock, a floating dry dock, a building or sliding ways, on the ground, on board a vessel, and at berth (NSRP, 2000). Open-area blasting of bridges, structures, and ship hulls, is conducted by construction industry contractors or by shipyard operators. To estimate the number of workers engaged in open-air abrasive blasting work in construction, OSHA used estimates originally prepared as part of a regulatory impact assessment of OSHA's draft silica regulation (ERG, 2008). OSHA estimated the number of construction blasting workers based on (1) disaggregated construction investment data in the 1997 Economic Census for painting and other contractors (i.e., contractors likely to perform abrasive blasting) and (2) the 2000 Bureau of Labor Statistics (BLS) Occupational Employment Survey which reports "construction and maintenance painters" (U.S. Census Bureau, 1997; BLS, 2001).[341] OSHA extrapolated these estimates to 2006 by multiplying by the overall rates of employment growth in the relevant construction industries. Using this approach, OSHA estimated that 21,643 workers perform abrasive blasting in NAICS 238320 (Painting and Wall Covering Contractors) and 4,403 in NAICS 238990 (All Other Specialty Trade Contractors). The total, 26,047, is assumed to include blasting helpers and cleanup workers.

In ship and boat building and repairing (NAICS 336611), the 2007 County Business Patterns reports 638 establishments and 94,876 employees (U.S. Census Bureau, 2007). According to estimates from Maritime Standards about 1 percent of shipyard employees may be involved in abrasive blasting, painting and cleanup operations (Daddura, 2011). Using this percentage, OSHA estimates that 949 (.01 x 94,876) employees work as painters in ship and boat yards and might perform abrasive blasting as part of their work. This estimate also includes blasting helpers and cleanup workers.

No information is available regarding the number of abrasive blasting workers in the construction sector who use various blasting media, such as silica sand, coal slag, and copper slag abrasives. OSHA based its exposure profile estimates on the presumption that one-quarter of abrasive blasting workers in the construction sector are potentially exposed to beryllium and estimated that approximately 6,500 (0.25 x 26,047) construction blasters are potentially exposed to beryllium. This conclusion is consistent with the relatively low beryllium exposure levels found for workers engaged in construction industry blasting operations.

For ship and boat building and repair, OSHA relied on a U.S. Navy study that reported coal and copper slag account for 94 percent of the blast media used at Naval ship repair facilities (NSRP, 1999). Since it is unlikely that some blasting workers use only one type of blast media, OSHA assumed that all 949 shipyard blasters are potentially exposed to beryllium.

The primary abrasive blasting job categories in the construction and maritime industries include the abrasive blasting operator (blaster) and the pot tender (blaster's helper or assistant). Support personnel might also be employed to clean up (e.g., by vacuuming or sweeping) and recycle spent abrasive and to set up, dismantle, and move containment systems and supplies (NIOSH, 1995).

Abrasive Blasting Operator (blaster): Abrasive blasting operators abrade the surfaces of metal or hard-composition products using abrasive blasting equipment. The most common method of abrasive blasting is dry abrasive blasting or air nozzle blasting. In dry abrasive blasting, compressed air is used to propel abrasive material (media) from a blast pot (container or pressure vessel to contain the abrasive), through a flexible hose to a nozzle, where the operator directs it to the work piece at high velocity. Air pressure is typically high at 100 pounds per square inch, and nozzle velocities can approach 650-1700 feet per second (Brantley and Reist, 1994).

[341] Comparably disaggregated data are not available from the 2002 or 2007 Economic Censuses.

Abrasive blasting operators manually direct abrasive blasting nozzles over the surfaces of large parts in open-air, portable or fixed facilities, blast cleaning rooms or booths, or in other enclosures or environments. Alternatively, these workers might operate automatic machines or hand-operated blasting cabinets.

Pot Tender/Helper (also called machine tender, blast pot equipment operator, abrasive blasting helper or assistant): Pot tenders are responsible for maintaining the blasting machine and assisting the blasting operator (e.g., shutting off the blasting machine upon a signal from the operator or in the event of an emergency such as accidental dropping of the nozzle end of the hose). These workers keep the blasting pot (or hoppers) filled with clean abrasive, ensure proper abrasive feed rate, move air hoses, and tend the air compressors supplying breathing air and the blasting hose. Pot tenders may also be responsible for cleaning up the spent abrasive (e.g., by vacuuming or sweeping) at the end of the day's blasting. If a temporary enclosure has been erected, pot tenders might watch for dust leaks in the containment (Meeker et al., 2005).

Abrasive Media Cleanup Workers: Laborers designated as cleanup or recovery workers are responsible for cleaning up spent abrasive (e.g., by vacuuming or sweeping) at the end of the day's blasting.

EXPOSURE PROFILE

To estimate the exposure profile for abrasive blasters, pot tenders/helpers, and abrasive media cleanup workers, OSHA used the findings from two National Institute for Occupational Safety and Health (NIOSH) evaluations of beryllium exposure from abrasive blasting with coal slag, unpublished shipyard results (1995 to 2004) for abrasive blasting operations from four U.S. shipyards, and data submitted by the U.S. Navy (NIOSH, 1983b; NIOSH, 2007; OSHA, 2005; U.S. Navy, 2003). The latter was provided in response to the OSHA request for information regarding occupational exposure to beryllium (Federal Register, 2002). These samples represent the best available data to characterize beryllium exposures for abrasive blasters. Although OSHA's Integrated Management Information System (IMIS) database also includes exposure monitoring results indicating beryllium exposures in abrasive blasting operations, the IMIS data are not sufficiently detailed to be included in the exposure profile. However, the IMIS data are discussed in this analysis as supporting information for the exposure profile. Additional technical literature was also examined. In the general literature, most studies have focused on other health hazards, particularly silica and lead exposures. Nevertheless, some of the technical literature includes useful data on beryllium and is discussed below to support this analysis.

Integrated Management Information System

OSHA reviewed unpublished exposure data from IMIS for beryllium for the time period June 1978 through September 2008 (OSHA, 2004 and 2009). As shown in Table IV.C-2, the OSHA IMIS data indicates a possibility of elevated beryllium exposures for abrasive blasting activities. The data show detectable beryllium exposures occur frequently among construction workers (SIC major groups 15 to 17) performing blasting. Out of a total 182 construction industry samples, 110 (60 percent) show detectible levels of beryllium, with a median of 0.7 $\mu g/m^3$ (positive results). Approximately 35 percent of the positive samples exceed 2.0 $\mu g/m^3$. For shipyards (SIC group 373), 33 of the 57 samples are for shipyard blasters . Of these, 14 are detectible for beryllium with a median of 4.3 μg/m^3 (positive results) and 50 percent greater than 2.0 μg/m^3. For the fabricated metal products industry (SIC major group 34), 17 out of a total of 40 samples are positive for beryllium, with a median of 0.55 μg/m^3 (positive results) and 12 percent greater than 2.0 μg/m^3. For this application group, most of the positive exposure results are associated with fabricated metal products and coating, engraving, and allied services.

The rest of the manufacturing industry (SIC goups 28-32, 33, 35, 36, and 38-39) accounted for 47 samples, with 15 showing detectable beryllium levels. The range, mean and median reported in Table IV.C-2 include only positive IMIS results because the volume-adjusted reporting limit concentrations for nondetectable samples are not available. Since a significant number of the sample entries are nondetectable for all sectors evaluated (51 percent), the summary statistics based on the samples with detectable results are likely to overestimate the true exposure profile for abrasive blasters. For the remaining industries (SIC groups 40-49, 70-89, and 91-99), the 14 abrasive blasting observations are concentrated among several four-digit industries. Of the 6 positive samples for these groups, one (0.3 μg/m^3) is accounted for by SIC 4231, Terminal and Joint Terminal Maintenance Facilities for Motor Freight Transportation. Two of the positive samples (0.071 μg/m^3 and 47.0 μg/m^3) are accounted for by SIC 7538, General Automotive Repair Shops. The remaining three positive samples (0.18 μg/m^3, 0.44 μg/m^3, and 0.7 μg/m^3) are accounted for by SIC 7699, Repair Shops and Related Services, Not Elsewhere Classified.

Table IV.C-2 includes three positive abrasive blasting results from OSHA consultation surveys; however, SIC codes for these establishments are not available. The OSHA consultation results include the highest beryllium concentration in the IMIS database for a PBZ abrasive blasting sample (1,781 μg/m^3).

The results from the IMIS database suggest that blasting in blast cabinets or similar enclosures does not result in elevated beryllium exposures. Based on the job descriptions provided in the IMIS records, OSHA identified 18 samples of abrasive blasting that might reflect use of blast cabinets and enclosures (e.g., wheelabrator operator, rotoblast man, blaster-shothouse, or booth blaster). Of these samples, seven showed detectible levels of beryllium, but only one exceeded 0.2 μg/m^3 (0.25 μg/m^3). The median (0.05 μg/m^3) and the mean (0.084 μg/m^3) of the detectible samples are both well below the lowest of the Permissible Exposure Limit (PEL) options. The IMIS data do not, however, provide information about the conditions of blasting operations so little interpretation of the results is possible. As noted, the IMIS data does not report the volume-adjusted nondetectable sample concentrations so some non-detectable samples might not have fallen below the lower PEL options.

For all SIC codes combined (including the OSHA consultation data), the IMIS database contains 343 entries with job descriptions representative of abrasive blasting operators. Of these, 49% found detectable beryllium. As noted, the volume-adjusted reporting limit concentrations for the nondetectable samples are not available. The 169 positive results are described by a median of 0.56 μg/m^3, a mean of 34.95 μg/m^3, and a range from 0.02 μg/m^3 to 1,781 μg/m^3. Since approximately 51 percent of the abrasive blaster results are nondetectable, the positive IMIS results for abrasive blasters likely overestimate the true median for this group of workers.

Table IV.C-2—OSHA IMIS PBZ Total Beryllium Air Sampling Results for Abrasive Blasting Workers[a]						
SIC Group	**SIC Description**	**No. PBZ Samples with Positive Results/Total No. PBZ Samples[b]**	**Job Descriptions (as listed in the IMIS database)**	**Range[c] (μg/m³)**	**Mean[c] (μg/m³)**	**Median[c] (μg/m³)**
15-17	*Construction*	*110/182 (60% positive)*	*Abrasive, abrasive blaster, abrasive blasters, abrasive blasting, blast oper, blaster, blaster 1, blaster helper, blaster/painter, blaster/painter-mix, blaster/shooter, blasting operator, grinder blaster, interior blaster, machine tender, painter blaster, painter/blaster, pot tender, sand blaster, sand blasters, sandblaster, sandblaster asst, sandblaster/assistant, sandblasters, sandblasting, shot blast assist, shot blaster, shot vacuum operator*	*0.01-1,400.00*	*35.12*	*0.70*
28-32	*Manufacturing: Chemicals/allied products; petroleum refining/related industries; rubber/miscellaneous plastics products; leather/leather products; stone/clay/glass/concrete products*	*5/5 (100% positive)*	*Painter/sandblaster, sandblaster*	*0.10-2.90*	*0.83*	*0.10*
33	*Manufacturing: Primary metal industries*	*6/21 (29% positive)*	*Abrasive blaster, abrasive blastings, abrasive cutting, balance blast operat, blast oper, blaster, blaster operator, roto blaster, rotoblast man, sand blaster, sand room, sandblast opr, sandblaster, shot blast oper, shot blast operator, wheelabrator, wheelabrator oper, wheelabrator operator*	*0.02-0.10*	*0.08*	*0.10*
34	*Manufacturing: Fabricated metal products*	*17/40 (43% positive)*	*Abras blaster, abrasive blast, abrasive blaster, abrasive blaster ope, abrasive blasting, blaster, blasting operator, paint and blast, painter/sandblaster, sand blaster, sandblaster, sandblaster/painter, sandblasting, shot dumper, wheelarator oper, wheelbrator/welder, yard man preblast*	*0.02-3.50*	*0.90*	*0.55*
35	*Manufacturing: Industrial and commercial machinery and computer equipment*	*1/13 (8% positive)*	*Abrasive blaster, blaster-shot house #, sand blaster, sandblaster, sandblaster primer, sandblaster/painter, shot blaster, wheelabrator*	*0.60-0.60*	*0.60*	*0.60*

Table IV.C-2—OSHA IMIS PBZ Total Beryllium Air Sampling Results for Abrasive Blasting Workers[a]

SIC Group	SIC Description	No. PBZ Samples with Positive Results/Total No. PBZ Samples[b]	Job Descriptions (as listed in the IMIS database)	Range[c] (µg/m^3)	Mean[c] (µg/m^3)	Median[c] (µg/m^3)
36	*Manufacturing: Electronic and other electrical equipment/components*	*3/5 (60% positive)*	*Abrasive blaster, sandblaster, sandblasting oper.*	*0.05-0.06*	*0.06*	*0.06*
37	*Manufacturing: Transportation equipment*	*18/57 (32% positive)*	*Abrasive, abrasive blast, abrasive blaster, abrasive blaster pai, beadblast, blast tender, blaster, blasting helper, booth 1 blaster, booth 2 blaster, grit blaster, painter sandblaster, sand blaster, sandblaster, shot blaster, wheelabrator*	*0.03-22.00*	*6.57*	*1.30*
38-39	*Manufacturing: Instruments, photographic/medical/optical goods; watches/clocks and miscellaneous manufacturing industries*	*0/3 (0% positive)*	*Pot tender, wheelabrator oper*	*None*	*None*	*None*
40-49	*Transportation, Communications, Electric, Gas, and Sanitary Services*	*1/2 (50% positive)*	*Blaster, cylinder rotoblast*	*0.30-0.30*	*0.30*	*0.30*
70-89	*Services*	*5/9 (56% positive)*	*Abrasive blaster, abrasive blasting sw, blaster, blaster/painter, driver/sandblaster, sandblaster, spray painter/blaster*	*0.07-47.00*	*9.68*	*0.44*
91-99	*Public Administration*	*0/3 (0% positive)*	*Blaster, sand blaster, sandblaster*	*None*	*None*	*None*
N/A	*OSHA On-Site Consultation Services*	*3/3 (100% positive)*	*Abrasive blast op, blaster, peterlangblast*	*0.50-1,781.00*	*618.50*	*74.00*
Total		*169/343 (49% positive)*		*0.01-1,781.0*	*34.95*	*0.56*

[a] *Information regarding worker activities, the engineering controls in place, personal protective equipment worn during sampling, nondetectable sample concentrations, and sample duration is not available.*

[b] *Includes all PBZ samples by SIC code.*

[c] *The range, mean, and median results are based on positive sample results only. All positive results are included.*

PBZ: personal breathing zone
N/A: not available

Source: OSHA, 2009 (OSHA Integrated Management Information System (IMIS) Database, June 1978 through September 2008)

Exposure Profile Data

Table IV.C-3 shows the estimated exposure profile for abrasive blasting workers. The exposure profile is also assumed to represent the baseline or typical exposure level for abrasive blasting workers. These tables summarize the NIOSH, shipyard, and U.S. Navy full-shift personal breathing zone (PBZ) lapel-type total beryllium exposure data and report the distribution of the results in relation to PEL options.[342, 343] These data are 8-hour time-weighted average (TWA) samples that reflect 280 minutes or more of sampling time.[344] For this industry group, OSHA considered full-shift samples to be those with sampling durations of at least 280 minutes. This minimum sample duration was selected in an effort to incorporate as much of the available data as possible into the exposure profile. Industry contacts suggest this timeframe is a reasonable estimate of full-shift exposure because four to five hours of abrasive blasting typically would be a full-shift sample in a construction/shipyard environment.

Abrasive Blasters: As shown in Table IV.C-3, the exposure profile for abrasive blasters is described by a median of 0.2 μg/m^3, a mean of 2.18 μg/m^3, and a range from 0.03 μg/m^3 to 66.5 μg/m^3. These values represent 114 full-shift PBZ total beryllium sample results reported for U.S. Navy and shipyard workers (including shipyard workers from one NIOSH investigation) engaged in abrasive blasting. About 16 percent of the values exceed the current PEL. Nondetectable sample results (for NIOSH, 1983b and four U.S. shipyards) are incorporated into the exposure profile by assigning the detection limit value to each result reported as less than the sample limit of detection. Of the 114 sample results included in the abrasive blaster exposure profile, 56 percent (64 samples) are nondetectable and range from less than 0.03 μg/m^3 to less than 55 μg/m^3. Thus, the estimated exposure profile for abrasive blasters might overestimate the true median for this job category. If the full-shift nondetectable results are eliminated from the abrasive blasters dataset, the remaining 50 samples are described by a median of 0.36 μg/m^3, a mean of 2.93 μg/m^3, and a range from 0.029 μg/m^3 to 66.5 μg/m^3.

Table IV-C.3—Personal Exposure Profile for Abrasive Blasting Workers[a]

Job Category	Number of Samples	Range (μg/m^3)[b]	Mean[b] (μg/m^3)	Median[b] (μg/m^3)
Abrasive Blasters[c]	*114*	*0.03 to 66.5*	*2.18*	*0.2*
Pot Tenders/Helpers	*14*	*0.04 to 0.13*	*0.08*	*0.08*

[342] Note that the U.S. Navy adjusts (censors) sample results less than the analytical limit of detection by dividing the analytical limit of detection by the square root of two prior to calculating the 8-hour time-weighted average (TWA) concentration (NEHC, 1999). See also the welding exposure profile discussion.

[343] For one of the two NIOSH data sources (NIOSH, 1983b), OSHA estimated the nondetectable sample concentrations. OSHA used the analytical limit of detection (0.5 micrograms) specified in the NIOSH report. To estimate the sample volumes, OSHA used the sampling times specified in the NIOSH report and an average flow rate of 1.6 liters per minute (lpm). This sample flow rate is the average of the range of sample flow rates (1.5 to 1.7 lpm) specified in the NIOSH report.

[344] The samples in the exposure profile have been time-weighted for eight hours by the data sources. In nearly all cases the data sources treated the unsampled time as periods of non-exposure.

Table IV-C.3—Personal Exposure Profile for Abrasive Blasting Workers[a]

Job Category	Number of Samples	Range (µg/m³)[b]	Mean[b] (µg/m³)	Median[b] (µg/m³)
Abrasive Media Cleanup	*27*	*0.01 to 7.4*	*0.38*	*0.06*
Total	**155**	**0.01 to 66.5**	**1.68**	**0.1**

[a] *Sample results are expressed as eight-hour time-weighted averages and include sampling durations of 280 minutes or longer.*

[b] *Non-detected shipyard results are incorporated into the exposure profile by assigning the detection limit value to each result reported as less than the sample limit of detection.*

[c] *Excludes results where garnet was used as the abrasive due to high nondetectable reporting limits.*

PBZ: personal breathing zone

Source: NIOSH, 1983b; OSHA, 2005; U.S. Navy, 2003

High reporting limits for some nondetectable samples may be due to several factors such as high analytical limits of detection, low sample volumes (sample air volumes less than the minimum volume required to meet the detection limit of the analytical method), and high iron content in the samples. NIOSH reports that samples with high iron content must be diluted numerous times to eliminate spectral saturation interferences. This action substantially increases (e.g., up to forty times) the analytical limits of detection and quantitation for the analytical method and produces insensitive and unreliable results (NIOSH, 1993a; NIOSH 1996b). The highest volume-adjusted nondetectable sample concentrations in the exposure profile might be due to this phenomenon. Such results make it impossible to determine if the nondetectable sample concentrations are below the PEL options or the current PEL of 2 µg/m^3. For this reason, four full-shift sample results where garnet was used as the abrasive are not included in the exposure profile for abrasive blasters. All four of these samples are nondetectable with high reporting limits ranging from less than 8 µg/m^3 to less than 35 µg/m^3 (< 8 µg/m^3, < 19 µg/m^3, < 19 µg/m^3, and < 35 µg/m^3).

The entire database of PBZ abrasive blasting samples compiled from NIOSH, the U.S. Navy, and four shipyards includes 323 observations. Of these samples, 118 have sample durations greater than or equal to 280 minutes (i.e., full-shift). Of these, 114 are included in the abrasive blasting exposure profile and four were excluded because of high nondetectable reporting limits. Two hundred and five of the abrasive blasting observations have sampling durations less than full-shift (less than 280 minutes) and are not included in the exposure profile. Approximately 62 percent (128 samples) of these less than full-shift observations are non-detectable for beryllium and range from less than 0.01 µg/m^3 to less than 22 µg/m^3. Seventy-seven (38 percent) of the less than full-shift observations are positive for beryllium with 8-hr TWA concentrations ranging from 0.029 µg/m^3 to 135 µg/m^3. Of these, 38 (49 percent) have 8-hr TWA concentrations that exceed 2 µg/m^3 and sampling durations ranging from 104 minutes to 273 minutes. This finding shows that less than full-shift abrasive blasting activities ranging in duration from about 2 to 4.5 hours can result in exposures that exceed the current PEL.

Pot Tenders/Helpers: As shown in Table IV.C-3, the exposure profile for abrasive blasting pot tenders is described by a median of 0.08 µg/m^3, a mean of 0.08 µg/m^3, and a range from 0.04 to 0.13 µg/m^3. All of the pot tender exposure results are less than or equal to 0.2 µg/m^3. Of these, 64 percent (nine samples) are nondetectable for beryllium with volume-adjusted limit of detection concentrations ranging from less than 0.04 µg/m^3 to less than 0.12 µg/m^3. If the full-shift non-detectable results are eliminated from the pot tenders dataset, the remaining five samples are described by a median of 0.1 µg/m^3, a mean of 0.1 µg/m^3, and a range from 0.09 µg/m^3 to 0.13 µg/m^3.

Abrasive Media Cleanup: The estimated exposure profile for workers engaged in abrasive media cleanup is also shown in Table IV.C-3. Eight-one percent (22 samples) of the abrasive media cleanup worker samples are nondetectable for beryllium with volume-adjusted limit of detection concentrations ranging from less than 0.02 µg/m^3 to less than 0.15 µg/m^3. If the full-shift nondetectable results are eliminated from the abrasive media cleanup workers dataset, the remaining five samples are described by a median of 0.18 µg/m^3, a mean of 1.75 µg/m^3, and a range from 0.01 µg/m^3 to 7.4 µg/m^3. One cleanup worker had a positive 8-hour TWA sample result of 1.1 µg/m^3; however, blasting took place in the area during this worker's cleanup task (recovery of Black Beauty™ mineral grit) and it is likely that the nearby abrasive blasting contributed to the sample result. Another cleanup worker had a positive sample result of 7.4 µg/m^3 (8-hour TWA). This worker's exposure appears to be associated with the use of compressed air for cleaning (blowing down the area to remove dust) in conjunction with nearby abrasive blasting.

The available data suggest that most pot tenders and cleanup workers have low beryllium exposures. The median exposure levels for both of these job categories are less than 0.1 µg/m^3 and nearly all results are less than or equal to 0.2 µg/m^3. These findings are generally supported by relevant information for pot tenders and cleanup workers in the OSHA IMIS database. The database contains 17 entries with job descriptions representative of pot tenders (e.g., blast tender, blaster helper, sandblaster assistant, and others) and one entry representative of cleanup workers (i.e., shot dumper). Of the 18 entries, ten (56 percent) are nondetectable for beryllium including the sample entry for abrasive cleanup. The volume-adjusted reporting limit concentrations for the ten nondetectable samples are not available. The remaining eight positive results for pot tenders are described by a median of 0.14 µg/m^3, a mean of 0.18 µg/m^3, and a range from 0.01 µg/m^3 to 0.43 µg/m^3.

<u>Beryllium Exposures by Type of Blast Media</u>

OSHA also analyzed the abrasive blasting exposure profile data (full-shift PBZ 8-hour TWA total beryllium sample results) by the type of blasting media used. These findings are summarized in Table IV.C-4. In most cases, the composition of the base material blasted is not specified. In the limited number of cases where it is (one shipyard and the U.S. Navy), the base material blasted includes steel, aluminum, and galvanized parts. The highest sample results are associated with the use of mineral grit blasting media and are described by a median of 0.42 µg/m^3, a mean of 4.1 µg/m^3, and a range from 0.03 µg/m^3 to 66.5 µg/m^3. Eighty-one percent (46 samples) of the mineral grit blasting samples are positive for beryllium and 16 (35 percent) of these exceed the current PEL. According to a Navy source, coal, copper, and iron slags are the most commonly used types of mineral grit (Bishop, 2005). In the construction industry, coal slag and steel grit are reported to be among the most commonly used abrasives (Meeker et al., 2006).

Nearly all of the available exposure results for workers using abrasive blasting cabinets or other types of enclosures are nondetectable for beryllium and below 0.1 μg/m^3. This finding is consistent with the IMIS results for blasting cabinets discussed earlier. All of the garnet samples are reported to be nondetectable, but the reporting limits are so high it is not possible to determine if the non-detectable results are below the PEL options or the current PEL. For this reason the garnet results are not included in the exposure profile. The four garnet samples came from one shipyard and it is possible that the high nondetectable reporting limits are due to the (high) iron content phenomenon discussed earlier. Ten of the eleven glass bead samples are reported to be nondetectable with volume-adjusted limit of detection concentrations ranging from less than 0.03 μg/m^3 to less than 0.2 μg/m^3. The only positive result for glass bead as the abrasive is 0.15 μg/m^3. All seven of the organic media samples are reported as nondetectable with six of the volume-adjusted limit of detection concentrations ranging from less than 0.03 μg/m^3 to less than 0.08 μg/m^3. One sample is reported as less than 0.37 μg/m^3 (390 minutes). Twenty-six of the 28 samples where steel shot or grit was used as the abrasive are nondetectable with volume-adjusted reporting limits ranging from less than 0.03 μg/m^3 to less than 1 μg/m^3. The two positive steel grit/shot samples have results of 0.2 μg/m^3 and 0.95 μg/m^3. Two samples each for wet soda (< 0.04 μg/m^3 and < 0.04 μg/m^3) and unspecified blast media (< 3 μg/m^3 and < 4 μg/m^3) are nondetectable for beryllium; however, the reporting limits for the unspecified media are higher than the current PEL.

Table IV.C-4—Abrasive Blasting Exposure Profile by Type of Blasting Media[a, b, c]

Media/Base Material Type	Total No. of Samples	No. of Non-Detectable Samples	Range (μg/m^3)[b]	Mean[b] (μg/m^3)	Median[b] (μg/m^3)
Abrasive Blasting Cabinet/Glove Box (media not specified)	*7*	*6 (86%)*	*0.07 to 0.08*	*0.07*	*0.07*
Garnet[d]	*4*	*4 (100%)*	*8 to 35*	*20.2*	*19*
Glass Bead	*11*	*10 (91%)*	*0.03 to 0.2*	*0.10*	*0.08*
Mineral Grit	*57*	*11 (19%)*	*0.03 to 66.5*	*4.1*	*0.42*
Organic Media (not otherwise specified)	*7*	*7 (100%)*	*0.03 to 0.37*	*0.096*	*0.04*
Steel Grit/Steel Shot	*28*	*26 (93%)*	*0.03 to 1*	*0.22*	*0.1*
Wet Soda	*2*	*2 (100%)*	*0.04 to 0.04*	*0.04*	*0.04*
Unspecified Blast Media	*2*	*2 (100%)*	*3 to 4*	*3.5*	*3.5*
Total (excludes garnet, see footnote d)	*114*	*64 (56%)*	*0.03 to 66.5*	*2.18*	*0.2*

Table IV.C-4—Abrasive Blasting Exposure Profile by Type of Blasting Media[a, b, c]

Media/Base Material Type	Total No. of Samples	No. of Non-Detectable Samples	Range ($\mu g/m^3$)[b]	Mean[b] ($\mu g/m^3$)	Median[b] ($\mu g/m^3$)

[a] *Full-shift personal breathing zone total beryllium sample results included in the abrasive blasting exposure profile by type of blasting media. Sample results are expressed as eight-hour time-weighted averages and include a minimum of 280 minutes of sampling time.*

[b] *Non-detected (NIOSH and shipyard) results are incorporated into the exposure profile by assigning the detection limit value to each result reported as less than the sample detection limit.*

[c] *The composition of the base material blasted is generally not specified. In the limited number of cases where it is specified (one shipyard and the U.S. Navy), the base material blasted includes steel, aluminum, and galvanized parts.*

[d] *All four of the samples where garnet was used as the abrasive are nondetectable. However, due to the high reporting limits, these data are not included in the exposure profile. The reporting limits may be due to high iron content in the samples requiring numerous dilutions to eliminate spectral saturation interferences.*

Source: NIOSH, 1983b; OSHA, 2005; U.S. Navy, 2003

Focusing primarily on the blast media, a NIOSH sponsored study of shipyard abrasive blasting examined the apparent contributions to air contaminants of hazardous components of blast media, including the most common alternatives to silica sand, and coal and copper slag. Overall, NIOSH comprehensively evaluated 40 abrasive blasting products, including nine different coal slag abrasive products. Looking at the field simulation portion of that study, NIOSH found that blasting with coal slag abrasive resulted in airborne concentrations of beryllium that implied exposure levels well above the NIOSH recommended exposure limit (REL) of 0.5 $\mu g/m^3$ (NIOSH/KTA-Tator, 1999).[345] Of the alternative abrasives investigated, coal slag and copper slag both produced elevated beryllium levels in the operator's breathing zone.

Other studies also report elevated beryllium exposures with coal slag abrasives. In a study of exposures among painters using three alternative blasting abrasives during a New Jersey highway footbridge repainting project, Meeker et al. (2005 and 2006) reported that coal slag was associated with higher beryllium exposures compared with both specular hematite and steel grit. Beryllium was detected in all five personal breathing zone samples (obtained outside protective equipment) following abrasive blasting with coal slag with task-based (2 to 3 hours) concentrations ranging from 2.5 $\mu g/m^3$ to 9.5 $\mu g/m^3$ and a geometric mean of 5.0 $\mu g/m^3$.

In June 2004, NIOSH conducted a field study to investigate beryllium exposures during abrasive blasting operations with coal slag abrasive at the Annapolis Water Reclamation Facility in Annapolis, Maryland (NIOSH, 2007). Abrasive blasting was conducted inside an empty open-top, in-ground circular vessel approximately 10 feet deep and 110 feet in diameter. Personal breathing zone samples were obtained for both the abrasive blaster and the helper. For the abrasive blaster, two eight-hour TWA PBZ beryllium sample results of 0.03 $\mu g/m^3$ and 2.1 $\mu g/m^3$ were reported for task-based sampling durations of 62 minutes and 189 minutes, respectively. The blaster's helper, who worked outside a

[345] The NIOSH finding is based on the extrapolation of the results from short-term personal breathing zone samples.

temporary containment enclosure erected over areas of the tank being blasted, had negligible sample results. One 8-hour TWA sample result was nondetectable (less than 0.01 µg/m^3) for beryllium (sampling duration of 75 minutes) and a second sample result was reported as 0.01 µg/m^3 (sampling duration of 196 minutes).

Table IV-C.5—NIOSH Comparative Field Simulation Study of Abrasive Blasting Media[a]
Short-Term (24 minutes) PBZ Total Beryllium Sample Results and Beryllium Content in Blasting Media

Abrasive Type	Beryllium Concentration Operator's Breathing Zone[b] (µg/m^3)	Beryllium Content in Blast Media Virgin Pre-Blast Bulk Analysis (µg/gm)
Coal slag	*4.83*	*0.11*
Nickel slag	*0.17*	*0.04*
Staurolite	*0.53*	*0.005*
Silica sand	*4.83*	*0.05*
Silica sand with dust suppressant	*0.14*	*0.005*
Copper slag	*1.24*	*0.90*
Garnet	*0.62*	*0.02*
Steel grit	*ND (< 0.082)*	*0.005*

[a] *This field study (Phase 2 of the NIOSH study) was conducted at the Consolidated Coal Company Shipyard in Elizabeth, Pennsylvania. One product from each of eight generic types of abrasives was tested. Personal breathing zone sampling was conducted for a total of 24 minutes for each abrasive tested during open nozzle dry abrasive blast cleaning operations conducted on the exterior hull of a coal barge in temporary dry dock. The hull was free of any coating and consisted of heavily rusted and pitted steel. Throughout all abrasive tests, the same abrasive blast cleaning equipment and portable blast containment (16 ft. long by 8 ft wide by 8 ft high) were used. The containment was equipped with a 5,000 cubic feet per minute capacity dust collector. After each abrasive test, the containment was cleaned and moved to a new location on the barge to prevent cross-contamination between abrasives.*

[b] *The personal air sampling pumps were programmed to initiate sampling 3 minutes after the abrasive trial began (to allow airborne concentrations of dust to equilibrate) and to stop sampling after a sampling duration of 24 minutes (to prevent overloading of the filter media). Sample concentrations are based on the sampling period and have not been time-weighted for 8 hours.*

PBZ: personal breathing zone
ND: nondetectable
<: less than

Source: NIOSH/KTA-Tator, 1998

ENGINEERING CONTROLS FOR ABRASIVE BLASTING

Abrasive Blaster - Baseline Controls: Baseline conditions reflect compliance with the elements of OSHA's standard covering abrasive blasting operations in 29 CFR 1910.94(a). Specifically, paragraph 1910.94(a)(5) requires operators to use abrasive blasting respirators when working inside of blast-cleaning rooms, when silica sand is used in manual blasting operations and the nozzle and blast are not physically separated from the operator in an exhaust ventilated enclosure, or where the concentrations of toxic contaminants exceed the limits set in 1910.1000 and a separate, ventilated blast enclosure is not used. Similar requirements are specified by OSHA's standards addressing abrasive blasting operations in construction (29 CFR 1926.57) and shipyard (29 CFR 1915.34) environments. Open-air blasting might be performed with coal or copper slag. This is particularly true of shipyard blasting. Other blast media such as aluminum oxide, glass beads, and steel shot or grit are more common when blast cabinets or similar enclosures are used.

Blast cleaning enclosures such as blasting rooms and cabinets and containment structures are typically ventilated to maintain operator visibility and/or limit the escape of dust emissions (Flynn and Susi, 2004; SBAR, 2008). These baseline conditions are associated with a median beryllium exposure level of 0.2 $\mu g/m^3$ for workers engaged in abrasive blasting.

Abrasive Blaster - Other Control Options: All blast-cleaning enclosures must be adequately ventilated, and increased or improved ventilation in blasting cabinets might reduce exposures. Seals should be inspected and replaced, if necessary, to reduce leakage. Abrasive blasting rooms, portable blast-cleaning equipment, and temporary containment structures must have sufficient exhaust ventilation to (1) prevent a build-up of dust-laden air and reduce the concentrations of hazardous air contaminants; (2) increase operator visibility; and (3) prevent any leakage of dust to the outside. Exhaust ventilation systems for such enclosures must be constructed, installed, inspected, and maintained according to the Ventilation standard (29 CFR 1910.94). The exhaust air from blast-cleaning equipment must be discharged through an appropriate dust collector to protect the workplace from hazardous air contaminants, and the dust collector must be set up so that the accumulated dust can be emptied and removed without contaminating work areas (29 CFR 1910.94(a)(4)(iii); NIOSH, 1992).

For transportable objects too large for blasting cabinets, employers could use a blasting room where one or more operators work inside the room. Blasting rooms should have sufficient ventilation to (1) provide good operator visibility, (2) prevent dust from settling and accumulating in the room, (3) reduce dust concentrations so personal protective equipment (PPE) provides adequate protection, and (4) control the escape of contaminants into adjacent work areas or the environment. Operators working inside abrasive blasting rooms must be protected by hoods and airline respirators, or by positive-pressure air helmets.

For large objects or structures that cannot be transported, or for fixed structures, temporary enclosures should be used. Whenever possible, objects or structures should be fully enclosed. When full enclosure is not possible, extend screening above the object or structure, and blast downwards. Air monitoring should be used to ensure that workers and others outside the enclosure are not exposed to elevated levels of air contaminants. If high levels of air contaminants are detected outside the enclosure, (1) workers should be excluded from these areas through the use of warnings signs and barricades or provided with appropriate PPE; and (2) all feasible control measures must be investigated and implemented when exposures exceed an OSHA PEL (see, e.g., 29 CFR 1910.1000(e)).

***Substitution**:* The easiest way to eliminate hazardous air contaminants associated with abrasive media is to select a blasting agent that does not contain beryllium. Meeker et al. (2005 and 2006) and the NIOSH/KTA-Tator (1999) study suggest that substitution of abrasive blasting agents is possible. When selecting an alternative blasting abrasive, employers should consider that:

- Depending on the abrasive, alternative media can result in elevated levels of other hazardous air contaminants. These contaminants may be associated with virgin and recycled abrasives (i.e., contamination due to recycling activities) (NIOSH, 1994b).
- The nature of the coating being removed and the underlying substrate also affect the toxicity of the dust generated.
- Alternative media containing small amounts of crystalline silica (one percent or less) might result in elevated levels of airborne crystalline silica if used in confined or enclosed spaces (NIOSH, 1993b).
- Supplemental use of respiratory protection may be needed depending on the abrasive and whether work is being performed inside enclosures.

Additional literature suggests various more benign abrasive media substitutes. For example, Flynn and Susi (2004) report that dolomite (calcium magnesium carbonate) may be a good alternative to other problematic blasting media. The authors also comment on the apparent potential for good results with crushed glass and with specular hematite (ferric oxide mineral).

Process or Equipment Change: Alternative techniques to dry abrasive blasting can be used to reduce or eliminate the amount of dust generated during surface preparation. These techniques are summarized in Table IV.C-6 and include wet abrasive blasting, hydroblasting, centrifugal wheel blasting, vacuum blasting, and blasting with dry ice pellets. Cleaning techniques that do not use abrasive blasting and are suitable for smaller jobs include thermal, chemical, and mechanical stripping methods (NIOSH 1994a, 1995, 1999b). Other removal techniques that may reduce or eliminate toxic dust levels during surface preparation include blast cleaning with baking soda (sodium bicarbonate), reusable sponge abrasives, or plastic media (PMB); cryogenic stripping (immersing small parts into liquid nitrogen, followed by gentle abrasion or PMB); and laser paint stripping (generates no waste and uses a pulsed carbon dioxide laser as the stripping agent).

Other control options to reduce beryllium exposures associated with abrasive blasting include selecting a beryllium-free blasting agent, and alternative techniques to dry abrasive blasting that reduce or eliminate the amount of dust generated during surface preparation. Where exposure is due to the blasting agent, substitution with a beryllium-free blasting agent should be considered but this should be done with caution to ensure that the alternative does not pose other health risks.

Table IV.C-6—Alternative Methods for Dry Abrasive Blasting

Name	Description/Comments
Wet Abrasive Blasting	*Can be used in most instances where dry abrasive blasting is used. Includes (1) compressed air blasting with the addition of water into the blast stream before the*

Table IV.C-6—Alternative Methods for Dry Abrasive Blasting	
Name	**Description/Comments**
	abrasive leaves the nozzle and (2) water jetting with the addition of abrasive into the water stream at the nozzle. Additives and rust inhibitors may be used.
Hydroblasting	*High Pressure Water Jetting:* *Uses pressure pump, large volume of water, specialized lance and nozzle. Pressures range from 3,000 to 25,000 pounds per square inch (psi). Can remove loose paint and rust; will not efficiently remove tight paint, tight rust, or mill scale. Can be used in most instances where abrasive blasting is used. Primary application is for an older surface rusted in a saline environment rather than new steel. Rust inhibitors may be required to prevent flash rusting.*
	Ultra High Pressure Water Jetting: *Similar to high pressure water blasting. Uses pressurized water from 25,000 to 50,000 psi. Removes tight paint and rust, but not mill scale.*
Centrifugal Wheel Blasting	*Uses a rotating wheel assembly inside an enclosure equipped with a dust collector. Abrasive is propelled outwards from the rotating wheel and removes rust, paint, and mill scale. Abrasives are recycled and include steel shot, steel grit, cut wire, and chilled iron grit. No contact with airborne dust or high velocity particles.*
Vacuum Blasting	*Uses standard blast nozzle inside a shroud (head) that forms a tight seal with the work surface. Vacuum is applied inside shroud during blasting to remove dust and debris. Abrasives are recycled and include aluminum oxide, garnet, steel shot, steel grit, and chilled iron grit. When used properly, cleans effectively with minimal dust.*
Dry Ice Pellets	*Dry ice blast cleaning with solid carbon dioxide. Waste is minimized and includes paint chips and rust. Storage and handling costs may be significant.*
Thermal Stripping	*Uses a flame or stream of superheated air to soften paint, allowing for easy removal. Generates one waste stream; i.e., waste paint. Effective for small parts; not suitable for heat-sensitive surfaces. Very labor intensive.*
Chemical Stripping	*Uses hazardous chemical strippers such as methylene chloride-based or caustic solutions. Effective for small fiberglass, aluminum, and delicate steel parts. Requires adequate ventilation and other safety measures. Generates multiple waste streams; i.e., contaminated rinse water and waste strippers.*
Mechanical Stripping	*Involves chipping, grinding, sanding, or scraping the coating off small parts or surfaces through the use of needle guns, chipping hammers, sanders, and grinders. Generates paint waste and airborne dust. Some power tools may be equipped with dust collection systems.*
Source: EPA, 1991; Kura, B. et al. (undated); NIOSH, 1994a, 1995, 1999a, 1999b, 1999c	

Pot Tender - Baseline Controls: Pot tenders work within the immediate vicinity of the abrasive blasting equipment (air compressors, abrasive blast machine, media hopper). As such, these workers may be located near the abrasive blasting operation or outside a temporary or permanent blast-cleaning enclosure. Baseline controls for pot tenders include the controls in use for the abrasive blasting operation such as an enclosed and ventilated blasting room or containment structure. In addition, these workers may wear particulate filter respirators for short, intermittent, or occasional dust exposures associated with media handling (receipt, cleanup/recovery, recycle, disposal). These baseline conditions are associated with a median beryllium exposure level less than 0.1 $\mu g/m^3$ (0.08 $\mu g/m^3$).

Pot Tender - Other Controls Options: For abrasive blasting pot tenders, the median and baseline beryllium exposure level is below 0.1 $\mu g/m^3$. A majority of these workers have low exposures and additional controls are not needed. For those pot tenders that might experience higher exposure levels, implementing additional controls for abrasive blasters, as described above, will further reduce the exposures of these workers.

Abrasive Media Cleanup - Baseline Controls: Abrasive media cleanup/recovery may be an automated or semi-automated process such as a blast room equipped with a full recovery system that automatically collects and separates reusable abrasive from dust and debris or a recovery system in which the abrasive blaster sweeps the spent media into a recovery hopper or floor trough. Alternatively, the pot tender (or workers designated as media cleanup or recovery workers) may be engaged in spent media clean up. These workers use various types of equipment to collect and load the spent abrasive into containers for recovery or disposal such as mechanical loaders (e.g., Bobcat skid steer), sweepers, brooms, and vacuum trucks or portable vacuum machines (some of which are HEPA-filtered) (SBAR, 2008; SCA, 2005).[346] Baseline controls for media cleanup/recovery also include any controls in use for abrasive blasting such as an enclosed and ventilated blasting room or containment structure. These baseline conditions are associated with a median beryllium level less than 0.1 $\mu g/m^3$ (0.06 $\mu g/m^3$).

Abrasive Media Cleanup - Other Control Options: For cleanup workers recovering spent abrasive blasting media, the median and baseline beryllium exposure level is below 0.1 $\mu g/m^3$. A majority of these workers have low exposures. For those workers that might experience higher exposure levels, other options to further reduce exposures include (1) implementing additional controls for abrasive blasters, as described above (e.g., using a beryllium-free abrasive), (2) prohibiting the use of compressed air for cleaning, and (3) initiating recovery of spent media after the completion of the blasting process and airborne particulate has settled (NIOSH, 1993a and 1994b).

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CHAPTER V: COSTS OF COMPLIANCE

INTRODUCTION

In this chapter, OSHA assesses the costs to establishments in all affected application groups of reducing worker exposures to beryllium to an eight-hour time-weighted average (TWA) permissible exposure limit (PEL) of 0.2 $\mu g/m^3$ and to the proposed short-term exposure limit (STEL) of 2.0 $\mu g/m^3$, as well as of complying with the proposed standard's ancillary provisions. These ancillary provisions encompass the following requirements: exposure monitoring, regulated areas, a written exposure control plan, protective work clothing, hygiene areas and practices, housekeeping, medical surveillance, medical removal, and worker training. This preliminary cost assessment is based in part on OSHA's technological feasibility analysis presented in Chapter IV of this PEA; analyses of the costs of the proposed standard conducted by OSHA's contractor, Eastern Research Group (ERG); and the comments submitted to the docket in response to the request for information (RFI) and as part of the SBREFA process. Where costs are presented with no explicit source they come either from industry experts at ERG or industry experts contacted by ERG.

OSHA estimates that the proposed standard would have an annualized cost of $37.8 million. All costs in this chapter are expressed in 2010 dollars and were annualized using a discount rate of 3 percent, which—along with 7 percent—is one of the discount rates recommended by OMB.[347] Annualization periods for expenditures on equipment are based on equipment life, and one-time costs are annualized over a 10-year period.[348]

OSHA used its typical time horizon for analysis for the proposed rule, 60 years, which reflects the typical time needed to recognize the full benefits of a rule with cancer-avoiding benefits (45-year working life + 15-year gestation period for cancer) and reach steady-state values. Therefore, the benefits of the proposed standard, discussed in Chapter VII of this PEA, were annualized over that 60-year period. Note that, over this time horizon, employment and production in affected industries are being held constant for purposes of the analysis. All non-annual costs are estimated to repeat over the 60-year time horizon, including one-time costs that recur because of changes in operations over time or because of new entrants that must comply with the proposed standard.[349] OSHA welcomes comment on the choice of time horizons for the purpose of this analysis, recognizing the uncertainties of long-term forecasts and the need for long-term forecasts to capture the full effects of the standard on benefits.

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[347] Appendix V-A of this PEA presents costs by NAICS industry and establishment size categories using, as alternatives, a 7 percent discount rate—shown in Table V-A-1—and a 0 percent discount rate—shown in Table V-A-2.

[348] Executive Order 13563 directs agencies "to use the best available techniques to quantify anticipated present and future benefits and costs as accurately as possible." In addition, OMB Circular A-4 states that analysis should include all future costs and benefits using a "rule of reason" to consider for how long it can reasonably predict the future and limit its analysis to this time period. Annualization should not be confused with depreciation or amortization for tax purposes. Annualization spreads costs out evenly over the time period (similar to the payments on a mortgage) to facilitate comparison of costs and benefits across different years. In cases where costs occur on an annual basis, but do not change between years, annualization is not necessary, and OSHA may refer simply to "annual" costs.

[349] To the extent one-time costs do not recur, OSHA's cost estimates, when expressed as a series of annualizations over 10-year periods, will overstate the cost of the proposed standard.

Table V-1 shows, by affected application group and six-digit NAICS code, annualized compliance costs for all establishments, for all small entities (as defined by the Small Business Act and the Small Business Administration's—SBA's—implementing regulations; see 15 U.S.C. 632 and 13 CFR 121.201), and for all very small entities (as defined by OSHA, those with fewer than 20 employees).

Table V-1

Total Annualized Costs, by Application Group and Six-Digit NAICS Industry, for Entities Affected by the Proposed Beryllium Standard; Results Shown by Size Category

NAICS Code	Industry	All Establishments	Small Entities (SBA-defined)	Very Small Entities (<20 Employees)
Beryllium Production				
331419	Primary smelting and refining of nonferrous metals	$1,257,214	--	--
Beryllium Oxide Ceramics and Composites				
327113a	Porcelain electrical supply manufacturing (primary)	$240,744	$95,814	--
327113b	Porcelain electrical supply manufacturing (secondary)	$234,736	$145,706	$47,923
334220	Cellular telephones manufacturing	$172,668	$172,668	$24,697
334310	Compact disc players manufacturing	$83,118	$83,118	$33,694
334411	Electron tube manufacturing	$355,950	$355,950	$64,948
334415	Electronic resistor manufacturing	$203,316	$136,206	$22,903
334419	Other electronic component manufacturing	$150,998	$102,089	$34,507
334510	Electromedical equipment manufacturing	$155,964	$62,287	$20,120
336322b	Other motor vehicle electrical & electronic equipment manufacturing	$169,385	$169,385	$38,648
Nonferrous Foundries				
331521	Aluminum die-casting foundries	$325,402	$221,157	--
331522	Nonferrous (except aluminum) die-casting foundries	$1,737,643	$1,225,990	--
331524	Aluminum foundries (except die-casting)	$318,816	$252,667	--
331525a	Copper foundries (except die-casting) (non-sand casting foundries)	$902,464	$774,277	--
331525b	Copper foundries (except die-casting) (sand casting foundries)	$1,228,568	$1,057,758	--
Secondary Smelting, Refining, and Alloying				
331314	Secondary smelting & alloying of aluminum	$33,757	$33,757	--
331421b	Copper rolling, drawing, and extruding	$34,206	$34,206	--
331423	Secondary smelting, refining, & alloying of copper	$100,916	$100,916	$29,684
331492	Secondary smelting, refining, & alloying of nonferrous metal (except copper & aluminum)	$582,301	$582,301	$161,819
Precision Turned Products				
332721a	Precision turned product manufacturing (high beryllium content)	$386,669	$345,499	$79,981
332721b	Precision turned product manufacturing (low beryllium content)	$4,496,280	$4,018,603	$935,281
Copper Rolling, Drawing and Extruding				
331421a	Copper rolling, drawing, and extruding	$1,302,977	$1,302,977	$23,090
331422	Copper wire (except mechanical) drawing	$4,584,858	$4,584,858	$139,155
Fabrication of Beryllium Alloy Products				
332612	Light gauge spring manufacturing	$2,815,387	$1,906,531	$542,834
332116	Metal stamping	$674,558	$572,260	$142,568
334417	Electronic connector manufacturing	$432,136	$202,922	$34,360
336322a	Other motor vehicle electrical & electronic equipment	$1,469,583	$1,469,583	$180,001

Table V-1, continued				
Total Annualized Costs, by Application Group and Six-Digit NAICS Industry, for Entities Affected by the Proposed Beryllium Standard; Results Shown by Size Category				
NAICS Code	Industry	All Establishments	Small Entities (SBA-defined)	Very Small Entities (<20 Employees)
Arc and Gas Welding				
331111	Iron and steel mills	$53,997	$53,997	--
331221	Rolled steel shape manufacturing	$14,371	$14,371	--
331513	Steel foundries (except investment)	$14,203	$10,020	--
332117	Powder metallurgy part manufacturing	$10,846	$8,278	--
332212	Hand and edge tool manufacturing	$25,998	$18,776	$6,311
332312	Fabricated structural metal manufacturing	$445,083	$299,365	$81,499
332313	Plate work manufacturing	$168,261	$147,812	$40,115
332322	Sheet metal work manufacturing	$545,151	$441,411	$119,486
332323	Ornamental and architectural metal work manufacturing	$307,521	$245,865	$101,308
332439	Other metal container manufacturing	$54,614	$32,072	$5,646
332919	Other metal valve and pipe fitting manufacturing	$24,506	$13,384	$2,412
332999	All other miscellaneous fabricated metal product manufacturing	$266,338	$216,517	$61,809
333111	Farm machinery and equipment manufacturing	$158,660	$70,271	$15,244
333414a	Heating equipment (except warm air furnaces) manufacturing	$49,114	$30,746	$5,618
333911	Pump and pumping equipment manufacturing	$54,108	$20,681	$3,589
333922	Conveyor and conveying equipment manufacturing	$72,144	$55,985	$9,089
333924	Industrial truck, tractor, trailer, and stacker machinery	$36,813	$36,813	$2,845
333999	All other miscellaneous general purpose machinery manufacturing	$141,023	$85,082	$22,468
336211	Motor vehicle body manufacturing	$119,147	$119,147	$9,477
336214	Travel trailer and camper manufacturing	$109,673	$51,992	$10,781
336399a	All other motor vehicle parts manufacturing	$59,753	$59,753	$2,779
336510	Railroad rolling stock	$24,403	$24,403	--
336999	All other transportation equipment manufacturing	$31,018	$14,502	$5,743
337215	Showcase, partition, shelving, and locker manufacturing	$28,643	$21,350	$5,118
811310	Commercial and industrial machinery and equipment repair	$1,135,568	$702,622	$480,339
Resistance Welding				
333411	Air purification equipment manufacturing	$376,997	$165,677	$33,158
333412	Industrial and commercial fan and blower manufacturing	$159,013	$97,299	$10,086
333414b	Heating equipment (except warm air furnaces) manufacturing	$484,410	$292,339	$45,976
333415	Air-conditioning, warm air heating, and industrial refrigeration equipment manufacturing	$887,734	$887,734	$30,249
335211	Electric housewares and household fan manufacturing	$79,732	$79,732	$4,028
335212	Household vacuum cleaner manufacturing	$25,574	$25,574	--
335221	Household cooking appliance manufacturing	$72,210	$72,210	$2,152
335222	Household refrigerator and home freezer manufacturing	$16,548	$16,548	--
335224	Household laundry equipment manufacturing	$8,274	$8,274	--
335228	Other major household appliance manufacturing	$28,583	$2,088	--

Table V-1, continued				
Total Annualized Costs, by Application Group and Six-Digit NAICS Industry, for Entities Affected by the Proposed Beryllium Standard; Results Shown by Size Category				
NAICS Code	**Industry**	**All Establishments**	**Small Entities (SBA-defined)**	**Very Small Entities (<20 Employees)**
Resistance Welding				
336311	Carburetor, piston, piston ring, and valve manufacturing	$81,989	$23,261	$4,116
336312	Gasoline engine and engine parts manufacturing	$558,125	$558,125	$36,262
336321	Vehicular lighting equipment manufacturing	$69,954	$22,816	$2,128
336322c	Other motor vehicle electrical and electronic equipment manufacturing	$478,393	$478,393	$28,021
336330	Motor vehicle steering and suspension components (except spring) manufacturing	$185,039	$185,039	$5,455
336340	Motor vehicle brake system manufacturing	$149,686	$149,686	$3,377
336350	Motor vehicle transmission and power train parts manufacturing	$358,042	$358,042	$9,660
336360	Motor vehicle seating and interior trim manufacturing	$303,132	$89,894	$7,295
336370	Motor vehicle metal stamping	$553,612	$240,150	$14,949
336391	Motor vehicle air-conditioning manufacturing	$60,175	$60,175	$1,374
336399b	All other motor vehicle parts manufacturing	$1,015,456	$1,015,456	$41,377
Dental Laboratories				
339116	Dental laboratories	$2,854,507	$2,336,090	$1,471,074
621210	Offices of dentists	$388,569	$366,976	$320,259
	Total	**$37,597,325**	**$30,336,277**	**$5,618,888**

"--" denotes industries where OSHA has preliminarily determined that there are no affected small or very small establishments.

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis.

OSHA's exposure profile, presented in Chapter III of this PEA, represents the Agency's best estimate of current exposures (i.e., baseline exposures). OSHA did not attempt to determine the extent to which current exposures in compliance with the current beryllium PEL and STEL are the result of baseline engineering controls or the result of circumstances leading to low exposures. If exposures were above the proposed PEL for worker in a given occupation and sector, then OSHA assumed that all engineering controls would be needed to bring those exposures for that occupation and sector into compliance. If exposures were at or below the proposed PEL, OSHA estimated costs only for those establishments that had no controls at all and would be required by paragraph (f)(2)(i) of the proposed standard to use one or more of the specified engineering or work practice controls where exposures equal or exceed the action level

The estimated costs for the proposed beryllium rule represent the additional costs necessary for employers to achieve full compliance. They do not include costs associated with current compliance that may already have been achieved with regard to existing beryllium requirements. The cost of complying with the proposed standard's program requirements depends on the extent to which employers in affected application groups are already undertaking some of the required actions. For example, regulated areas would be required where employee exposures cannot be reduced below the proposed PEL by using engineering and work practice controls. If all employers in an industry have already provided regulated areas, perhaps by physically isolating high exposure processes and restricting access, then the industry's compliance rate for that requirement would be 100 percent, and that industry would incur no new costs for this provision under the proposed standard.

Throughout this chapter, OSHA presents cost formulas in the text, usually in parentheses, to help explain the derivation of cost estimates for individual provisions. Because the values used in the formulas shown in the text are shown only to the second decimal place, while the actual spreadsheet formulas used to create final costs are not limited to two decimal places, the calculation using the presented formula will sometimes differ slightly from the presented total in the text, which is the actual and mathematically correct total as shown in the tables.

The remainder of this chapter is organized as follows. First, OSHA explains how estimates of the costs of meeting the proposed PEL and STEL were developed. Then, OSHA describes how estimates of the costs of the ancillary (or program) provisions of the proposed standard were developed. The chapter concludes with a summary of the estimated costs of the proposed rule for all affected application groups and NAICS codes.

COMPLIANCE WITH THE PROPOSED PEL/STEL

In this section, OSHA estimates the costs for affected employers to comply with the proposed PEL of 0.2 $\mu g/m^3$ and the proposed STEL of 2.0 $\mu g/m^3$. The cost estimation consists of two parts. First, costs are estimated for the engineering controls, additional studies, and custom design requirements to implement those controls, work practices, and specific training required for those work practices (as opposed to general training in compliance with the rule) needed for affected employers to meet the proposed PEL and STEL, as well as the opportunity costs (lost productivity) that may result from working with some of the new controls.[350] OSHA judged that the two-year lead-in time to comply with the proposed PEL would be sufficiently long that, in general, employers would be able to schedule the installation of any needed compliance equipment during periodic maintenance shifts or other planned production downtime with no, or de minimus, production disruptions. The Agency invites comment on this issue.

Second, for employers unable to meet the proposed PEL and STEL using engineering controls and work practices alone, costs are estimated for respiratory protection sufficient to reduce worker exposure to the proposed PEL and STEL or below.

In the technological feasibility analysis presented in Chapter IV of this PEA, OSHA concluded that implementing all engineering controls and work practices necessary to reach the proposed PEL will, except for a small residual group (accounting for about 6 percent of all exposures above the STEL), also reduce exposures below the STEL. However, based on the nature of the processes this residual group is likely to be engaged in, the Agency expects that employees would already be using respirators to comply with the PEL under the proposed standard. Therefore, with the proposed STEL set at ten times the proposed PEL, the Agency has preliminarily determined that engineering controls, work practices, and (when needed) respiratory protection sufficient to meet the proposed PEL are also sufficient to meet the proposed STEL. For that reason, OSHA has estimated no additional costs in this chapter for affected employers to meet the proposed STEL. The Agency invites comment and requests that the public provide data on this issue.

[350] In most cases the costs to meet the proposed PEL/STEL are broken out, but in other instances some or all of the costs are shortened simply to "engineering controls" in the text, for convenience.

Control Costs: Methodological Considerations

For this preliminary cost analysis, OSHA estimated the necessary engineering controls and work practices for each affected application group according to the exposure profile of current exposures by occupation presented in Chapter III of this PEA. Under the requirements of the proposed standard, employers would be required to implement engineering or work practice controls whenever beryllium exposures exceed the proposed PEL of 0.2 $\mu g/m^3$ or the proposed STEL of 2.0 $\mu g/m^3$.

In addition, even if employees are not exposed above the proposed PEL or proposed STEL, paragraph (f)(2) of the proposed standard would require employers at or above the action level to use at least one engineering or work practice control to minimize worker exposure. Based on the technological feasibility analysis presented in Chapter IV of this PEA, OSHA has determined that, for only two job categories in two application groups—chemical process operators in the Stamping, Spring and Connection Manufacture application group and machinists in the Machining application group—do the majority of facilities at or above the proposed action level, but below the proposed PEL, lack the baseline engineering or work controls required by paragraph (f)(2). Therefore, OSHA has estimated costs, where appropriate, for employers in these two application groups to comply with paragraph (f)(2).

By assigning controls based on application group, the Agency is best able to identify those workers with exposures above the proposed PEL and to design a control strategy for, and attribute costs specifically to, these groups of workers. By using this approach, controls are targeting those specific processes, emission points, or procedures that create beryllium exposures. Moreover, this approach allows OSHA to assign costs for technologies that are demonstrated to be the most effective in reducing exposures resulting from a particular process.

The engineering controls necessary to comply with the proposed standard, which form the basis for estimating these compliance costs, are identified for each affected application group in Chapter IV of this PEA. Engineering costs estimated in this section are based on reports and analyses prepared by OSHA's contractor, ERG, and can be found in the docket for the Small Business Advocacy Review (SBAR) Panel (SBAR, 2008). All proposed requirements for specific control devices and practices, including necessary increases in ventilation, are based on OSHA's technological feasibility analysis in Chapter IV of this PEA. In some instances, additional measures are necessary for the engineering controls to be installed and used effectively, such as additional special equipment-specific training, or additional assessment and design by an industrial hygienist. These additional measures are also based on OSHA's technological feasibility analysis and explained in Chapter IV.

In developing cost estimates, OSHA took into account the wide variation in the size or scope of the engineering or work practice changes necessary to minimize beryllium exposures based on technical literature, judgments of knowledgeable consultants, industry observers, and other sources. The resulting cost estimates reflect the representative conditions for the affected workers in each application group and across all work settings. In all but a handful of cases (with the exceptions noted in the text), all wage costs come from the 2010 Occupational Employment Statistics (OES) of the Bureau of Labor Statistics (BLS, 2010a) and utilize the median wage for the appropriate occupation. OSHA provides in the text for each wage rate the Standard Occupational Classification (SOC) code for the specific occupation. The wages used include a 30.35 percent markup for fringe benefits as a percentage of total compensation, which is the average percentage markup for fringe benefits for all civilian workers from the 2010 Employer Costs for Employee Compensation of the BLS (BLS, 2010b). All descriptions of production processes are drawn from the relevant sections of Chapter IV: Technical Feasibility in this PEA.

The specific engineering costs for each of the applications groups, and the NAICS industries that contain those application groups, are discussed in the following section of this cost chapter. Like the industry profile and technological feasibility analysis presented in earlier chapters in this document, this section of the cost chapter will present engineering control costs for the following application groups:

Beryllium Production

Beryllium Oxide, Ceramics & Composites Production

Nonferrous Foundries

Stamping, Spring and Connection Manufacture

Secondary Smelting, Refining, and Alloying

Copper Rolling, Drawing, and Extruding

Secondary Smelting, Refining, and Alloying

Precision Machining

Welding

Dental Laboratories

The costs within these application groups are estimated by occupation and/or operation. One application group could have multiple occupations, operations, or activities where workers are exposed to levels of beryllium above the proposed PEL, and each will need its own set of controls. Capital costs and annual operation and maintenance (O&M) costs, as well as any other annual costs, are estimated for the set of engineering controls estimated to be necessary for limiting beryllium exposures for each occupation or operation within each application group.

Unit Costs Per Worker and Per Establishment

Some engineering control costs are estimated on a per-worker basis and then multiplied by the estimated number of affected workers—as identified in Chapter III: Profile of Affected Industries in this PEA—to arrive at a total cost for a particular control within a particular application group. This worker-based method is necessary because—even though OSHA has data on the number of firms in each affected industry, the occupations and industrial activities that result in worker exposure to beryllium, and the exposure profile of at-risk occupations—the Agency does not have a way to match up these data at the firm level. Nor does the Agency have establishment-specific data on worker exposure to beryllium for all establishments, or even establishment-specific data on the level of activity involving worker exposure to beryllium. Thus, OSHA could not always directly estimate per-affected-establishment costs, but instead first had to estimate aggregate compliance costs (using an estimated per-worker cost multiplied by the number of affected workers) and then calculate the average per-affected-establishment costs by dividing those aggregate costs by the number of affected establishments. This method, while correct on average, may under- or over-state costs for certain firms. For other controls that are implemented on a fixed-cost basis per establishment (e.g., creating a training program, writing a control program), the costs are estimated on an establishment basis, and these costs were multiplied by the number of affected establishments in the given application group to obtain total control costs.

In developing cost estimates, the Agency sometimes had to make case-specific judgments about the number of workers affected by each engineering control. Because work environments vary within occupations and across establishments, there are no definitive data on how many workers are likely to have their exposures reduced by a given set of controls. In the smallest establishments, especially those that might operate only one shift per day, some controls would limit exposures for only a single worker in one specific affected occupation. More commonly, however, several workers are likely to benefit from each enhanced engineering control. Many controls were judged to reduce exposure for employees in multi-shift work or where workstations are used by more than one worker per shift.

In general, improving work practices involves operator training, actual work practice modifications, and better enforcement or supervision to minimize potential exposures. The costs of these process improvements consist of the supervisor and worker time involved and would include the time spent by supervisors to develop a training program.

Estimating Current Compliance

In general, OSHA viewed the extent to which exposure controls are already in place to be reflected in the distribution of exposures at levels above the proposed PEL among affected workers. Thus, for example, if 50 percent of workers in a given occupation are found to be exposed to beryllium at levels above the proposed PEL, OSHA judged this equivalent to 50 percent of facilities lacking adequate exposure controls. OSHA has provided a sensitivity analysis of this judgment in Chapter VII of this PEA.

As noted above, OSHA also judged that if an exposure is over the proposed PEL, all necessary controls would be needed. OSHA believes that the combination of these two judgments is more likely to result in an overestimate of costs than an underestimate. On the one hand, it possible that every facility has at least one person above the PEL and thus all would need to incur expenditures on controls, resulting in possible underestimates of costs. However, this possibility seems unlikely. A more likely scenario is that many facilities would not need any or all controls, either because baseline conditions produce exposures below the proposed PEL or because these facilities have already installed some controls. The facilities may, for example, have the correct equipment installed but without adequate ventilation to provide protection to workers exposed to beryllium. In this example, the Agency would expect that the remaining 50 percent of facilities to either have installed the relevant controls to reduce beryllium exposures below the PEL or that they engage in activities that do not require that the exposure controls be in place (for example, they do not perform any work with beryllium-containing materials). To estimate the need for incremental controls on a per-worker basis, OSHA used the exposure profile information as the best available data.

OSHA recognizes that a very small percentage of facilities might have all the relevant controls in place but are still unable, for whatever reason, to achieve the proposed PEL through controls alone. ERG's review of the industrial hygiene literature and other source materials (ERG, 2007b), however, suggest that the large majority of workplaces where workers are exposed to high levels of beryllium lack at least some of the relevant controls. Thus, in estimating the costs associated with the proposed standard, OSHA has generally assumed that high levels of exposure to beryllium occur due to the absence of suitable controls. This assumption likely results in an overestimate of costs since, in some cases, employers may not need to install and maintain new controls in order to meet the proposed PEL but merely need to upgrade or better maintain existing controls, or to improve work practices.

Control Costs for Individual Application Groups

BERYLLIUM PRODUCTION

Materion Corporation's Elmore, Ohio, plant is the only facility in the United States that currently produces beryllium metal.[351,352] In addition to producing pure

[351] Materion Corporation previously was named Brush Wellman, and some of the data used in this chapter was collected prior to this name change in 2011. "Brush Wellman" is used whenever the data being discussed pre-dates the name change.

beryllium, beryllium oxide, and beryllium oxide products, a large part of the facility's operations are devoted to manufacturing a range of beryllium alloy products. This facility is primarily in NAICS 331419: Primary smelting and refining of nonferrous metal (except copper and aluminum), but it also performs processes found in many of the other application groups affected by the proposed rule. As a result, some of the engineering controls for the beryllium production application group will be the same as those in other application groups discussed later in this section. Many of the activities undertaken by Materion in its processing of beryllium metal require ventilation enhancements and the installation of pharmaceutical-quality high containment isolators to comply with the proposed standard. Because these items are included in multiple places throughout the remainder of this section, and to avoid repeating this detailed discussion of these costs, OSHA is presenting the estimates for these two cost items before the discussion of the individual activities where these controls are necessary.

OSHA applied a standard cost for ventilation enhancements of $25 per cubic foot per minute (cfm) for additional exhaust capacity in this application group, along with $5 per cfm for make-up air (air introduced into the environment to replace air that is displaced through the suction of the additional exhaust ventilation). These ventilation cost estimates are based on ERG research identifying an average cost across different facilities, recognizing that the actual capacity of the equipment is likely to vary by facility, and factoring in the cost of ductwork. The $30 ($25 + $5) per cfm figure is higher than that estimated in other application groups and is based on Materion's

[352] All operations discussed in this section (Beryllium Production) refer to Materion Corporation's Elmore, Ohio, facility.

estimates of representative costs for ventilation enhancements it has made in several plant renovations. These higher costs appear to be related to exceptional costs for filtering of exhaust air.

For all other application groups the cost per cfm of ventilator enhancements is $13.18, which is based on ERG's research (ERG, 2013). Also, O&M expenses for such enhancements are estimated to be $3.92 per additional cfm, which ERG based on its research of energy costs incurred in the operation of an LEV system, averaged across a number of representative cities, plus an estimated annual maintenance cost amounting to 10 percent of capital investment (10 percent of the $13.18 per cfm) (ERG, 2013).

The installation of pharmaceutical-quality high containment isolators is needed for several processes: impact grinding, compact loading/sintering, near net shape fabrication, beryllium sulfate salt processing, and atomization. The containment isolators have a total capital cost of $517,500. This capital cost is made up of a filling and weighing system ($117,500), a drum unload/cleaning system ($300,000), and a cost for integrating new technology with existing systems ($100,000) (Bernero, 2005). The total cost, annualized over a ten year period at a three percent discount rate, is $60,667. There is an additional annual operating and maintenance cost for filling and weighing and drum unload/cleaning systems, estimated to be 15 percent of the total non-annualized capital cost for these systems, or $62,625 (0.15 x $417,500). The total annualized per-unit cost for a pharmaceutical-quality high containment isolator is $123,292 ($60,667 + $62,625).

The remainder of this section presents detailed estimates either by type of worker who may be exposed to beryllium or by type of activity that may result in beryllium exposures. Each subsection presents the categories of controls that the Agency has estimated are necessary to reduce beryllium exposures to limits at or below the proposed PEL for each type of worker or type of activity. For this application group, OSHA has estimated the following types of workers or activities will need additional engineering controls:

Wastewater Treatment Workers

Decontamination Workers

Mix/Makeup Workers

Scrap Recycling/Reclamation Workers

Production Equipment, Furnace, and Tool Maintenance Workers

Machining Operations

Welders

Impact Grinders

Compact Loading and Cisterning

Near Net Shape Fabrication

Beryllium Sulfate Salt Processing

Alloy Induction and Alloy Arc Furnace Workers

Vacuum Casting

Atomization

Beryllium Oxide Furnace Workers

The total costs for this application group are presented in Table V-2 at the end of this section.

Wastewater Treatment Workers[353]

Wastewater treatment worker exposures to high levels of beryllium result from beryllium contamination in the treatment plant water, and are estimated to be associated primarily with sludge cake operation (operating and cleaning the filter presses and monitoring bag filling). Once sludge contaminated with beryllium has been allowed to dry, the resulting dust can become easily airborne and is a potential source of beryllium exposure. High exposures for wastewater treatment workers are reportedly a result of poor work practices and inadequate housekeeping (Kent, 2005).

The Agency has estimated costs for enhanced work practices through operator training, work practice modification, and better supervision that will minimize exposures associated with the sludge cake operation. For example, wastewater treatment operators need to limit the number of times the sludge cake is pressed to avoid making it too dry. A dry cake can increase the amount of dust generated during sludge bag filling and directly affect worker exposure and contaminate the work environment.

OSHA estimates that, in the first year that the proposed standard is in effect, a supervisor, with an hourly wage of $37.11 (First-Line Supervisors of Production and Operating Workers, SOC: 51-1011[354]), will initially spend eight hours per worker

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[353] Wastewater treatment operators are a type of site support worker. Site support workers do not work with beryllium directly but may occasionally become exposed as they enter beryllium production areas or when they handle materials that have become contaminated in a beryllium production area. The Agency believes that the controls that would be installed in manufacturing operations to achieve compliance with the proposed PEL would also reduce exposures to site support workers such that exposures above the PEL would not occur—except in the case of wastewater treatment operators.

[354] As stated earlier, all wage rates with no explicit source other than the given Standard

developing a training program, resulting in a cost of $297 (8 x $37.11) per worker. The supervisor will then provide an eight-hour training-course to the workers. Assuming that, on average, the class contains 4 employees, the supervisor time per employee will be 2 hours, at a cost of $74 (2 x $37.11). Each worker, with a wage of $22.16 (Production Occupations, SOC: 51-0000), will spend eight hours in the training session, for a total of $177 (8 x $22.16), resulting in a per-employee cost of $548 ($297 + $74 + $177). After the first year, annual training is estimated to require four hours of training per worker, with the supervisor spending one hour per worker (4 supervisor hours of training/4 workers) for an annual cost of $126 ($37.11 + (4 x $22.16)). The total annualized cost per wastewater treatment worker is $190. OSHA preliminarily estimates that there are seven affected wastewater treatment workers in this application group, resulting in a total cost of $1,330 to control beryllium exposures for these workers.

Decontamination Workers

Decontamination workers perform large-scale surface cleaning in places that do not get cleaned frequently. Entire areas are shut down based on a predetermined work schedule. Small equipment (not currently installed) can be decontaminated in enclosed/sealed cleaning cabinets (NIOSH, 1977). Using such equipment, decontamination workers' exposures would be greatly reduced. An industry consultant suggests that perhaps 20 percent of the equipment that is decontaminated (e.g., engines) could be cleaned in a leak-tight decontamination chamber (Corbett, 2004).

Occupational Classification (SOC) are from the 2010 Occupational Employment Statistics (OES) of the Bureau of Labor Statistics (BLS, 2010a), and is the median wage for that SOC.

OSHA preliminarily estimates that each facility will need one enclosed, sealed leak-tight decontamination chamber. The cabinet requires an additional 100 cfm of ventilation capacity. At $30 per cfm (including $5 per cfm for make-up air), the additional ventilation capacity is estimated to cost $3,000 (100 x $30). From discussion with manufacturers, operating and maintenance costs are estimated to be 15 percent of the initial capital cost, for an annual operating and maintenance cost of $450 (0.15 x $3,000) resulting in a total annualized cost per facility of $802. Since there is only one facility in this application group and only one cabinet is needed to control exposures for decontamination workers, the above per-facility cost of $802 represents the total annualized engineering control costs for this process.

Mix/Makeup Workers

Makeup workers prepare and charge (load) furnaces with alloy melting mixes. This activity involves using material-handling equipment, such as industrial lift trucks, and transferring bulk material between charge tubs and furnaces. Based on discussions with manufacturers, OSHA preliminarily estimates that each facility will need four enclosed cabs for industrial trucks located at that facility in order to isolate the workers from the source of possible beryllium exposures. Based on manufacturer quotes, the capital cost per industrial truck enclosure is estimated to be $13,000, with an annualized cost of $1,524. Operating and maintenance costs are estimated to be 15 percent of the initial capital cost, for an annual operating and maintenance cost of $1,950. The total annualized cost per truck enclosure is therefore $3,474, yielding an annualized, per-facility cost of $13,896 (4 x $3,474). Since there is only one facility in this application group, the above per-facility cost of $13,896 represents the total engineering control costs for this process.

Scrap Reclamation Workers

Scrap reclamation workers receive high-beryllium-content scrap chips that are then degreased, magnetically screened to remove iron, sorted, inspected, and containerized for reuse internally. Based on discussions with manufacturers, OSHA preliminarily estimates that each facility will need four enclosed cabs for industrial trucks located at that facility in order to isolate the workers from the source of possible beryllium exposures. The total annualized cost of four enclosed cabs per facility is $13,896 (as explained above in the Mix/Makeup subsection).

Based on the findings of the technological feasibility analysis, OSHA estimates that each facility will also need three automatic material samplers with glove boxes. Automatic material samplers have a capital cost of $12,500 and require an additional 150 cfm of ventilation capacity (Werra, 2005). At $30 per cfm (including $5 per cfm for make-up air), the additional ventilation capacity is estimated to cost $4,500 (150 x $30), resulting in a total capital cost per sampler of $17,000 ($12,500 + $4,500) and a per facility cost of $51,000 (3 x 17,000). Operating and maintenance costs are estimated to be 15 percent of the initial capital cost for an annual per-facility cost of $7,650 (0.15 x $51,000).

The cost of each enclosed glove box is $4,000 with a total capital cost per facility of $12,000 (3 x $4,000) (Werra, 2005). An additional 100 cfm of ventilation capacity per device is required at $30 per cfm (including $5 per cfm for make-up air) for a cost of

$3,000 (100 x $30) and a per facility cost of $9,000 (3 x $3,000), resulting in total capital cost per facility of $21,000 ($12,000 + $9,000). Operating and maintenance costs per facility are estimated to be 15 percent for an annual cost of $3,150 (0.15 x $21,000). The total per-facility capital costs of three solid material samplers with glove boxes is $72,000 ($21,000 + $51,000) and the total maintenance costs per facility is $10,800 ($7,650 + $3,150), resulting in an annualized per facility cost of $19,241. The total annualized cost of the engineering controls for this process is $33,137.

Production Equipment, Furnace, and Tool Maintenance Workers

The process of maintaining the furnace and associated tools requires engineering controls for jackhammers along with enhanced work practices and training. Depending on the type and size of the furnace, the refractory lining may either be hydraulically extracted or removed using manual demolition methods (i.e., jackhammers). For example, large induction furnace linings (that are about eight feet long and five feet in diameter) are removed by hydraulically extracting the lining using a "pusher." The lining is then transferred to the furnace rebuild room where maintenance workers (furnace rebuilders) equipped with appropriate personal protective equipment and respirators use jackhammers to break the lining into smaller pieces.

Making a jackhammer water-capable (equipping it with a controlled water spray at the chisel point) to wet down dust potentially containing beryllium, is estimated to cost $200 (NIOSH, 2003). An industry source has estimated that the average facility will require five jackhammers (Corbett, 2005), for a total cost of $1,000 (5 x $200) and an annualized cost of $117. The O&M cost, estimated to be 15 percent of the initial cost, would be $150 (0.15 x $1,000) for the five jackhammers, for a total annualized cost of $267 ($117 + $150) per facility. With one facility represented in this application group, the total annualized cost of $267 represents the total cost of engineering controls for this application-group process.

Machining Operations

Machining at Materion in Elmore, Ohio involves the use of metal forming equipment to machine and/or fabricate low- and high-content beryllium-containing parts or shapes. The Agency has preliminarily estimated that controlling beryllium exposures for a machinist will require an additional 675 cfm of ventilation capacity.[355] With a $30 cost per additional cfm of exhaust ventilation (including $5 per cfm for make-up air) the capital cost is $20,250 per machine (675 x $30). OSHA preliminarily estimates that each machine will be used by two workers ((ERG, 2003a; ERG, 2004), resulting in a per-worker capital cost of $10,125 ($20,250/2) and an annualized cost of $1,187. The O&M cost per worker, estimated to be 15 percent of the initial cost, is $1,519 (0.15 x $10,125), resulting in a total per-worker annualized cost of $2,706. With an estimated 95 workers in this application-group process, the total annualized cost of engineering controls is $257,042 (95 x $2,706).

[355] This estimate is derived based on an average machine equal to 2.25 square feet (ACGIH, 2001, p. 10-63) with an exhaust requirement of 300 cfm per square foot of opening for a total cfm of 675 (300 x 2.25).

Welders

Welding is discussed in detail in the welding application group later in this cost chapter. Engineering controls for welders at the Materion plant differ from the general welding application group so are separately broken out here. The Agency has estimated, based on the findings in the Technological Feasibility chapter of this PEA, that welding operations in this application group will also require one chemical dip tank per facility. Based on information received from Materion, OSHA estimates that a chemical dip tank costs $70,000 for an annualized, per-establishment cost of $8,206 (Kent, 2005). The O&M cost per chemical dip tank, estimated to be 15 percent of the initial cost, is $10,500 (0.15 x $70,000), resulting in a total per-facility annualized cost of $18,706. With only one facility represented in this application group, the per-establishment cost of $18,706 represents the total annualized engineering control costs for this application-group process.

Impact Grinders

During impact grinding, vacuum-cast billets are prepared for machining, loaded into lathes, and milled into chips. The beryllium chips are vacuum-conveyed into collection containers and subsequently loaded into an impact-grinding (powder-generating) operation. During impact grinding, beryllium chips are injected into a high-speed air stream and sprayed against a beryllium target to generate beryllium powder. Based on information provided by an industry consultant, OSHA has determined that impact grinding would require the installation of one additional pharmaceutical-quality high-containment isolator (Kent, 2005). The annualized cost per facility to install such a system is $123,292.[356] With only one facility represented in this application group, the per-establishment cost of $123,292 represents the total annualized engineering control costs for this application-group process.

Compact Loading and Cisterning

During compact loading, workers load and cap vertically oriented cylindrical graphite dies with beryllium powder. The dies are placed in a tall, fully enclosed loading hood equipped with back and side-draft exhaust ventilation, and are top-loaded with beryllium. A worker will observe the loading process in an effort to prevent overloading of the die and a subsequent powder spill. During loading, the beryllium powder is vibratorily packed (shaken and compacted as much as possible). The loaded die is capped with a graphite plug, removed from the loading hood, and transferred to a below-ground sintering furnace.

During the sintering process, the powder is consolidated into a billet in an inert environment using heat and pressure. The finished billet is removed from the die (pushed out with a hydraulic ram) in a die-stripping hood that is equipped with back-draft exhaust ventilation. Worker exposure is primarily associated with two activities—installing and removing containers of powder from both the compact loading hood and the die loading area. Based on the findings of the technological feasibility analysis, OSHA has determined that controlling worker exposure to beryllium during the compact

[356] See the introduction of this section for a detailed discussion of this cost estimate.

loading and sintering process requires installation of a remote viewing system so that workers do not need to enter the die-loading hood. The closed-circuit remote TV installation is estimated to cost $2,000 with an annualized cost of $234 (Kent, 2005). The annual operating and maintenance costs are estimated to be 15 percent of the initial equipment cost, or $300 (0.15 x $2,000), for a total annualized cost of $534. Based on information from the same industry consultant, the Agency estimates that a facility would need to install one additional pharmaceutical-quality high-containment isolator with an annualized cost of $123,292 per facility (Kent, 2005).[357] With only one facility represented in this application group, the total annualized cost for engineering control for this application-group process is $123,826.

Near Net Shape (NNS) Fabrication

NNS fabrication is a process of fabricating beryllium metal parts that minimizes the amount of beryllium scrap generated during this process. Beryllium powder is loaded into dies and consolidated into preformed shapes with one or more techniques involving heat and/or pressure (cold and hot isostatic pressing). After consolidation, the dies are unloaded using different techniques depending on the type of die (rubber, steel, or copper). In order to protect workers performing NNS fabrication by reducing beryllium exposures to levels at or below the proposed PEL, the Agency estimates, based on information provided by an industry consultant, that a facility would need to install one additional pharmaceutical-quality high-containment isolator with an annualized cost of

[357] See the introduction of this section for a detailed discussion of this cost estimate.

$123,292 per facility (Kent, 2005).[358] With only one facility represented in this application group, the per-establishment cost of $123,292 represents the total annualized engineering control costs for this application-group process.

Beryllium Sulfate Salt Processing

Beryllium sulfate salt processing is a process that produces high-purity beryllium sulfate salts by dissolving beryllium hydroxide in sulfuric acid, filtering the solution to remove insoluble materials/impurities, and then concentrating the resulting filtrate through evaporation/cooling. This process is almost entirely enclosed and isolated from workers (i.e., chemical additions and mixing is automated and enclosed) except at the process entry and exit points. Based on information from the Director of Environmental, Health and Safety at Brush Wellman Inc., OSHA estimates that Brush Wellman's facility (the only affected facility) would need to install one additional pharmaceutical-quality high-containment isolator in order to reduce beryllium exposures to workers performing beryllium sulfate salt processing activities to levels at or below the proposed PEL at an estimated annualized cost of $123,292 per facility (Kent, 2005).[359] With only one facility represented in this application group, the per-establishment cost of $123,292 represents the total annualized engineering control costs for this application-group process.

[358] See the introduction of this section for a detailed discussion of this cost estimate.

[359] See the introduction of this section for a detailed discussion of this cost estimate.

Alloy Arc Furnace Workers

The alloy arc furnace operations produce an ingot of four percent copper-beryllium master alloy that is subsequently re-melted and diluted with other metals to form alloys with a reduced percentage of beryllium that are cast, hot rolled, and otherwise fabricated (NIOSH, 1972). Furnace operators weigh raw copper, transfer 55-gallon drums of beryllium hydroxide into the calciner (kiln burner) feed station, wash empty drums in the calciner feed station, charge and tap the furnace, remove and recycle dross (oxides and other contaminants that form a scum at the surface of the molten metal), add furnace electrodes, and cast ingots (Corbett, 2006; Kent et al., 2001).

Based on the findings of the technological feasibility analysis, two enclosed sampling devices and enhanced work practices with better training and supervision are needed to reduce beryllium exposures to the proposed PEL for workers performing alloy arc furnace operations. The capital cost of an enclosed sampling device is $16,500 (Werra, 2005) with a total per-facility cost of $33,000 for two devices (2 x $16,500). Each enclosed sampling device requires an additional 100 cfm of local exhaust ventilation at a cost of $30 per additional cfm (including $5 per cfm for make-up air) of ventilation for a total of $3,000 (100 x $30) per device and $6,000 (2 x $3,000) per facility for a total capital cost of $39,000 ($33,000 + $6,000). The annual operating and maintenance costs are estimated to be 15 percent of the initial equipment cost, or $5,850 (0.15 x $39,000), for a total annualized cost of $10,422. The cost of enhanced work practices—estimated as time required for training—is an annualized, per-worker cost of

$190.[360] With one facility and an estimated 30 affected workers in this application-group process, the total annualized cost of engineering controls and enhanced work practices is $16,123.

Alloy Induction Furnace Workers

The alloy induction furnace process produces beryllium alloys containing a concentration of beryllium of 0.1 percent to 2 percent. Two workers operate each furnace: a deck worker and a floor worker. Tasks conducted by the deck worker with potential exposure include charging, rubbing, skimming, degassing, and changing full dross barrels. Tasks performed by the floor worker include setting up the mold; heating, placing, and cleaning the tundish (the reservoir in the top part of a mold into which molten metal is poured); and pouring the furnace (transferring the molten metal from the furnace into molds).

Based on the findings of the technological feasibility analysis, OSHA has estimated that increased local exhaust ventilation (LEV) and enhanced work practices are necessary to reduce beryllium exposures at or below the proposed PEL. The Agency has determined that four LEV units are needed per facility to control beryllium exposures to workers performing these types of operations. In order to meet the requirements of the proposed rule, ERG estimates that each LEV will need to supply 1,500 cfm of exhaust ventilation at a cost of $30 per additional cfm (including $5 per cfm for make-up air) for a total capital cost of $180,000 for four LEV units (1,500 x 4 x $30). Operating and

[360] See the wastewater treatment section of this application group for a detailed discussion of this cost.

maintenance costs are estimated to be 15 percent of the initial equipment for an annual operating and maintenance cost of $27,000 (0.15 x $180,000) resulting in a total annualized cost of $48,101. The Agency estimates that enhanced work practice control will cost $190 per worker.[361] With one facility and an estimated 13 affected workers in this application-group process, the total annualized cost of engineering controls is $50,572.

Vacuum Casting

Vacuum casting is a furnace operation designed to produce feedstock (vacuum-cast billets) for powder-making operations (NMAB, 1989). Beryllium feed material (e.g., reclaimed chips and scrap) is vacuum-melted inside a tilt-pour induction furnace and poured into graphite molds to produce round billets that are approximately three to four feet in length. The billets are manually cleaned (pressure washed) and prepared inside an exhaust hood and then transferred to the powder-making operation.

There are two engineering controls needed for the vacuum casting process based on the findings of the technological feasibility analysis: redesigning the charge make-up (filling and weighing) process and performing a task analysis. Redesigning the charge make-up process has a capital cost of $117,500 and an integration cost of $100,000, for a total annualized cost of $25,498 (Bernero, 2005). Redesigning the charge make-up process also has an annual 15 percent operating and maintenance cost, for an annual cost

[361] See the wastewater treatment section of this application group for a detailed discussion of this cost.

of $17,625 (0.15 x $117,500), resulting in a total annualized cost of $43,123 ($25,498 + $17,625).

The task analysis is intended to identify work methods associated with the vacuum casting process (e.g., filling, weighing, and rubbing/skimming) that contribute most to worker exposure, and result in the implementation of work-practice improvements to further reduce worker exposure. OSHA preliminarily estimates that improved work practices will not affect worker productivity and will not require additional time to complete tasks relative to the current work practices. The task analysis study requires labor from three individuals: 8 hours by a certified industrial hygienist at $125 dollars an hour or $1,000 (8 x $125), 24 hours by a ventilation engineer at $125 an hour for a total of $3,000 (24 x $125), and four hours of a supervisor's time at $30 an hour for a total of $120 (4 x $30)—yielding an estimated total cost of $4,120 ($1,000 + $3,000 + $120), and an annualized cost of $483.[362] With one affected establishment in this application group, the total engineering control costs for this application-group process are $43,606.

Atomization

Atomization is a furnace process where the final product is aluminum-beryllium or beryllium powder. For the reasons explained in the technological feasibility analysis, this process requires two types of engineering controls to limit beryllium exposure: a one-time task analysis and a pharmaceutical-quality high containment isolator. The task

[362] Wage rates here were estimated based on discussions between ERG and industry representatives.

analysis is intended to identify work methods associated with atomization (e.g., charge make-up, rubbing/skimming, and make/break connections) that contribute most to worker exposure and result in the implementation of work-practice improvements to further reduce worker exposure. OSHA preliminarily estimates that improved work practices will not affect worker productivity and will not require additional time to complete tasks relative to the current work practices. Task analysis costs are the same as in vacuum casting and explained in the subsection above, and have an estimated annualized per-facility cost of $483. OSHA has estimated that a facility will need to install one additional pharmaceutical-quality high-containment isolator in order to reduce worker exposures to levels at or below the PEL and that the isolator has a per-facility annualized cost of $123,292.[363] With one affected establishment in this application group, the total annualized engineering control costs for this application-group process are $123,775.

Beryllium Oxide Furnace Workers

In this process, wet-screened beryllium sulfate salt is calcined in hearth furnaces to produce beryllium oxide powders. The furnaces have top-ventilated, full enclosures at the loading/unloading point that consist of removable metal wall panels. To load the furnaces, operators remove one of the front wall panels from the enclosure, empty drums of wet beryllium sulfate salt into large rectangular refractory containers with a lift truck equipped with a barrel grabber, and then load the refractory containers into the furnace

[363] See the introduction of this section for a detailed discussion of this cost estimate.

chamber. The beryllium sulfate salt gets fired in the furnace for several days and is transformed into a fluidized bed of beryllium oxide powder.

OSHA has estimated that, as discussed in the technological feasibility analysis, the engineering controls required for beryllium oxide furnaces in order to reduce worker exposures to beryllium to levels at or below the proposed PEL are a task analysis, enhanced LEV, and the installation of one additional pharmaceutical-quality high containment isolator (Bernero, 2005). As discussed above in the vacuum casting section, the task analysis, which is intended to identify work methods associated with beryllium oxide furnace processes that contribute most to worker exposure and result in the implementation of work-practice improvements to reduce worker exposure, has an annual cost of $4,120 and an annualized cost of $483. As with the vacuum casting task analysis, OSHA preliminarily estimates that improved work practices will not affect worker productivity or require additional time to complete tasks relative to the current work practices.

Based on discussions with industry experts, enhanced LEV requires 1,500 cfm of additional exhaust ventilation capacity at a cost of $30 per additional cfm (including $5 per cfm for make-up air) for a capital cost of $45,000 (1,500 x $30). With an operating and maintenance cost of 15 percent of capital costs, annual operating and maintenance cost would be $6,750 (.15 x $45,000). The annualized total cost for these items is $12,025 per facility. Based on information provided by an industry consultant, OSHA has estimated that a facility will need to install one additional pharmaceutical-quality high-containment isolator in order to reduce worker exposures to levels below the PEL and that this isolator has a per-facility annualized cost of $123,292 (Kent, 2005).[364] With one affected establishment in this application group, the total annualized engineering control costs for this application-group process are $135,800.

Table V-2 below summarizes the unit capital costs and operating and maintenance costs for each affected process in beryllium production. For the one firm engaged in beryllium manufacturing in NAICS 331419: Primary Smelting and Refining of Nonferrous Metals, the entire annualized cost of complying with engineering controls for each of the above processes is estimated to be $1,188,758.

[364] See the introduction of this section for a detailed discussion of this cost estimate.

Table V-2

Engineering Costs for Beryllium Production, by Process (PEL - 0.2)

NAICS Code	Industry	Affected Employees	Establishment-Based Costs – Number of Establishments Needing Controls	Employee-Based Costs – Number of Employees Needing Controls	Initial Capital Cost	Annualized Capital Costs	Annual O&M Costs	Total
331419	**Primary Smelting and Refining of Nonferrous Metals**	**616**	**1**	**168**	**$4,840,156**	**$567,414**	**$621,344**	**$1,188,758**
	Wastewater Treatment	7	-	7	$3,839	$450	$880	$1,330
	Decontamination	7	1	-	$3,000	$352	$450	$802
	Mix/Makeup Operations	5	1	-	$52,000	$6,096	$7,800	$13,896
	Scrap Recycling	22	1	-	$124,000	$14,537	$18,600	$33,137
	Maintenance/Furnace & Tools	23	1	23	$1,000	$117	$150	$267
	Machining	95	-	95	$961,875	$112,761	$144,281	$257,042
	Welding	1	1	-	$70,000	$8,206	$10,500	$18,706
	Impact Grinding	1	1	-	$517,500	$60,667	$62,625	$123,292
	Compact loading/Sintering	1	1	-	$519,500	$60,901	$62,925	$123,826
	NNS Operator	2	1	-	$517,500	$60,667	$62,625	$123,292
	Chemical Operations (Beryllium Sulfate Salt Process)	18	1	-	$517,500	$60,667	$62,625	$123,292
	Alloy Arc Furnace Operator	30	-	30	$55,452	$6,501	$9,623	$16,123
	Alloy Induction Furnace Operator	13	-	13	$187,129	$21,937	$28,635	$50,572
	Vacuum Casting	3	1	-	$221,620	$25,981	$17,625	$43,606
	Atomization	3	1	-	$521,620	$61,150	$62,625	$123,775
	Beryllium Oxide Furnace	9	1	-	$566,620	$66,425	$69,375	$135,800
	All Jobs	**240**	**1**	**168**	**$4,840,156**	**$567,414**	**$621,344**	**$1,188,758**

Source: OSHA Office of Regulatory Analysis.

BERYLLIUM OXIDE, CERAMICS & COMPOSITES

Beryllium oxide ceramics and beryllium oxide-metal matrix composites are used to manufacture materials with unique physical, thermal, and electrical properties for use in electronic equipment in the aerospace and other industries (Parsonage, 2011). In examining engineering control costs for this application group, the Agency notes that not all jobs occur at all establishments covered in every six-digit NAICS industry. In particular, only a small number of facilities that work with beryllium oxide perform powder-handling operations or operate kilns. Additionally, a number of beryllium oxide-using establishments are not assigned any control costs because they are estimated to perform only operations where workers are assembling finished parts made of materials that contain beryllium but are not machining parts or performing any other operations that would produce beryllium-containing dust and thus.

According to the technological feasibility report and analysis presented in Chapter IV: Technological Feasibility in this PEA, a variety of engineering, ventilation, and work practice adjustments are needed to control beryllium exposures and ensure that workers are not exposed to beryllium at levels above the proposed PEL for the following processes:

Material Preparation

Forming Press Operations

Forming-Extruding Operations

Kiln Operations

Machine Operations

Metallization

Material Preparation

In the material preparation process, beryllium oxide powder is refined through a series of dry and wet processing steps in order to create materials with the properties necessary for subsequent forming/shaping operations. The material preparation operator receives bulk beryllium oxide powder in drums and transfers the material—automatically or manually—to mixing equipment where an aqueous suspension of beryllium oxide, binder additives, and water is prepared. Next, the operator uses mixing equipment to blend the ingredients to create a homogeneous slurry. The beryllium oxide material is shaped using a pressed-powder process; the material preparation operator then finishes by pumping slurry to a spray dryer that disperses the material under a high pressure stream of air for rapid drying inside an enclosed chamber. Based on the findings of the technological feasibility analysis, OSHA estimates that, in order to reduce worker's beryllium exposures to levels at or below the proposed PEL, facilities engaged in the material preparation process require review and enhancement of operating and cleaning procedures along with installation of one additional pharmaceutical-quality high-containment isolator per facility.

Review and enhancement of operating and cleaning procedures require a one-time investment of 40 hours by an engineer with a wage rate of $54.70 an hour (Industrial Engineers, SOC: 17-2112), for a total cost of $2,188 (40 x $54.70), and an annualized cost of $256. Annual training in these revised procedures requires four hours of training at $22.16 an hour (Production Occupations, SOC: 51-0000) for two workers per facility, resulting in an annual cost of $177 (2 x 4 x $22.16). The final annualized cost per facility is $434 ($256 + $177), and with an estimated 2 facilities, this results in a total cost of $868.

The installation of one pharmaceutical-quality high-containment isolator per facility is needed for multiple process steps This capital cost is made up of a filling and weighing system ($117,500), a powder transfer system ($20,000), and an integration cost for new technology ($100,000) for a total capital cost of $237,500 (Bernero, 2005). This total, annualized over a ten-year period at a three percent discount rate, is $27,842. The Agency also applied an annual operating and maintenance cost of 15 percent (the same as for beryllium production O&M) for the filling and weighing system and the powder transfer system, resulting in $20,625 (0.15 x $137,500) for annual operating and maintenance costs. The total per-unit annualized cost is then $48,467 ($27,842 + $20,625). With an estimated 2 facilities needing these controls, the total annualized cost for installing these isolators is $96,934, resulting in a total annualized engineering control cost for this application-group process of $97,802.

Forming - Pressing

Prepared beryllium oxide materials are used in forming operations to shape a variety of small specialty ceramics products (ranging in size from a few millimeters to several inches). The forming processes include a variety of techniques common to the ceramics industry. For example, forming operators typically mold beryllium oxide using one of the following processes:

1. *Dry (powder) pressing*: a process in which forming operators oversee equipment that compresses spray dried, low-moisture beryllium oxide powder material into a die with a ram.
2. *Isostatic pressing*: an advanced powder compaction process in which hydrostatic forming equipment applies even pressure on all sides of a liquid-tight rubber die containing beryllium oxide powder.
3. *Hot pressing*: a process whereby beryllium oxide powder is simultaneously subjected to high temperature and high pressure in heated dies.
4. *Extrusion*: a conventional mechanical process in which moist, paste-like beryllium oxide material is forced through a shaped orifice or die.
5. *Tape casting*: a technique in which the beryllium oxide paste is extruded into a long bendable strip that can then be rolled up for further processing.

The Agency has estimated, based on the findings of the technological feasibility analysis, that forming press operations require engineering controls both to modify presses in order to reduce the dust released and to enclose presses. Two presses per establishment are estimated to need modification in order to reduce dust and therefore beryllium exposures. ERG estimates that the cost per establishment for modifying a press includes 150 hours of an industrial engineer's time at an hourly wage of $54.70 (Production Occupations, SOC: 51-0000) for a total cost of $8,205 (150 x $54.70) per press. This gives a total cost for two presses of $16,409 (2 x $8,205). The total cost, annualized over ten years at a three percent discount rate, is estimated to be $1,924 per facility. With one facility estimated to have workers performing this process who are at risk of beryllium exposures above the PEL, the total annualized cost of these controls is $1,924.

OSHA determined that three presses per establishment require an enclosure. Each press requires a capital investment of $12,500 for enclosures. This results in a cost per facility for enclosing three presses of $37,500 (3 x $12,500), or an annualized cost of $4,396 (Frigon, 2005). Each enclosure is also estimated to require an additional 200 cfm in ventilation capacity, which ERG estimated at $13.18 per additional cfm (ERG, 2013). This yields a total cost per facility of $7,908 (200 x 3 x $13.18), or an annualized cost of $927. O&M expenses for the new ventilation system are the standard $3.92 per additional cfm. The total O&M cost for the additional ventilation capacity is therefore $2,350 (200 x 3 x $3.92). The total annualized cost per facility for the three enclosures is $7,673 ($4,396 + $927 + $2,350). OSHA estimates that one facility in the application-group process will need these controls for this process, resulting in a total annualized cost for these enclosures of $7,673. The total of all controls for this application group process is $9,597.

Forming - Extruding

In this process, workers force beryllium oxide material that is of a paste-like consistency through a die in order to form the product. The operator manually cuts and removes the product from the press as it is being extruded and places it on a product transfer cart for subsequent firing or other processing.

Based on exposures for extruders described in Chapter IV of this PEA, OSHA has estimated that the forming-extruding process requires engineering controls for ventilation enhancements and ventilation enclosure in order to reduce worker's exposure to beryllium to levels at or below the proposed PEL. While industry representatives did not specify the cost of a ventilation enclosure, ERG's industry experts estimate that a typical enclosure would cost $5,000 and that the enhanced LEV would require an additional 500 cfm of ventilation capacity at $13.18 per cfm for a capital cost of $6,588 (500 x $13.18)—yielding a total capital cost of $11,588 ($5,000 + $6,588) and an annualized cost of $1,359. There is an O&M cost of $3.92 per additional cfm for the ventilation, for a total O&M cost of $1,958 (500 x $3.92). The total annualized cost is $3,317 per facility. With one facility estimated to have workers performing this process who are at risk of exposure to beryllium at levels above the PEL, the total cost for this application-group process is $3,317.

Kiln Operations

The kiln operator ensures that the kiln is working properly and that material is fired properly. These employees load firing carts containing beryllium oxide ceramic parts into the kilns and remove the carts once the firing process is complete. OSHA has estimated, based on the findings of the technological feasibility analysis, that kiln operations will require both increased ventilation controls and HEPA vacuums for cleaning in order to reduce worker exposures to beryllium to levels below the proposed PEL.

OSHA estimates that these facilities have, on average, three kilns. Industry experts indicated that a custom design will need to be developed for the LEV in this setting and that costs for this study are $30,000. In addition, installation of the ventilation enhancement requires 1,500 cfm of additional ventilation capacity per kiln at $13.18 per cfm for a cost of $19,765 per kiln and $59,294 (3 x $19,765) per facility, resulting in a total capital cost of approximately $89,294 ($30,000 + $59,294). OSHA includes an annual operating and maintenance cost of $3.92 per additional cfm of ventilation, for a total annual operating and maintenance cost of $5,875 (1,500 x $3.92) per kiln, and approximately $17,624 (3 x $5,875) per facility. The total annualized cost per facility is $28,092. The Agency preliminarily estimates that there are two facilities where workers are engaged in this process and where beryllium exposures are above the PEL. Therefore, the total annualized cost for kiln LEV is $56,185.

OSHA has preliminarily estimated that an additional one percent of a kiln operator's time will be spent operating HEPA vacuums to clean contaminated saggers and reduce worker exposures to beryllium. Based on a kiln operator wage rate of $21.61 per hour (Production Occupations, SOC: 51-9051), total labor costs for this activity as a result of the requirements of the proposed rule are $432 per worker annually (2,000 hours annually x 0.01 x $21.61). With an estimated 20 workers at risk of exposure to beryllium, the total cost for additional time spent cleaning is $8,646. For the two establishments and

20 workers affected, the total cost of engineering controls for this application-group process is $64,830.

Machining Operations

Machining operators receive sintered beryllium oxide shapes in the form of blocks that must be shaped to size. For larger-scale machining jobs, machining operators might oversee automated electrostatic discharge machines. These enclosed machines use jigs that operate under water to convert large ceramic blocks into finished shapes. In other cases, machining operators receive the ceramics in "near-net-shapes" that require only small-scale machining to meet final product specifications. Such machining processes include grinding, lapping, drilling, laser cutting/scribing, trimming, diamond dicing, water cutting, sanding, abrasive cutting, polishing, chemical etching, and other surface abrasion techniques.

Based on the technological feasibility analysis in Chapter IV: Section 4 of this PEA, many machining facilities have controls currently installed but may need to improve the efficiency of these controls. OSHA has estimated that these machining operations will require improved enclosures, including additional LEV capacity, for three units per establishment, on average. The Agency estimates that each enclosure modification will take 24 hours of a senior engineer's time at an hourly rate of $54.70 (Industrial Engineers, SOC: 17-2112, in NAICS industries: 327100, 334200, 334300, 334400, 334500, and 336300), for a cost of $1,313 (24 x $54.70). Each modification will also need an additional $1,000 for materials. Finally, enhanced LEV per unit is estimated to require an additional 788 cfm of ventilation capacity, at a cost of $13.18 per cfm, for a capital cost of $10,386 (788 x $13.18)—yielding a total capital cost per enclosure for improvements and additional LEV capacity of $12,689 ($1,000+ $1,313 + $10,386). An annual operating and maintenance cost of $3.92 per additional cfm of ventilation capacity is calculated to add an annual cost of $9,253 per facility (788 x 3 x $3.92), resulting in a total annualized cost of $13,715 per facility. OSHA's exposure profile in Chapter IV indicates that exposure levels of 37.44 percent of machining operators are above the PEL. OSHA preliminarily estimates that this exposure profile is distributed uniformly throughout the establishments in this process group such that 34 (Table V-3 shows just 33 due to rounding) facilities of the 90 establishments will need to improve their enclosures to protect machining operators, resulting in a total annualized cost of $462,105 for machining operations. Machining operators, as well as metallization operators below, work in several NAICS industries within this application group. Total costs were allocated across these different NAICS industries by their share of establishments within this application group, and are so presented in Table V-3 below.

Metallization workers

Some beryllium oxide ceramics are metallized, which involves plating or brazing with metal to permit the joining of the ceramic part to other pieces of equipment. OSHA has estimated that each facility where metallization processes are performed will require a one-time review of ventilation controls by an industrial engineer to ensure that controls are working properly in order to achieve the proposed PEL. OSHA estimated that the review requires eight hours of an industrial engineer's time at an hourly wage rate of $54.70 (Industrial Engineers, SOC: 17-2112, in NAICS industries: 327100, 334200, 334300, 334400, 334500, 336300), for a cost per facility of $438 (8 x $54.70), and an annualized cost of $51.30. With 28 establishments estimated to have workers performing this process with risk of exposure above the proposed PEL, the total annualized cost for this application-group process is $1,411. Similar to machining operators discussed above, metallization operators work in several NAICS industries within this application group. Total costs are allocated across these different NAICS industries by their share of establishments within this application group, and are so presented in Table V-3 below.

The total control costs for the beryllium oxide, ceramics & composites application group is $639,061. The cost by NAICS is presented in Table V-3, below.

Table V-3

Engineering Control Costs for Beryllium Oxide Ceramics and Composites, by NAICS Industry

NAICS Code	Industry	Affected Establishments	Affected Employees	Establishment-Based Costs – Number of Establishments Needing Controls	Employee-Based Costs – Number of Employees Needing Controls	Initial Capital Costs	Annualized Capital Costs	Operating and Maintenance Costs	Total Annualized Costs
327113a	**Porcelain electrical supply manufacturing (primary)**	**2**	**83**	**2**	**20**	**$731,367**	**$85,738**	**$89,807**	**$175,546**
	Material preparations operators	--	7	2	-	$479,376	$56,197	$41,605	$97,802
	Forming operators - pressing	--	28	1	-	$61,815	$7,247	$2,350	$9,597
	Forming operators - extruding	--	28	1	-	$11,588	$1,358	$1,958	$3,317
	Kiln operators	--	20	2	20	$178,588	$20,936	$43,894	$64,830
327113b	**Porcelain electrical supply manufacturing (secondary)**	**14**	**168**	**5**	**0**	**$201,384**	**$23,608**	**$48,494**	**$72,102**
	Machining operators	--	61	5	-	$199,513	$23,389	$48,494	$71,883
	Metallization Workers	--	9	4	-	$1,872	$219	$0	$219
334220	**Cellular telephones manufacturing**	**10**	**120**	**4**	**0**	**$143,846**	**$16,863**	**$34,639**	**$51,502**
	Machining operators	--	43	4	-	$142,509	$16,706	$34,639	$51,345
	Metallization Workers	--	7	3	-	$1,337	$157	$0	$157
334310	**Compact disc players manufacturing**	**5**	**60**	**2**	**0**	**$71,923**	**$8,432**	**$17,319**	**$25,751**
	Machining operators	--	22	2	-	$71,254	$8,353	$17,319	$25,672
	Metallization Workers	--	3	2	-	$669	$78	$0	$78
334411	**Electron Tube Manufacturing BeO traveling wave tubes**	**21**	**252**	**8**	**0**	**$302,077**	**$35,413**	**$72,741**	**$108,154**
	Machining operators	--	91	8	-	$299,269	$35,083	$72,741	$107,824
	Metallization Workers	--	14	6	-	$2,808	$329	$0	$329
334415	**Electronic resistor manufacturing**	**12**	**144**	**4**	**0**	**$172,615**	**$20,236**	**$41,566**	**$61,802**
	Machining operators	--	52	4	-	$171,011	$20,048	$41,566	$61,614
	Metallization Workers	--	8	4	-	$1,604	$188	$0	$188
334419	**Other electronic component manufacturing**	**9**	**108**	**3**	**0**	**$129,461**	**$15,177**	**$31,175**	**$46,352**
	Machining operators	--	39	3	-	$128,258	$15,036	$31,175	$46,210
	Metallization Workers	--	6	3	-	$1,203	$141	$0	$141
334510	**Electromedical equipment manufacturing**	**9**	**108**	**3**	**0**	**$129,461**	**$15,177**	**$31,175**	**$46,352**
	Machining operators	--	39	3	-	$128,258	$15,036	$31,175	$46,210
	Metallization Workers	--	6	3	-	$1,203	$141	$0	$141
336322b	**Other motor vehicle electrical & electronic equipment**	**10**	**120**	**4**	**0**	**$143,846**	**$16,863**	**$34,639**	**$51,502**
	Machining operators	--	43	4	-	$142,509	$16,706	$34,639	$51,345
	Metallization Workers	--	7	3	-	$1,337	$157	$0	$157
	Total	**92**	**1,163**	**36**	**20**	**$2,025,981**	**$237,507**	**$401,554**	**$639,061**

Source: OSHA, Office of Regulatory Analysis.

NONFERROUS FOUNDRIES

Nonferrous foundries produce a variety of cast products using alloyed and unalloyed copper, aluminum, and other metals that at some foundries include castings of copper-beryllium and, to a lesser extent, aluminum-beryllium. Employees can have exposures above the proposed PEL while performing several job tasks in foundries. The job categories with potential for beryllium exposure in foundries are as follows:

Molder

Material handler

Furnace operator

Pouring operator

Shakeout operator

Grinding and finishing operator

Abrasive blasting operator

Maintenance operator

Several of the controls are specific to workers in sand-casting foundries while others apply only to non-sand-casting operations (e.g., permanent mold casting). OSHA preliminarily estimates that no foundries specialize in casting alloys containing beryllium, meaning that the controls—mainly improved local exhaust ventilation—necessary to reduce worker exposures to beryllium to levels at or below the proposed PEL would not need to be used one hundred percent of the time. Facilities in this application group that are affected by the proposed rulemaking would only need to operate the additional LEV while processing beryllium. ERG's industry expert determined that the foundries in question commonly cast a number of other non-beryllium alloys (e.g., bronze), and estimated that work involving beryllium will be performed 20 percent of the time. This estimate is also reflected in the control costs through lower operating and maintenance costs for additional ventilation capacity and in the number of hours workers are estimated to be working with beryllium. For example, in other application groups, OSHA estimated that operating and maintenance costs would normally be $3.92 per cfm of additional ventilation capacity. For foundries, operating and maintenance costs are estimated to be 20 percent of that amount, or $0.78 (0.20 x $3.92) per cfm of additional ventilation capacity. Where the cost estimates associated with processes in this application group use a percentage of work hours needed to complete the task involving beryllium, the Agency has estimated that the typical worker, working an estimated 2,000 hours per year, would only spend 400 hours (20 percent of 2,000 hours) a year performing beryllium-related work.

Several job categories within this application group work in different NAICS industries. Total costs for each job category were allocated across these different NAICS industries by their share of establishments within this application group, and are so presented in Table V-4 below.

Molder

There are two processes for molding: sand casting and non-sand casting. Some engineering controls needed for these two processes differ due to the nature of the respective processes. In sand-casting foundries where non-permanent molds are used, molders typically prepare molds by shaping granular media (sand or similar substances) and a binder into shapes that will form molten metal but will disintegrate to the original granular structure when casting is complete. In some facilities, that media is a beryllium-containing sand. Reducing beryllium exposures associated with sand cast molding can be accomplished by installing covered or enclosed systems for transporting sand through or near the molding area. In sand-casting foundries, this would take the form of conveyor belt enclosures.

The Agency's technical feasibility analysis indicates that a conveyor enclosure would enclose and maintain sand-mixing or recycling equipment under exhaust ventilation. An ERG industry expert examined a previous ERG study (ERG 2013) and determined that a conveyer enclosure requires 1,225 cfm of exhaust ventilation at $13.18 per cfm, for an initial capital investment of $16,141 (1,225 x $13.18). The associated annual maintenance cost is $0.78 per cfm, for a total annual operating and maintenance cost of $956 (1,225 x $0.78). The total annualized cost is $2,852. OSHA estimates that each machine for molding processes that is improved as a result of the proposed rulemaking is used by four employees, which results in an annualized cost of $713 ($2,852/4) per worker. OSHA preliminarily estimates that there are 128 workers performing molding activities who may be exposed to beryllium at levels at or above the PEL. Therefore, the total annualized cost for enclosing conveyors in sand-casting foundries is $91,323.

The non-sand-casting foundries use permanent (reusable) molds or dies, requiring little daily preparation other than assembly and cleaning (brushing, sweeping, scraping, minor grinding, and applying mold release agents). Beryllium-containing residue (in the form of oxides and base metal) can build up on the molds during the casting process, and molders may be exposed to beryllium as they remove this material. Non-sand-casting foundries need the following additional controls in order to reduce beryllium exposure: wet wiping of molds and working surfaces, use of HEPA vacuums to clean molds, and additional LEV with movable exhaust hoods. For the first type of controls for non-sand-casting foundries, ERG has estimated that wet wiping would take two percent, or 8 hours, of a worker's time spent working with beryllium-containing materials each year.[365] The hourly wage for foundry mold and core makers is $20.66 (Foundry Mold and Coremakers, SOC: 51-4071). As a result, the annual cost per worker for wet wiping is estimated to be $165.28 (8 x $20.66). OSHA estimates that there are 369 affected workers in this application-group process, resulting in a total annual cost for wet wiping of $60,974.

The second category of new controls (and costs) for non-sand-casting foundries is use of HEPA vacuums. The housekeeping provisions for this standard (under ancillary provisions) will require such vacuums, and the purchase of this equipment is costed there. Therefore, for this engineering control, there are no purchase costs reported in this section. Additional vacuuming is estimated to take one percent of a worker's time each year. Using the estimated hourly wage presented above and total hours worked per year, the resulting annual cost per worker of additional vacuuming is $83 (400 x 0.01 x $20.70). Using the above estimate of 369 affected workers, the total annual cost for additional vacuuming is $30,487.

The third category of engineering controls for non-sand-casting foundries is increased LEV for their existing movable exhaust hoods. Each hood requires an additional 600 cfm of ventilation capacity (ACGIH, 2001) with a cost of $13.18 per cfm, resulting in a capital cost per hood of $7,906 (600 x $13.18). The operating and maintenance costs are $0.78 per cfm, for an

[365] The work year has 50 weeks, 5 days a week, resulting in 250 work days (5 X 50) per year. As noted above, 20 percent of a worker's time will be spent working with beryllium-containing materials, resulting in 50 days (0.20 X 250) with such materials. With an 8-hour workday, this is a total of 400 hours (8 x 50). Finally, 2 percent of these total hours is 8 hours (0.02 X 400).

annual cost per hood of $468 (600 x $0.78). The total annualized cost per establishment is $1,397. OSHA estimates that each movable exhaust hood is used by two employees, resulting in a per-worker annualized cost of $698. With 369 affected workers, the total annualized cost for increased ventilation capacity for movable exhaust hoods is $257,642.

The final engineering control cost for molders is the same for both types of foundries. OSHA estimates that both sand and non-sand-casting foundries will need to increase general ventilation primarily to protect molders. This general ventilation upgrade is needed to reduce possible cross contamination from other workers. An upgrade will be needed for an average area of 10,000 square feet per establishment. ERG's industry experts estimate a cost of $5.00 per square foot to improve general ventilation (often through the introduction of make-up air). The cost per establishment is then $50,000 (10,000 x $5), which, when annualized at 3 percent over 10 years, gives an annual per-establishment cost of $5,862. With an estimated 97 sand and non-sand foundry establishments that will need to perform general ventilation upgrades, the total annualized cost is $568,568. The total annualized cost of the controls identified in this section for this application-group process, for both sand-casting and non-sand-casting foundries, is $1,008,995 ($91,323 + $60,974 + $30,487 + $257,642 + $568,568).

Material Handler

Material handlers transport materials and castings between workstations. These employees need sealed cabs on machinery in order to reduce beryllium exposures to meet the proposed PEL. Based on discussions with vendors, the initial capital cost of sealing a cab is $13,000, including the installation of retrofitted cabs with filtered ventilation systems (ERG, 2004). OSHA estimates that the annual operating and maintenance costs are 15 percent of the initial non-annualized capital costs, or $1,950 (0.15 x $13,000). Total annualized cost per cab is $3,474, which, based on the Agency's estimate that each machine is used by two workers, gives a per-worker annualized cost of $1,737 ($3,474/2).

Using a sealed cab will slow the material handling process. OSHA preliminarily estimates that using a sealed cab will require additional time equal to 2.5 percent of a worker's total hours as a material handler. Given an average work year of 400 hours as a material handler and an average wage of $20.93 (Production Occupations, SOC: 53-7051), the productivity cost per worker incurred as a result of using sealed machine cabs is $209 (400 hours x 0.025 x $20.93). The total annualized cost per employee for a sealed cab is $1,946 ($1,737 + $209). OSHA preliminarily estimates that each of the 97 facilities projected to be affected by the proposed rule in this application group employs one material handler, resulting in a total annualized cost of engineering controls of $188,794.

Furnace Operation

Furnace operators charge (load) furnaces with new and/or reused metal (foundry scrap returns), supervise the melting process, sparge molten metal in the furnace (i.e., bubble gas through molten metal to promote mixing), and skim dross (use a scoop/wand to remove oxides and other contaminants that form a scum at the surface of the molten metal). OSHA has preliminarily estimated that these employees require enhanced furnace ventilation in order to be adequately protected against beryllium exposures above the proposed PEL. The Agency estimates that one furnace per facility will require 1,750 cfm of additional ventilation (ACGIH, 2001). At a cost of $13.18 per cfm of additional ventilation capacity, the initial capital cost is $23,059 per furnace (1,750 x $13.18). The annual operating and maintenance cost is $0.78 per cfm of additional ventilation capacity (20 percent of the usual $3.92 O&M cost) for a total cost of $1,371 (1,750 x $0.78). Total annualized cost per facility is $4,074. With 79 affected facilities, this results in a total cost of $321,846.

As described in Chapter IV of this PEA, local exhaust ventilation is needed for dross receptacles and furnace tools. A ventilated dross collection tray integrates fume control with furnace-mounted slot hood exhaust ventilation. The dross receptacle requires 1,600 cfm of additional ventilation capacity. With an initial cost of $16.47 (1.25 x $13.18) per cfm (including a 25 percent premium for needed custom design), the capital cost for ventilating dross receptacles is $26,353 (1,600 x $16.47). Operating costs are estimated to be $0.78 per cfm of additional ventilation capacity for a total annual operating and maintenance cost of $1,253 (1,600 x $0.78). With one dross receptacle per facility, the total annualized cost per facility is $4,343, and with 79 affected facilities, the total annualized cost is $343,097.

The proposed rulemaking will also require furnace operators to vacuum the work area using HEPA filtration vacuums. OSHA has estimated that facilities already have the necessary equipment but that employing this equipment will require additional time for vacuuming equal to one percent of a worker’s time. With an hourly wage of $23.16 (Production Occupations, SOC: 51-4051) and an estimated 400 hours spent working with beryllium-containing materials per year, the annual cost per worker for additional time spent vacuuming is $93 (0.01 x 400 x $23.16). With an estimated 94 affected workers, the total annual cost is $8,742 (94 x $93).

In order to reduce beryllium exposures to below the proposed PEL, furnace operators are also estimated to need pressurized air supplied to the operator booths, which requires additional ventilation capacity. The operator booth requires 1,500 cfm (ERG, 2004) of additional ventilation at a cost of $13.18 per cfm, for a capital cost of $19,765 per unit (1,500 x $13.18). The annual operating and maintenance cost is estimated to be $0.78 per cfm of additional ventilation capacity for a total of $1,175 per unit (1,500 x $0.78). OSHA estimates that facilities have, on average, one operator booth, which results in a per-facility annualized cost of $3,492. OSHA estimates that there are 79 affected facilities, yielding a total annualized cost of $275,868 (79 x $3,492). Combining the costs of these required engineering controls results in a total annualized cost for furnace operations in this application group of $952,459.

Pouring Operator

Pouring operators supervise the transfer of molten metal from the furnace (and any intermediary ladles) into molds. Beryllium fumes can enter a pouring operator's breathing zone as the fumes rise off molten metal in open ladles, tundishes, and molds. Beryllium fumes and dust released from the furnace area can be a substantial source of exposure for pouring operators.

LEV is the primary control measure for pouring that involves toxic metals, such as beryllium (and lead), and exhaust ventilation systems are available in the market for numerous types of equipment used in the pouring area. However, this equipment is currently not consistently used properly in foundries. Special mobile ventilation hoods that pouring operators can attach to ladles or crucibles are needed to achieve the PEL. These hoods connect to flexible ducts extending from overhead trunks and are used to remove fumes during transport and pouring. OSHA preliminarily estimates that facilities have these ventilation hoods but that they currently are not providing ventilation adequate to protect workers.

The ventilation for pouring operators requires 350 cfm of additional ventilation capacity (CCMA, 2000) at a cost of $13.18 per cfm, resulting in an initial capital cost of $4,612 (350 x $13.18). The operating and maintenance cost for the additional ventilation capacity is estimated to be $0.78 per cfm for a total annual operating and maintenance cost of $274 (350 x $0.78). With one pouring operator per facility, total annualized cost of ventilation to reduce beryllium exposure for these workers to levels at or below the proposed PEL is $815 per establishment. With an estimated 58 affected facilities, the total annualized cost for pouring operators is $47,421 (58 x $815).

Shakeout Operator

Shakeout operators separate molds from castings. If sand molds or sand cores are used in the casting process, these operators use vibrating equipment to dislodge the sand from around the formed metal pieces. Under some casting conditions, beryllium oxide can form on the casting surface. In these cases, sand can be contaminated with residual beryllium oxide from contact with the cast metal surface. OSHA preliminarily estimates that shakeout operators need improved LEV in order to reduce beryllium exposures to levels at or below the proposed PEL. The Agency estimates that firms will need 1,013 cfm of additional ventilation capacity in order to adequately protect these workers.[366] At a cost of $13.18 per cfm the total capital cost is

[366]This reflects a 25 percent increase in cfm, based on 450 cfm per sq ft of grate area; 3'x3' grate (ACGIH, 2001).

$13,348 per unit (1,013 x $13.18). Operating and maintenance costs are $0.78 per cfm for a total O&M annual cost of $793 (1,013 x $0.78). The Agency estimates an average of one shakeout operator per facility, which results in a total annualized cost per facility of $2,358. With an estimated 25 affected establishments, the total annualized engineering control costs for this application-group process are $58,956 (25 x $2,358).

Grinding and Finishing Operator

Grinding/finishing operators perform any required steps needed to finish castings (except cleaning steps performed by shakeout operators and abrasive blasting operators). They may use saws to remove imperfections left from the casting process or to trim the casting to specification. These workers also perform grinding to remove minor casting surface defects. They finish castings by polishing, sanding, or grinding pieces to customer specifications. Based on the findings of the technological feasibility analysis in Chapter IV of this PEA, OSHA estimates that facilities with grinding and finishing operations will need to improve ventilation enclosures in order to meet the proposed beryllium PEL.

The Agency estimates that, on average, a facility will have one ventilation enclosure and that four workers will use the enclosure. Each enclosure requires an estimated 525 cfm of additional ventilation capacity at a cost of $13.18 per cfm, for a capital cost of $6,918 (525 x $13.18).[367] Operating and maintenance costs are estimated to be $0.78 per cfm of additional ventilation capacity, for a total annual cost of $411 (525 x $0.78). Total annualized cost per unit,

[367] This reflects a 25 percent increase in cfm, based on 350 cfm/sq ft requirement for an opening of 6 square feet.

including operating and maintenance, is $1,224, and the per-worker annualized cost is $306 ($1,224/4). OSHA preliminarily estimates that there are 120 affected workers in this application-group process, resulting in a total annualized cost for engineering controls of $36,713 (120 x $306).

Abrasive blasting operator

Abrasive blasting operators in foundries typically use enclosed and ventilated blasting units that are partially or fully automated. Based on the findings of the technological feasibility analysis, the Agency has preliminarily concluded that blasters in this application group are not using beryllium-containing blasting media in any operations where the blasters are within an enclosure or performing open blasting, and hence this analysis estimates no cost for this operation.

Maintenance operator

Maintenance operators repair equipment throughout the facility. Maintenance operators are exposed to beryllium when they disturb equipment and work surfaces that are contaminated with beryllium. When working on ventilated equipment, such as furnaces, the process exhaust ventilation system may offer some degree of exposure control for the maintenance operator, but is unlikely to be designed to provide optimal control of maintenance activities. Maintenance workers may be required to clean and maintain their work stations throughout the day and at the end of the work shift. Maintenance workers may disturb dust containing beryllium when handling contaminated equipment, dry sweeping, dry wiping, moving dusty items, and chipping splattered metal, leading to worker exposures to a level of beryllium in excess of the proposed PEL.

To reduce exposure to beryllium during these activities in accordance with the recommendations of the technological feasibility analysis, maintenance workers would perform additional vacuuming of their work areas (beyond the vacuuming required for normal housekeeping) using the vacuums purchased to comply with the housekeeping provision, which is discussed as part of the ancillary provisions cost estimates presented later in this chapter. OSHA preliminarily estimates that vacuuming would require an additional 30 minutes of time per worker per day, which is ERG's estimate of the time needed based on the amount of time required to comply with similar types of cleaning provisions in other OSHA standards. With 50 working days per year—a full working year has 250 days and, as previously noted, OSHA estimates that 20 percent of a worker's time in this application group would be spent working with beryllium-containing materials, so, 0.2 x 250—and an hourly wage of $21.91 (Production Occupation, SOC: 51-0000), the vacuuming labor costs would be $548 per worker per year (50 days x 0.5 hours x $21.91). OSHA preliminarily estimates that there are 99 affected employees who will need to perform this additional vacuuming, resulting in a total annual cost of $54,225 (99 x $548).

In addition to the vacuuming requirements, OSHA estimates that workers would also need to wet wipe their work area. Wet wiping would require an additional 30 minutes of time per worker per day. Applying a 50-day work year working with beryllium-containing materials, as previously explained, and the $21.91 hourly wage (Production Occupation, SOC: 51-0000), the time cost would be $548 per worker per year (50 hours x 0.5 x $21.91). With 99 affected employees, the total annual labor cost for wet wiping is $54,225 (99 x $548).

For most maintenance workers or maintenance activities, the Agency estimates, based on the findings of the technological feasibility analysis, that controls will include portable LEV systems. In a portable LEV system, an enclosure or booth is placed around the work area, or the work is placed inside an enclosure that the operator reaches into. Openings in the enclosure, such as access hatches and gas vents, are used to maintain favorable circulation (Refractory, 2003). OSHA estimates that two employees will share one portable LEV system and that each system will require 800 cfm of additional ventilation capacity (ACGIH, 2001) at a cost of $13.18 per cfm, for a total capital cost per LEV system of $10,541 (800 x $13.18). Operating and maintenance costs are estimated to be $0.78 per additional cfm of ventilation capacity, for a total annual cost of $627 (800 x $0.78). Total annualized cost, including O&M, is $1,862 per unit, or $931 ($1,862/2) per employee. With an estimated 99 affected employees, the cost of a portable LEV system for maintenance operators in this application group is $92,188 (99 x $931).

Based on the demonstrated benefits of tool-mounted exhaust systems for controlling hazardous dusts (such as crystalline silica) in other industries, OSHA preliminarily estimates that facilities in this application group will need to employ these exhaust systems in order to protect maintenance operators from exposures to beryllium-containing dust above the proposed PEL.[368] Dust shroud adapters cost $100 per unit with a one year life span (Contractors Direct, 2009; Berland, 2009; Dust-Buddy, 2009; Martin, 2008), and the Agency estimates that each unit with such an adapter will be shared by two employees. This results in an annual cost per worker of $50. This control also requires a large capacity vacuum that costs $1,552 (based on the average

[368] For a more in-depth discussion of the demonstrate benefits of tool-mounted exhaust systems, see the foundries discussion in Chapter IV: Technical Feasibility of this PEA.

of estimates from Nikro Industries, 2012, and Nilfisk, 2012a) with an average life span of two years. OSHA estimates that the operating and maintenance costs are 15 percent of the annual cost of the high capacity vacuum, for an annual per-worker cost of $116. The total annualized cost for the large capacity vacuum is $522 per worker, resulting in a total annualized cost for the entire tool-mounted exhaust system—dust shroud adapter and large capacity vacuum—of $572 ($50 + $522) per employee. With an estimated 99 affected workers in this application-group process, the total cost for this exhaust system is $56,623 (99 x $572). The total control costs to protect maintenance operators in the nonferrous foundries application group is $2,563,348. The total cost for the application group by NAICS industry is represented in Table V-4 below.

Table V-4

Engineering Control Costs for Nonferrous Foundries, by NAICS industry

NAICS	Industry	Affected Establishments	Affected Employees	Establishment-Based Costs – Number of Establishments Needing Controls	Employee-Based Costs – Number of Employees Needing Controls	Initial Capital Costs	Annualized Capital Costs	Operating and Maintenance Costs	Total Annualized Costs
331521	**Aluminum die-casting foundries**	**7**	**98**	**7**	**67**	**$1,016,236**	**$121,381**	**$61,505**	**$182,887**
	Molder	--	36	7	36	$491,775	$57,651	$17,320	$74,971
	Material Handler	--	6	-	7	$45,500	$5,334	$8,290	$13,624
	Furnace Operator	--	7	6	6	$396,190	$46,446	$22,289	$68,734
	Pouring operator	--	11	4	-	$19,369	$2,271	$1,151	$3,422
	Grinding/finishing operator	--	19	-	12	$20,202	$2,368	$1,201	$3,569
	Maintenance	--	14	-	7	$43,199	$7,312	$11,254	$18,565
331522	**Nonferrous (except aluminum) die-casting foundries**	**38**	**534**	**38**	**366**	**$5,516,708**	**$658,927**	**$333,886**	**$992,813**
	Molder	--	195	38	195	$2,669,637	$312,963	$94,024	$406,987
	Material Handler	--	31	-	38	$247,000	$28,956	$45,005	$73,961
	Furnace Operator	--	37	31	31	$2,150,747	$252,133	$120,995	$373,128
	Pouring operator	--	59	23	-	$105,148	$12,327	$6,251	$18,577
	Grinding/finishing operator	--	101	-	63	$109,670	$12,857	$6,520	$19,376
	Maintenance	--	78	-	39	$234,507	$39,692	$61,092	$100,783
331524	**Aluminum foundries (except die-casting)**	**7**	**98**	**7**	**67**	**$1,016,236**	**$121,381**	**$61,505**	**$182,887**
	Molder	--	36	7	36	$491,775	$57,651	$17,320	$74,971
	Material Handler	--	6	-	7	$45,500	$5,334	$8,290	$13,624
	Furnace Operator	--	7	6	6	$396,190	$46,446	$22,289	$68,734
	Pouring operator	--	11	4	-	$19,369	$2,271	$1,151	$3,422
	Grinding/finishing operator	--	19	-	12	$20,202	$2,368	$1,201	$3,569
	Maintenance	--	14	-	7	$43,199	$7,312	$11,254	$18,565
331525a	**Copper foundries (except die-casting) (non-sand casting foundries)**	**20**	**281**	**20**	**193**	**$2,903,531**	**$346,804**	**$175,730**	**$522,533**
	Molder	--	102	20	102	$1,405,072	$164,717	$49,486	$214,204
	Material Handler	--	16	-	20	$130,000	$15,240	$23,687	$38,927
	Furnace Operator	--	19	16	16	$1,131,972	$132,702	$63,682	$196,383
	Pouring operator	--	31	12	-	$55,341	$6,488	$3,290	$9,778
	Grinding/finishing operator	--	53	-	33	$57,721	$6,767	$3,431	$10,198
	Maintenance	--	41	-	20	$123,425	$20,890	$32,154	$53,044
331525b	**Copper foundries (except die-casting) (sand casting foundries)**	**25**	**393**	**25**	**199**	**$3,973,654**	**$473,860**	**$208,369**	**$682,229**
	Molder	--	128	25	128	$1,766,889	$207,133	$30,728	$237,861
	Material Handler	--	20	-	25	$162,500	$19,050	$29,608	$48,658
	Furnace Operator	--	24	20	20	$1,414,965	$165,877	$79,602	$245,479
	Pouring operator	--	39	15	-	$69,176	$8,110	$4,112	$12,222
	Shakeout operator	--	41	25	-	$333,692	$39,119	$19,837	$58,956
	Maintenance	--	51	-	26	$154,281	$26,113	$40,192	$66,305
	Total	**97**	**1,405**	**97**	**893**	**$14,426,365**	**$1,722,353**	**$840,995**	**$2,563,348**

Source: OSHA, Office of Regulatory Analysis.

SECONDARY SMELTING, REFINING AND ALLOYING

This section focuses on one job category—Furnace Operators—where exposures are estimated to be greater than 0.2 μg/m^3 in industries where smelting, refining, and alloying activities are performed.

Furnace Operations

The term "furnace operations" is here used broadly to include activities performed by melting and casting operators and helpers, as well as operation of furnaces and incinerators. The melting process separates the metals of interest from their metallic compounds, removes contaminants remaining after the pretreatment process, and allows operators to make alloys and castings from the liquid metal. After the metal is melted and refined, it may be formed into bars and ingots, or a final product. OSHA has estimated that two engineering controls are necessary in order to reduce exposure to beryllium among workers performing furnace operations to levels at or below the proposed PEL. These controls are: additional furnace ventilation and additional ventilation for dross removal.[369]

The Agency has estimated, that each facility in the secondary smelting, refining, and alloying application group would require 1,800 cfm[370] of additional ventilation for one furnace per facility at an estimated cost of $13.18 per cfm, resulting in a capital cost of $23,718 (1,800 x $13.18). Operating and maintenance costs are estimated to be $3.92 per cfm of additional

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[369] Half-mask respirators will also be required. Their costs will be discussed later in this chapter.

[370] Based on 200 cfm of ventilation needed per square foot of hood opening and a 3'x3' hood (ACGIH, 2001; p. 10-77).

ventilation capacity, for an annual operating and maintenance cost of $7,050 (1,800 x $3.92). Total annualized costs per facility, including operating and maintenance, is $9,830. With 20 estimated affected establishments, the total annualized cost for additional furnace ventilation is $196,600 (20 x $9,830).

OSHA has estimated that each facility would also require one additional custom-designed ventilation system for areas where dross removal and furnace "plugging" occur (see Chapter IV: Technological Feasibility Analysis, Section 5, of this PEA). The Agency estimates that this additional ventilation system would need to provide an additional 1,600 cfm of ventilation capacity per facility. At a cost of $16.47 per cfm[371] of additional ventilation capacity, the capital costs are estimated to be $26,353 (1,600 x $16.47) per facility. Operating and maintenance costs are estimated to be $3.92 per cfm, for an annual operating and maintenance cost of $6,266 (1,600 x $3.92). The total annualized cost per facility for this custom ventilation, including operating and maintenance, is $9,356; with 20 affected establishments, the total annualized cost is $187,120.

The total annualized control costs for the secondary smelting, refining, and alloying application group is $383,719. Several job categories within this application group, such as "furnace operator," appear in several different NAICS industries. Total costs for each job category were therefore allocated across these different NAICS industries by their share of establishments within this application group, and are so presented in Table V-5 below.

[371] ERG estimates that the custom design system would require a 25 percent cost premium to build; hence, the standard base rate of $13.92 would increase to $16.47 (1.25 x $13.92).

Table V-5

Engineering Control Costs for Secondary Smelting, Refining, and Alloying, by NAICS industry

NAICS	Industry	Affected Establishments	Affected Employees	Establishment-Based Costs – Number of Establishments Needing Controls	Employee-Based Costs – Number of Employees Needing Controls	Initial Capital Costs	Annualized Capital Costs	Operating and Maintenance Costs	Total Annualized Costs
331314	**Secondary smelting & alloying of aluminum**	**1**	**9**	**1**	**0**	**$50,070**	**$5,870**	**$13,316**	**$19,186**
	Mechanical processing operator	--	3	-	-	$0	$0	$0	$0
	Furnace operator	--	6	1	-	$50,070	$5,870	$13,316	$19,186
331421b	**Copper rolling, drawing, and extruding**	**1**	**9**	**1**	**0**	**$50,070**	**$5,870**	**$13,316**	**$19,186**
	Mechanical processing operator	--	3	-	-	$0	$0	$0	$0
	Furnace operator	--	6	1	-	$50,070	$5,870	$13,316	$19,186
331423	**Secondary smelting, refining, & alloying of copper**	**3**	**27**	**3**	**0**	**$150,211**	**$17,609**	**$39,948**	**$57,558**
	Mechanical processing operator	--	9	-	-	$0	$0	$0	$0
	Furnace operator	--	18	3	-	$150,211	$17,609	$39,948	$57,558
331492	**Secondary Smelting, Refining, and Alloying of Nonferrous**	**30**	**270**	**15**	**0**	**$751,054**	**$88,046**	**$199,742**	**$287,789**
	Mechanical processing operator	--	90	-	-	$0	$0	$0	$0
	Furnace operator	--	180	15	-	$751,054	$88,046	$199,742	$287,789
	Total	**35**	**315**	**20**	**0**	**$1,001,406**	**$117,395**	**$266,323**	**$383,719**

Source: OSHA, Office of Regulatory Analysis.

Precision Turned Products

The precision turned product manufacturing industry includes companies that produce metal products by a combination of machining processes, including, but not limited to, turning, milling, tapping, drilling, sawing, and grinding. Beryllium-containing materials that might be used for these products include beryllium metal and beryllium alloyed with other metals, including copper, nickel, aluminum, magnesium, gold, and zinc.

OSHA has determined that ventilated enclosures for machining equipment are an effective strategy for reducing a machining equipment operator's exposure to beryllium to levels at or below the proposed PEL.

Installing ventilated enclosures would first require a machine-specific engineering and industrial hygiene study to determine the design parameters of the ventilation equipment. The Agency has estimated that this study would take eight hours for a consulting industrial hygienist to complete—at a wage rate of $150 per hour, for a cost of $1,200 (8 x $150)—plus 16 hours for a ventilation mechanical engineer—at a wage rate of $48.83 per hour (Mechanical Engineer, SOC: 17-2141), for a cost of $781 (16 x $48.83). Four hours of a machinist's time is also required to explain the workings of the machine in question (to assist the engineer and industrial hygienist in determining the best way to design the enclosure)—at a wage rate of $25.00 per hour (Machinists, SOC: 51-4041), for a cost of $100 (4 x $25). The total initial cost to complete the industrial hygiene study is $2,081 per machine ($1,200 + $781 + $100). OSHA estimates that each machine that is subject to one of these studies will be used by four machinists, which results in a total initial cost of $520 per worker ($2,081/4), and a total annualized cost of $61 per worker. OSHA preliminarily estimates that there are 697 workers at risk and in need of controls, resulting in a total annualized cost of $42,511 (697 x $61) for the studies.

The Agency estimated the cost of a standard hood based on the exhaust requirements of a "high toxicity materials milling machine hood" shown in the ACGIH ventilation manual (ACGIH, 2001). OSHA believes this type of hood will be representative of the type of hood that industrial hygienists will recommend in most cases for facilities in this application group to comply with the requirements of the proposed rule. OSHA estimates that this type of enclosure will require 675 cfm of additional exhaust ventilation capacity. Based on these specifications, total capital costs for the ventilation enclosure, using a per-cfm cost of $13.18, is $8,894 (675 x $13.18). Additional annual operating and maintenance costs, estimated to be $3.92 per cfm of additional ventilation capacity, are $2,644 (675 x $3.92). The total annualized cost per machine is $3,686. Given the previous estimate of four workers per machine, the cost per worker is $922 ($3,686/4). With 697 affected employees in this application-group process, the resulting total annualized cost is $642,285 (697 x $922) for the ventilation enclosure and additional ventilation.

The precision machining application group must incur additional costs for engineering controls or work practices to comply with paragraph (f)(2) of the proposed standard, which requires employers to protect employees with exposures at or above the proposed action level and at or below the proposed PEL. Machinists working with low content beryllium require enhanced LEV for employees exposed at or above the proposed action level but at or below the proposed PEL. OSHA estimates that LEV for these machinists would be similar to that used in high-content beryllium machining operations with four workers per machine. Adding 675 cfm of additional ventilation capacity at a cost of $13.18 per cfm has a capital cost of $8,894 (675 x

$13.18), or $2,224 ($8,894/4) per worker. Operating and maintenance costs are estimated at $3.92 per cfm of additional ventilation capacity and therefore total $2,644 (675 x $3.92), or $661 ($2,644/4) per worker, annually. Total annualized costs, including O&M, are $3,686, or $922 (($3,686/4) per worker. OSHA has estimated that approximately 11.3 percent of machinists working with low content beryllium, or 398 machinists, have exposures at or above the proposed action level and at or below the proposed PEL. The total cost of implementing engineering controls to comply with paragraph (f)(2) for this application group is therefore $366,444 ($922 x 398).

The total control costs for the machining application group is $1,051,240. Several job categories within this application group work in different NAICS industries. Total costs for each job category were allocated across these different NAICS industries by their share of establishments within this application group, and are so presented in Table V-6 below.

Table V-6

Engineering Control Costs for Precision Machining, by NAICS industry

NAICS	Industry	Occupation Group	Affected Establishments	Affected Employees	Establishment-Based Costs – Number of Establishments Needing Controls	Employee-Based Costs – Number of Employees Needing Controls	Initial Capital Costs	Annualized Capital Costs	Operating and Maintenance Costs	Total Annualized Costs
332721a	Precision turned product manufacturing (high beryllium	Machinist (high)	18	222	-	166	$454,447	$53,275	$109,464	$162,739
332721b	Precision turned product manufacturing (low beryllium	Machinist (low)	294	3,542	-	531	$2,341,975	$274,551	$613,951	$888,502
	Total		**312**	**3,764**	**0**	**697**	**$2,796,422**	**$327,826**	**$723,414**	**$1,051,240**

Source: OSHA, Office of Regulatory Analysis.

Copper Rolling, Drawing, and Extruding

Copper rolling, drawing, and extruding mills produce copper and copper alloy rod, bar, sheet, strip, plate, pipe, tube, and wire. The metal-forming processes used to produce copper-beryllium alloy products (which typically contain 2 percent or less beryllium) are common to other metals and, depending on the product, may include rolling, extrusion, pickling, annealing, and hot or cold drawing. OSHA has determined that employees in only a few operations in this application group are currently exposed above the PEL. These include rod and wire production workers and strip metal production workers (both of whom are exposed to high levels of beryllium mainly during bulk pickling and annealing) and wastewater treatment workers.

The costs for this application group, presented by NAICS industry, are shown in Table V-7 at the end of this application group section.

Wastewater Treatment Operators

Industrial wastewater treatment facilities at copper rolling, drawing, and extruding facilities process wastewater containing dilute acids and caustics. Sludge from the clarified wastewater is dewatered in a filter press, collected in a container, and removed from the facility by a licensed contractor for landfill disposal. Worker activities where beryllium exposures occur include handling both universal and process-related waste and maintaining the industrial wastewater treatment facility.

Based on materials presented in the technology feasibility analysis describing a housekeeping program implemented by Materion, the Agency estimates that affected workers would each need to devote an additional 10 minutes per day to clean their work area in order to reduce beryllium exposures to levels at or below the proposed PEL. Based on a 250 day work-year and an hourly wage rate of $29.62 (Water and Liquid Waste Treatment Plant Operators: SOC 51-8031), this requirement would result in a yearly cost of $1,234 per worker ((10/60) x 250 x $29.62). With an estimated 26 affected workers needing controls to reduce beryllium exposures, the total annual cost of cleaning is $31,544.

Rod and Wire Production Workers

Rod and wire production workers perform the following job tasks: wire annealing and pickling; wire drawing; straightening; point and chamfer; rod and wire packaging; and die grinding. All of these processes are equipped with LEV except for rod and wire packaging and the rod/tube straightening process, where finished product is cut to length prior to packaging and shipping.

Within this job category, bulk pickling and annealing operations have the highest beryllium exposures (see Table 8-4 in Chapter IV: Section 8 of this PEA). In one facility, these higher exposures are likely caused in part by a bulk pickling tank equipped with an ineffective push-pull LEV system (Kent, 2004), which results in workers being exposed to beryllium at levels above the proposed PEL. OSHA therefore expects that at that facility and all other similar facilities in the application group, additional controls are necessary. In order to reduce beryllium exposures to levels at or below the proposed PEL, the Agency has estimated that these firms will need to use an interim restricted access zone to enclose the bulk pickling and annealing operations with floor-to-ceiling walls that contain two rapid-access doors to isolate these activities from the rest of the facility.

Based on an ERG site visit to a copper-beryllium alloy facility, OSHA estimates that the average plant area devoted to pickling and annealing is 1,250 square feet (ERG, 2004b). Based on industry data, OSHA estimates that it would cost $15.00 per square foot of area to enclose the activity (RS Means, 2005), so the initial capital cost to erect an interim restricted access zone is $18,750 (1,250 x $15), and the annualized cost is $2,198.

This enclosure will also require enhanced ventilation equal to a 25 percent increase in ventilation capacity, which OSHA has estimated, for the baseline, to be 225,000 cubic feet per hour, or 3,750 cfm (225,000/ 60) per minute.[372] The extra ventilation capacity required is estimated to be 938 (0.25 x 3,750) cfm in order to provide adequate ventilation to meet the proposed PEL. At a cost of $13.18 per cfm, this results in a total capital cost of $12,353 (938 x $13.18). OSHA estimates that the operating and maintenance cost is $3.92 per cfm of additional ventilation capacity, for a total annual operating and maintenance cost of $3,672 (938 x $3.92). The annualized capital cost for enhanced ventilation is $1,448, and the total annualized cost, including operating and maintenance, is $5,120 per facility.

The total annualized cost per facility for enclosures of the rod and wire production areas and to provide ventilation enhancements is $7,318 ($2,198 + $5,120) per facility. With an estimated 10 facilities engaged in these activities— all in NAICS 331422 Copper wire (except mechanical) drawing— the total annualized engineering control costs are $71,960.

[372] This was calculated as the base LEV already included with the construction of the enclosure, where ERG estimated 15-foot walls, and therefore a total volume of 18,750 cubic feet (15 x 1,250). A total of 12 air changes are needed per hour, resulting in a total ventilation capacity of 225,000 (12 x 18,750).

Strip Metal Production Worker

The strip metal production processes at copper-beryllium rolling and drawing facilities include strip rolling, annealing, pickling, slitting, inspection, and shipping and receiving.

The Agency estimates that three ventilation controls would be needed per facility to meet the proposed PEL. ERG estimates that each ventilation control requires 1,000 cfm at $13.18 per cfm, for a total capital cost of $39,529 (1,000 x 3 x $13.18). Operating and maintenance costs are $3.92 per cfm, for a total annual operating and maintenance cost of $11,750 (1,000 x 3 x $3.92). The total annualized cost, including maintenance, is $16,384 per facility. With one affected facility in NAICS 331421a: Copper rolling, drawing, and extruding, the total annualized cost for these ventilation controls is $16,384.

OSHA estimates that the total annualized engineering controls for the copper rolling and drawing application group are $119,887. Several job categories within this application group fall into different NAICS industries. Total costs for each job category were allocated across these different NAICS industries according to the percentage of establishments by NAICS industry within this application group, and are so presented in Table V-7 below.

Table V-7

Engineering Control Costs for Copper Rolling, Drawing and Extruding, by NAICS industry

NAICS	Industry	Affected Establishments	Affected Employees	Establishment-Based Costs – Number of Establishments Needing Controls	Employee-Based Costs – Number of Employees Needing Controls	Initial Capital Costs	Annualized Capital Costs	Operating and Maintenance Costs	Total Annualized Costs
331422	**Copper wire (except mechanical) drawing**	**59**	**5,096**	**10**	**20**	**$305,845**	**$35,854**	**$60,377**	**$96,231**
	Wastewater treatment operator	--	59	-	20	$0	$0	$24,272	$24,272
	Production	--	3,070	10	-	$305,845	$35,854	$36,105	$71,960
331421a	**Copper rolling, drawing, and extruding**	**15**	**1,539**	**1**	**6**	**$39,529**	**$4,634**	**$19,022**	**$23,656**
	Wastewater treatment operator	--	18	-	6	$0	$0	$7,273	$7,273
	Production	--	927	1	-	$39,529	$4,634	$11,750	$16,384
	Total	**74**	**4,073**	**11**	**26**	**$345,374**	**$40,488**	**$79,399**	**$119,887**

Source: OSHA, Office of Regulatory Analysis.

FABRICATION OF BERYLLIUM ALLOY PRODUCTS

Copper-beryllium alloys (less than or equal to 2 percent beryllium) are used to make a variety of products for electrical applications. Copper wire and flat copper plate are used to make light-gauge springs, electronic connectors, and other stamped and formed metal products. Large and medium-size stamping operations, involving procedures such as punching, bending, and other metal forming activities, are primarily automated and enclosed, meaning that the potential for beryllium exposures is low. In addition, stamped copper-beryllium parts are usually plated—typically with nickel, tin, or gold (Downing, 2002)—and this plating serves to further protect workers from beryllium exposures since the beryllium metals are covered with another, non-toxic metal. Electronic connector manufacturers may either stamp copper-beryllium components in-house or purchase these components from a stamper. There is a potential for workers to be exposed to beryllium if stamping is done in-house. Most workers in the stamping, spring, and connector manufacture application group have low beryllium exposures, although the potential for higher exposures exists for chemical process operators and deburring operators. Exposures can be reduced to or below the proposed PEL through enhanced LEV for these operations.

Deburring Operator

Deburring operators in this application group use the same range of deburring equipment as other metal product fabrication industries, including manual filing, brushing with wire or other stiff bristles brushes, abrasive action, and media barrel finishing (Corbett, 2007). This same reference and a standard industrial hygienist design manual (Corbett, 2007; ACGIH, 2010) suggest that in beryllium handling facilities this equipment is usually attached to exhaust ventilation trunks, but air flow rates might not meet the levels necessary to adequately protect workers from beryllium exposures.

Based on ACGIH (2010), OSHA has preliminarily estimated that each enhanced ventilation control will require an additional 1,750 cfm of ventilation capacity in order to reduce worker exposures to beryllium to levels at or below the proposed PEL.[373] With a cost of $13.18 per cfm of additional ventilation capacity, the initial capital cost is estimated to be $23,059 (1,750 x $13.18). Operating and maintenance costs are $3.92 per cfm of additional ventilation capacity, for an annual operating and maintenance cost of $6,854 (1,750 x $3.92). The total annualized cost for enhanced ventilation is $9,557 per facility. OSHA preliminarily estimates that there are 86 facilities engaged in deburring that would need engineering controls in order to reduce exposures to beryllium to the proposed PEL. This results in a total annualized cost for this application-group process of $822,183.

Chemical Process Operator

Based on the technological feasibility assessment in Chapter IV, Section 9: Fabrication of Beryllium Alloy Products, in this PEA, OSHA has determined that firms in this application group will need enhanced LEV for chemical processing tanks in order to reduce worker exposures to beryllium, since the LEV currently in use does not meet the established performance criteria. The Agency has estimated that there are two tanks per facility that will

[373] This assumes square mill of 37 to 42 inches in diameter or round mill of 43 to 48 inches in diameter.

each require 600 cfm of additional ventilation capacity in order to meet the requirements of this rulemaking.[374] At a cost of $13.18 per cfm, this results in a capital cost of $7,906 per tank (600 x $13.18). The operating and maintenance cost is $3.92 per cfm of additional ventilation capacity, for an annual operating and maintenance cost of $2,350 per tank (600 x $3.92). The total annualized cost per tank, including operating and maintenance costs, is $3,277, or $6,553 (2 x $3,277) per facility. OSHA preliminarily estimates that there are 28 (Table V-8 only shows 27 due to rounding) facilities that will need enhanced LEV in this application-group process, resulting in a total annualized cost of $183,557.

Chemical process operators are one of the two job categories that would require engineering controls under paragraph (f)(2) of the proposed rule, which requires employers to take certain actions if their employees are exposed to beryllium in the range above the proposed action level (0.1) but at or below the proposed PEL (0.2) (if the exposure is above the PEL, then additional controls are required). Based on the technological feasibility analysis in Chapter IV of this PEA, the Agency has determined that chemical processing requires enhanced maintenance of local exhaust ventilation. OSHA has estimated that enhanced maintenance of LEV would require a five percent increase, per establishment per year, in the amount of labor provided by a maintenance worker. Using a wage rate of $22.16 (Production Occupations, SOC: 51-0000), 250 work days per year, and eight hour shifts, a five percent increase in labor results in 100 additional hours annually (0.05 x 250 x 8) necessary to maintain LEV at a cost of $2,216 (100 x $22.16) per establishment annually. Approximately 6.8 percent of spring manufacturers, or 19 establishments, have exposures at or above the proposed action level and at or below the

[374] This assumes a surface area of 8 sq. feet per tank and 75 cfm exhaust ventilation per sq. foot (ACGIH, 2001; p. 10-109).

proposed PEL, resulting in a total annual cost of $42,106 (19 x $2,216). Approximately 7.0 percent of stamping manufacturers, or 22 establishments, have exposures at or above the proposed action level and at or below the proposed PEL, resulting in a total annual cost of $48,754 (22 x $2,216). The total cost of implementing engineering controls and work practices to comply with paragraph (f)(2) for this application-group process is therefore $90,860 ($42,106 + $48,754).

The total control costs for the stamping, spring, and connection manufacturing application group is $1,096,600. Several job categories within this application group fall into different NAICS industries. Total costs for each job category were allocated across these different NAICS industries by their share of establishments within this application group, and are so presented in Table V-8 below.

Table V-8										
Engineering Control Costs for Stamping, Spring, and Connector Manufacturing, by NAICS industry										
NAICS	**Industry**	**Affected Establishments**	**Affected Employees**	**Establishment-Based Costs – Number of Establishments Needing Controls**	**Employee-Based Costs – Number of Employees Needing Controls**	**Initial Capital Costs**	**Annualized Capital Costs**	**Operating and Maintenance Costs**	**Total Annualized Costs**
332612	**Light gauge spring manufacturing**	**323**	**2,071**	**46**	**0**	**$1,301,537**	**$152,580**	**$435,620**	**$588,200**
	Deburring Operator	--	507	46	-	$1,063,994	$124,733	$316,259	$440,991
	Chemical process operator	--	28	15	-	$237,543	$27,847	$119,361	$147,208
332116	**Metal stamping**	**74**	**496**	**11**	**0**	**$298,185**	**$34,956**	**$99,792**	**$134,748**
	Deburring Operator	--	315	11	-	$243,763	$28,576	$72,456	$101,032
	Chemical process operator	--	11	3	-	$54,422	$6,380	$27,336	$33,716
334417	**Electronic connector manufacturing**	**46**	**310**	**7**	**0**	**$186,164**	**$21,824**	**$62,302**	**$84,126**
	Deburring Operator	--	197	7	-	$152,187	$17,841	$45,236	$63,077
	Chemical process operator	--	7	2	-	$33,977	$3,983	$17,067	$21,050
336322a	**Other motor vehicle electrical & electronic equipment**	**159**	**1,066**	**23**	**0**	**$640,695**	**$75,109**	**$214,417**	**$289,526**
	Deburring Operator	--	677	23	-	$523,762	$61,401	$155,682	$217,082
	Chemical process operator	--	23	7	-	$116,933	$13,708	$58,736	$72,444
	Total	**602**	**3,943**	**86**	**0**	**$2,426,580**	**$284,469**	**$812,131**	**$1,096,600**

Source: OSHA, Office of Regulatory Analysis.

WELDING

Beryllium-containing materials are welded using mainly two techniques: arc welding and resistance welding. Fumes are generated in welding operations when metals and oxides vaporize in the arc area, and rapid condensation (of the vapors) occurs to form particles.

All arc welding processes create an electric arc (current) between the welding electrode (stick, rod, or wire filler metals) and the surface of the work piece.[375] The heat of the arc melts the electrode (or filler metal if a non-consumable electrode is used) and the work pieces to be joined. Both metal inert gas (MIG) and tungsten inert gas (TIG) welding are well suited for welding copper-beryllium. When copper-beryllium is welded to itself or to other metals, a copper-beryllium rod is typically used as the filler metal. Aluminum-bronze filler can also be used for welding copper-beryllium to steel.

The second type of welding is resistance welding, which refers to a group of welding processes that apply electric current and mechanical pressure to create a weld between two pieces of metal. Resistance welding electrodes can include beryllium material (see Chapter IV of this PEA). Resistance welding is frequently used to attach electrical contacts to copper-beryllium flat springs. Exposure data for resistance welding used in the exposure profile (from the Welding section of Chapter IV of this PEA, Tables 10-1, 10-2) are all below the action level. Hence there are no control costs estimated for resistance welders.

Control options for this application group include taking steps to enhance exhaust ventilation and/or minimize the presence and release of beryllium oxide, which can flake off the

[375] In arc welding, an electrode is used to conduct a current through a work piece to fuse two pieces together. Electrodes are either consumable or non-consumable (depending on the process) and are classified into three types: solid (bare metal electrode with no covering), covered (composite electrode with metal core and a covering), and flux-cored (composite electrode with a metal tube containing flux material) (AIHA, 1984).

surface of the metal work piece when the welder handles it (applicable only to facilities and operations where beryllium alloy has not been treated to prevent loose oxide from forming).

Reducing surface oxidation

The presence and release of flaking beryllium oxide on the surface of pieces that welders are handling may account for as much as ninety percent of the beryllium exposure experienced by a welder, and has been implicated in the high exposure levels recorded among welders at the Materion Elmore facility (Corbett, 2006; Kent, 2005). Reducing the flaking surface oxide as a source of contamination could have a dramatic effect on lowering these exposure levels. OSHA has determined that facilities would be able to eliminate the release of loosely adhered beryllium oxide by chemically stripping and pickling the beryllium alloy work piece prior to welding. These procedures remove the loose surface oxides and stabilize the surface to prevent additional loosely adhered beryllium oxides from forming (Materion Information Meeting, 2012). Although no formal studies have been conducted examining the efficacy of this method, safety and health professionals at Materion's Elmore facility report that the beryllium exposure of welders on their strip welding line decreased substantially when welding was performed only on pre-cleaned, pickled alloy strip (Kent 2012). The costs for this method, involving a chemical dip tank, were already accounted for in the earlier estimation of welding costs during beryllium production.

Local Exhaust Ventilation Hoods

Where welding fumes are the primary source of beryllium exposure, LEV would be needed as a control measure. When existing LEV is not adequate to reduce exposures to levels at or below the PEL, employers must improve the quality of the enclosed hood control or the placement of the exhaust pickup or hood relative to the work piece in order to optimize the capabilities of the hood and to reduce exposures to the maximum amount possible.

For temporary or mobile operations, OSHA has estimated that a firm will employ movable LEV systems and that two welders will be able to utilize each enclosed hood control. The Agency estimates that a movable LEV system requires an estimated 800 cfm (ACGIH, 2001, p. 10-150) of additional ventilation capacity at a cost of $13.18 per cfm. This results in a capital cost of $10,541 per hood (800 x $13.18). The operating and maintenance cost is estimated to be $3.92 per cfm of additional ventilation capacity, for an annual O&M cost of $3,133 (800 x $3.92). The total annualized cost, including operating and maintenance, for an enclosed hood control is $4,369, or $2,184 ($4,369/2) per employee. With an estimated 586 workers at risk of exposure to beryllium in this application-group process, the total annualized cost is $1,279,161.

Correct use of portable ventilation systems can greatly improve system effectiveness, and OSHA has determined that workers are currently lacking in training on how to correctly use these systems. The Agency has judged that employers in this application group will need to provide additional training in order for their workplaces to be able to meet the proposed PEL. ERG has estimated that annual training on the correct use of portable LEV will take four hours and will be provided by a single instructor to an average class size of six. At a production worker wage rate of $22.16 an hour, an employer will incur a cost of $88.64 (Production Occupation, SOC: 51-0000) for the worker's time to receive this training (4 x $22.16). The instructor's wage rate is $37.39 an hour (Training and Development Specialist, SOC 13-1151), and the total cost for the instructor for four hours, $149.55 (4 x $37.39), will be spread across the class size of six, resulting in a per worker annual cost for the instructor of $24.92 ($149.55/6). This results in an annual labor cost per worker of $114 ($88.64 + $24.92) to receive training on the correct use of portable LEV systems. In addition to the time necessary for training to be provided, OSHA has estimated that an employer will make training materials available, which are estimated to cost $2.00 per employee. The total annual cost to receive training on the correct use of portable LEV systems is then $116 ($114 + $2) per worker. OSHA preliminarily estimates that there are 586 workers who will need training, resulting in a total annual cost of $67,674. The total control costs for this application group is $1,346,835.

The welding application group encompasses numerous NAICS industries. Total costs are allocated across these different NAICS industries by their share of establishments within this application group, and are so presented in Table V-9 below.

Table V-9									
Engineering Control Costs for Arc and Gas Welding, by NAICS industry									
NAICS	Industry	Affected Establishments	Affected Employees[a]	Establishment-Based Costs – Number of Establishments Needing Controls	Employee-Based Costs – Number of Employees Needing Controls	Initial Capital Costs	Annualized Capital Costs	Operating and Maintenance Costs	Total Annualized Costs
331111	Iron and Steel Mills	7	27	-	8	$41,529	$4,868	$13,255	$18,123
331221	Rolled Steel Shape Manufacturing	1	6	-	2	$8,629	$1,012	$2,754	$3,766
331513	Steel Foundries (except Investment)	1	5	-	2	$8,490	$995	$2,710	$3,705
332117	Powder Metallurgy Part Manufacturing	1	4	-	1	$5,703	$669	$1,820	$2,489
332212	Hand and Edge Tool Manufacturing	3	12	-	3	$18,283	$2,143	$5,835	$7,979
332312	Fabricated Structural Metal Manufacturing	56	224	-	67	$350,601	$41,101	$111,900	$153,001
332313	Plate Work Manufacturing	21	85	-	25	$132,543	$15,538	$42,303	$57,841
332322	Sheet Metal Work Manufacturing	69	274	-	81	$429,427	$50,342	$137,058	$187,400
332323	Ornamental and Architectural Metal Work Manufacturing	39	155	-	46	$242,241	$28,398	$77,315	$105,713
332439	Other Metal Container Manufacturing	7	27	-	8	$42,041	$4,929	$13,418	$18,347
332919	Other Metal Valve and Pipe Fitting Manufacturing	3	11	-	3	$17,044	$1,998	$5,440	$7,438
332999	All Other Miscellaneous Fabricated Metal Product	33	134	-	40	$209,800	$24,595	$66,961	$91,556
333111	Farm Machinery and Equipment Manufacturing	20	80	-	24	$124,979	$14,651	$39,889	$54,540
333414a	Heating Equipment (except Warm Air Furnaces) Manufacturing	6	24	-	7	$37,475	$4,393	$11,961	$16,354
333911	Pump and Pumping Equipment Manufacturing	7	27	-	8	$41,621	$4,879	$13,284	$18,163
333922	Conveyor and Conveying Equipment Manufacturing	9	36	-	11	$56,564	$6,631	$18,053	$24,684
333924	Industrial Truck, Tractor, Trailer, and Stacker Machinery	4	17	-	5	$27,262	$3,196	$8,701	$11,897
333999	All Other Miscellaneous General Purpose Machinery	18	71	-	21	$111,087	$13,023	$35,455	$48,478
336211	Motor Vehicle Body Manufacturing	15	60	-	18	$93,855	$11,003	$29,955	$40,958
336214	Travel Trailer and Camper Manufacturing	14	55	-	16	$86,392	$10,128	$27,573	$37,701
336399a	All Other Motor Vehicle Parts Manufacturing	7	30	-	9	$46,308	$5,429	$14,780	$20,208
336510	Railroad Rolling Stock	3	11	-	3	$16,958	$1,988	$5,412	$7,400
336999	All Other Transportation Equipment Manufacturing	4	14	-	4	$22,451	$2,632	$7,165	$9,797
337215	Showcase, Partition, Shelving, and Locker Manufacturing	3	13	-	4	$20,478	$2,401	$6,536	$8,937
811310	Commercial and Industrial Machinery and Equipment Repair	143	571	-	170	$894,511	$104,864	$285,497	$390,361
	Total	**492**	**1,970**	**0**	**586**	**$3,086,272**	**$361,805**	**$985,030**	**$1,346,835**
Source: OSHA, Office of Regulatory Analysis.									

DENTAL LABORATORIES

Some dental laboratories use beryllium alloys in the oral appliances they manufacture. Some of the manufacturing processes—including grinding, polishing, abrasive blasting, and melting metal beryllium alloys— may generate significant exposures among technicians. For those employers currently using beryllium alloys, two options are available to comply with the requirements of the proposed standard. Employers can either substitute a product which does not contain beryllium, or they can continue to work with beryllium alloys and comply with the proposed standard's provisions.[376]

During the Small Business Advocacy Review panel, Small Entity Representatives (SERs) informed OSHA that dental labs using beryllium typically use ventilation controls for processes that can result in workers being exposed to beryllium. However, SERs reported that these controls may not be HEPA-filtered or vented to the outside, which the Agency has concluded is necessary to control exposure. OSHA believes it is reasonable to estimate that the dental laboratories most likely to opt for substitution are those with the highest exposures and that those laboratories with exposures below the proposed PEL have already invested in the necessary engineering controls. However, the Agency acknowledges the possibility that, for some dental labs (for example, those processing the highest volume of beryllium-containing alloys per technician), it might be less expensive to institute LEV and comply with the ancillary provisions than to substitute materials.[377] OSHA invites comment on this point, and has provided a

[376] As indicated in Chapter III: Industry Profile of this PEA, based on current market developments, dental labs may often find shifting to ceramic dental prosthetics to be the most economic option in the long run.

[377] To the extent this is true, it would require a more nuanced approach to determine which dental labs, and what percentage, choose to opt for substitution—beyond OSHA's assumption, made above, that the dental laboratories most likely to opt for substitution are those with the highest exposures. (See the related benefits

sensitivity analysis in Chapter VII addressing a scenario if controls are used instead of substitution.

Based on the technological feasibility analysis, the Agency has estimated that all dental laboratories with exposure above 0.1 $\mu g/m^3$ and an additional 5.3 percent of laboratories exposed below 0.1 $\mu g/m^3$ would substitute to beryllium-free alloys, so that after the beryllium rule took effect, 75 percent of dental labs would not be working with beryllium.[378] Of the 25 percent of dental labs continuing to use beryllium, the Agency estimates that these laboratories will have low levels of beryllium exposures due to the engineering controls they have already implemented. Because of this, OSHA estimates that no dental laboratories would require additional engineering controls, although the laboratories that continue to work with beryllium-containing alloys would incur costs, as discussed later in this chapter, to come into compliance with the ancillary provisions.

OSHA estimates that the cost to substitute to beryllium-free alloys consists of the price differential between beryllium-free alloys and alloys that contain beryllium, plus additional training needed to teach dental technicians how to cast the beryllium-free alloys. As indicated in Chapter III: Industry Profile of this PEA, ERG interviewed consultants in the dental laboratory market industry who estimated that roughly 60 percent of dental prosthetics are made from

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discussion and sensitivy analysis in Chapter VII of this PEA.) To the extent that commenters believe that substitution would not occur, OSHA invites comment on the LEV and other engineering controls and the associated unit cost esimates as they would apply to dental labs.

[378] OSHA explored the cost of putting in LEV instead of substitution. The Agency costed an enclosure for 2 technicians: the Powder Safe Type A Enclosure, 32 inch wide with HEPA filter, AirClean Systems (2011), which including operating and maintenance, was annualized at $411 per worker. This is significantly higher than the annual cost for substitution of $166 per worker, shown later in this section. The Agency recognizes that these estimates are averages and that a more complicated analysis—see the preceding footnote—might yield different results. OSHA invites comment on these cost estimates.

metals and 40 percent are made from ceramics (Cascone, 2012). The consultants estimated that half of the dental laboratory market for metals is precious metals (gold, etc.), while the other half is base metals (nickel, chromium, etc.). Of the share of the market that is base metals, 90 percent is estimated to contain beryllium (Cascone, 2012). Based on these estimates, OSHA has calculated that beryllium-containing metals account for 27 percent (0.6 x 0.5 x 0.9) of the materials purchased by makers of dental appliances. In order to simplify the remaining calculations, that estimate has been rounded down to 25 percent.

The same industry consultants indicated that Ni-Cr-Be alloys are most frequently used to manufacture crowns and multi-unit crowns or bridges (Cascone, 2012; O'Brien, 2002). ERG interviewed suppliers of dental alloys and found that they frequently offer a beryllium-free Ni-Cr alloy for a slightly higher price (Cascone, 2012; Nowak, 2012; CMP, 2013). Alloy manufacturers noted that the prices of these two groups of alloys have remained fairly stable since 2010 and that they expect this trend to continue (Cascone, 2013; CMP, 2013). Neither consultants nor literature indicated a significant difference in performance of beryllium-free Ni-Cr alloys and Ni-Cr-Be alloys. The only significant difference is that beryllium-free alloys are somewhat more difficult to cast (Cascone, 2013; Wassell, et al., 2010; Wataha, 2002; Bezzon, et al., 1998; Leinfelder, 1997).

OSHA determined from discussions with an industry consultant that two hours was an adequate amount of time to train dental technicians to work with beryllium-free alloys (Cascone, 2013b). Based on the large share of dental laboratories with fewer than 20 employees and evidence both from the American Dental Association (ADA, 2011) and an industry consultant (Cascone, 2013a) that most dental laboratories using beryllium are small entities, the Agency estimated that only two dental technicians would be trained in each training session. The wage for a dental technician is $24.91 per hour (Dental Laboratory Technician, SOC: 51-9081), while the trainer's wage is $37.11 per hour (First-Line Supervisors of Production and Operating Workers, SOC: 51-1011). The total cost for training two dental technicians per facility is then $173.86 ((2 x 2 x $24.91) + (2 x $37.11)), or $86.93 per dental technician ($173.86/2). Annualized over ten years, this cost per worker is $10.19 per year.

To determine the difference in total cost between using beryllium-free alloys and those with beryllium, OSHA examined both the quantities used and the difference in cost. Consultants estimated that approximately 16 million crown units are made from base metal alloys each year and that one ounce of base metal yields 20 crowns (Cascone, 2012). Based on these estimates, OSHA calculates that 800,000 (16,000,000/20) ounces of base metal alloys are sold to dental appliance makers in a given year. Using the prior estimate that 90 percent of base metal alloys sold contain beryllium, this means that 720,000 (0.9 x 800,000) ounces of beryllium-containing base-metal alloys are sold to dental appliance manufacturers each year. An ounce of beryllium-free Ni-Cr costs $20.50 and an ounce of Ni-Cr-Be costs $18.50, resulting in a $2.00 price differential between beryllium-free Ni-Cr and Ni-Cr-Be alloys (Cascone, 2004). At $2.00 an ounce, the aggregate cost of purchasing beryllium-free alloys instead of beryllium-containing alloys is $1,440,000 (720,000 x $2) each year.

OSHA estimated that 75 percent of dental laboratories would substitute away from beryllium-containing alloys due to the combined cost of installing engineering controls and complying with the ancillary provisions of the proposed standard. With this substitution rate, the aggregate cost to purchase beryllium-free alloys, instead of beryllium-containing alloys, would be reduced to $1,080,000 (0.75 x $1,440,000) per year. From Chapter III: Industry Profile of this PEA, there are 9,255 dental technicians with beryllium exposure, and with a proportional allocation, 6,941 technicians will substitute to beryllium-free alloys (.75 x 9,255). This gives a per-technician substitution cost of $155.59 (1,080,000/6,941) per year. Including training costs, the total annual per technician cost of substitution is $165.78 ($155.59 + $10.19). This yields a total annualized cost for dental laboratories of $1,150,739. Job categories within this application group work in different NAICS industries. Total costs for each job category were allocated across these different NAICS industries by their share of establishments within this application group, and are so presented in Table V-10 below.

Table V-10

Engineering Control Costs for Dental Laboratories, by NAICS industry

NAICS	Industry	Occupation Group	Affected Establishments	Affected Employees	Establishment-Based Costs – Number of Establishments Needing Controls	Employee-Based Costs – Number of Employees Needing Controls	Initial Capital Costs	Annualized Capital Costs	Operating and Maintenance Costs	Total Annualized Costs
339116	Dental laboratories	Technician	1,749	8,148	-	6,111	$0	$0	$1,013,143	$1,013,143
621210	Offices of dentists	Technician	238	1,107	-	830	$0	$0	$137,596	$137,596
	Total		**1,986**	**9,255**	**0**	**6,941**	**$0**	**$0**	**$1,150,739**	**$1,150,739**

Source: OSHA, Office of Regulatory Analysis.

Respiratory Protection Costs

Based on the findings of the technological feasibility analysis, a small subset of employees working with a few processes in a handful of application groups will need to use respirators, in addition to required engineering controls and improved work practices, to reduce employee exposures to meet the proposed PEL. Specifically, furnace operators—both in non-ferrous foundries (both sand and non-sand) and in secondary smelting, refining, and alloying—as well as welders in a few other processes, will need to wear half-mask respirators. In beryllium production, workers who rebuild or otherwise maintain furnaces and furnace tools will need to wear full-face powered air-purifying respirators. Finally, the Agency recognizes the possibility that, after all feasible engineering and other controls are in place, there may still be a residual group with potential exposure above the proposed PEL and/or STEL. To account for these residual cases, OSHA estimates that 10 percent of the workers, across all application groups and job categories, who are above the proposed PEL before the beryllium proposed standard is in place (according to the baseline exposure profile presented in Chapter III of this PEA), would still be above the PEL after all feasible controls are implemented and, hence, would need to use half-mask respirators to achieve compliance with the proposed PEL.

There are five primary costs for respiratory protection. First, there is a cost per establishment to set up a written respirator program in accordance with the respiratory protection standard (29 CFR 1910.134). The respiratory protection standard requires written procedures for the proper selection, use, cleaning, storage, and maintenance of respirators. OSHA estimates that these procedures will take a human resources manager 8 hours to develop, at an hourly wage of

$70.44 (Human Resources Managers, SOC: 11-3121), for an initial cost of $564 (8 x $70.44). Every year thereafter, OSHA estimates that the same employee will take 2 hours to update the respirator program, for an annual cost of $141 (2 x $70.44). OSHA annualized the initial program cost over 10 years, yielding an annualized per-establishment cost for a written respirator program of $207.

ERG's research indicates that, for reasons unrelated to the proposed standard, certain establishments will already have a respirator program in place. Based on this research, table V-11 below presents OSHA's estimates, by application group, of current levels of compliance with the respirator program provision of the proposed rule.

Table V-11 Rates of Compliance with the Respirator Program Requirements of the Proposed Beryllium Standard, by Application Group	
Application Group	**Percent Compliant**
Beryllium Production	100%
Beryllium Oxide Ceramics and Composites	
Primary	50%
Secondary	50%
Nonferrous Foundries	
Non sand-casting foundries	50%
Sand-casting foundries	50%
Secondary Smelting, Refining, and Alloying	
Smelting of beryllium alloys	50%
Smelting of precious metals	50%
Precision Machining	
Machining of high-content beryllium metals	50%
Machining of low content beryllium metals	50%
Copper Rolling, Drawing and Extruding	
Drawing	50%
Rolling	50%
Stamping, Spring, & Connector Manufacturing	
Spring manufacturing	25%
Stamping	25%
Arc and Gas Welding	25%
Resistance Welding	0%
Dental Laboratories	50%
Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis.	

The four other major costs of respiratory protection are the per-employee costs for all aspects of respirator use: equipment, training, fit-testing, and cleaning. Table V-12 breaks out OSHA's estimate of the unit costs for the two types of respirators needed: a half-mask respirator and a full-face powered air-purifying respirator.[379] These unit costs are further described below in the text.

[379] Retail costs are based on an average of price quotes found in the market. References are given in the text for the all priced items that make up the final average.

Table V-12

Unit Respiratory Protection Costs

Respirator Fit Test and Training Assumptions					
Training					
Class size		4			
Employee Wage		$22.16			
Supervisor wage		$37.11			
Cost per employee per hour of training		$31.44			
		Half-mask resp	**PAPR**		
Fit Testing		Qualitative	Quantitative		
Testing group size		4	2		
Employee hours		1	2		
Employee Wage		$22.16	$22.16		
Supervisor wage		$37.11	$37.11		
Cost per employee		$31.44	$81.43		
Respirator Cleaning Costs					
Frequency per year		125			
time (hours)		0.08			
labor rate		$22.16			
Yearly cost		$230.85			
Cost Items and Assumptions			**Half-Mask Respirator**		**PAPR**
Equipment Cost			$29.32		$845.50
Equipment service life (years)			2		3
Annualized equipment cost			$15.32		$298.91
Accessory annual cost			$183.20		$510.46
Total annualized equipment costs			$198.53		$809.37
Training hours			2		4
Annual training Cost			$62.88		$125.76
Annual fit test cost			$31.44		$81.43
Respirator cleaning			$230.85		$0.00
Total annualized costs			$523.69		$1,016.56
Equipment			$198.53		$809.37
Training + Fit Test + Cleaning			$325.16		$207.19
Respirator Program Unit Costs					
Program development (hours)					
	Hours			8	
	Labor value			$564	
Program Updates					
	Hours			2	
	Labor value			$141	
Annualized cost per establishment				$207	

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis.

A half-mask respirator is estimated to cost $29.32 [380] and to have a service life of two years, yielding an estimated annualized cost of $15.32. OSHA estimates that 100 disposable filters would be needed each year at a cost of $183.20.[381] Therefore, total annualized half-mask equipment costs (for respirator and filters) are $198.53 ($15.32 + $183.20). Annual training for respirator use is estimated to be done for a class size of 4, where each trainee's hourly wage is $22.16 (Production Occupations, SOC: 51-0000) and the trainer's wage is $37.11 (First-Line Supervisors of Production and Operating Workers, SOC: 51-1011). This results in a per-employee hourly training cost of $31.44 ($22.16 + ($37.11/4)). Half-mask respirator training is estimated to last 2 hours, so the per-employee annual training cost is estimated to be $62.88 (2 x $31.44). Fit-testing will need to be done annually and is estimated to have the same parameters as for training: it will be done in groups of four, and wage rates will be the same. Fit testing, however, is estimated to take only one hour, so the annual cost would be $31.44 per worker. The final half-mask respirator cost is periodic cleaning, which is estimated to be needed every two days, or 125 times annually (250/2). Each cleaning is estimated to take 5 minutes, or 0.08 (5/60) hours, and the wage cost per hour is $22.16 ((Production Occupations, SOC: 51-0000). Multiplied together, this gives an annual respirator cleaning cost of $230.85 (125 x 0.08 x $22.16). Summing these various respirator costs together yields an annualized per-employee cost for a half-mask respirator of $523.69 ($198.53 + $62.88 + $31.44 + $230.85).

[380] Based on the average of North, 3M, and Wilson respirator costs (Magidglove, 2012; Grainger, 2012e; Restockit, 2012; and Spectrumchemical, 2012).

[381] Based on the average of North and 3M filter prices (Conney, 2012a; Conney, 2012b; and Zorotools, 2012a).

A full-face powered air-purifying respirator (PAPR) is estimated to cost $848.50[382] and to have a service life of three years, yielding an annualized cost of $298.91. The annual cost for a cartridge, a breathing tube, and replacement parts is $510.46,[383] for a total annualized equipment cost of $809.37 ($298.91 + $510.46). Class size and wage costs are the same as for the half-mask respirator (see above), so the per-employee hourly training cost is $31.44. But the increased complexity of the full-mask respirator means that four hours of training are needed; therefore the per-employee annual training cost is $125.76 (4 x 31.44). Two hours are estimated to be needed for fit testing, which will be done in groups of two (with all else the same as for half-mask respirators). Therefore, the per-employee annual fit-testing cost is $81.43 (2 x ($22.16 + ($37.11/2)). Because PAPRs are expected to be assigned to individual workers, no respirator cleaning is required. Summing these costs together, the total annualized per-employee cost for a full-face powered air-purifying respirator is $1,016.56 ($809.37 + $125.76 + $81.43).

Table V-13 presents the number of additional employees by application group and NAICS industry that will need to wear respirators to comply with the proposed standard and the cost to industry to supply those respirators and to comply with the other respirator protection provisions in the proposed rule. OSHA estimates that only the workers in Beryllium Production work with processes that would require a full-face respirator would need additional respiratory protection and that there are 23 of those workers. Three hundred and eighteen workers in other assorted application groups are estimated to need half-mask respirators. A total of 341 (23 + 318)

[382] Based on the average of GVP and 3M respirator costs as listed on (Gemplers, 2012; Buyingdirect, 2012).

[383] Based on the cost of 3M replacement visors, breathing tubes, and cartridges, as listed on (Amazon, 2013; Zorotools, 2013; Grainger, 2013; Envirosafety, 2013). Cost for breathing tubes is an average of (Zorotools, 2013; Grainger, 2013) and all costs are deflated to 2010 dollars.

employees will need to wear some type of respirator, resulting in a total annualized cost of $249,684 for affected industries to comply with the respiratory protection requirements of the proposed standard.

Table V-13

Number of Workers Needing Respirators, by Application Group and NAICS Industry

NAICS code	Industry	Workers Needing Full-Face Respirators	Workers Needing Half-Mask Respirators	Total Workers Needing Respirators	Total Respirator Cost
Beryllium Production		23		23	$23,381
331419	Primary smelting and refining of nonferrous metals	23		23	$23,381
Beryllium Oxide Ceramics and Composites			25	25	$13,989
327113a	Porcelain electrical supply manufacturing (primary)		5	5	$2,702
327113b	Porcelain electrical supply manufacturing (secondary)		3	3	$1,744
334220	Cellular telephones manufacturing		2	2	$1,246
334310	Compact disc players manufacturing		1	1	$675
334411	Electron tube manufacturing		5	5	$2,617
334415	Electronic resistor manufacturing		3	3	$1,495
334419	Other electronic component manufacturing		2	2	$1,132
334510	Electromedical equipment manufacturing		2	2	$1,132
336322b	Other motor vehicle electrical and electronic equipment manufacturing		2	2	$1,246
Nonferrous Foundries			105	105	$55,522
331521	Aluminum die-casting foundries		7	7	$4,054
331522	Nonferrous (except aluminum) die-casting foundries		39	39	$20,709
331524	Aluminum foundries (except die-casting)		7	7	$4,003
331525a	Copper foundries (except die-casting) (non-sand casting foundries)		21	21	$10,949
331525b	Copper foundries (except die-casting) (sand casting foundries)		30	30	$15,807
Secondary Smelting, Refining, and Alloying			39	39	$21,334
331314	Secondary smelting & alloying of aluminum		6	6	$3,246
331421b	Copper rolling, drawing, and extruding		6	6	$3,246
331423	Secondary smelting, refining, & alloying of copper		18	18	$9,820
331492	Secondary smelting, refining, & alloying of nonferrous metal (except copper & aluminum)		9	9	$5,024
Precision Turned Products			70	70	$39,731
332721a	Precision turned product manufacturing (high beryllium content)		17	17	$8,864
332721b	Precision turned product manufacturing (low beryllium content)		53	53	$30,866
Copper Rolling, Drawing, and Extruding			56	56	$30,102
331421a	Copper rolling, drawing, and extruding		3	3	$1,677
331422	Copper wire (except mechanical) drawing		53	53	$28,425
Fabrication of Beryllium Alloy Products			25	25	$22,195
332612	Light gauge spring manufacturing		7	7	$8,874
332116	Metal stamping		5	5	$3,531
334417	Electronic connector manufacturing		3	3	$2,204

Table V-13, continued					
Number of Workers Needing Respirators, by Application Group and NAICS Industry					
NAICS code	**Industry**	**Workers Needing Full-Face Respirators**	**Workers Needing Half-Mask Respirators**	**Total Workers Needing Respirators**	**Total Respirator Cost**
336322a	Other motor vehicle electrical & electronic equipment		10	10	$7,586
Arc and Gas Welding			66	66	$43,431
331111	Iron and steel mills		1	1	$679
331221	Rolled steel shape manufacturing		1	1	$679
331513	Steel foundries (except investment)		1	1	$679
332117	Powder metallurgy part manufacturing		1	1	$679
332212	Hand and edge tool manufacturing		1	1	$679
332312	Fabricated structural metal manufacturing		7	7	$4,352
332313	Plate work manufacturing		3	3	$1,645
332322	Sheet metal work manufacturing		8	8	$5,330
332323	Ornamental and architectural metal work manufacturing		5	5	$3,007
332439	Other metal container manufacturing		1	1	$679
332919	Other metal valve and pipe fitting manufacturing		1	1	$679
332999	All other miscellaneous fabricated metal product manufacturing		4	4	$2,604
333111	Farm machinery and equipment manufacturing		2	2	$1,551
333414a	Heating equipment (except warm air furnaces) manufacturing		1	1	$679
333911	Pump and pumping equipment manufacturing		1	1	$679
333922	Conveyor and conveying equipment manufacturing		1	1	$717
333924	Industrial truck, tractor, trailer, and stacker machinery manufacturing		1	1	$679
333999	All other miscellaneous general purpose machinery manufacturing		2	2	$1,379
336211	Motor vehicle body manufacturing		2	2	$1,165
336214	Travel trailer and camper manufacturing		2	2	$1,072
336399a	All other motor vehicle parts manufacturing		1	1	$679
336510	Railroad rolling stock		1	1	$679
336999	All other transportation equipment manufacturing		1	1	$679
337215	Showcase, partition, shelving, and locker manufacturing		1	1	$679
811310	Commercial and industrial machinery and equipment repair		17	17	$11,103
	Total	**23**	**384**	**407**	**$249,684**
Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis.					

Annualized Cost of Complying with the Proposed PEL/STEL

Table V-14 presents a summary of the total annualized costs for affected firms to meet the proposed beryllium PEL/STEL. As shown, these costs are disaggregated by engineering controls and work practices and by respiratory protection, as well as by application group and six-digit NAICS industry.

Table V-14

Annualized Costs to Industries Affected by the Proposed Beryllium Standard, by Application Group and Six-Digit NAICS

NAICS code	Industry	Engineering Controls and Work Practices	Respirator Costs	Total Costs
Beryllium Production				
331419	Primary smelting and refining of nonferrous metals	$1,188,758	$23,381	$1,212,139
Beryllium Oxide Ceramics and Composites				
327113a	Porcelain electrical supply manufacturing (primary)	$175,546	$2,702	$178,248
327113b	Porcelain electrical supply manufacturing (secondary)	$72,102	$1,744	$73,847
334220	Cellular telephones manufacturing	$51,502	$1,246	$52,748
334310	Compact disc players manufacturing	$25,751	$675	$26,426
334411	Electron tube manufacturing	$108,154	$2,617	$110,770
334415	Electronic resistor manufacturing	$61,802	$1,495	$63,297
334419	Other electronic component manufacturing	$46,352	$1,132	$47,483
334510	Electromedical equipment manufacturing	$46,352	$1,132	$47,483
336322b	Other motor vehicle electrical and electronic equipment manufacturing	$51,502	$1,246	$52,748
Nonferrous Foundries				
331521	Aluminum die-casting foundries	$182,887	$3,899	$186,786
331522	Nonferrous (except aluminum) die-casting foundries	$992,813	$20,999	$1,013,812
331524	Aluminum foundries (except die-casting)	$182,887	$3,899	$186,786
331525a	Copper foundries (except die-casting) (non-sand casting foundries)	$522,533	$11,052	$533,585
331525b	Copper foundries (except die-casting) (sand casting foundries)	$682,229	$15,962	$698,191
Secondary Smelting, Refining, and Alloying				
331314	Secondary smelting & alloying of aluminum	$19,186	$3,246	$22,432
331421b	Copper rolling, drawing, and extruding	$19,186	$3,246	$22,432
331423	Secondary smelting, refining, & alloying of copper	$57,558	$9,530	$67,088
331492	Secondary smelting, refining, & alloying of nonferrous metal (except copper & aluminum)	$287,789	$5,024	$292,813
Precision Turned Products				
332721a	Precision turned product manufacturing (high beryllium content)	$162,739	$8,864	$171,603
332721b	Precision turned product manufacturing (low beryllium content)	$888,502	$30,866	$919,368
Copper Rolling, Drawing and Extruding				
331421a	Copper rolling, drawing, and extruding	$23,656	$1,677	$25,334
331422	Copper wire (except mechanical) drawing	$96,231	$28,425	$124,656
Fabrication of Beryllium Alloy Products				
332612	Light gauge spring manufacturing	$588,200	$8,874	$597,074
332116	Metal stamping	$134,748	$3,531	$138,279
334417	Electronic connector manufacturing	$84,126	$2,204	$86,331
336322a	Other motor vehicle electrical & electronic equipment	$289,526	$7,586	$297,112

Table V-14, continued				
Annualized Costs to Industries Affected by the Proposed Beryllium Standard, by Application Group and Six-Digit NAICS				
NAICS code	Industry	Engineering Controls and Work Practices	Respirator Costs	Total Costs
Arc and Gas Welding				
331111	Iron and steel mills	$18,123	$679	$18,802
331221	Rolled steel shape manufacturing	$3,766	$679	$4,445
331513	Steel foundries (except investment)	$3,705	$679	$4,384
332117	Powder metallurgy part manufacturing	$2,489	$679	$3,168
332212	Hand and edge tool manufacturing	$7,979	$679	$8,658
332312	Fabricated structural metal manufacturing	$153,001	$4,352	$157,353
332313	Plate work manufacturing	$57,841	$1,645	$59,486
332322	Sheet metal work manufacturing	$187,400	$5,330	$192,730
332323	Ornamental and architectural metal work manufacturing	$105,713	$3,007	$108,720
332439	Other metal container manufacturing	$18,347	$679	$19,026
332919	Other metal valve and pipe fitting manufacturing	$7,438	$679	$8,117
332999	All other miscellaneous fabricated metal product manufacturing	$91,556	$2,604	$94,160
333111	Farm machinery and equipment manufacturing	$54,540	$1,551	$56,092
333414a	Heating equipment (except warm air furnaces) manufacturing	$16,354	$679	$17,033
333911	Pump and pumping equipment manufacturing	$18,163	$679	$18,842
333922	Conveyor and conveying equipment manufacturing	$24,684	$717	$25,402
333924	Industrial truck, tractor, trailer, and stacker machinery	$11,897	$679	$12,576
333999	All other miscellaneous general purpose machinery manufacturing	$48,478	$1,379	$49,857
336211	Motor vehicle body manufacturing	$40,958	$1,165	$42,123
336214	Travel trailer and camper manufacturing	$37,701	$1,072	$38,773
336399a	All other motor vehicle parts manufacturing	$20,208	$679	$20,887
336510	Railroad rolling stock	$7,400	$679	$8,079
336999	All other transportation equipment manufacturing	$9,797	$679	$10,476
337215	Showcase, partition, shelving, and locker manufacturing	$8,937	$679	$9,616
811310	Commercial and industrial machinery and equipment repair	$390,361	$11,103	$401,464
Resistance Welding				
333411	Air purification equipment manufacturing	$0	$0	$0
333412	Industrial and commercial fan and blower manufacturing	$0	$0	$0
333414b	Heating equipment (except warm air furnaces) manufacturing	$0	$0	$0
333415	Air-conditioning, warm air heating, and industrial refrigeration equipment manufacturing	$0	$0	$0
335211	Electric housewares and household fan manufacturing	$0	$0	$0
335212	Household vacuum cleaner manufacturing	$0	$0	$0
335221	Household cooking appliance manufacturing	$0	$0	$0
335222	Household refrigerator and home freezer manufacturing	$0	$0	$0
335224	Household laundry equipment manufacturing	$0	$0	$0
335228	Other major household appliance manufacturing	$0	$0	$0

Table V-14, continued				
Annualized Costs to Industries Affected by the Proposed Beryllium Standard, by Application Group and Six-Digit NAICS				
NAICS code	Industry	Engineering Controls and Work Practices	Respirator Costs	Total Costs
Resistance Welding				
336311	Carburetor, piston, piston ring, and valve manufacturing	$0	$0	$0
336312	Gasoline engine and engine parts manufacturing	$0	$0	$0
336321	Vehicular lighting equipment manufacturing	$0	$0	$0
336322c	Other motor vehicle electrical and electronic equipment manufacturing	$0	$0	$0
336330	Motor vehicle steering and suspension components (except spring) manufacturing	$0	$0	$0
336340	Motor vehicle brake system manufacturing	$0	$0	$0
336350	Motor vehicle transmission and power train parts manufacturing	$0	$0	$0
336360	Motor vehicle seating and interior trim manufacturing	$0	$0	$0
336370	Motor vehicle metal stamping	$0	$0	$0
336391	Motor vehicle air-conditioning manufacturing	$0	$0	$0
336399b	All other motor vehicle parts manufacturing	$0	$0	$0
Dental Laboratories				
339116	Dental laboratories	$1,013,143	$0	$1,013,143
621210	Offices of dentists	$137,596	$0	$137,596
	Total	**$9,540,189**	**$249,684**	**$9,789,873**
Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis.				

PROGRAM COSTS AND DEFINITIONS OF AFFECTED WORKER POPULATIONS

This section presents OSHA's estimated costs for ancillary beryllium control programs required under the proposed rule. Based on the program requirements contained in the proposed standard, OSHA considered nine potential cost elements in the following employer duties: (1) assess employees' exposure to airborne beryllium, (2) establish regulated areas, (3) develop a written exposure control plan, (4) provide protective work clothing, (5) establish hygiene areas and practices, (6) implement housekeeping measures, (7) provide medical surveillance, (8) provide medical removal for employees who have developed CBD or been confirmed positive for beryllium sensitization, and (9) provide appropriate training.

The worker population affected by each program element varies by several criteria discussed in detail in each subsection below. In general, some elements would apply to all workers exposed to beryllium at or above the action level. Other elements would apply to a smaller set of workers who are exposed above the PEL. The training requirements would apply to all employees who work in a beryllium work area (e.g., an area with any level of exposure to airborne beryllium). The regulated area program elements triggered by the proposed PEL of 0.2 $\mu g/m^3$ would apply to those workers for whom feasible controls are not adequate. In the earlier discussion of respiratory protection, OSHA estimated that 10 percent of all affected workers with current exposures above the proposed PEL would fall in this category.

Costs for each program requirement are aggregated by employment and by industry. For the most part, unit costs do not vary by industry, and any variations are specifically noted.

Current Compliance Rates

The current levels of baseline compliance rates for each provision were estimated based on site visits, industry contacts, published literature, and the Final Report of the Small Business Advocacy Review (SBAR) Panel (SBAR 2008). As part of the SBAR Panel, small entity representatives (SERs) reported current compliance measures present in their respective industries. Based on information provided by ERG experts, the Agency believes the application groups copper rolling, drawing & extruding; precision turned products; and beryllium oxide ceramics & composites are currently undertaking some of the required actions with respect to three of the ancillary provisions: exposure assessment, regulated areas, and medical surveillance. SERs who make products from materials with high beryllium content as an important part of their business, as well as a SER from a precious metal recovery and recycling employer, indicated that they performed considerable air sampling for exposure monitoring purposes (SBAR, 2008, p. 9).

OSHA estimates that at least some percentage of firms affected by the proposed rulemaking are currently complying with the training and housekeeping requirements in the majority of application groups. The estimated compliance rate for each provision of the proposed standard by application group, based on information provided by ERG, is presented in Table V-15, below.

Table V-15

Rates of Compliance with the Ancillary Provisions of the Proposed Beryllium Standard

Application Group	Exposure Assessment	Regulated Areas	Written Exposure Control Plan	Protective Work Clothing & Equipment*	Hygiene Areas and Practices*	House-keeping	Medical Surveillance	Medical Removal Provision	Training
Beryllium Production	100%	100%	100%	--	--	100%	100%	0%	100%
Beryllium Oxide Ceramics and Composites				--	--			0%	
Primary	50%	50%	50%	--	--	50%	50%	0%	50%
Secondary	0%	0%	0%	--	--	25%	0%	0%	25%
Aluminum and Copper Foundries				--	--			0%	
Non sand-casting foundries	0%	0%	0%	--	--	25%	0%	0%	25%
Sand-casting foundries	0%	0%	0%	--	--	25%	0%	0%	25%
Secondary Smelting, Refining, and Alloying				--	--			0%	
Smelting of beryllium alloys	0%	0%	0%	--	--	25%	0%	0%	25%
Smelting of precious metals	0%	0%	0%	--	--	25%	0%	0%	25%
Precision Turned Products				--	--			0%	
Machining of high-content beryllium metals	50%	25%	25%	--	--	50%	25%	0%	50%
Machining of low content beryllium metals	0%	0%	0%	--	--	25%	0%	0%	25%
Copper Rolling, Drawing and Extruding				--	--			0%	
Drawing	25%	25%	25%	--	--	25%	25%	0%	25%
Rolling	25%	25%	25%	--	--	25%	25%	0%	25%
Fabrication of Beryllium Alloys Products				--	--			0%	
Spring manufacturing	0%	0%	0%	--	--	0%	0%	0%	0%
Stamping	0%	0%	0%	--	--	0%	0%	0%	0%
Arc and Gas Welding	0%	0%	0%	--	--	0%	0%	0%	0%
Resistance Welding	0%	0%	0%	--	--	0%	0%	0%	0%
Dental Laboratories	0%	0%	0%	--	--	25%	0%	0%	25%

*Compliance rates for protective work clothing & equipment and the hygiene program element estimated separately, by job category, not by sector

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis.

EXPOSURE ASSESSMENT

Most establishments wishing to perform exposure monitoring would require the assistance of an outside consulting industrial hygienist (IH) to obtain accurate results. While some firms might already employ or train qualified staff, OSHA judged that the testing protocols are fairly challenging and that few firms have sufficiently skilled staff to eliminate the need for outside consultants (ERG, 2007b).

The proposed standard requires that, after receiving the results of any exposure monitoring where exposures exceed the TWA PEL or STEL, the employer notify each such affected employee in writing of suspected or known sources of exposure, and the corrective action(s) being taken to reduce exposure to or below the PELs. Those workers exposed at or above the action level and at or below the PEL must have their exposure levels monitored annually.

For costing purposes, based on ERG (2007b), OSHA estimates that, on average, there are four workers per work area. OSHA interpreted the initial exposure assessment as requiring first-year testing of at least one worker in each distinct job classification and work area who is, or may reasonably be expected to be, exposed to airborne concentrations of beryllium at or above the action level.

The proposed standard requires that whenever there is a change in the production, process, control equipment, personnel, or work practices that may result in new or additional exposures, or when the employer has any reason to suspect that a change may result in new or additional exposures, the employer must conduct additional monitoring. The Agency has estimated that this provision would require an annual sampling of 10 percent of the affected workers.

OSHA estimates that an industrial hygienist (IH) would spend one day each year—at a cost of $513.43, based on the professional judgment of an IH (ERG, 2007b), brought forward to 2010 dollars—to sample 2 workers, for a per worker IH fee of $257 ($513/2). This exposure monitoring requires that three samples be taken per worker: one TWA and two STEL for an annual IH fee per sample of $85.57 ($257/3). Based on the 2000 EMSL Laboratory Testing Catalog (ERG, 2007b), OSHA estimated that analysis of each sample would cost $137 in lab fees. When combined with the IH fee, OSHA estimated the annual cost to obtain a TWA sample to be $222.53 ($137 + $85.57) per sampled worker and the annual cost to obtain the two STEL samples to be $445.07 (2 x ($137 + $85.57)) per sampled worker. The direct exposure monitoring unit costs are summarized in Table V-16 below.

Table V-16
Direct Exposure Monitoring Unit Costs

Industrial hygienist daily rate	$513
Total samples collected per day[1]	6
Industrial hygienist cost per sample	$85.50
Laboratory cost to process sample	$137
Total cost per time weighted average sample[2]	$222.50
Total cost for two STEL samples[3]	$445

[1] Assumes two workers sampled per day and three samples (one TWA sample and two STEL samples) taken per worker

[2] Includes the cost for one sample plus laboratory cost to process sample

[3] Includes the cost for two samples plus laboratory costs to process samples

Source: See text. ERG, 2007b, OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis.

The cost of the sample also incorporates a productivity loss due to the additional time for the worker to participate in the sampling (30 minutes per worker sampled)[384] as well as for the associated recordkeeping time incurred by a manager (15 minutes per worker sampled).[385] The STEL samples are assumed to be taken along with the TWA sample and, thus, labor costs were not added to both unit costs. Including the costs related to lost productivity, OSHA estimates the total annual cost of a TWA sample to be $251.22 ($222.53 + $11.08 + $17.61), and 2 STEL samples, $445.07. The total annual cost per worker for all sampling taken is then $696.29 ($251.22 + $445.07). OSHA estimates the total annualized cost of this provision to be $2,208,950 for all affected industries. The annualized cost of this provision for each affected NAICS industry is shown in Table V-19 at the end of this section.

BERYLLIUM WORK AREAS AND REGULATED AREAS

The proposed beryllium standard requires the employer to establish and maintain a regulated area wherever employees are, or can reasonably expected to be, exposed to airborne beryllium at levels above the TWA PEL or STEL. Regulated areas require specific provisions that both limit employee exposure within its boundaries and curb the migration of beryllium outside the area. The Agency judged, based on the preliminary findings of the technological feasibility analysis, that companies can reduce establishment-wide exposure by ensuring that only authorized employees wearing proper protective equipment have access to areas of the establishment where such higher concentrations of beryllium exist, or can be reasonably

[384] Based on the wage rate of $22.16 for a production worker, SOC 51-0000, this productivity cost is estimated to be $11.08 ($22.16 x (30/60)).

[385] Based on a wage rate of $70.44 for a human resources manager, SOC 11-3121, this recordkeeping cost is estimated to be $17.61 ($70.44 x (15/60)).

expected to exist. Workers in other parts of the establishment are also likely to see a reduction in beryllium exposures due to these measures since fewer employees would be traveling through regulated areas and subsequently carrying beryllium residue to other work areas on their clothes and shoes.

Requirements in the proposed rule for a regulated area include: demarcating the boundaries of the regulated area as separate from the rest of the workplace, limiting access to the regulated area, providing an appropriate respirator to each person entering the regulated area and other protective clothing and equipment as required by paragraph (g) and paragraph (h), respectively. OSHA estimated costs for establishing and maintaining regulated areas to comply with these requirements.

OSHA estimated that one regulated area would be established for every 4 employees exposed above the TWA PEL or STEL. The initial set up time by a supervisor is estimated to require eight hours at an hourly wage of $37.11 (First-Line Supervisors of Production and Operating Workers, SOC 51-1011) for a total of $296.88 (8 x $37.11). The annualized cost would be $34.81. Demarcating the regulated area was estimated to require 300 feet of hazard tape at a cost of $25.83—$15.50 per 180 feet (Grainger, 2012a)—so that the total cost is ($15.50 x (300/180)). Demarcation will also need six 6 x 24 inch warning signs, with a per-sign cost of $21.87 (Grainger, 2012b), and hence a total cost of $131.22 (6 x $21.87). The hazard tape will need to be replaced yearly while the signs are estimated to last 10 years. Together these materials have an annualized cost of $41.22. The total annualized cost for setting up a regulated area including labor and supplies is $76.02 ($34.81 + $41.22).

The Agency has estimated an annual cost of $1,767.50 for two disposable respirators per day[386] to be used by authorized persons (other than those who regularly work in the regulated area) who might need to enter the area in the course of their job duties. In addition, for costing purposes, OSHA estimated that in response to the protective work clothing and equipment requirements in regulated areas, employees (other than those who regularly work in the regulated area and would otherwise be covered under the requirements for protective clothing) would, collectively, on average wear two suits of disposable protective clothing daily at $9.00 per suit,[387] with 250 work days per year, this gives an annual cost of $4,500 (2 x 250 x $9.00). Total annualized cost per regulated area including set up costs, respirators and protective clothing is $6,343.52 ($76.02 + $1,767.50 + $4,500).

When establishments are in full compliance with the standard, regulated areas would be required only for those workers for whom controls could not feasibly reduce their exposures to or below the 0.2 $\mu g/m^3$ TWA PEL and the 2 $\mu g/m^3$ STEL. Based on the findings of the technological feasibility analysis, OSHA estimated that 10 percent of the affected workers would be exposed above the TWA PEL or STEL after implementation of engineering controls and thus would require regulated areas (with one regulated area, on average, for every four workers exposed above the proposed TWA PEL or STEL).

The proposed standard requires that all beryllium work areas are adequately established and demarcated. ERG estimated that one work area would need to be established for every 12 at-risk workers. The initial set up time by a supervisor is estimated to require four hours at an

[386] OSHA estimates that a single disposable respirator costs $3.54 (an average of Masksnmore, 2012; Activeforever, 2012; and Globalindustry, 2012). At two regulated area entries per day and a 250-day work-year, this results in an annual cost of $1,767.50. (2 x 250 x $3.54)

[387] This is an average of (Grainger, 2012d) and (Drillspot, 2012).

hourly wage of $37.11 (First-Line Supervisors of Production and Operating Workers, SOC 51-1011) for a total of $148.45 (4 x $37.11). As with regulated areas, six signs would be needed to demarcate each work area, with the same type and costs as for regulated areas (see above). The annualized cost (over 10 years, the life span of the signs) is $32.79 per work area.

OSHA estimates the total annualized cost of the regulated areas and work areas is $629,031 for all affected industries. The cost for each affected NAICS industry is shown in Table V-19 at the end of this section.

WRITTEN EXPOSURE CONTROL PLAN

The proposed standard requires that employers must establish and maintain a written exposure control plan for beryllium work areas. The written program must contain:

1. An inventory of operations and job titles reasonably expected to have exposure.
2. An inventory of operations and job titles reasonably expected to have exposure at or above the action level.
3. An inventory of operations and job titles reasonably expected to have exposure above the TWA PEL or STEL.
4. Procedures for minimizing cross-contamination, including but not limited to preventing the transfer of beryllium between surfaces, equipment, clothing, materials and articles within beryllium work areas.
5. Procedures for keeping surfaces in the beryllium work area free as practicable of beryllium.

6. Procedures for minimizing the migration of beryllium from beryllium work areas to other locations within or outside the workplace.
7. An inventory of engineering and work practice controls required by paragraph (f)(2) of this standard.
8. Procedures for removal, laundering, storage, cleaning, repairing, and disposal of beryllium-contaminated personal protective clothing and equipment, including respirators.

The unit cost estimates below take into account the judgment that (1) most establishments have an awareness of beryllium risks and, thus, should be able to develop or modify existing safeguards in an expeditious fashion, and (2) many operations have limited beryllium activities and these establishments need to make only modest changes in procedures to create the necessary exposure control plan. The unit costs presented include estimates by ERG's experts that managers, earning an hourly wage of $70.44 (Human Resources Managers, SOC: 11-3121), would spend eight hours per establishment to develop and implement such a written exposure control plan. The total cost per establishment to develop and implement the written control plan is then $563.53 ($70.44 x 8), for an annualized cost of $66. In addition, because larger firms with more affected workers will need to develop more complicated written control plans, the development of a plan would require an extra thirty minutes of a manager's time per affected employee, for a cost of $35.22 (0.5 x $70.44) per affected employee and an annualized cost of $4.13 per employee. There are various triggers under which the employer must update the plan and the Agency estimates that, on average, this will occur annually. The agency invites comment on whether this frequency is correct. Managers would also need 12 minutes (0.2 hours) per affected employee per quarter, or 48 minutes (4 x 12), (0.8 hours) per affected employee per year to review and update the plan, for a recurring cost of $56.35 (0.8 x $70.44) per affected employee per year to maintain and update the plan. Five minutes of clerical time would also be needed per employee for providing each employee with a copy of the written exposure control plan. With a clerical wage of $19.97 (File Clerks SOC 43-4071) this is a per employee cost of $1.66. The total annual per-employee cost for development, implementation, review, and update of a written exposure control plan is then $62.14 ($4.13 + $56.35 + $1.66). The Agency estimates the total annualized cost of this provision to be $1,769,506 for all affected establishments. The breakdown of these costs by NAICS code is presented in Table V-19 at the end of this program cost section.

PERSONAL PROTECTIVE CLOTHING AND EQUIPMENT

The proposed standard requires personal protective clothing and equipment for workers:

1. Whose exposure can reasonably be expected to exceed the TWA PEL or STEL.
2. When work clothing or skin may become visibly contaminated with beryllium, including during maintenance and repair activities or during non-routine tasks.
3. Where employees' skin can reasonably be expected to be exposed to soluble beryllium compounds.

OSHA has determined that it would be necessary for employers to provide reusable overalls and/or lab coats at a cost of $283.92 and $86.06, respectively (from Crown Uniform, 2012; Dempsey Uniform, 2012), for operations in the following application groups:

Beryllium Production

Beryllium Oxide, Ceramics & Composites

Nonferrous Foundries

Fabrication of Beryllium Alloy Products

Copper Rolling, Drawing & Extruding

Secondary Smelting, Refining and Alloying

Precision Turned Products

Dental Laboratories

Chemical process operators in the spring and stamping application group would require chemical resistant protective clothing at an annual cost of $848.66 (Grainger, 2012c). Gloves and/or shoe covers would be required when performing operations in several different application groups, depending on the process being performed, at an annual cost of $50 (OSHA estimate) and $78 (Grainger 2012c), respectively.

The proposed standard requires that all reusable protective clothing and equipment be cleaned, laundered, repaired, and replaced as needed to maintain their effectiveness. This includes such safeguards as transporting contaminated clothing in sealed and labeled impermeable bags and informing any third party businesses coming in contact with such materials of the risks associated with beryllium exposure. OSHA estimates that the lowest cost alternative to satisfy this provision is for an employer to rent and launder reusable protective clothing—at an estimated annual cost per employee of $48.62.[388] Ten minutes of clerical time would also be needed per establishment with laundry needs to notify the cleaners in writing of the potentially harmful effects of beryllium exposure and how the protective clothing and equipment must be handled in accordance with this standard. With.a wage of $19.97 (File Clerks SOC 43-4071) this per establishment cost is $3.33.

The Agency estimates the total annualized cost of this provision to be $1,407,365 for all affected establishments. The breakdown of these costs by NAICS code is shown in Table V-19 at the end of this program cost section.

HYGIENE AREAS AND PRACTICES

The proposed standard requires employers to provide readily accessible washing facilities to remove beryllium from the hands, face, and neck of each employee working in a beryllium work area and also to provide a designated change room in workplaces where employees would

[388] This cost is the average of two quotes by uniform/laundry venders obtained by ERG and includes the renting and laundering a set of reusable clothing for one worker (Crown Uniform, 2012; Dempsey Uniform, 2012).

have to remove their personal clothing and don the employer-provided protective clothing. The proposed standard also requires that employees shower at the end of the work shift or work activity if the employee reasonably could have been exposed to beryllium at levels above the PEL or STEL, and if those exposures could reasonably be expected to have caused contamination of the employee's hair or body parts other than hands, face, and neck.

In addition to other forms of PPE costed previously, for processes where hair may become contaminated, head coverings can be purchased at an annual cost of $28.37 per employee (Grainger, 2013a). This could satisfy the requirement to avoid contaminated hair. If workers are covered by protective clothing such that no body parts (including their hair where necessary, but not including their hands, face, and neck) could reasonably be expected to have been contaminated by beryllium, and they could not reasonably be expected to be exposed to beryllium while removing their protective clothing, they would not need to shower at the end of a work shift or work activity. OSHA notes that some facilities already have showers, and the Agency judges that all employers either already have showers where needed or will have sufficient measures in place to ensure that employees could not reasonably be expected to be exposed to beryllium while removing protective clothing. Therefore, OSHA has preliminarily determined that employers will not need to provide any new shower facilities to comply with the standard.[389]

The Agency estimated the costs for the addition of a change room and segregated lockers based on the costs for acquisition of portable structures. The change room is presumed to be used

[389]For information purposes, OSHA estimated the initial cost of installing portable showers at $39,687 (Bert, 2003; updated to 2010 values) with an annualized cost of $4,653 per facility. The annual cost per employee for shower supplies, towels, and time required for showering is $1,519. The Agency believes employers will be able to comply with the standard by less costly means than the installation of show facilities.

in providing a transition zone from general working areas into beryllium-using regulated areas. OSHA estimated that portable structures, adequate for 10 workers per establishment can be rented annually for $3,251 (Lerch, 2003), and that lockers could be procured for a capital cost of $407—or $48 annualized—per establishment (Lab Safety, 2004). This results in an annualized cost of $3,299 ($3,251 + $48) per facility to rent a portable change room with lockers. OSHA estimates that the 10 percent of affected establishments unable to meet the proposed TWA PEL would require change rooms. The Agency expects that, in many cases, a worker would simply be adding and later removing a layer of clothing (such as a lab coat, coverall, or shoe covers) at work, which might involve no more than a couple of minutes a day. However, in other cases, a worker may need a full clothing change. Taking all these factors into account, OSHA estimates that a worker using a change room would need 5 minutes per day to change clothes. OSHA welcomes comment on this time estimate. At a production worker wage rate of $22.16 an hour (Production Occupation, SOC: 51-0000) and for 2 minutes (2/60 of an hour) per day for 250 days per year, this annual time cost to changing clothes is $184.68 per employee ((2/60) X 250 X $22.16).

The Agency estimates the total annualized cost of the provision on hygiene areas and practices to be $389,241 for all affected establishments. The breakdown of these costs by NAICS code can be seen in Table V-19 at the end of this program cost section.

HOUSEKEEPING

The proposed rule specifies requirements for cleaning and disposing of beryllium-contaminated wastes. The employer shall maintain all surfaces in beryllium work areas as free as practicable of accumulations of beryllium and shall ensure that all spills and emergency releases of beryllium are cleaned up promptly, in accordance with the employer's written exposure control plan and using a HEPA-filtered vacuum or other methods that minimize the likelihood and level of exposure. The employer shall not allow dry sweeping or brushing for cleaning surfaces in beryllium work areas unless HEPA-filtered vacuuming or other methods that minimize the likelihood and level of exposure have been tried and were not effective.

ERG's experts estimated that each facility would need to purchase a single vacuum at a cost of $2,900 (Nilfisk, 2012b) for every five affected employees in order to successfully integrate housekeeping into their daily routine. The per-employee cost would be $580 ($2,900/5), resulting in an annualized cost of $67.99 per worker. ERG's experts also estimated that all affected workers would require an additional five minutes per work day (.083 hours) to complete vacuuming tasks and to label and dispose of beryllium-contaminated waste. While this allotment is modest, OSHA judged that the steady application of this incremental additional cleaning, when combined with currently conducted cleaning, would be sufficient in average establishments to address dust or surface contamination hazards. The Agency estimated that the median work wage (including fringe benefits) for workers affected by this provision would be $22.16 an hour (Production Occupations, SOC: 51-0000) and that these workers would be working 250 days per year. Given these factors, OSHA estimates that the annual per employee labor cost for additional time spent cleaning in order to comply with this provision is $461.69 ($22.16 x 250 x .083).

The proposed standard requires each disposal bag with contaminated materials to be properly labeled. ERG estimated a cost of 10 cents per label with one label needed per day for every five workers. With the disposal of one labeled bag each day and 250 working days, $5 would be the per employee cost (($0.10 X 250)/5). The annualized cost of a HEPA-filtered vacuum, combined with the additional time needed to perform housekeeping and the labeling of disposal bags, results in a total annualized cost of $534.68 ($461.69 + $67.99 + $5.00) per employee.

The Agency estimates the total annualized cost of this provision to be $12,574,921 for all affected establishments. The breakdown of these costs by NAICS code is shown in Table V-19 at the end of this program cost section.

MEDICAL SURVEILLANCE

The proposed standard requires the employer to make medical surveillance available at no cost to the employee, and at a reasonable time and place, for the following employees:

1. Employees who have worked in a regulated area for more than 30 days in the last 12 months
2. Employees showing signs or symptoms of chronic beryllium disease (CBD)
3. Employees exposed to beryllium during an emergency; and
4. Employees exposed to airborne beryllium above 0.2 $\mu g/m^3$ for more than 30 days in a 12-month period for 5 years or more.[390]

[390] The Summary and Explanation, chapter XVIII, discussion of paragraph (k) discusses workers who would already receive some of the same medical surveillance examinations under the Energy Employees Occupational Illness Compensation Program Act (EEOICPA) (42 USC 7384-7385s-15). At this time, OSHA does not have estimates of how many workers under the scope of the proposed standard would be covered by the EEOICPA; hence, our cost estimates will be too high to the extent that these specific workers would already be receiving medical exams. The Agency solicits data that can help on this issue.

For the purposes of estimating the program costs of medical surveillance, OSHA has calculated the fees and other medical expenses that employers will incur to comply fully with the medical surveillance requirements in this standard. These costs do not include costs to comply with the medical removal requirements in this standard, which are addressed as separate program costs under "medical removal." If an employee is confirmed positive, is diagnosed with CBD, or shows signs or symptoms associated with exposure, then the employer has the obligation to update the written exposure control plan, and these costs are fully accounted for in the cost analysis (as discussed in the section on the written exposure control plan earlier in this chapter).. As discussed in the regulated areas section of this analysis of program costs, the Agency estimates that approximately 10 percent of affected employees would have exposure in excess of the PEL after the standard goes into effect and would therefore be placed in regulated areas. The Agency further estimates that a very small number of employees will be affected by emergencies in a given year, likely less than 0.1 percent of the affected population, representing a small additional cost.[391] The number of workers who would suffer signs and symptoms of CBD after the rule takes effect is difficult to estimate, but would likely substantially exceed those with actual cases of CBD.[392]

While the symptoms of CBD vary greatly, the first to appear are usually chronic dry cough (generally defined as a nonproductive cough, without phlegm or sputum, lasting two months or more) and shortness of breath during exertion. Ideally, in developing these costs

[391] Note the annualized minimal increase for costs due to emergencies are included in regulated areas costs.

[392] A full discussion of likely CBD rates before and after promulgation of the standard appears in Chapter VII of this PEA.

estimates, OSHA would first estimate the percent of affected workers who might be presenting with a chronic cough and/or experiencing shortness of breath.

Studies have found the prevalence of a chronic cough ranging from 10 to 38 percent across various community populations, with smoking accounting for up to 18 percent of cough prevalence (Irwin et al., 1990; Barbee et al., 1991). However, these studies are over twenty years old, and the number of smokers has decreased substantially since then.[393] It is also not clear whether the various segments of the US population studied are similar enough to the population of workers exposed to beryllium such that results of these studies could be generalized to the affected worker population.

A more recent study from a plant in Cullman, Alabama that works with beryllium alloy found that about five percent of employees said they were current smokers, with roughly 52 percent saying they were previous smokers and approximately 43 percent stating they had never smoked (Newman et al., 2001). This study does not, however, report on the prevalence of chronic cough in this workplace.

OSHA was unable to identify any studies on the general prevalence of the other common early symptom of CBD, shortness of breath. Lacking any better data to base an estimate on, the Agency used the studies cited above (Irwin et al., 1990; Barbee et al., 1991) showing the prevalence of chronic cough in the general population, adjusted to account for the long term decrease in smoking prevalence (and hence, the amount of overall cases of chronic cough), and estimated that 15 percent of the worker population with beryllium exposure covered by the

[393] Current cigarette smoking among adults has declined from 42 percent in 1965 to 18 percent in 2012 (U.S. HHS, 2014, p. 761). “Overall, the prevalence of daily smoking declined by 7.8 percent for males and 6.8 percent for females from 1991–2011” (Ibid., p. 720).

proposed rule would exhibit a chronic cough or other sign or symptom of CBD that would trigger medical surveillance. The Agency welcomes comment and further data on this question.

According to the proposed rule, the initial (baseline) medical examination would consist of the following:

1. A medical and work history, with emphasis on past and present exposure, smoking history and any history of respiratory system dysfunction;
2. A physical examination with emphasis on the respiratory tract;
3. A physical examination for skin breaks and wounds;
4. A pulmonary function test;
5. A standardized beryllium lymphocyte proliferation test (BeLPT) upon the first examination and within every two years from the date of the first examination until the employee is confirmed positive for beryllium sensitization;
6. A CT scan, offered every two years for the duration of the employee's employment, if the employee was exposed to airborne beryllium at levels above 0.2 ug/m^3 for more than 30 days in a 12-month period for at least 5 years. This obligation begins on the start-up date of this standard, or on the 15^{th} year after the employee's first exposure above for more than 30 days in a 12-month period, whichever is later; and
7. Any other test deemed appropriate by the Physician or other Licensed Health Care Professional (PLHCP).

Table V-17 below lists the direct unit costs for initial medical surveillance activities including: work and medical history, physical examination, pulmonary function test, BeLPT, CT scan, and costs of additional tests. In OSHA's cost model, all of the activities will take place during an employee's initial visit and on an annual basis thereafter and involve a single set of travel costs, except that: (1) the BeLPT tests will only be performed at two-year intervals after the initial test, but will be conducted in conjunction with the annual general examination (no additional travel costs); and (2) the CT scans will typically involve different specialists and are therefore treated as separate visits not encompassed by the general exams (therefore requiring separate travel costs). Not all employees would require CT scans, and employers would only be required to offer them every other year. A discussion of the derivation of the unit costs follows.

Table V-17	
Direct Costs for the Medical Surveillance Program	
Work and medical history	$33.33
Physical examination (skin and respiratory tract)	$100
Pulmonary Function Test	$54.69
Cost of additional tests deemed appropriate by PLHCP	$200
Percent of workers requiring additional tests	10%
Total initial medical costs per worker	**$208.03**
Cost of lost work time[1]	$63.78
Total per worker cost of medical surveillance	**$271.80**
BeLPT	$259
Annualized per worker cost of biannual BePLTs for ten years [2]	$161.33
Annualized per worker cost of bi-annual CT scan[3]	$573.76
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[1] Assumes 125 minutes of employee time at $22.16/hour and 15 minutes of a human resource manager's time at $70.44/hour	
[2] Calculated as the annualized net present value of $1,407.	
[3] Calculated as annualized cost of CT scan of $1,020 plus $111 in lost work time.	
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Source: Intellimed International, 2003, National Jewish Medical Center, 2005, ct-scan-info.com, and OSHA, Directorate of Standards and Guidance,	

Annual examination and testing

The fees for the initial (and annual) medical examination are estimated to be: an average fee of $33.33 for gathering or updating work and medical history (estimated to be one-third the cost of a full physical exam), a $100 fee for a full physical exam (encompassing both respiratory and skin requirements), a $54.69 fee for a pulmonary function test, and $200 in fees for all additional tests (collectively) that the PLHCP may recommend (Intellimed International, 2003, National Jewish Medical Center, 2005). For this last element, the Agency estimates that 10 percent of the standard medical examinations will lead to further tests recommended by the PLCHP. This estimate does not include the cost of the initial BeLPT test, which is grouped with the costs for the subsequent BeLPT tests and addressed in the following paragraphs.

In addition to the fees for the annual medical exam, employers may also incur costs for lost work time when their employees are unavailable to perform their jobs. OSHA estimated the examination requires 120 minutes (or 2 hours) away from work for each employee each year (updated from ERG, 2013). This includes time for traveling, a health history review, the physical exam, and the pulmonary function test. Each examination would require 15 minutes (or 0.25 hours) of a human resource manager's time for recording the results of the exam and tests and the PLHCP's written opinion for each employee and any necessary post-exam consultation with the employee. The lost work time, based on an average production worker wage of $22.16 (Production Occupations, SOC: 51-0000), is $44.32 (2 x $22.16) per year. The cost of the lost work time for a human resource manager making $70.44 per hour (Human Resources Managers, SOC: 11-3121), is $17.61 ($70.44 x 0.25). There is a cost of 15 minutes of supervisor time to provide information to the physician, five minutes of supervisor time to process licensed physician's written medical opinion, and five minutes for a production worker to receive a licensed physician's written medical opinion. The total unit annual cost for the medical examinations and tests, excluding the BeLPT test, and the time required for both the employee and the supervisor is $296.95.

BeLPT testing

The estimated fee for the BeLPT is $259 (National Jewish Medical Center, 2005). With the addition of the time incurred by the worker to undergo the test (estimated to take five minutes, or 0.08 hours), the total cost for a BeLPT is $260.85 (0.08 x $22.16 + $259). The standard requires a biennial BeLPT for each employee covered by the medical surveillance provision, so most workers would receive between two and five BeLPT tests over a ten year period (including the BeLPT performed during the initial examination), depending on whether the results of these tests were positive.[394] OSHA therefore estimates a net present value (NPV) of $1,417 for all five tests. This NPV annualized over a ten year period is $166.13.

From the above cost for the annual medical examination, not including the BeLPT, is $269.96. Together, the annualized net present value of the BeLPT and the annualized cost of the remaining medical surveillance produce an annual cost of $436.09 ($166.13 + $269.96) per employee.

CT Scans

The proposed standard requires that a helical tomography (CT scan) be offered to employees exposed to airborne beryllium above 0.2 $\mu g/m^3$ for more than 30 days in a 12-month period, for a period of 5 years or more. The five years do not need to be consecutive, and the exposure does not need to occur after the effective date of the standard. The CT scan shall be offered every 2 years starting on the fifteenth year after the first year the employee was exposed above 0.2 $\mu g/m^3$ for more than 30 days in a 12-month period, for the duration of their employment. The total yearly cost for biennial CT scans consists of medical costs totaling $1,020, comprised of a $770 fee for the scan (CT-scan, 2012) and the cost of a specialist to review the results, which OSHA estimates would cost $250. The Agency estimates an additional

[394] Included in the final cost calculation is an inflation factor for an estimate of "false positive" BeLPT tests. These are tests where a single abnormal result is followed by a normal result. They do not necessarily mean that the worker is not sensitized, since either the abnormal result or the following normal result may be accurate. However, abnormal followed by normal results may cause a worker to receive a BeLPT test more than five times in ten years, and may therefore increase the cost of BeLPT testing for the employer. OSHA utilized a "false positive" rate of 1.09 percent, derived from Stange et al. (2004).

cost of $110.81 of lost work time,[395] for a total of $1,130.81 ($1,020 + $110.81). The annualized yearly cost for biennial CT scans is $573.76.

Number of workers requiring medical surveillance

Based on OSHA's estimates explained earlier in this section, all workers in regulated areas, workers exposed in emergencies, and an estimated 15 percent of workers not in regulated areas who exhibit signs and symptoms of CBD will be eligible for medical surveillance other than CT scans. The estimate for the number of workers eligible to receive CT scans is 25 percent of workers who are exposed above 0.2 in the exposure profile. The estimate of 25 percent is based on the facts that roughly this percentage of workers have 15+ years of job tenure in the durable manufacturing sector (BLS, 2013) and the estimate that all those with 15+ years of job tenure and current exposure over 0.2 would have had at least 5 years of such exposure in the past.

The costs estimated for this provision are likely to be significantly overestimated, since not all affected employees offered medical surveillance would necessarily accept the offer. At Department of Energy facilities, only about 50 percent of eligible employees participate in the voluntary medical surveillance tests, and a report on an initial medical surveillance program at four aluminum manufacture facilities found participation rates to be around 57 percent (Taiwo et al., 2008). Where employers already offer equivalent health surveillance screening, no new costs are attributable to the proposed standard.

[395] Time cost is calculated using a wage rate of $22.16 (Production Worker, SOC 51-0000) and a total of 5 hours lost: 120 minutes to travel to and from the appointment, 30 minutes to administer the scan, 120 minutes to travel to and from a meeting with a specialist to review the results and 30 minutes to review the results with the specialist (updated from ERG, 2013).

CBD Diagnostic Center Referrals and Evaluations

Within 30 days after an employer learns that an employee has been confirmed positive for beryllium sensitization, the employer's designated licensed physician shall consult with the employee to discuss referral to a CBD diagnostic center that is mutually agreed upon by the employer and the employee. If, after this consultation, the employee wishes to obtain a clinical evaluation at a CBD diagnostic center, the employer must provide the evaluation at no cost to the employee. OSHA estimates this consultation will typically be done by telephone and take less than 15 minutes. For purposes of costing this consultation, OSHA used the marginal costs of a doctor’s time (wages plus benefits) of $110.25 per hour (Physicians and Surgeons, All Other, SOC: 29-1069), the doctor’s cost for the 15 minute consultation is $27.56 ((15/60) X $110.25). Similarly the worker’s time for this consultation, with a production worker’s hourly wage of $22.16 (Production Occupations, SOC: 51-0000) results in a cost for the employee’s time of $5.54 ((15/60) X $22.16). Hence the total cost of the prior consultation is $33.10 ($27.56 + $5.54).

Table V-18 below lists the direct unit costs for a clinical evaluation with a specialist at a CBD diagnostic center. To estimate these costs, ERG contacted a healthcare provider who commonly treats patients with beryllium-related disease, and asked them to provide both the typical tests given and associated costs of an initial examination for a patient with a positive BeLPT test, presented in Table V-18 Their typical evaluation includes bronchoscopy with lung biopsy, a pulmonary stress test, and a chest CAT scan. The total cost for the entire suite of tests is $6,305.46.

Table V-18	
Unit Costs for Medical Evaluation and Testing per Worker Referred to a CBD Diagnostic Center	
Referral Examination for new patients (includes):	$6,305.46
Exam with specialist	
Blood Tests	
Plethysmography	
Pulmonary Stress Test	
Bronchoscopy with Lung Biopsy	
Chest CAT scan	
Per worker cost of lost work time[1]	$564.97
Per worker cost of travel & living expenses[2]	$750
Total per worker cost of treatment and evaluation at a CBD Diagnostic Center	**$7,620.43**
[1] Assumes 3 8-hour work days for the employee at $22.16/hour as well as a 15 minute consultation between the employee and the employer's physician at $110.25/hour	
[2] Includes travel costs and $50/day living expenses. See text.	
Source: ERG, OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis.	

In addition, there are costs for lost productivity and travel. The Agency has estimated the clinical evaluation would take three days of paid time for the worker to travel to and from one of two locations: Penn Lung Center at the Cleveland Clinic Foundation in Cleveland, Ohio or National Jewish Medical Center in Denver, Colorado. OSHA estimates lost work time is 24 (3 x 8) hours at a wage of $22.16 (Production Occupations, SOC: 51-0000) for a total cost for the three days of $531.87 (24 x $22.16).

OSHA estimates that roundtrip air-fare would be available for most facilities at $400 (U.S. DOT, 2012), and the cost of a hotel room would be approximately $100 per night, for a total cost of $200 for the hotel room. OSHA estimates a per diem cost of $50 for three days, for a total of $150 (3 x $50). The total cost per trip for traveling expenses is therefore $750 ($400 + $100 + $150).

The total cost of a clinical evaluation with a specialist at a CBD diagnostic center is equal to the cost of the examination plus the cost of lost work-time and the cost for the employee to travel to the CBD diagnostic center, or $7,620.43 ($33.10 + $6,305.46 + $531.87 + $750).

Based on the data from the exposure profile and the prevalence of beryllium sensitization observed at various levels of cumulative exposure,[396] OSHA estimated the number of workers eligible for BeLPT testing (4,181) and the percentage of workers who will be confirmed positive for sensitization (two positive BeLPT tests, as specified in the proposed standard) and referred to a CBD diagnostic center. During the first year that the medical surveillance provisions are in effect, OSHA estimates that 9.4 percent of the workers who are tested for beryllium sensitization will be identified as sensitized. This percentage is an average based on: (1) the number of employees in the baseline exposure profile that are in a given cumulative exposure range; (2) the expected prevalence for a given cumulative exposure range (from Table VI-6 in Section VI of the preamble); and (3) an assumed even distribution of employees by cumulative years of exposure at a given level—20 percent having exposures at a given level for 5 years, 20 percent for 15 years, 20 percent for 25 years, 20 percent for 30 years, and 20 percent for 40 years.

OSHA did not assume that all workers with confirmed sensitization would choose to undergo evaluation at a CBD diagnostic center, which may involve invasive procedures and/or travel. For purposes of this cost analysis, OSHA estimates that approximately two-thirds of workers who are confirmed positive for beryllium sensitization will choose to undergo evaluation for CBD. OSHA requests comment on the CBD evaluation participation rate. OSHA

[396] See Table VI-6 in Section VI of the preamble, Preliminary Risk Assessment.

estimates that about 264 of all non-dental lab workers will go to a diagnostic center for CBD evaluation in the first year.

The calculation method described above applies to all workers except dental technicians, who were analyzed with one modification. The rates for dental technicians are calculated differently due to the estimated 75 percent beryllium-substitution rate at dental labs, where the 75 percent of labs that eliminate all beryllium use are those at higher exposure levels. None of the remaining labs affected by this standard had exposures above 0.1 $\mu g/m^3$ (see the engineering control costs section for dental labs above). For the dental labs, the same calculation was done as presented in the previous paragraph, but only the remaining 25 percent of employees (2,314) who would still face beryllium exposures were included in the baseline cumulative exposure profile. With that one change, and all other elements of the calculation the same, OSHA estimates that 9 percent of dental lab workers tested for beryllium sensitization will be identified as sensitized. The predicted prevalence of sensitization among those dental lab workers tested in the first year after the standard takes effect is slightly lower than the predicted prevalence among all other tested workers combined. This slightly lower rate is not surprising because only dental lab workers with exposures below 0.1 $\mu g/m^3$ are included (after adjusting for substitution), and OSHA's exposure profile indicates that the vast majority of non-dental workers exposed to beryllium are also exposed at 0.1 $\mu g/m^3$ or lower. OSHA estimates that 20 dental lab workers (out of 347 tested for sensitization) would go to a diagnostic center for CBD evaluation in the first year.

In each year after the first year, OSHA relied on a 10 percent worker turnover rate in a steady state (as discussed in Chapter VII of this PEA) to estimate that the annual sensitization incidence rate is 10 percent of the first year's incidence rate. Based on that rate and the number of workers in the medical surveillance program, the CBD evaluation rate for workers other than those in dental labs would drop to 0.63 percent (.063 x .10). The evaluation rate for dental labs technicians is similarly estimated to drop to 0.58 percent (.058 x .10). These evaluation rates may be an overestimate to the extent that reduced worker exposures resulting from the proposed rule would tend to reduce the number of sensitized workers requiring CBD evaluation. OSHA invites comment on this issue.

Based on these unit costs and the number of employees requiring medical surveillance estimated above, OSHA estimates that the medical surveillance and referral provisions would result in an annualized total cost of $2,882,076. These costs by NAICS code are shown in Table V-19 at the end of the program cost section.

MEDICAL REMOVAL PROVISION

Once a licensed physician diagnoses an employee with CBD or the employee is confirmed positive for sensitization to beryllium, that employee is eligible for medical removal and has two choices:

a) Removal from current job, or
b) Remain in a job with exposure above the action level while wearing a respirator pursuant to 29 CFR 1910.134.

To be eligible for removal, the employee must accept comparable work if such is available, but if not available the employer would be required to place the employee on paid leave for six months or until such time as comparable work becomes available, whichever comes first. During that six-month period, whether the employee is re-assigned or placed on paid leave, the employer must continue to maintain the employee's base earnings, seniority and other rights, and benefits that existed at the time of the first test.

For purposes of this analysis, OSHA has conservatively estimated the costs as if all employees will choose removal, rather than remaining in the current job while wearing a respirator. In practice, many workers may prefer to continue working at their current job while wearing a respirator, and the employer would only incur the respirator costs identified earlier in this chapter. The removal costs are significantly higher over the same six-month period, so this analysis likely overestimates the total costs for this provision.

Reassignment to a comparable job

OSHA estimated that the majority of firms would be able to reassign the worker to a job at least at the clerical level. The employer will often incur a cost for re-assigning the worker because this provision requires that, regardless of the comparable work the medically removed worker is performing, the employee must be paid the full base earnings for the previous position for six months. The cost per hour of reassigning a production worker to a clerical job is based on the wage difference of a production worker of $22.16 (Production Occupations, SOC: 51-0000) and a clerical worker of $19.97 (File Clerks, SOC: 43-4071), for a difference of $2.19 ($22.16 – $19.97). Over the six-month period, the incremental cost of reassigning a worker to a clerical position would be $2,189.87 ($2.19 x (250 /12) x 6 x 8) per employee.[397] This estimate is based

[397] OSHA estimates that it will take one month of training of a production worker for the clerical position. However, anyone hired for this clerical position would also need this same training, so the firm's only extra cost by retraining the production worker is this wage differential. Note that the job is any position equivalent in productivity

on the employee remaining in a clerical position for the entire 6-month period, but the actual cost would be lower if there is turnover or if the employee is placed in any alternative position (for any part of the six-month period) that is compensated at a wage closer to the employee's previous wage.

Removal with 6 months paid leave

Some firms may not have the ability to place the worker in an alternate job. If the employee chooses not to remain in the current position, the additional cost to the employer would be at most the cost of equipping that employee with a respirator, which would be required if the employee would continue to face exposures at or above the action level. Based on the earlier discussion of respirator costs, that option would be significantly cheaper than the alternative of providing the employee with six months of paid leave. Therefore, in order to estimate the maximum potential economic cost of the remaining alternatives, the Agency has conservatively estimated the cost per worker based on the cost of 6 months paid leave. [398]

Using the wage rate of a production worker of $22.16 (production occupations, SOC: 51-0000), and six months (or one half) of a 250 day, eight hour per-day work year the total per-worker cost for this provision when a firm cannot place a worker in an alternate job is $22,161.13 ($22.16 x (250/12) x 6 x 8).

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to the clerical wage, not necessarily exactly those duties. And, since the wage cost differential occurs both during the training and while in the actual position, the assumption of a month's training can be relaxed with no change to the overall cost of medical removal.

[398] Note that paragraph (l)(4) provides that employer responsibilities for medical removal are reduced if the employee receives any benefit (worker's comp, EEOICPA funds, etc.). To the extent that occurs the Agency's cost analysis is conservative.

OSHA has estimated an average medical removal cost per worker assuming 75 percent of firms are able to find the employee an alternate job, and the remaining 25 percent of firms would not. The weighted average of these costs is $7,182.68 (0.75 x $2,189.87 + 0.25 x $22,161.13). Based on these unit costs OSHA estimates that the medical removal provision would result in an annualized total cost of $148,826. The breakdown of these costs by NAICS code can be seen in Table V-19 at the end of this program cost section.

TRAINING

As specified in the proposed standard and existing OSHA standard 29 CFR 1910.1200 on hazard communication, training is required for all employees where there is potential exposure to beryllium. In addition, newly hired employees would require training before starting work.

OSHA anticipates that training in accordance with the requirements of the proposed rule, which includes hazard communication training, would be conducted by in-house safety or supervisory staff with the use of training modules or videos. ERG estimated that this training would last, on average, eight hours. (Note that this estimate does not include the time taken for hazard communication training that is already required by 29 CFR 1910.1200.) The Agency judged that establishments could purchase sufficient training materials at an average cost of $2 per worker, encompassing the cost of handouts, video presentations, and training manuals and exercises. For initial and periodic training, ERG estimated an average class size of five workers (each at a wage of $22.16 (Production Occupations, SOC: 51-0000)) with one instructor (at a wage of $37.39 (Median Wage for Training and Development Specialists, SOC: 13-1151)) over an eight hour period. The per-worker cost of initial training is therefore $239.11 (8 x ($22.16 +

($37.39/5)) + $2).

Annual retraining of workers is also required by the standard. OSHA estimates the same unit costs as for initial training, so retraining would require the same per-worker cost of $239.11.

Finally, to calculate training costs, the Agency needs the turnover rate of affected workers to know how many workers are receiving initial training versus retraining.[399] Using these elements and based on a 26.3 percent new hire rate (BLS 2012, annual manufacturing new hire rate), OSHA calculated a total net present value (NPV) of ten years of initial and annual retraining of $2,100.69 per employee. Annualizing this NPV gives a total annual cost for training of $246.27.

Based on these unit costs, OSHA estimates that the training requirements in the standard would result in an annualized total cost of $5,797,535. The breakdown of these costs by NAICS code is presented in Table V-19 below.

[399] Of course since the per worker cost for initial training and retraining is the same, for most purposes this doesn't matter. It does, though, for the first year of the standard since then all existing workers will have to be trained as well as the standard number of new workers who enter the firm during the first year due to turnover.

Table V-19

Annualized Cost of Program Requirements for Industries Affected by the Proposed Beryllium Standard by Application Group and Six-Digit NAICS Industry (in 2010 dollars)

NAICS Code	Industry	Exposure Assessment	Regulated Areas and Beryllium Work Areas	Medical Surveillance	Medical Removal Provision	Written Exposure Control Plan	Protective Work Clothing & Equipment	Hygiene Areas and Practices	House-keeping	Training	Total Program Costs
Beryllium Production											
331419	Primary smelting and refining of nonferrous metals	$0	$1,683	$11,121	$6,359	$0	$17,801	$8,112	$0	$0	$45,075
Beryllium Oxide Ceramics and Composites											
327113a	Porcelain electrical supply manufacturing (primary)	$6,959	$4,162	$9,205	$1,912	$2,645	$2,761	$2,432	$22,189	$10,230	$62,495
327113b	Porcelain electrical supply manufacturing (secondary)	$17,311	$5,303	$20,307	$1,276	$11,365	$4,938	$1,959	$67,370	$31,060	$160,889
334220	Cellular telephones manufacturing	$12,365	$3,788	$14,505	$911	$8,118	$8,526	$1,399	$48,122	$22,186	$119,920
334310	Compact disc players manufacturing	$6,183	$1,894	$7,252	$456	$4,059	$830	$864	$24,061	$11,093	$56,692
334411	Electron tube manufacturing	$25,967	$7,955	$30,460	$1,914	$17,048	$11,252	$2,938	$101,055	$46,590	$245,179
334415	Electronic resistor manufacturing	$14,838	$4,545	$17,406	$1,094	$9,742	$6,346	$1,679	$57,746	$26,623	$140,019
334419	Other electronic component manufacturing	$11,129	$3,409	$13,054	$820	$7,306	$3,227	$1,292	$43,309	$19,967	$103,514
334510	Electromedical equipment manufacturing	$11,129	$3,409	$13,054	$820	$7,306	$8,193	$1,292	$43,309	$19,967	$108,480
336322b	Other motor vehicle electrical and electronic equipment manufacturing	$12,365	$3,788	$14,505	$911	$8,118	$5,243	$1,399	$48,122	$22,186	$116,637
Aluminum and Copper Foundries											
331521	Aluminum die-casting foundries	$18,965	$11,764	$22,386	$2,948	$6,580	$14,421	$3,882	$39,473	$18,199	$138,616
331522	Nonferrous (except aluminum) die-casting foundries	$102,953	$63,860	$121,522	$16,003	$35,718	$50,165	$20,536	$214,281	$98,792	$723,831
331524	Aluminum foundries (except die-casting)	$18,965	$11,764	$22,386	$2,948	$6,580	$7,835	$3,882	$39,473	$18,199	$132,030
331525a	Copper foundries (except die-casting) (non-sand casting foundries)	$54,186	$33,610	$63,959	$8,423	$18,799	$14,318	$10,808	$112,780	$51,996	$368,879
331525b	Copper foundries (except die-casting) (sand casting foundries)	$75,706	$48,627	$91,350	$11,940	$26,047	$31,197	$15,520	$157,416	$72,575	$530,377
Secondary Smelting, Refining, and Alloying											
331314	Secondary smelting & alloying of aluminum	$1,687	$984	$1,926	$251	$625	$284	$294	$3,609	$1,664	$11,325
331421b	Copper rolling, drawing, and extruding	$1,687	$984	$1,926	$251	$625	$733	$294	$3,609	$1,664	$11,774
331423	Secondary smelting, refining, & alloying of copper	$5,062	$2,953	$5,779	$752	$1,876	$706	$882	$10,827	$4,992	$33,829
331492	Secondary smelting, refining, & alloying of nonferrous metal (except copper & aluminum)	$38,355	$15,256	$40,496	$4,129	$18,761	$9,889	$4,411	$108,274	$49,918	$289,489
Precision Turned Products											
332721a	Precision turned product manufacturing (high beryllium content)	$19,773	$20,306	$39,419	$6,022	$11,265	$22,809	$8,725	$59,373	$27,373	$215,066
332721b	Precision turned product manufacturing (low beryllium content)	$339,855	$93,938	$406,491	$22,244	$239,550	$363,790	$35,735	$1,420,434	$654,876	$3,576,912
Copper Rolling, Drawing and Extruding											
331421a	Copper rolling, drawing, and extruding	$77,074	$7,662	$109,469	$1,983	$72,471	$105,427	$1,919	$617,121	$284,517	$1,277,644
331422	Copper wire (except mechanical) drawing	$330,266	$77,096	$426,151	$23,234	$240,458	$349,147	$27,975	$2,043,664	$942,210	$4,460,202

Table V-19, continued

Annualized Cost of Program Requirements for Industries Affected by the Proposed Beryllium Standard by Application Group and Six-Digit NAICS Industry (in 2010 dollars)

NAICS Code	Industry	Exposure Assessment	Regulated Areas and Beryllium Work Areas	Medical Surveillance	Medical Removal Provision	Written Exposure Control Plan	Protective Work Clothing & Equipment	Hygiene Areas and Practices	House-keeping	Training	Total Program Costs
Fabrication of Beryllium Alloy Products											
332612	Light gauge spring manufacturing	$147,766	$22,281	$192,128	$4,170	$150,032	$80,612	$3,613	$1,107,234	$510,479	$2,218,314
332116	Metal stamping	$37,074	$9,640	$51,382	$1,355	$35,726	$11,246	$2,229	$265,310	$122,318	$536,280
334417	Electronic connector manufacturing	$23,146	$6,018	$32,079	$846	$22,304	$18,014	$1,392	$165,639	$76,366	$345,805
336322a	Other motor vehicle electrical & electronic equipment	$79,660	$20,712	$110,402	$2,911	$76,762	$44,357	$4,789	$570,058	$262,819	$1,172,471
Arc and Gas Welding											
331111	Iron and steel mills	$3,167	$1,467	$3,792	$295	$2,085	$0	$3,685	$14,171	$6,533	$35,195
331221	Rolled steel shape manufacturing	$658	$305	$788	$61	$433	$0	$3,379	$2,945	$1,358	$9,926
331513	Steel foundries (except investment)	$647	$300	$775	$60	$426	$0	$3,378	$2,897	$1,336	$9,819
332117	Powder metallurgy part manufacturing	$435	$201	$521	$41	$286	$0	$3,352	$1,946	$897	$7,679
332212	Hand and edge tool manufacturing	$1,394	$646	$1,669	$130	$918	$0	$3,469	$6,239	$2,876	$17,341
332312	Fabricated structural metal manufacturing	$26,737	$12,383	$32,010	$2,493	$17,601	$0	$21,713	$119,636	$55,157	$287,730
332313	Plate work manufacturing	$10,108	$4,681	$12,101	$942	$6,654	$0	$8,208	$45,228	$20,852	$108,775
332322	Sheet metal work manufacturing	$32,749	$15,168	$39,207	$3,053	$21,558	$0	$26,594	$146,534	$67,558	$352,421
332323	Ornamental and architectural metal work manufacturing	$18,474	$8,556	$22,117	$1,722	$12,161	$0	$15,002	$82,660	$38,110	$198,802
332439	Other metal container manufacturing	$3,206	$1,485	$3,838	$299	$2,111	$0	$3,690	$14,346	$6,614	$35,589
332919	Other metal valve and pipe fitting manufacturing	$1,300	$602	$1,556	$121	$856	$0	$3,457	$5,816	$2,681	$16,389
332999	All other miscellaneous fabricated metal product manufacturing	$16,000	$7,410	$19,155	$1,492	$10,532	$0	$12,993	$71,590	$33,006	$172,178
333111	Farm machinery and equipment manufacturing	$9,531	$4,414	$11,411	$889	$6,274	$0	$7,740	$42,647	$19,662	$102,568
333414a	Heating equipment (except warm air furnaces) manufacturing	$2,858	$1,324	$3,421	$266	$1,881	$0	$3,647	$12,788	$5,896	$32,081
333911	Pump and pumping equipment manufacturing	$3,174	$1,470	$3,800	$296	$2,089	$0	$3,686	$14,202	$6,548	$35,266
333922	Conveyor and conveying equipment manufacturing	$4,314	$1,998	$5,164	$402	$2,840	$0	$3,825	$19,301	$8,899	$46,743
333924	Industrial truck, tractor, trailer, and stacker machinery manufacturing	$2,079	$963	$2,489	$194	$1,369	$0	$3,552	$9,303	$4,289	$24,237
333999	All other miscellaneous general purpose machinery manufacturing	$8,472	$3,924	$10,142	$790	$5,577	$0	$6,880	$37,906	$17,476	$91,167
336211	Motor vehicle body manufacturing	$7,157	$3,315	$8,569	$667	$4,712	$0	$5,812	$32,026	$14,765	$77,024
336214	Travel trailer and camper manufacturing	$6,588	$3,051	$7,888	$614	$4,337	$0	$5,350	$29,480	$13,591	$70,900
336399a	All other motor vehicle parts manufacturing	$3,531	$1,636	$4,228	$329	$2,325	$0	$3,729	$15,802	$7,285	$38,865
336510	Railroad rolling stock	$1,293	$599	$1,548	$121	$851	$0	$3,456	$5,787	$2,668	$16,323
336999	All other transportation equipment manufacturing	$1,712	$793	$2,050	$160	$1,127	$0	$3,508	$7,661	$3,532	$20,542
337215	Showcase, partition, shelving, and locker manufacturing	$1,562	$723	$1,870	$146	$1,028	$0	$3,489	$6,988	$3,222	$19,027
811310	Commercial and industrial machinery and equipment repair	$68,217	$31,594	$81,669	$6,360	$44,906	$0	$55,397	$305,236	$140,726	$734,105

Table V-19, continued

Annualized Cost of Program Requirements for Industries Affected by the Proposed Beryllium Standard by Application Group and Six-Digit NAICS Industry (in 2010 dollars)

NAICS Code	Industry	Exposure Assessment	Regulated Areas and Beryllium Work Areas	Medical Surveillance	Medical Removal Provision	Written Exposure Control Plan	Protective Work Clothing & Equipment	Hygiene Areas and Practices	House-keeping	Training	Total Program Costs
Resistance Welding											
333411	Air purification equipment manufacturing	$22,068	$1,036	$32,575	$0	$25,212	$0	$0	$202,669	$93,438	$376,997
333412	Industrial and commercial fan and blower manufacturing	$9,308	$437	$13,740	$0	$10,634	$0	$0	$85,483	$39,411	$159,013
333414b	Heating equipment (except warm air furnaces) manufacturing	$28,356	$1,331	$41,856	$0	$32,395	$0	$0	$260,413	$120,061	$484,410
333415	Air-conditioning, warm air heating, and industrial refrigeration equipment manufacturing	$51,965	$2,439	$76,705	$0	$59,367	$0	$0	$477,235	$220,024	$887,734
335211	Electric housewares and household fan manufacturing	$4,667	$219	$6,889	$0	$5,332	$0	$0	$42,863	$19,762	$79,732
335212	Household vacuum cleaner manufacturing	$1,497	$70	$2,210	$0	$1,710	$0	$0	$13,748	$6,339	$25,574
335221	Household cooking appliance manufacturing	$4,227	$198	$6,239	$0	$4,829	$0	$0	$38,819	$17,897	$72,210
335222	Household refrigerator and home freezer manufacturing	$969	$45	$1,430	$0	$1,107	$0	$0	$8,896	$4,101	$16,548
335224	Household laundry equipment manufacturing	$484	$23	$715	$0	$553	$0	$0	$4,448	$2,051	$8,274
335228	Other major household appliance manufacturing	$1,673	$79	$2,470	$0	$1,912	$0	$0	$15,366	$7,084	$28,583
336311	Carburetor, piston, piston ring, and valve manufacturing	$4,799	$225	$7,084	$0	$5,483	$0	$0	$44,076	$20,321	$81,989
336312	Gasoline engine and engine parts manufacturing	$32,671	$1,533	$48,225	$0	$37,325	$0	$0	$300,041	$138,331	$558,125
336321	Vehicular lighting equipment manufacturing	$4,095	$192	$6,044	$0	$4,678	$0	$0	$37,606	$17,338	$69,954
336322c	Other motor vehicle electrical and electronic equipment manufacturing	$28,004	$1,314	$41,336	$0	$31,993	$0	$0	$257,178	$118,569	$478,393
336330	Motor vehicle steering and suspension components (except spring) manufacturing	$10,832	$508	$15,988	$0	$12,374	$0	$0	$99,474	$45,862	$185,039
336340	Motor vehicle brake system manufacturing	$8,762	$411	$12,934	$0	$10,010	$0	$0	$80,469	$37,099	$149,686
336350	Motor vehicle transmission and power train parts manufacturing	$20,959	$984	$30,937	$0	$23,944	$0	$0	$192,479	$88,740	$358,042
336360	Motor vehicle seating and interior trim manufacturing	$17,744	$833	$26,192	$0	$20,272	$0	$0	$162,960	$75,131	$303,132
336370	Motor vehicle metal stamping	$32,407	$1,521	$47,835	$0	$37,023	$0	$0	$297,614	$137,212	$553,612
336391	Motor vehicle air-conditioning manufacturing	$3,522	$165	$5,199	$0	$4,024	$0	$0	$32,349	$14,914	$60,175
336399b	All other motor vehicle parts manufacturing	$59,441	$2,789	$87,741	$0	$67,909	$0	$0	$545,896	$251,680	$1,015,456
Dental Laboratories											
339116	Dental laboratories	$118,601	$14,334	$172,420	$0	$155,480	$187,007	$0	$816,900	$376,623	$1,841,363
621210	Offices of dentists	$16,107	$1,947	$23,417	$0	$21,116	$26,293	$0	$110,944	$51,150	$250,973
	Total	**$2,208,950**	**$629,031**	**$2,882,076**	**$148,826**	**$1,769,506**	**$1,407,365**	**$389,241**	**$12,574,921**	**$5,797,535**	**$27,807,451**

NOTE: Totals may not sum due to rounding.

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis.

TOTAL ANNUALIZED COST

As shown in Table V-20, the total annualized cost of the proposed rule is estimated to be about $37.6 million. As shown, at $27.8 million, the program costs represent about 74 percent of the total annualized costs of the proposed rule. The annualized cost of complying with the PEL accounts for the remaining 26 percent, almost all of which is for engineering controls and work practices. Respiratory protection, at about $250,000, represents only 3 percent of the annualized cost of complying with the PEL and less than 1 percent of the annualized cost of the proposed rule.

Table V-20

Annualized Costs to Industries Affected by the Proposed Beryllium Standard, by Application Group and Six-Digit NAICS

NAICS code	Industry	Engineering Controls and Work Practices	Respirator Costs	Program Costs	Total Costs
Beryllium Production					
331419	Primary smelting and refining of nonferrous metals	$1,188,758	$23,381	$45,075	$1,257,214
Beryllium Oxide Ceramics and Composites					
327113a	Porcelain electrical supply manufacturing (primary)	$175,546	$2,702	$62,495	$240,744
327113b	Porcelain electrical supply manufacturing (secondary)	$72,102	$1,744	$160,889	$234,736
334220	Cellular telephones manufacturing	$51,502	$1,246	$119,920	$172,668
334310	Compact disc players manufacturing	$25,751	$675	$56,692	$83,118
334411	Electron tube manufacturing	$108,154	$2,617	$245,179	$355,950
334415	Electronic resistor manufacturing	$61,802	$1,495	$140,019	$203,316
334419	Other electronic component manufacturing	$46,352	$1,132	$103,514	$150,998
334510	Electromedical equipment manufacturing	$46,352	$1,132	$108,480	$155,964
336322b	Other motor vehicle electrical and electronic equipment manufacturing	$51,502	$1,246	$116,637	$169,385
Nonferrous Foundries					
331521	Aluminum die-casting foundries	$182,887	$3,899	$138,616	$325,402
331522	Nonferrous (except aluminum) die-casting foundries	$992,813	$20,999	$723,831	$1,737,643
331524	Aluminum foundries (except die-casting)	$182,887	$3,899	$132,030	$318,816
331525a	Copper foundries (except die-casting) (non-sand casting foundries)	$522,533	$11,052	$368,879	$902,464
331525b	Copper foundries (except die-casting) (sand casting foundries)	$682,229	$15,962	$530,377	$1,228,568
Secondary Smelting, Refining, and Alloying					
331314	Secondary smelting & alloying of aluminum	$19,186	$3,246	$11,325	$33,757
331421b	Copper rolling, drawing, and extruding	$19,186	$3,246	$11,774	$34,206
331423	Secondary smelting, refining, & alloying of copper	$57,558	$9,530	$33,829	$100,916
331492	Secondary smelting, refining, & alloying of nonferrous metal (except copper & aluminum)	$287,789	$5,024	$289,489	$582,301
Precision Turned Products					
332721a	Precision turned product manufacturing (high beryllium content)	$162,739	$8,864	$215,066	$386,669
332721b	Precision turned product manufacturing (low beryllium content)	$888,502	$30,866	$3,576,912	$4,496,280
Copper Rolling, Drawing and Extruding					
331421a	Copper rolling, drawing, and extruding	$23,656	$1,677	$1,277,644	$1,302,977
331422	Copper wire (except mechanical) drawing	$96,231	$28,425	$4,460,202	$4,584,858
Fabrication of Beryllium Alloy Products					
332612	Light gauge spring manufacturing	$588,200	$8,874	$2,218,314	$2,815,387
332116	Metal stamping	$134,748	$3,531	$536,280	$674,558
334417	Electronic connector manufacturing	$84,126	$2,204	$345,805	$432,136
336322a	Other motor vehicle electrical & electronic equipment	$289,526	$7,586	$1,172,471	$1,469,583

Table V-20, continued					
Annualized Costs to Industries Affected by the Proposed Beryllium Standard, by Application Group and Six-Digit NAICS					
NAICS code	**Industry**	**Engineering Controls and Work Practices**	**Respirator Costs**	**Program Costs**	**Total Costs**
Arc and Gas Welding					
331111	Iron and steel mills	$18,123	$679	$35,195	$53,997
331221	Rolled steel shape manufacturing	$3,766	$679	$9,926	$14,371
331513	Steel foundries (except investment)	$3,705	$679	$9,819	$14,203
332117	Powder metallurgy part manufacturing	$2,489	$679	$7,679	$10,846
332212	Hand and edge tool manufacturing	$7,979	$679	$17,341	$25,998
332312	Fabricated structural metal manufacturing	$153,001	$4,352	$287,730	$445,083
332313	Plate work manufacturing	$57,841	$1,645	$108,775	$168,261
332322	Sheet metal work manufacturing	$187,400	$5,330	$352,421	$545,151
332323	Ornamental and architectural metal work manufacturing	$105,713	$3,007	$198,802	$307,521
332439	Other metal container manufacturing	$18,347	$679	$35,589	$54,614
332919	Other metal valve and pipe fitting manufacturing	$7,438	$679	$16,389	$24,506
332999	All other miscellaneous fabricated metal product manufacturing	$91,556	$2,604	$172,178	$266,338
333111	Farm machinery and equipment manufacturing	$54,540	$1,551	$102,568	$158,660
333414a	Heating equipment (except warm air furnaces) manufacturing	$16,354	$679	$32,081	$49,114
333911	Pump and pumping equipment manufacturing	$18,163	$679	$35,266	$54,108
333922	Conveyor and conveying equipment manufacturing	$24,684	$717	$46,743	$72,144
333924	Industrial truck, tractor, trailer, and stacker machinery	$11,897	$679	$24,237	$36,813
333999	All other miscellaneous general purpose machinery manufacturing	$48,478	$1,379	$91,167	$141,023
336211	Motor vehicle body manufacturing	$40,958	$1,165	$77,024	$119,147
336214	Travel trailer and camper manufacturing	$37,701	$1,072	$70,900	$109,673
336399a	All other motor vehicle parts manufacturing	$20,208	$679	$38,865	$59,753
336510	Railroad rolling stock	$7,400	$679	$16,323	$24,403
336999	All other transportation equipment manufacturing	$9,797	$679	$20,542	$31,018
337215	Showcase, partition, shelving, and locker manufacturing	$8,937	$679	$19,027	$28,643
811310	Commercial and industrial machinery and equipment repair	$390,361	$11,103	$734,105	$1,135,568
Resistance Welding					
333411	Air purification equipment manufacturing	$0	$0	$376,997	$376,997
333412	Industrial and commercial fan and blower manufacturing	$0	$0	$159,013	$159,013
333414b	Heating equipment (except warm air furnaces) manufacturing	$0	$0	$484,410	$484,410
333415	Air-conditioning, warm air heating, and industrial refrigeration equipment manufacturing	$0	$0	$887,734	$887,734
335211	Electric housewares and household fan manufacturing	$0	$0	$79,732	$79,732
335212	Household vacuum cleaner manufacturing	$0	$0	$25,574	$25,574
335221	Household cooking appliance manufacturing	$0	$0	$72,210	$72,210
335222	Household refrigerator and home freezer manufacturing	$0	$0	$16,548	$16,548
335224	Household laundry equipment manufacturing	$0	$0	$8,274	$8,274
335228	Other major household appliance manufacturing	$0	$0	$28,583	$28,583

Table V-20, continued					
Annualized Costs to Industries Affected by the Proposed Beryllium Standard, by Application Group and Six-Digit NAICS					
NAICS code	**Industry**	**Engineering Controls and Work Practices**	**Respirator Costs**	**Program Costs**	**Total Costs**
Resistance Welding					
336311	Carburetor, piston, piston ring, and valve manufacturing	$0	$0	$81,989	$81,989
336312	Gasoline engine and engine parts manufacturing	$0	$0	$558,125	$558,125
336321	Vehicular lighting equipment manufacturing	$0	$0	$69,954	$69,954
336322c	Other motor vehicle electrical and electronic equipment manufacturing	$0	$0	$478,393	$478,393
336330	Motor vehicle steering and suspension components (except spring) manufacturing	$0	$0	$185,039	$185,039
336340	Motor vehicle brake system manufacturing	$0	$0	$149,686	$149,686
336350	Motor vehicle transmission and power train parts manufacturing	$0	$0	$358,042	$358,042
336360	Motor vehicle seating and interior trim manufacturing	$0	$0	$303,132	$303,132
336370	Motor vehicle metal stamping	$0	$0	$553,612	$553,612
336391	Motor vehicle air-conditioning manufacturing	$0	$0	$60,175	$60,175
336399b	All other motor vehicle parts manufacturing	$0	$0	$1,015,456	$1,015,456
Dental Laboratories					
339116	Dental laboratories	$1,013,143	$0	$1,841,363	$2,854,507
621210	Offices of dentists	$137,596	$0	$250,973	$388,569
	Total	**$9,540,189**	**$249,684**	**$27,807,451**	**$37,597,325**
Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis.					

TIME DISTRIBUTION OF COSTS

OSHA analyzed the stream of (unannualized) compliance costs for the first ten years after the rule would take effect. As shown in Table V-21, compliance costs are expected to decline from Year 1 to Years 2 by about two-thirds after the initial set of capital and program start-up expenditures has been incurred. Costs are then essentially flat with small variation for the following years. Table V-22 breaks out total costs by each application group for the first ten years. Each application group follows the same pattern of a sharp decrease in compliance costs between years 1 and 2, and then stays essentially flat for the remaining years.

Table V-21

Distribution of Compliance Costs by Year

Year	Ancillary Provisions	Respirators	Engineering	Total
1	$54,855,000	$327,952	$36,829,487	**$92,012,439**
2	$23,325,298	$228,912	$5,880,931	**$29,435,140**
3	$24,828,689	$240,178	$5,957,755	**$31,026,621**
4	$23,480,995	$248,358	$5,880,931	**$29,610,284**
5	$24,715,341	$240,178	$5,957,755	**$30,913,274**
6	$23,563,512	$228,912	$5,880,931	**$29,673,354**
7	$24,655,269	$259,624	$5,957,755	**$30,872,648**
8	$23,607,245	$228,912	$5,880,931	**$29,717,087**
9	$24,623,432	$240,178	$5,957,755	**$30,821,364**
10	$23,630,422	$248,358	$5,880,931	**$29,759,711**

Source: OSHA, Office of Regulatory Analysis.

Table V-22

Total Costs of the Proposed Beryllium Standard Over 10 Years

Sector	Year 1	2	3	4	5	6	7	8	9	10
Dental Labs	$5,571,915	$2,894,658	$2,942,637	$2,907,708	$2,933,137	$2,914,625	$2,928,101	$2,918,291	$2,925,433	$2,920,233
Rolling	$2,548,876	$1,113,533	$1,143,972	$1,120,113	$1,139,181	$1,123,600	$1,136,643	$1,125,448	$1,135,297	$1,126,428
Drawing	$8,925,987	$3,885,550	$4,083,660	$3,908,382	$4,067,038	$3,920,482	$4,058,229	$3,926,895	$4,053,560	$3,930,294
Machining (high)	$956,750	$291,704	$332,220	$293,040	$331,247	$293,749	$330,731	$294,124	$330,458	$294,323
Machining (low)	$9,864,155	$3,653,091	$3,884,548	$3,674,768	$3,868,767	$3,686,257	$3,860,404	$3,692,345	$3,855,971	$3,695,572
Springs	$6,276,940	$2,308,087	$2,372,951	$2,320,003	$2,364,277	$2,326,318	$2,359,679	$2,329,665	$2,357,243	$2,331,439
Stamping	$5,668,700	$2,108,654	$2,198,512	$2,119,762	$2,190,425	$2,125,649	$2,186,139	$2,128,769	$2,183,868	$2,130,423
Non Sand Foundries	$13,534,884	$1,780,956	$2,080,682	$1,789,049	$2,074,790	$1,793,339	$2,071,667	$1,795,612	$2,070,012	$1,796,817
Sand Foundries	$5,135,116	$654,314	$771,428	$657,487	$769,119	$659,168	$767,895	$660,059	$767,246	$660,531
Smelting - Be Alloys	$437,887	$128,054	$138,701	$128,404	$138,446	$128,589	$138,311	$128,688	$138,240	$128,740
Smelting - Precious metals	$1,509,207	$442,715	$475,078	$444,525	$473,760	$445,485	$473,062	$445,993	$472,691	$446,263
Welding_GI	$9,117,203	$3,151,199	$3,366,395	$3,164,180	$3,356,945	$3,171,060	$3,351,937	$3,174,706	$3,349,282	$3,176,639
Be Oxide - Primary	$941,425	$143,614	$151,927	$143,927	$151,699	$144,093	$151,578	$144,182	$151,514	$144,228
Be Oxide - Secondary	$3,680,145	$1,195,790	$1,276,580	$1,202,509	$1,271,688	$1,206,070	$1,269,096	$1,207,957	$1,267,722	$1,208,957
Resistance Welding	$12,217,016	$5,011,412	$5,135,521	$5,045,170	$5,110,946	$5,063,061	$5,097,921	$5,072,543	$5,091,018	$5,077,568
Beryllium Production	$5,626,233	$671,809	$671,809	$691,255	$671,809	$671,809	$691,255	$671,809	$671,809	$691,255
Total	**$92,012,439**	**$29,435,140**	**$31,026,621**	**$29,610,284**	**$30,913,274**	**$29,673,354**	**$30,872,648**	**$29,717,087**	**$30,821,364**	**$29,759,711**

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis.

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Appendix V-A

Summary of Annualized Costs by Entity Size under Alternative Discount Rates

In addition to using a three percent discount rate in its cost analysis, OSHA estimated compliance costs using alternative discount rates of seven percent and zero percent. Tables V-A-1 and V-A-2 present— for seven percent and zero percent discount rates, respectively—total annualized costs for affected employers by NAICS industry code and employment size class (all establishments, small entities, and very small entities).

As shown in these tables, the choice of discount rate has only a minor effect on total annualized compliance costs—for example, with annualized costs for all establishments increasing from $37.6 million using a three percent discount rate to $39.1 million using a seven percent discount rate, and declining to $36.5 million using a zero percent discount rate.

Table V-A-1

Total Annualized Costs, for Entities Affected by the Proposed Beryllium Standard; Results Shown by Size Category (7% Discount Rate) by Application Group and Six-Digit NAICS Industry (in 2010 dollars)

Application Group	NAICS Code	Industry	All Establishments	Small Entities (SBA-defined)	Very Small Entities (<20 Employees)
Beryllium Production					
	331419	Primary Smelting and Refining of Nonferrous Metals (Brush Wellmar	$1,381,849	NA	NA
Beryllium Oxide Ceramics and Composites					
	327113a	Porcelain electrical supply manufacturing (primary)	$260,650	$105,269	NA
	327113b	Porcelain electrical supply manufacturing (secondary)	$244,166	$152,298	$50,847
	334220	Cellular telephones manufacturing	$179,403	$179,403	$26,281
	334310	Compact disc players manufacturing	$86,489	$86,489	$35,536
	334411	Electron Tube Manufacturing BeO traveling wave tubes	$370,094	$370,094	$69,054
	334415	Electronic resistor manufacturing	$211,399	$142,105	$24,298
	334419	Other electronic component manufacturing	$157,060	$106,661	$36,591
	334510	Electromedical equipment manufacturing	$162,026	$65,592	$21,408
	336322b	Other motor vehicle electrical & electronic equipment	$176,120	$176,120	$41,113
Nonferrous Foundries					
	331521	Aluminum die-casting foundries	$353,744	$242,960	NA
	331522	Nonferrous (except aluminum) die-casting foundries	$1,891,484	$1,352,558	NA
	331524	Aluminum foundries (except die-casting)	$347,157	$277,128	NA
	331525a	Copper foundries (except die-casting) (non-sand casting foundries)	$983,433	$847,984	NA
	331525b	Copper foundries (except die-casting) (sand casting foundries)	$1,339,601	$1,159,104	NA
Secondary Smelting, Refining, and Alloying					
	331314	Secondary smelting & alloying of aluminum	$35,283	$35,283	NA
	331421b	Copper rolling, drawing, and extruding	$35,732	$35,732	NA
	331423	Secondary smelting, refining, & alloying of copper	$105,480	$105,480	$31,493
	331492	Secondary Smelting, Refining, and Alloying of Nonferrous Metal (Ex	$608,465	$608,465	$171,726
Precision Machining					
	332721a	Precision turned product manufacturing (high beryllium content)	$402,670	$359,808	$83,350
	332721b	Precision turned product manufacturing (low beryllium content)	$4,646,934	$4,153,537	$968,033
Copper Rolling, Drawing and Extruding					
	331422	Copper wire (except mechanical) drawing	$4,706,098	$4,706,098	$144,612
	331421a	Copper rolling, drawing, and extruding	$1,337,872	$1,337,872	$23,885
Stamping, Spring, and Connector Manufacturing					
	332612	Light gauge spring manufacturing	$2,912,876	$1,977,103	$568,225
	332116	Metal stamping	$697,600	$592,328	$149,044
	334417	Electronic connector manufacturing	$446,521	$210,646	$36,020
	336322a	Other motor vehicle electrical & electronic equipment	$1,519,091	$1,519,091	$188,753
Dental Laboratories					
	339116	Dental laboratories	$2,925,401	$2,394,911	$1,509,803
	621210	Offices of dentists	$398,198	$376,088	$328,274
Arc and Gas Welding					
	331111	Iron and Steel Mills	$55,958	$55,958	NA
	331221	Rolled Steel Shape Manufacturing	$14,796	$14,796	NA
	331513	Steel Foundries (except Investment)	$14,621	$10,299	NA
	332117	Powder Metallurgy Part Manufacturing	$11,134	$8,477	NA
	332212	Hand and Edge Tool Manufacturing	$26,874	$19,391	$6,492
	332312	Fabricated Structural Metal Manufacturing	$461,578	$310,474	$84,546
	332313	Plate Work Manufacturing	$174,498	$153,292	$41,611
	332322	Sheet Metal Work Manufacturing	$565,356	$457,780	$123,947

Table V-A-1, continued					
Total Annualized Costs, for Entities Affected by the Proposed Beryllium Standard; Results Shown by Size Category (7% Discount Rate) by Application Group and Six-Digit NAICS Industry (in 2010 dollars)					
Arc and Gas Welding					
	332323	Ornamental and Architectural Metal Work Manufacturing	$318,919	$254,984	$105,084
	332439	Other Metal Container Manufacturing	$56,599	$33,230	$5,845
	332919	Other Metal Valve and Pipe Fitting Manufacturing	$25,324	$13,811	$2,473
	332999	All Other Miscellaneous Fabricated Metal Product Manufacturing	$276,209	$224,547	$64,117
	333111	Farm Machinery and Equipment Manufacturing	$164,540	$72,885	$15,814
	333414a	Heating Equipment (except Warm Air Furnaces) Manufacturing	$50,886	$31,845	$5,812
	333911	Pump and Pumping Equipment Manufacturing	$56,073	$21,423	$3,715
	333922	Conveyor and Conveying Equipment Manufacturing	$74,807	$58,052	$9,424
	333924	Industrial Truck, Tractor, Trailer, and Stacker Machinery Manufactur	$38,107	$38,107	$2,936
	333999	All Other Miscellaneous General Purpose Machinery Manufacturing	$146,250	$88,241	$23,308
	336211	Motor Vehicle Body Manufacturing	$123,563	$123,563	$9,831
	336214	Travel Trailer and Camper Manufacturing	$113,738	$53,925	$11,184
	336399a	All Other Motor Vehicle Parts Manufacturing	$61,937	$61,937	$2,878
	336510	Railroad Rolling Stock	$25,216	$25,216	NA
	336999	All Other Transportation Equipment Manufacturing	$32,088	$14,973	$5,919
	337215	Showcase, Partition, Shelving, and Locker Manufacturing	$29,621	$22,064	$5,271
	811310	Commercial and Industrial Machinery and Equipment Repair	$1,177,655	$728,708	$498,207
Resistance Welding					
	333411	Air Purification Equipment Manufacturing	$388,113	$170,679	$34,271
	333412	Industrial and Commercial Fan and Blower Manufacturing	$163,701	$100,194	$10,427
	333414b	Heating Equipment (except Warm Air Furnaces) Manufacturing	$498,693	$301,079	$47,538
	333415	Air-Conditioning, Warm Air Heating, and Industrial Refrigeration Eq	$913,909	$913,909	$31,457
	335211	Electric Housewares and Household Fan Manufacturing	$82,083	$82,083	$4,186
	335212	Household Vacuum Cleaner Manufacturing	$26,329	$26,329	NA
	335221	Household Cooking Appliance Manufacturing	$74,339	$74,339	$2,238
	335222	Household Refrigerator and Home Freezer Manufacturing	$17,036	$17,036	NA
	335224	Household Laundry Equipment Manufacturing	$8,518	$8,518	NA
	335228	Other Major Household Appliance Manufacturing	$29,426	$2,163	NA
	336311	Carburetor, Piston, Piston Ring, and Valve Manufacturing	$84,406	$23,983	$4,270
	336312	Gasoline Engine and Engine Parts Manufacturing	$574,581	$574,581	$37,637
	336321	Vehicular Lighting Equipment Manufacturing	$72,016	$23,516	$2,213
	336322c	Other Motor Vehicle Electrical and Electronic Equipment Manufactur	$492,498	$492,498	$29,062
	336330	Motor Vehicle Steering and Suspension Components (except Spring)	$190,494	$190,494	$5,675
	336340	Motor Vehicle Brake System Manufacturing	$154,099	$154,099	$3,513
	336350	Motor Vehicle Transmission and Power Train Parts Manufacturing	$368,599	$368,599	$10,050
	336360	Motor Vehicle Seating and Interior Trim Manufacturing	$312,070	$92,645	$7,589
	336370	Motor Vehicle Metal Stamping	$569,935	$247,396	$15,516
	336391	Motor Vehicle Air-Conditioning Manufacturing	$61,949	$61,949	$1,430
	336399b	All Other Motor Vehicle Parts Manufacturing	$1,045,396	$1,045,396	$42,966
		Total	**$39,147,434**	**$31,545,672**	**$5,826,797**

"NA" indicates not applicable because ERG determined there were no affected entites in a particular industry of a particular size.

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis

Table V-A-2

Total Annualized Costs, for Entities Affected by the Proposed Beryllium Standard; Results Shown by Size Category (0% Discount Rate) by Application Group and Six-Digit NAICS Industry (in 2010 dollars)

Application Group	NAICS Code	Industry	All Establishments	Small Entities (SBA-defined)	Very Small Entities (<20 Employees)
Beryllium Production					
	331419	Primary Smelting and Refining of Nonferrous Metals (Brush Wellmar	$1,171,789	NA	NA
Beryllium Oxide Ceramics and Composites					
	327113a	Porcelain electrical supply manufacturing (primary)	$227,095	$89,334	NA
	327113b	Porcelain electrical supply manufacturing (secondary)	$228,260	$141,182	$45,919
	334220	Cellular telephones manufacturing	$168,042	$168,042	$23,611
	334310	Compact disc players manufacturing	$80,802	$80,802	$32,431
	334411	Electron Tube Manufacturing BeO traveling wave tubes	$346,236	$346,236	$62,134
	334415	Electronic resistor manufacturing	$197,765	$132,156	$21,947
	334419	Other electronic component manufacturing	$146,834	$98,951	$33,078
	334510	Electromedical equipment manufacturing	$151,800	$60,020	$19,237
	336322b	Other motor vehicle electrical & electronic equipment	$164,759	$164,759	$36,958
Nonferrous Foundries					
	331521	Aluminum die-casting foundries	$305,951	$206,199	NA
	331522	Nonferrous (except aluminum) die-casting foundries	$1,632,056	$1,139,165	NA
	331524	Aluminum foundries (except die-casting)	$299,364	$235,884	NA
	331525a	Copper foundries (except die-casting) (non-sand casting foundries)	$846,892	$723,700	NA
	331525b	Copper foundries (except die-casting) (sand casting foundries)	$1,152,362	$988,214	NA
Secondary Smelting, Refining, and Alloying					
	331314	Secondary smelting & alloying of aluminum	$32,709	$32,709	NA
	331421b	Copper rolling, drawing, and extruding	$33,158	$33,158	NA
	331423	Secondary smelting, refining, & alloying of copper	$97,783	$97,783	$28,445
	331492	Secondary Smelting, Refining, and Alloying of Nonferrous Metal (Ex	$564,340	$564,340	$155,028
Precision Machining					
	332721a	Precision turned product manufacturing (high beryllium content)	$375,667	$335,660	$77,664
	332721b	Precision turned product manufacturing (low beryllium content)	$4,392,766	$3,925,890	$912,781
Copper Rolling, Drawing and Extruding					
	331422	Copper wire (except mechanical) drawing	$4,501,480	$4,501,480	$135,408
	331421a	Copper rolling, drawing, and extruding	$1,279,001	$1,279,001	$22,544
Stamping, Spring, and Connector Manufacturing					
	332612	Light gauge spring manufacturing	$2,748,461	$1,858,096	$525,423
	332116	Metal stamping	$658,732	$558,479	$138,126
	334417	Electronic connector manufacturing	$422,256	$197,620	$33,222
	336322a	Other motor vehicle electrical & electronic equipment	$1,435,579	$1,435,579	$174,000
Dental Laboratories					
	339116	Dental laboratories	$2,805,844	$2,295,715	$1,444,493
	621210	Offices of dentists	$381,960	$360,721	$314,757
Arc and Gas Welding					
	331111	Iron and Steel Mills	$52,650	$52,650	NA
	331221	Rolled Steel Shape Manufacturing	$14,079	$14,079	NA
	331513	Steel Foundries (except Investment)	$13,916	$9,829	NA
	332117	Powder Metallurgy Part Manufacturing	$10,648	$8,142	NA
	332212	Hand and Edge Tool Manufacturing	$25,397	$18,353	$6,186
	332312	Fabricated Structural Metal Manufacturing	$433,751	$291,734	$79,406
	332313	Plate Work Manufacturing	$163,978	$144,048	$39,088
	332322	Sheet Metal Work Manufacturing	$531,272	$430,167	$116,423

Table V-A-2, continued					
Total Annualized Costs, for Entities Affected by the Proposed Beryllium Standard; Results Shown by Size Category (0% Discount Rate) by Application Group and Six-Digit NAICS Industry (in 2010 dollars)					
Arc and Gas Welding					
	332323	Ornamental and Architectural Metal Work Manufacturing	$299,692	$239,600	$98,715
	332439	Other Metal Container Manufacturing	$53,250	$31,277	$5,510
	332919	Other Metal Valve and Pipe Fitting Manufacturing	$23,944	$13,091	$2,370
	332999	All Other Miscellaneous Fabricated Metal Product Manufacturing	$259,557	$211,001	$60,224
	333111	Farm Machinery and Equipment Manufacturing	$154,620	$68,475	$14,852
	333414a	Heating Equipment (except Warm Air Furnaces) Manufacturing	$47,897	$29,991	$5,485
	333911	Pump and Pumping Equipment Manufacturing	$52,758	$20,172	$3,502
	333922	Conveyor and Conveying Equipment Manufacturing	$70,314	$54,566	$8,859
	333924	Industrial Truck, Tractor, Trailer, and Stacker Machinery Manufactur	$35,923	$35,923	$2,782
	333999	All Other Miscellaneous General Purpose Machinery Manufacturing	$137,433	$82,912	$21,891
	336211	Motor Vehicle Body Manufacturing	$116,114	$116,114	$9,234
	336214	Travel Trailer and Camper Manufacturing	$106,881	$50,664	$10,504
	336399a	All Other Motor Vehicle Parts Manufacturing	$58,252	$58,252	$2,711
	336510	Railroad Rolling Stock	$23,844	$23,844	NA
	336999	All Other Transportation Equipment Manufacturing	$30,283	$14,179	$5,623
	337215	Showcase, Partition, Shelving, and Locker Manufacturing	$27,971	$20,858	$5,014
	811310	Commercial and Industrial Machinery and Equipment Repair	$1,106,657	$684,704	$468,067
Resistance Welding					
	333411	Air Purification Equipment Manufacturing	$369,361	$162,240	$32,394
	333412	Industrial and Commercial Fan and Blower Manufacturing	$155,792	$95,311	$9,852
	333414b	Heating Equipment (except Warm Air Furnaces) Manufacturing	$474,598	$286,336	$44,904
	333415	Air-Conditioning, Warm Air Heating, and Industrial Refrigeration Eq	$869,753	$869,753	$29,420
	335211	Electric Housewares and Household Fan Manufacturing	$78,117	$78,117	$3,919
	335212	Household Vacuum Cleaner Manufacturing	$25,056	$25,056	NA
	335221	Household Cooking Appliance Manufacturing	$70,748	$70,748	$2,092
	335222	Household Refrigerator and Home Freezer Manufacturing	$16,213	$16,213	NA
	335224	Household Laundry Equipment Manufacturing	$8,106	$8,106	NA
	335228	Other Major Household Appliance Manufacturing	$28,004	$2,037	NA
	336311	Carburetor, Piston, Piston Ring, and Valve Manufacturing	$80,328	$22,764	$4,010
	336312	Gasoline Engine and Engine Parts Manufacturing	$546,820	$546,820	$35,318
	336321	Vehicular Lighting Equipment Manufacturing	$68,537	$22,335	$2,069
	336322c	Other Motor Vehicle Electrical and Electronic Equipment Manufactur	$468,702	$468,702	$27,306
	336330	Motor Vehicle Steering and Suspension Components (except Spring)	$181,291	$181,291	$5,304
	336340	Motor Vehicle Brake System Manufacturing	$146,654	$146,654	$3,283
	336350	Motor Vehicle Transmission and Power Train Parts Manufacturing	$350,790	$350,790	$9,393
	336360	Motor Vehicle Seating and Interior Trim Manufacturing	$296,992	$88,005	$7,093
	336370	Motor Vehicle Metal Stamping	$542,398	$235,172	$14,559
	336391	Motor Vehicle Air-Conditioning Manufacturing	$58,956	$58,956	$1,336
	336399b	All Other Motor Vehicle Parts Manufacturing	$994,887	$994,887	$40,287
		Total	**$36,532,926**	**$29,505,790**	**$5,476,195**

"NA" indicates not applicable because ERG determined there were no affected entites in a particular industry of a particular size.

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis

Appendix V-B

Summary of Annualized Costs by Cost Type under Alternative Discount Rates

In addition to using a three percent discount rate in its cost analysis, OSHA estimated compliance costs using alternative discount rates of seven percent and zero percent. Tables V-B-1 and V-B-2 present— for seven percent and zero percent discount rates, respectively— total annualized costs for affected employers by NAICS industry code and type of cost.

NAICS Code	Industry	Engineering Controls and Work Practices	Respirator Costs	Program Costs	Total Costs
Beryllium Production					
331419	Primary smelting and refining of nonferrous metals	$1,310,473	$23,916	$47,459	$1,381,849
Beryllium Oxide Ceramics and Composites					
327113a	Porcelain electrical supply manufacturing (primary)	$193,937	$2,714	$63,999	$260,650
327113b	Porcelain electrical supply manufacturing (secondary)	$77,167	$1,757	$165,242	$244,166
334220	Cellular telephones manufacturing	$55,119	$1,255	$123,029	$179,403
334310	Compact disc players manufacturing	$27,560	$683	$58,247	$86,489
334411	Electron tube manufacturing	$115,750	$2,636	$251,708	$370,094
334415	Electronic resistor manufacturing	$66,143	$1,506	$143,750	$211,399
334419	Other electronic component manufacturing	$49,607	$1,141	$106,313	$157,060
334510	Electromedical equipment manufacturing	$49,607	$1,141	$111,278	$162,026
336322b	Other motor vehicle electrical and electronic equipment manufacturing	$55,119	$1,255	$119,746	$176,120
Nonferrous Foundries					
331521	Aluminum die-casting foundries	$208,471	$3,913	$141,360	$353,744
331522	Nonferrous (except aluminum) die-casting foundries	$1,131,702	$21,061	$738,721	$1,891,484
331524	Aluminum foundries (except die-casting)	$208,471	$3,913	$134,773	$347,157
331525a	Copper foundries (except die-casting) (non-sand casting foundries)	$595,633	$11,085	$376,716	$983,433
331525b	Copper foundries (except die-casting) (sand casting foundries)	$782,260	$16,007	$541,334	$1,339,601
Secondary Smelting, Refining, and Alloying					
331314	Secondary smelting & alloying of aluminum	$20,445	$3,258	$11,579	$35,283
331421b	Copper rolling, drawing, and extruding	$20,445	$3,258	$12,029	$35,732
331423	Secondary smelting, refining, & alloying of copper	$61,335	$9,553	$34,592	$105,480
331492	Secondary smelting, refining, & alloying of nonferrous metal (except copper & aluminum)	$306,676	$5,053	$296,736	$608,465
Precision Machining					
332721a	Precision turned product manufacturing (high beryllium content)	$174,167	$8,892	$219,611	$402,670
332721b	Precision turned product manufacturing (low beryllium content)	$947,395	$31,122	$3,668,417	$4,646,934
Copper Rolling, Drawing and Extruding					
331421a	Copper rolling, drawing, and extruding	$24,650	$1,691	$1,311,532	$1,337,872
331422	Copper wire (except mechanical) drawing	$103,922	$28,514	$4,573,662	$4,706,098
Stamping, Spring, and Connector Manufacturing					
332612	Light gauge spring manufacturing	$620,930	$9,224	$2,282,723	$2,912,876
332116	Metal stamping	$142,246	$3,613	$551,740	$697,600
334417	Electronic connector manufacturing	$88,808	$2,256	$355,458	$446,521
336322a	Other motor vehicle electrical & electronic equipment	$305,638	$7,764	$1,205,689	$1,519,091
Dental Laboratories					
339116	Dental laboratories	$1,026,503	$0	$1,898,898	$2,925,401
621210	Offices of dentists	$139,411	$0	$258,787	$398,198

Table V-B-1, continued					
Annualized Compliance Costs for Employers Affected by the Proposed Beryllium Standard (using a 7% discount rate) by Application Group and Six-Digit NAICS Industry (in 2010 dollars)					
NAICS Code	**Industry**	**Engineering Controls and Work Practices**	**Respirator Costs**	**Program Costs**	**Total Costs**
Arc and Gas Welding					
331111	Iron and steel mills	$19,167	$690	$36,100	$55,958
331221	Rolled steel shape manufacturing	$3,983	$690	$10,123	$14,796
331513	Steel foundries (except investment)	$3,918	$690	$10,012	$14,621
332117	Powder metallurgy part manufacturing	$2,632	$690	$7,812	$11,134
332212	Hand and edge tool manufacturing	$8,438	$690	$17,745	$26,874
332312	Fabricated structural metal manufacturing	$161,817	$4,417	$295,344	$461,578
332313	Plate work manufacturing	$61,174	$1,670	$111,653	$174,498
332322	Sheet metal work manufacturing	$198,199	$5,410	$361,746	$565,356
332323	Ornamental and architectural metal work manufacturing	$111,804	$3,052	$204,062	$318,919
332439	Other metal container manufacturing	$19,404	$690	$36,505	$56,599
332919	Other metal valve and pipe fitting manufacturing	$7,866	$690	$16,767	$25,324
332999	All other miscellaneous fabricated metal product manufacturing	$96,832	$2,643	$176,734	$276,209
333111	Farm machinery and equipment manufacturing	$57,683	$1,575	$105,282	$164,540
333414a	Heating equipment (except warm air furnaces)	$17,296	$690	$32,899	$50,886
333911	Pump and pumping equipment manufacturing	$19,210	$690	$36,173	$56,073
333922	Conveyor and conveying equipment manufacturing	$26,107	$729	$47,972	$74,807
333924	Industrial truck, tractor, trailer, and stacker machinery	$12,582	$690	$24,835	$38,107
333999	All other miscellaneous general purpose machinery	$51,271	$1,400	$93,579	$146,250
336211	Motor vehicle body manufacturing	$43,318	$1,182	$79,063	$123,563
336214	Travel trailer and camper manufacturing	$39,873	$1,088	$72,776	$113,738
336399a	All other motor vehicle parts manufacturing	$21,373	$690	$39,874	$61,937
336510	Railroad rolling stock	$7,827	$690	$16,699	$25,216
336999	All other transportation equipment manufacturing	$10,362	$690	$21,036	$32,088
337215	Showcase, partition, shelving, and locker manufacturing	$9,452	$690	$19,479	$29,621
811310	Commercial and industrial machinery and equipment repair	$412,855	$11,270	$753,530	$1,177,655
Resistance Welding					
333411	Air purification equipment manufacturing	$0	$0	$388,113	$388,113
333412	Industrial and commercial fan and blower manufacturing	$0	$0	$163,701	$163,701
333414b	Heating equipment (except warm air furnaces)	$0	$0	$498,693	$498,693
333415	Air-conditioning, warm air heating, and industrial	$0	$0	$913,909	$913,909
335211	Electric housewares and household fan manufacturing	$0	$0	$82,083	$82,083
335212	Household vacuum cleaner manufacturing	$0	$0	$26,329	$26,329
335221	Household cooking appliance manufacturing	$0	$0	$74,339	$74,339
335222	Household refrigerator and home freezer manufacturing	$0	$0	$17,036	$17,036
335224	Household laundry equipment manufacturing	$0	$0	$8,518	$8,518
335228	Other major household appliance manufacturing	$0	$0	$29,426	$29,426

Table V-B-1, continued					
Annualized Compliance Costs for Employers Affected by the Proposed Beryllium Standard (using a 7% discount rate) by Application Group and Six-Digit NAICS Industry (in 2010 dollars)					
NAICS Code	**Industry**	**Engineering Controls and Work Practices**	**Respirator Costs**	**Program Costs**	**Total Costs**
Resistance Welding					
336311	Carburetor, piston, piston ring, and valve manufacturing	$0	$0	$84,406	$84,406
336312	Gasoline engine and engine parts manufacturing	$0	$0	$574,581	$574,581
336321	Vehicular lighting equipment manufacturing	$0	$0	$72,016	$72,016
336322c	Other motor vehicle electrical and electronic equipment manufacturing	$0	$0	$492,498	$492,498
336330	Motor vehicle steering and suspension components (except spring) manufacturing	$0	$0	$190,494	$190,494
336340	Motor vehicle brake system manufacturing	$0	$0	$154,099	$154,099
336350	Motor vehicle transmission and power train parts manufacturing	$0	$0	$368,599	$368,599
336360	Motor vehicle seating and interior trim manufacturing	$0	$0	$312,070	$312,070
336370	Motor vehicle metal stamping	$0	$0	$569,935	$569,935
336391	Motor vehicle air-conditioning manufacturing	$0	$0	$61,949	$61,949
336399b	All other motor vehicle parts manufacturing	$0	$0	$1,045,396	$1,045,396
	Total	**$10,334,036**	**$252,281**	**$28,561,116**	**$39,147,434**

NOTE: Totals may not sum due to rounding.

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis.

Table V-B-2

Annualized Compliance Costs for Employers Affected by the Proposed Beryllium Standard (using a 0% discount rate) by Application Group and Six-Digit NAICS Industry (in 2010 dollars)

NAICS Code	Industry	Engineering Controls and Work Practices	Respirator Costs	Program Costs	Total Costs
Beryllium Production					
331419	Primary smelting and refining of nonferrous metals	$1,105,360	$22,988	$43,441	$1,171,789
Beryllium Oxide Ceramics and Composites					
327113a	Porcelain electrical supply manufacturing (primary)	$162,944	$2,694	$61,457	$227,095
327113b	Porcelain electrical supply manufacturing (secondary)	$68,632	$1,736	$157,892	$228,260
334220	Cellular telephones manufacturing	$49,023	$1,240	$117,779	$168,042
334310	Compact disc players manufacturing	$24,512	$669	$55,621	$80,802
334411	Electron tube manufacturing	$102,949	$2,603	$240,684	$346,236
334415	Electronic resistor manufacturing	$58,828	$1,488	$137,450	$197,765
334419	Other electronic component manufacturing	$44,121	$1,126	$101,588	$146,834
334510	Electromedical equipment manufacturing	$44,121	$1,126	$106,553	$151,800
336322b	Other motor vehicle electrical and electronic equipment manufacturing	$49,023	$1,240	$114,496	$164,759
Nonferrous Foundries					
331521	Aluminum die-casting foundries	$165,347	$3,890	$136,714	$305,951
331522	Nonferrous (except aluminum) die-casting foundries	$897,595	$20,954	$713,506	$1,632,056
331524	Aluminum foundries (except die-casting)	$165,347	$3,890	$130,128	$299,364
331525a	Copper foundries (except die-casting) (non-sand casting foundries)	$472,419	$11,029	$363,445	$846,892
331525b	Copper foundries (except die-casting) (sand casting foundries)	$613,654	$15,930	$522,777	$1,152,362
Secondary Smelting, Refining, and Alloying					
331314	Secondary smelting & alloying of aluminum	$18,323	$3,237	$11,149	$0
331421b	Copper rolling, drawing, and extruding	$18,323	$3,237	$11,598	$0
331423	Secondary smelting, refining, & alloying of copper	$54,970	$9,513	$33,300	$0
331492	Secondary smelting, refining, & alloying of nonferrous metal (except copper & aluminum)	$274,848	$5,003	$284,489	$564,340
Precision Machining					
332721a	Precision turned product manufacturing (high beryllium content)	$154,908	$8,844	$211,914	$375,667
332721b	Precision turned product manufacturing (low beryllium content)	$848,148	$30,688	$3,513,929	$4,392,766
Copper Rolling, Drawing and Extruding					
331421a	Copper rolling, drawing, and extruding	$90,961	$28,361	$4,382,157	$4,501,480
331422	Copper wire (except mechanical) drawing	$22,975	$1,668	$1,254,358	$1,279,001
Stamping, Spring, and Connector Manufacturing					
332612	Light gauge spring manufacturing	$565,774	$8,634	$2,174,053	$2,748,461
332116	Metal stamping	$129,610	$3,474	$525,649	$658,732
334417	Electronic connector manufacturing	$80,919	$2,169	$339,168	$0
336322a	Other motor vehicle electrical & electronic equipment	$278,487	$7,464	$1,149,628	$1,435,579
Dental Laboratories					
339116	Dental laboratories	$1,003,989	$0	$1,801,854	$2,805,844
621210	Offices of dentists	$136,353	$0	$245,607	$381,960

NAICS Code	Industry	Engineering Controls and Work Practices	Respirator Costs	Program Costs	Total Costs
Table V-B-2, continued					
Annualized Compliance Costs for Employers Affected by the Proposed Beryllium Standard (using a 0% discount rate) by Application Group and Six-Digit NAICS Industry (in 2010 dollars)					
Arc and Gas Welding					
331111	Iron and steel mills	$17,408	$671	$34,571	$52,650
331221	Rolled steel shape manufacturing	$3,617	$671	$9,791	$14,079
331513	Steel foundries (except investment)	$3,559	$671	$9,686	$0
332117	Powder metallurgy part manufacturing	$2,390	$671	$7,587	$10,648
332212	Hand and edge tool manufacturing	$7,664	$671	$17,062	$25,397
332312	Fabricated structural metal manufacturing	$146,960	$4,307	$282,485	$433,751
332313	Plate work manufacturing	$55,557	$1,628	$106,792	$163,978
332322	Sheet metal work manufacturing	$180,001	$5,275	$345,996	$531,272
332323	Ornamental and architectural metal work manufacturing	$101,539	$2,976	$195,177	$299,692
332439	Other metal container manufacturing	$17,622	$671	$34,957	$53,250
332919	Other metal valve and pipe fitting manufacturing	$7,144	$671	$16,129	$23,944
332999	All other miscellaneous fabricated metal product manufacturing	$87,941	$2,577	$169,039	$259,557
333111	Farm machinery and equipment manufacturing	$52,387	$1,535	$100,698	$154,620
333414a	Heating equipment (except warm air furnaces)	$15,708	$671	$31,518	$47,897
333911	Pump and pumping equipment manufacturing	$17,446	$671	$34,641	$52,758
333922	Conveyor and conveying equipment manufacturing	$23,710	$709	$45,896	$70,314
333924	Industrial truck, tractor, trailer, and stacker machinery	$11,427	$671	$23,825	$35,923
333999	All other miscellaneous general purpose machinery	$46,564	$1,365	$89,505	$137,433
336211	Motor vehicle body manufacturing	$39,341	$1,153	$75,620	$0
336214	Travel trailer and camper manufacturing	$36,212	$1,061	$69,607	$0
336399a	All other motor vehicle parts manufacturing	$19,411	$671	$38,171	$58,252
336510	Railroad rolling stock	$7,108	$671	$16,065	$23,844
336999	All other transportation equipment manufacturing	$9,411	$671	$20,202	$30,283
337215	Showcase, partition, shelving, and locker manufacturing	$8,584	$671	$18,716	$27,971
811310	Commercial and industrial machinery and equipment repair	$374,948	$10,988	$720,722	$1,106,657
Resistance Welding					
333411	Air purification equipment manufacturing	$0	$0	$369,361	$369,361
333412	Industrial and commercial fan and blower manufacturing	$0	$0	$155,792	$155,792
333414b	Heating equipment (except warm air furnaces)	$0	$0	$474,598	$474,598
333415	Air-conditioning, warm air heating, and industrial	$0	$0	$869,753	$869,753
335211	Electric housewares and household fan manufacturing	$0	$0	$78,117	$0
335212	Household vacuum cleaner manufacturing	$0	$0	$25,056	$25,056
335221	Household cooking appliance manufacturing	$0	$0	$70,748	$70,748
335222	Household refrigerator and home freezer manufacturing	$0	$0	$16,213	$16,213
335224	Household laundry equipment manufacturing	$0	$0	$8,106	$8,106
335228	Other major household appliance manufacturing	$0	$0	$28,004	$28,004

Table V-B-2, continued					
Annualized Compliance Costs for Employers Affected by the Proposed Beryllium Standard (using a 0% discount rate) by Application Group and Six-Digit NAICS Industry (in 2010 dollars)					
NAICS Code	**Industry**	**Engineering Controls and Work Practices**	**Respirator Costs**	**Program Costs**	**Total Costs**
Resistance Welding					
336311	Carburetor, piston, piston ring, and valve manufacturing	$0	$0	$80,328	$80,328
336312	Gasoline engine and engine parts manufacturing	$0	$0	$546,820	$546,820
336321	Vehicular lighting equipment manufacturing	$0	$0	$68,537	$68,537
336322c	Other motor vehicle electrical and electronic equipment manufacturing	$0	$0	$468,702	$468,702
336330	Motor vehicle steering and suspension components (except spring) manufacturing	$0	$0	$181,291	$181,291
336340	Motor vehicle brake system manufacturing	$0	$0	$146,654	$146,654
336350	Motor vehicle transmission and power train parts manufacturing	$0	$0	$350,790	$350,790
336360	Motor vehicle seating and interior trim manufacturing	$0	$0	$296,992	$296,992
336370	Motor vehicle metal stamping	$0	$0	$542,398	$542,398
336391	Motor vehicle air-conditioning manufacturing	$0	$0	$58,956	$58,956
336399b	All other motor vehicle parts manufacturing	$0	$0	$994,887	$994,887
	Total	**$8,996,119**	**$247,860**	**$27,288,947**	**$36,532,926**
NOTE: Totals may not sum due to rounding.					
Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis.					

CHAPTER VI: ECONOMIC FEASIBILITY ANALYSIS AND REGULATORY FLEXIBILITY DETERMINATION

In this chapter OSHA investigates the economic impacts of its proposed beryllium rule on affected employers. This impact investigation has two overriding objectives: (1) to establish whether the proposed rule is economically feasible for all affected application groups/industries,[400] and (2) to determine if the Agency can certify that the proposed rule will not have a significant economic impact on a substantial number of small entities.

In the discussion below, OSHA first presents its approach for achieving these objectives and next applies this approach to industries with affected employers. The Agency invites comment on any aspect of the methods and data used in this chapter and on any of the preliminary economic impact and economic feasibility findings presented in this chapter.

ANALYTIC APPROACH

Economic Feasibility

Section 6(b)(5) of the OSH Act states:

> The Secretary . . . shall set the standard which most adequately assures, *to the extent feasible*, on the basis of the best available evidence, that no employee will

[400] As noted in prior chapters in this PEA, OSHA has used the umbrella term “application group” to refer either to an industrial sector or to a cross-industry group with a common process. In this chapter, because some of the legal discussion being presented has historically been framed in the context of the economic feasibility for an “industry,” the Agency will be using the term “application group” and “industry” interchangeably.

suffer material impairment of health or functional capacity . . . .[401] [emphasis added]

OSHA interpreted the phrase "to the extent feasible" to encompass economic feasibility and was supported in this view by the U.S. Court of Appeals for the D.C. Circuit in its 1974 asbestos decision.[402] The court noted that "Congress does not appear to have intended to protect employees by putting their employers out of business . . ."[403] and then proceeded to define the concept of economic feasibility and to indicate its boundaries:

> Standards may be economically feasible even though, from the standpoint of employers, they are financially burdensome and affect profit margins adversely. Nor does the concept of economic feasibility necessarily guarantee the continued existence of individual employers. It would appear to be consistent with the purposes of the Act to envisage the economic demise of an employer who has lagged behind the rest of the industry in protecting the health and safety of employees and is consequently financially unable to comply with new standards as quickly as other employers. As the effect becomes more widespread within an industry, the problem of economic feasibility becomes more pressing.[404]

Thus, according to the court, OSHA standards would satisfy the economic feasibility criterion even if they imposed significant costs on regulated industries and forced some marginal

[401] 29 U.S.C. 655(b)(5).

[402] *Indus. Union Dep't v. Hodgson*, 499 F.2d 467 (D.C. Cir. 1974).

[403] *Id.* at 478.

[404] *Id*.

firms out of business, so long as they did not cause massive economic dislocations within a particular industry or imperil the existence of the industry.[405]

The implication, for analysis of economic impacts, is that OSHA is required to determine whether its standards will eliminate or alter the competitive structure of an industry, not to determine whether any individual plants will close, or whether some marginal plants may close earlier than they otherwise might have. OSHA thus has an obligation to examine industries, and to consider industry definitions carefully. However, OSHA does not have an obligation to conduct a facility-by-facility analysis of the thousands of facilities in the dozens of industries covered by a major standard.

The Price Elasticity of Demand and Its Relationship to Economic Feasibility

In practice, the economic burden of an OSHA standard on an industry—and whether the standard is economically feasible for that industry—depends on the magnitude of compliance costs incurred by establishments in that industry and the extent to which they are able to pass those costs on to their customers. That, in turn, depends, to a significant degree, on the price elasticity of demand for the products sold by establishments in that industry.

The price elasticity of demand refers to the relationship between the price charged for a product and the demand for that product: the more elastic the relationship, the less an establishment's compliance costs can be passed through to customers in the form of a price increase and the more the establishment has to absorb compliance costs in the form of reduced profits. When demand is inelastic, establishments can recover most of the costs of compliance

[405] *Id.*; see also *Am. Iron and Steel Inst. v. OSHA*, 939 F.2d 975, 980 (D.C. Cir. 1991); *United Steelworkers of Am., AFL-CIO-CLC v. Marshall*, 647 F.2d 1189, 1265 (D.C. Cir. 1980).

by raising the prices they charge; under this scenario, profit rates are largely unchanged and the industry remains largely unaffected. Any impacts are primarily on those customers using the relevant product. On the other hand, when demand is elastic, establishments cannot recover all compliance costs simply by passing the cost increase through in the form of a price increase; instead, they must absorb some of the increase from their profits. Commonly, this will mean reductions both in the quantity of goods and services produced and in total profits, though the profit rate may remain unchanged. In general, "[w]hen an industry is subjected to a higher cost, it does not simply swallow it; it raises its price and reduces its output, and in this way shifts a part of the cost to its consumers and a part to its suppliers," in the words of the court in *Am. Dental Ass'n v. Sec'y of Labor* (984 F.2d 823, 829 (7th Cir. 1993)).

The court's summary is in accord with microeconomic theory. In the long run, firms can remain in business only if their profits are adequate to provide a return on investment that ensures that investment in the industry will continue. Over time, because of rising real incomes and productivity increases, firms in most industries are able to ensure an adequate profit. As technology and costs change, however, the long-run demand for some products naturally increases and the long-run demand for other products naturally decreases. In the face of additional compliance costs (or other external costs), firms that otherwise have a profitable line of business may have to increase prices to stay viable. Increases in prices typically result in reduced quantity demanded, but rarely eliminate all demand for the product. Whether this decrease in the total production of goods and services results in smaller output for each establishment within the industry or the closure of some plants within the industry, or a combination of the two, is dependent on the cost and profit structure of individual firms within the industry.

If demand is perfectly inelastic (i.e., the price elasticity of demand is zero), then the impact of compliance costs that are one percent of revenues for each firm in the industry would be a one percent increase in the price of the product, with no decline in quantity demanded. Such a situation represents an extreme case, but might be observed in situations in which there were few, if any, substitutes for the product in question, or if the products of the affected sector account for only a very small portion of the revenue or income of its customers.

If the demand is perfectly elastic (i.e., the price elasticity of demand is infinitely large), then no increase in price is possible and before-tax profits would be reduced by an amount equal to the costs of compliance (net of any cost savings—such as reduced workers' compensation insurance premiums—resulting from the proposed standard) if the industry attempted to maintain production at the same level as previously. Under this scenario, if the costs of compliance are such a large percentage of profits that some or all plants in the industry could no longer operate in the industry with hope of an adequate return on investment, then some or all of the firms in the industry would close. This scenario is highly unlikely to occur, however, because it can only arise when there are other products—unaffected by the proposed rule—that are, in the eyes of their customers, perfect substitutes for the products the affected establishments make.

A commonly-discussed intermediate case would be a price elasticity of demand of one.[406] In this situation, if the costs of compliance amount to one percent of revenues, then production would decline by one percent and prices would rise by one percent. As a result, industry

[406] Here and throughout this chapter, the price elasticity of demand is reported as an absolute value.

revenues would remain the same, with somewhat lower production, but with similar profit rates per unit of output (in most situations where the marginal costs of production net of regulatory costs would fall as well). Customers would, however, receive less of the product for their (same) expenditures, and firms would have lower total profits; this, as the court described in *Am. Dental Ass'n v. Sec'y of Labor*, is the more typical case.

<u>Variable Costs Versus Fixed Costs</u>

A decline in output as a result of an increase in price may occur in a variety of ways: individual establishments could each reduce their levels of production; some marginal plants could close; or, in the case of an expanding industry, new entry may be delayed until demand equals supply. In some situations, there could be a combination of these three effects. Which possibility is most likely depends on the form that the costs of the regulation take. If the costs are variable costs (i.e., costs that vary with the level of production at a facility), then economic theory suggests that any reductions in overall output will be the result of reductions in output at each affected facility, with few, if any, plant closures. If, on the other hand, the costs of a regulation primarily take the form of fixed costs (i.e., costs that do not vary with the level of production at a facility), then reductions in overall output are more likely to take the form of plant closures or delays in new entry.

Most of the costs of this regulation, as estimated in Chapter V of this PEA, are variable costs in the sense that they will tend to vary by production levels and/or employment levels. Almost all of the major costs of program elements, such as medical surveillance and training, will vary in proportion to the number of employees (which is a rough proxy for the amount of production). Exposure monitoring costs will vary with the number of employees, but do have some economies of scale to the extent that a larger firm need only conduct representative sampling rather than sample every employee. Finally, the costs of operating and maintaining engineering controls tend to vary by usage—which typically closely tracks the level of production and are not fixed costs in the strictest sense.

This leaves two kinds of costs that are, in some sense, fixed costs—capital costs of engineering controls and certain initial costs. The capital costs of engineering controls due to the standard—many of which are scaled to production and/or employment levels—constitute a relatively small share of the total costs, representing 10 percent of total annualized costs (or approximately $870 per year per affected establishment).

Some ancillary provisions require initial costs that are fixed in the sense that they do not vary by production activity or the number of employees. Some examples are the costs to develop a training plan for general training not currently required and to develop a written exposure control plan.

As a result of these considerations, OSHA expects it to be quite likely that any reductions in total industry output would be due to reductions in output at each affected facility rather than as a result of plant closures. However, closures of some marginal plants or poorly performing facilities are always possible.

Economic Feasibility Screening Analysis

To determine whether a rule is economically feasible, OSHA begins with two screening tests to consider minimum threshold effects of the rule under two extreme cases: (1) all costs are passed through to customers in the form of higher prices (consistent with a price elasticity of demand of zero), and (2) all costs are absorbed by the firm in the form of reduced profits (consistent with an infinite price elasticity of demand).

In the former case, the immediate impact of the rule would be observed in increased industry revenues. While there is no hard and fast rule, in the absence of evidence to the contrary, OSHA generally considers a standard to be economically feasible for an industry when the annualized costs of compliance are less than a threshold level of one percent of annual revenues. Retrospective studies of previous OSHA regulations have shown that potential impacts of such a small magnitude are unlikely to eliminate an industry or significantly alter its competitive structure,[407] particularly since most industries have at least some ability to raise prices to reflect increased costs, and normal price variations for products typically exceed three percent a year.[408]

In the latter case, the immediate impact of the rule would be observed in reduced industry profits. OSHA uses the ratio of annualized costs to annual profits as a second check on economic feasibility. Again, while there is no hard and fast rule, in the absence of evidence to the contrary, OSHA generally considers a standard to be economically feasible for an industry when the annualized costs of compliance are less than a threshold level of ten percent of annual profits. In the context of economic feasibility, the Agency believes this threshold level to be fairly modest, given that normal year-to-year variations in profit rates in an industry can exceed 40 percent or more.[409] OSHA's choice of a threshold level of ten percent of annual profits is low enough that

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[407] See OSHA's web page, http://www.osha.gov/dea/lookback.html#Completed, for a link to all completed OSHA lookback reviews.

[408] See, for example, Table VI-3 and the accompanying text presented later in this chapter.

[409] See, for example, Table VI-5 and the accompanying text presented later in this chapter.

even if, in a hypothetical worst case, all compliance costs were upfront costs, then upfront costs—assuming a three percent discount rate and a ten-year time period—would be no more than 89 percent of first-year profits and thus would be affordable from profits without resort to credit markets.[410] If the threshold level were *first-year* costs of ten percent of annual profits, firms could even more easily expect to cover first-year costs at the threshold level out of current profits without having to access capital markets and otherwise being threatened with short-term insolvency.

In general, because it is usually the case that firms would be able to pass on to their customers some or all of the costs of the proposed rule in the form of higher prices, OSHA will tend to give much more weight to the ratio of industry costs to industry revenues than to the ratio of industry costs to industry profits. However, if costs exceed either the threshold percentage of revenue or the threshold percentage of profits for an industry, or if there is other evidence of a threat to the viability of an industry because of the proposed standard, OSHA will examine the effect of the rule on that industry more closely. Such an examination would include market factors specific to the industry, such as normal variations in prices and profits, and any special circumstances, such as close domestic substitutes of equal cost, which might make the industry particularly vulnerable to a regulatory cost increase.

The preceding discussion focused on the economic viability of the affected industries in their entirety. However, even if OSHA found that a proposed standard did not threaten the survival of affected industries, there is still the question of whether the industries' competitive

[410] Using, instead, a seven percent discount rate, taking all compliance costs as upfront costs would equal about 75 percent of first-year profits.

structure would be significantly altered. For example, if the annualized costs of an OSHA standard were equal to ten percent of an industry's annual profits, and the price elasticity of demand for the products in that industry were equal to one, then OSHA would not expect the industry to go out of business. However, if the increase in costs were such that most or all small firms in that industry would have to close, it might reasonably be concluded that the competitive structure of the industry had been altered. For this reason, OSHA also calculates compliance costs by size of firm and conducts its economic feasibility screening analysis for small and very small entities.

Regulatory Flexibility Screening Analysis

The Regulatory Flexibility Act (RFA), Pub. L. No. 96-354, 94 Stat. 1164 (codified at 5 U.S.C. 601), requires Federal agencies to consider the economic impact that a proposed rulemaking will have on small entities. The RFA states that whenever a Federal agency is required to publish general notice of proposed rulemaking for any proposed rule, the agency must prepare and make available for public comment an initial regulatory flexibility analysis (IRFA). 5 U.S.C. 603(a). Pursuant to section 605(b), in lieu of an IRFA, the head of an agency may certify that the proposed rule will not have a significant economic impact on a substantial number of small entities. A certification must be supported by a factual basis. If the head of an agency makes a certification, the agency shall publish such certification in the Federal Register at the time of publication of general notice of proposed rulemaking or at the time of publication of the final rule. 5 U.S.C. 605(b).

To determine if the Assistant Secretary of Labor for OSHA can certify that the proposed beryllium rule will not have a significant economic impact on a substantial number of small entities, the Agency has developed screening tests to consider minimum threshold effects of the proposed rule on small entities. These screening tests do not constitute hard and fast rules and are similar in concept to those OSHA developed above to identify minimum threshold effects for purposes of demonstrating economic feasibility.

There are, however, two differences. First, for each affected industry, the screening tests are applied, not to all establishments, but to small entities (defined as “small business concerns” by SBA) and also to very small entities (as defined by OSHA as businesses with fewer than 20 employees). Second, although OSHA’s regulatory flexibility screening test for revenues also uses a minimum threshold level of annualized costs equal to one percent of annual revenues, OSHA has established a minimum threshold level of annualized costs equal to five percent of annual profits for the average small entity or very small entity. The Agency has chosen a lower minimum threshold level for the profitability screening analysis and has applied its screening tests to both small entities and very small entities in order to ensure that certification will be made, and an IRFA will not be prepared, only if OSHA can be highly confident that a proposed rule will not have a significant economic impact on a substantial number of small entities or very small entities in any affected industry.

Furthermore, certification will not be made, and an IRFA will be prepared, if OSHA believes the proposed rule might otherwise have a significant economic impact on a substantial number of small entities, even if the minimum threshold levels are not exceeded for revenues or profitability for small entities or very small entities in all affected industries.

IMPACTS ON AFFECTED INDUSTRIES

In this section, OSHA applies its screening criteria and other analytic methods, as needed, to determine (1) whether the proposed rule is economically feasible for all affected industries within the scope of this proposed rule, and (2) whether the Agency can certify that the proposed rule will not have a significant economic impact on a substantial number of small entities.

Economic Feasibility Screening Analysis: All Establishments

Earlier chapters of this PEA identified the application groups potentially affected by the proposed rule; presented summary profile data for affected industries, including the number of affected entities and establishments, the number of at-risk workers, and average revenue for affected entities and establishments; and developed estimates, by affected industry, of the costs of the proposed rule. Obviously, the economic impacts of the proposed rule are driven, in part, by the costs of additional control measures, respirators, and ancillary beryllium program activities needed to comply with the proposed rule.

To determine whether the proposed rule's projected costs of compliance would threaten the economic viability of affected industries, OSHA first compared, for each affected industry, annualized compliance costs to annual revenues and profits per (average) affected establishment. The results for all affected establishments in all affected industries are presented in Table VI-1. Shown in the table for each affected industry are the total number of establishments, the total number of affected establishments, annualized costs per affected establishment, annual revenues per establishment, the profit rate, annual profits per establishment, annualized compliance costs as a percentage of annual revenues, and annualized compliance costs as a percentage of annual profits.

The annualized costs per affected establishment for each affected industry were calculated by distributing the industry-level (incremental) annualized compliance costs among all affected establishments in the industry, where annualized compliance costs reflect a 3 percent discount rate.[411] The annualized cost of the proposed rule for the average affected establishment is estimated at $9,197 in 2010 dollars. It is clear from Table VI-1 that the estimates of the annualized costs per affected establishment vary widely from industry to industry. These estimates range from $1,257,214 for NAICS 331419 (Beryllium Production) and $120,372 for NAICS 327113a (Porcelain Electrical Supply Manufacturing (primary)) to $1,636 for NAICS 621210 (Offices of Dentists) and $1,632 for NAICS 339116 (Dental Laboratories).

[411] Tables VI-A-1 and VI-A-2 in Appendix VI-A show per-establishment annualized costs and ratios of annualized cost to annual revenue and annualized costs to annual profit using discount rates of 7 percent and 0 percent, respectively, to annualize costs.

Table VI-1

Screening Analysis for Establishments Affected by the Proposed Beryllium Standard
With Costs Calculated Using a Three Percent Discount Rate

				Revenues		Profit		Compliance Costs		
NAICS Code	**Industry**	**Total Establishments**	**Total Affected Establishments**	**Total ($1,000)**	**Per Establishment ($s)**	**Rate**	**Per Establishment ($s)**	**Per Establishment ($s)**	**As a Percent of Revenues**	**As a Percent of Profits**
Beryllium Production										
331419	Primary smelting and refining of nonferrous metals	161	1	$8,524,863	--	--	--	$1,257,214	--	--
Beryllium Oxide Ceramics and Composites										
327113a	Porcelain electrical supply manufacturing (primary)	106	2	$789,731	--	--	--	$120,372	--	--
327113b	Porcelain electrical supply manufacturing (secondary)	106	14	$789,731	7,450,295	5.01%	373,542	$16,767	0.23%	4.49%
334220	Cellular telephones manufacturing	810	10	$35,475,343	43,796,720	6.08%	2,663,922	$17,267	0.04%	0.65%
334310	Compact disc players manufacturing	464	5	$3,975,351	8,567,567	4.39%	376,456	$16,624	0.19%	4.42%
334411	Electron tube manufacturing	79	21	$1,220,476	15,449,068	7.85%	1,212,421	$16,950	0.11%	1.40%
334415	Electronic resistor manufacturing	61	12	$560,967	9,196,181	7.85%	721,703	$16,943	0.18%	2.35%
334419	Other electronic component manufacturing	1,133	9	$10,013,730	8,838,244	7.85%	693,613	$16,778	0.19%	2.42%
334510	Electromedical equipment manufacturing	629	9	$27,480,966	43,689,930	6.75%	2,947,904	$17,329	0.04%	0.59%
336322b	Other motor vehicle electrical and electronic equipment manufacturing	636	10	$12,152,053	19,107,002	1.83%	348,832	$16,939	0.09%	4.86%
Nonferrous Foundries										
331521	Aluminum die-casting foundries	254	7	$4,310,021	16,968,585	5.22%	885,603	$46,486	0.27%	5.25%
331522	Nonferrous (except aluminum) die-casting foundries	140	38	$1,510,799	10,791,418	5.22%	563,212	$45,727	0.42%	8.12%
331524	Aluminum foundries (except die-casting)	394	7	$2,518,097	6,391,108	5.22%	333,557	$45,545	0.71%	13.65%
331525a	Copper foundries (except die-casting) (non-sand casting foundries)	208	20	$1,205,574	5,796,031	5.22%	302,499	$45,123	0.78%	14.92%
331525b	Copper foundries (except die-casting) (sand casting foundries)	208	25	$1,205,574	5,796,031	5.22%	302,499	$49,143	0.85%	16.25%
Secondary Smelting, Refining, and Alloying										
331314	Secondary smelting & alloying of aluminum	122	1	$4,837,129	39,648,599	4.54%	1,802,008	$33,757	0.09%	1.87%
331421b	Copper rolling, drawing, and extruding	96	1	$12,513,425	130,348,178	4.79%	6,248,900	$34,206	0.03%	0.55%
331423	Secondary smelting, refining, & alloying of copper	24	3	$723,759	30,156,619	4.79%	1,445,710	$33,639	0.11%	2.33%
331492	Secondary smelting, refining, & alloying of nonferrous metal (except copper & aluminum)	248	30	$8,195,807	33,047,610	4.79%	1,584,305	$19,410	0.06%	1.23%
Precision Turned Products										
332721a	Precision turned product manufacturing (high beryllium content)	3,124	18	$13,262,706	4,245,425	5.82%	247,032	$20,979	0.49%	8.49%
332721b	Precision turned product manufacturing (low beryllium content)	3,124	294	$13,262,706	4,245,425	5.82%	247,032	$15,295	0.36%	6.19%
Copper Rolling, Drawing and Extruding										
331421a	Copper rolling, drawing, and extruding	96	15	$12,513,425	130,348,178	4.79%	6,248,900	$86,865	0.07%	1.39%
331422	Copper wire (except mechanical) drawing	114	59	$6,471,491	56,767,462	4.79%	2,721,436	$77,709	0.14%	2.86%
Fabrication of Beryllium Alloy Products										
332612	Light gauge spring manufacturing	323	323	$2,167,977	6,712,003	5.61%	376,763	$8,716	0.13%	2.31%
332116	Metal stamping	1,484	74	$9,749,800	6,569,946	5.12%	336,300	$9,116	0.14%	2.71%
334417	Electronic connector manufacturing	231	46	$5,029,508	21,772,761	7.85%	1,708,696	$9,354	0.04%	0.55%
336322a	Other motor vehicle electrical & electronic equipment	636	159	$12,152,053	19,107,002	1.83%	348,832	$9,243	0.05%	2.65%

Table VI-1, continued											
Screening Analysis for Establishments Affected by the Proposed Beryllium Standard With Costs Calculated Using a Three Percent Discount Rate											
				Revenues		**Profit**		**Compliance Costs**			
NAICS Code	**Industry**	**Total Establishments**	**Total Affected Establishments**	**Total ($1,000)**	**Per Establishment ($s)**	**Rate**	**Per Establishment ($s)**	**Per Establishment ($s)**	**As a Percent of Revenues**	**As a Percent of Profits**
Arc and Gas Welding										
331111	Iron and steel mills	587	7	$92,726,004	157,965,934	5.41%	8,542,604	$8,149	0.01%	0.10%
331221	Rolled steel shape manufacturing	161	1	$8,376,271	52,026,531	5.41%	2,813,531	$10,438	0.02%	0.37%
331513	Steel foundries (except investment)	220	1	$4,251,852	19,326,599	5.22%	1,008,670	$10,486	0.05%	1.04%
332117	Powder metallurgy part manufacturing	133	1	$1,414,108	10,632,394	5.12%	544,246	$11,921	0.11%	2.19%
332212	Hand and edge tool manufacturing	1,066	3	$5,077,868	4,763,479	5.61%	267,387	$8,913	0.19%	3.33%
332312	Fabricated structural metal manufacturing	3,407	56	$26,119,614	7,666,455	4.74%	363,273	$7,957	0.10%	2.19%
332313	Plate work manufacturing	1,288	21	$6,023,356	4,676,519	4.74%	221,596	$7,957	0.17%	3.59%
332322	Sheet metal work manufacturing	4,173	69	$17,988,908	4,310,786	4.74%	204,266	$7,957	0.18%	3.90%
332323	Ornamental and architectural metal work manufacturing	2,354	39	$5,708,707	2,425,109	4.74%	114,913	$7,957	0.33%	6.92%
332439	Other metal container manufacturing	370	7	$3,565,875	9,637,500	4.30%	414,839	$8,142	0.08%	1.96%
332919	Other metal valve and pipe fitting manufacturing	265	3	$4,584,082	17,298,424	7.00%	1,211,086	$9,012	0.05%	0.74%
332999	All other miscellaneous fabricated metal product manufacturing	3,262	33	$13,963,184	4,280,559	7.00%	299,688	$7,957	0.19%	2.66%
333111	Farm machinery and equipment manufacturing	1,041	20	$24,067,145	23,119,255	6.36%	1,471,196	$7,957	0.03%	0.54%
333414a	Heating equipment (except warm air furnaces) manufacturing	460	6	$4,781,561	10,394,697	4.68%	486,402	$8,214	0.08%	1.69%
333911	Pump and pumping equipment manufacturing	571	7	$12,395,387	21,708,209	5.36%	1,163,538	$8,148	0.04%	0.70%
333922	Conveyor and conveying equipment manufacturing	776	9	$6,569,120	8,465,361	5.36%	453,735	$7,994	0.09%	1.76%
333924	Industrial truck, tractor, trailer, and stacker machinery manufacturing	374	4	$7,444,451	19,904,948	5.36%	1,066,885	$8,464	0.04%	0.79%
333999	All other miscellaneous general purpose machinery manufacturing	1,524	18	$10,972,258	7,199,644	5.36%	385,894	$7,957	0.11%	2.06%
336211	Motor vehicle body manufacturing	742	15	$9,877,558	13,312,072	1.83%	243,036	$7,957	0.06%	3.27%
336214	Travel trailer and camper manufacturing	683	14	$7,465,024	10,929,757	1.83%	199,542	$7,957	0.07%	3.99%
336399a	All other motor vehicle parts manufacturing	1,350	7	$32,279,766	23,910,938	1.83%	436,537	$8,087	0.03%	1.85%
336510	Railroad rolling stock	226	3	$11,927,191	52,775,180	5.47%	2,887,552	$9,019	0.02%	0.31%
336999	All other transportation equipment manufacturing	374	4	$5,250,368	14,038,417	6.56%	921,324	$8,660	0.06%	0.94%
337215	Showcase, partition, shelving, and locker manufacturing	1,194	3	$5,815,404	4,870,523	4.26%	207,405	$8,766	0.18%	4.23%
811310	Commercial and industrial machinery and equipment repair	21,960	143	$31,650,469	1,441,278	5.42%	78,080	$7,957	0.55%	10.19%
Resistance Welding										
333411	Air purification equipment manufacturing	358	25	$3,060,744	8,549,565	4.68%	400,062	$15,044	0.18%	3.76%
333412	Industrial and commercial fan and blower manufacturing	151	11	$1,681,585	11,136,327	4.68%	521,106	$15,044	0.14%	2.89%
333414b	Heating equipment (except warm air furnaces) manufacturing	460	32	$4,781,561	10,394,697	4.68%	486,402	$15,044	0.14%	3.09%
333415	Air-conditioning, warm air heating, and industrial refrigeration equipment manufacturing	843	59	$25,454,383	30,194,998	4.68%	1,412,924	$15,044	0.05%	1.06%
335211	Electric housewares and household fan manufacturing	106	5	$2,209,657	20,845,825	4.03%	840,119	$15,044	0.07%	1.79%
335212	Household vacuum cleaner manufacturing	34	2	$891,600	26,223,543	4.03%	1,056,849	$15,044	0.06%	1.42%
335221	Household cooking appliance manufacturing	96	5	$3,757,849	39,144,257	4.03%	1,577,573	$15,044	0.04%	0.95%
335222	Household refrigerator and home freezer manufacturing	22	1	$4,489,845	204,083,854	4.03%	8,224,892	$15,044	0.01%	0.18%
335224	Household laundry equipment manufacturing	11	1	$3,720,514	338,228,505	4.03%	13,631,126	$15,044	0.00%	0.11%
335228	Other major household appliance manufacturing	38	2	$3,499,273	92,086,126	4.03%	3,711,212	$15,044	0.02%	0.41%

				Revenues		Profit		Compliance Costs		
NAICS Code	Industry	Total Establishments	Total Affected Establishments	Total ($1,000)	Per Establishment ($s)	Rate	Per Establishment ($s)	Per Establishment ($s)	As a Percent of Revenues	As a Percent of Profits
Resistance Welding										
336311	Carburetor, piston, piston ring, and valve manufacturing	109	5	$1,715,429	15,737,881	1.83%	287,323	$15,044	0.10%	5.24%
336312	Gasoline engine and engine parts manufacturing	742	37	$20,000,705	26,955,128	1.83%	492,114	$15,044	0.06%	3.06%
336321	Vehicular lighting equipment manufacturing	93	5	$2,322,610	24,974,299	1.83%	455,950	$15,044	0.06%	3.30%
336322c	Other motor vehicle electrical and electronic equipment manufacturing	636	32	$12,152,053	19,107,002	1.83%	348,832	$15,044	0.08%	4.31%
336330	Motor vehicle steering and suspension components (except spring) manufacturing	246	12	$8,856,584	36,002,374	1.83%	657,287	$15,044	0.04%	2.29%
336340	Motor vehicle brake system manufacturing	199	10	$8,147,826	40,943,850	1.83%	747,503	$15,044	0.04%	2.01%
336350	Motor vehicle transmission and power train parts manufacturing	476	24	$21,862,014	45,928,600	1.83%	838,508	$15,044	0.03%	1.79%
336360	Motor vehicle seating and interior trim manufacturing	403	20	$15,168,862	37,639,856	1.83%	687,183	$15,044	0.04%	2.19%
336370	Motor vehicle metal stamping	736	37	$19,809,238	26,914,725	1.83%	491,376	$15,044	0.06%	3.06%
336391	Motor vehicle air-conditioning manufacturing	80	4	$3,798,464	47,480,804	1.83%	866,847	$15,044	0.03%	1.74%
336399b	All other motor vehicle parts manufacturing	1,350	68	$32,279,766	23,910,938	1.83%	436,537	$15,044	0.06%	3.45%
Dental Laboratories										
339116	Dental laboratories	6,995	1,749	$4,100,626	586,222	10.55%	61,873	$1,632	0.28%	2.64%
621210	Offices of dentists	129,830	238	$100,431,324	773,560	8.47%	65,557	$1,636	0.21%	2.50%
	Total/Average	207,586	4,088	$877,101,106	8,145,219	7.42%	604,340	$9,197	0.11%	1.52%

Table VI-1, continued
With Costs Calculated Using a Three Percent Discount Rate

"--" indicates areas where data are not available. (While the average revenues and implied profits for the Beryllium Production (NAICS 331419) and Beryllium Oxide (NAICS 327113a) industries can be calculated, they would in no way reflect the actual revenues and profits of the affected facilities

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis.

Based on analyses performed by OSHA's contractor (ERG, 2013), the Agency estimated revenues on a six-digit NAICS basis by applying revenue data from the Census Bureau's *Statistics of U.S. Businesses* for 2010 (U.S. Census Bureau, 2010). Although that data source from the Census Bureau provides annual industry-specific estimates of employment, establishments, firms, and payroll, revenue data are published only for years that coincide with the Economic Census (U.S. Census Bureau, 2007). Revenues for 2010 were estimated by extrapolating the 2007 revenue data based on the assumption that the ratio of revenues to payroll for each industry would remain consistent over that time period. The 2010 revenues were distributed among size categories (all entities, small entities, very small entities) in accordance with the proportion of total payroll found in those categories within each industry.[412]

Before-tax profit rates were estimated using corporate balance sheet data from the Internal Revenue Service's *Corporation Source Book* (IRS, 2010). Profit rates as the ratio of total receipts to net income were calculated for each of the years 2002 through 2009 for each NAICS industry and averaged across the eight-year period. Since some data provided by the IRS were not available at disaggregated levels for all industries and profit rates, data at more highly aggregated levels were used as proxy for such industries—that is, where data were not available for each six-digit NAICS code, corresponding 4- and 5-digit NAICS codes were used as appropriate.

As previously discussed, OSHA has established a minimum threshold level of annualized costs equal to one percent of annual revenues—and, secondarily, annualized costs equal to ten percent of annual profits—below which the Agency has concluded that

[412] For further details on ERG's methodology for estimating per-entity revenue by size class, see (ERG, 2007).

costs are unlikely to threaten the economic viability of an affected industry. The results of OSHA's threshold tests for all affected establishments are displayed in Table V-1. For all affected establishments, the estimated annualized cost of the proposed rule is, on average, equal to 0.11 percent of annual revenue and 1.52 percent of annual profit.

As Table VI-1 shows, there are no industries in which the annualized costs of the proposed rule exceed one percent of annual revenues.[413] However there are three six-digit NAICS industries where annualized costs exceed ten percent of annual profits.[414]

NAICS 331525 (Copper foundries except die-casting) has the highest cost impact as a percentage of profits. NAICS 331525 is made up of two types of copper foundries: sand casting foundries and non-sand casting foundries, incurring an annualized cost as a percent of profit of 16.25 percent and 14.92 percent, respectively. The other two six-digit NAICS industries where annualized costs exceed ten percent of annual profits are NAICS 331534: Aluminum foundries (except die-casting), 13.65 percent; and NAICS 811310: Commercial and industrial machinery and equipment repair, 10.19 percent.

OSHA believes that the beryllium-containing inputs used by these industries have a relatively inelastic demand for three reasons. First, beryllium has rare and unique characteristics, including low mass, high melting temperature, dimensional stability over a wide temperature range, strength, stiffness, light weight, and high elasticity ("springiness") that can significantly improve the performance of various alloys. These

[413] The three industries with the largest annualized cost as a percentage of revenue are all nonferrous foundries: NAICS 331525b: Copper foundries (except die-casting)(sand casting foundries), 0.85 percent; NAICS 331525a: Copper foundries (except die-casting)(non-sand casting foundries), 0.78 percent; and NAICS 331524: Aluminum foundries (except die-casting), 0.71 percent.

[414] Table VI-A-1 in Appendix VI-A shows that the number of NAICS industries above the 10 percent cost-to-profit threshold using a 7 percent discount rate is the same as when applying a 3 percent discount rate. Table VI-A-2 shows two NAICS industries are above the 10 percent cost-to-profit threshold using a 0 percent discount rate.

characteristics cannot easily be replicated by other materials. In economic terms, this means that the elasticity of substitution between beryllium and non-beryllium inputs will be low. Second, products which contain beryllium or beryllium-alloy components typically have high-performance applications (whose performance depends on the use of higher-cost beryllium). The lack of available competing products with these performance characteristics suggests that the price elasticity of demand for products containing beryllium or beryllium-alloy components will be low. Third, components made of beryllium or beryllium-containing alloys typically account for only a small portion of the overall cost of the finished goods that these parts are used to make. For example, the cost of brakes made of a beryllium-alloy used in the production of a jet airplane represents a trivial percentage of the overall cost to produce that airplane. As economic theory indicates, the elasticity of derived demand for a factor of production (such as beryllium) varies directly with the elasticity of substitution between the input in question and other inputs; the price elasticity of demand for the final product that the input is used to produce; and, in general, the share of the cost of the final product that the input accounts for.[415] Applying these three conditions to beryllium points to the relative inelastic derived demand for this factor of production and the likelihood that cost increases resulting from the proposed rule would be passed on to the consumer in the form of higher prices.

A secondary point is that the establishments in an industry that use beryllium may be more profitable than those that don't. This follows from the prior arguments about beryllium's rare and desirable characteristics and its valuable applications. For example,

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[415] For a discussion of the determinants of the price elasticity of demand for a factor of production, see, for example, (Layard and Walters, 1978), pp. 259-272. The third condition has a technical qualification, but it is more a curiosity (or contrived result) than a practical limitation.

of the 208 establishments that make up NAICS 331525, OSHA estimated that 45 establishments (or 21 percent) work with beryllium. Of the 394 establishments that make up NAICS 331524, OSHA estimated that only 7 establishments (less than 2 percent) work with beryllium. Of the 21,960 establishments that make up NAICS 811310, OSHA estimated that 143 (0.7 percent) work with beryllium. However, when OSHA calculated the cost-to-profit ratio, it used the average profit per firm for the entire NAICs industry, not the average profit per firm for firms working with beryllium.

Normal Year-to-Year Variations in Prices and Profit Rates

The United States has a dynamic and constantly changing economy in which an annual percentage increase in industry revenues or prices of one percent or more are common. Examples of year-to-year changes in an industry that could cause such an increase in revenues or prices include increases in fuel, material, real estate, or other costs; tax increases; and shifts in demand.

To demonstrate the normal year-to-year variation in prices for all the manufacturers in general industry affected by the proposed rule, OSHA developed Table VI-2, which shows year-to-year producer price indices from 1999-2010 (which are the most current data available), and Table VI-3, which shows year-to-year percentage changes in producer prices, by industry, over that time period.[416] For all of the industries estimated to be affected by this proposed standard over the 12-year period, Table VI-3 shows an average change in producer prices of 4.4 percent a year—which is over 4 times as high as OSHA's 1 percent cost-to-revenue threshold. For the industries found to have

[416] Note that NAICS 339116: Dental laboratories is not covered by the BLS producer price index system.

the largest estimated potential annual cost impact as a percentage of revenue in Table VI-1—NAICS 331524: Aluminum Foundries (except Die-Casting), (0.71 percent); NAICS 331525(a and b): Copper Foundries (except Die-Casting) (weighted average of 0.82 percent); NAICS 332721a: Precision Turned Product Manufacturing of high content beryllium (0.49 percent);[417] and NAICS 811310: Commercial and Industrial Machinery and Equipment (Except Automotive and Electronic) Repair and Maintenance (0.55 percent)—the data in Table VI-3 show that the average annual changes in producer prices in these industries over the 12-year period analyzed were 3.1 percent, 8.2 percent, 3.6 percent and 2.3 percent, respectively.

Based on these data, it is clear that the potential price impacts of the proposed rule in affected industries are all well within normal year-to-year variations in prices in those industries. The maximum cost impact of the proposed rule as a percentage of revenue in any affected industry is 0.85 percent, while, as just noted, the average annual change in producer prices for affected industries was 4.4 percent for the period 1999-2010. Furthermore, even a casual examination of Table VI-3 reveals that annual changes in producer prices in excess of 5 percent or even 10 percent are possible without threatening an industry's economic viability. In fact, in two of the industries within the secondary smelting, refining, and alloying group, for example, prices rose over 60 percent in one year without imperiling the existence of those industries. Thus, OSHA preliminarily concludes that the potential price impacts of the proposal would not threaten the economic viability of any industries affected by this proposed standard.

[417] By contrast, NAICS 332721b: Precision Turned Product Manufacturing of low content beryllium alloys has a cost to revenue ratio below 0.4 percent.

Table VI-2

Time Series of Producer Prices for Industries Affected by the Proposed Beryllium Standard

NAICS Code[1]	Industry	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Beryllium Production													
331419	Primary smelting and refining of nonferrous metals	93.9	94	93.2	85.6	84.3	95.4	114.9	167.9	204.6	190.9	181	--
Beryllium Oxide Ceramics and Composites													
327113	Porcelain electrical supply manufacturing	140.3	138.9	160.5	158.4	158.7	161.6	163.1	172.7	177.2	183.8	189.8	194.6
334220	Cellular telephones manufacturing	104.1	101.5	101.7	98.2	95.1	93.3	92.6	92.1	92.5	94.1	94.6	94.8
334310	Compact disc players manufacturing	77.8	76.1	74.6	74	72.8	71.1	69.2	67.9	65.8	64.7	61.9	61.1
334411	Electron tube manufacturing	111	109.5	110	105.4	101.9	94	82.6	80.3	74.7	72	72.8	73.6
334415	Electronic resistor manufacturing	175.4	178.3	181.3	184.3	175.4	166.4	158.3	158.9	160.7	164.7	165.9	166.4
334419	Other electronic component manufacturing	--	--	--	--	--	99.6	99.6	106.5	108.4	110.3	112	111.9
334510	Electromedical equipment manufacturing	101.4	98.5	96.6	96.1	95.2	92.5	90.7	89.9	87.6	85.9	84.4	83.7
Nonferrous Foundries													
331521	Aluminum die-casting foundries	108.5	109.9	110	109.6	111.5	114.1	116.4	125.1	126.4	133	119.4	127.2
331522	Nonferrous (except aluminum) die-casting foundries	106.1	106.8	107.3	106.3	106.4	108.3	113.1	126.9	154.9	174.3	165.9	173.1
331524	Aluminum foundries (except die-casting)	111.8	114	114.8	115.7	116.5	119.9	124.3	133.1	140.8	150.5	152.2	155.9
331525	Copper foundries (except die-casting)	148.4	150.3	152	155.6	156.9	168.3	186.9	244.6	271.7	288.4	276.9	317.1
Secondary Smelting, Refining, and Alloying													
331314	Secondary smelting & alloying of aluminum	--	--	--	--	--	108.9	112.2	137.2	144.1	148.5	108.6	133.5
331421	Copper rolling, drawing, and extruding	130	137.6	132.2	127.4	129.6	163.5	191.5	310.4	327.6	323	275.3	337.6
331423	Secondary smelting, refining, & alloying of copper	--	--	--	--	--	121.9	140.7	224.5	245.8	262.8	201.9	266.2
331492	Secondary smelting, refining, & alloying of nonferrous metal (except copper & aluminum)	--	--	--	--	--	109.5	123.2	155.7	188.4	194.8	178.3	202.8
Precision Machining													
332721a	Precision turned product manufacturing	127.5	130.2	129.8	130.1	130.4	134.6	138.4	154	174.1	179	175.8	178.6
Copper Rolling, Drawing and Extruding													
331422	Copper wire (except mechanical) drawing	--	--	--	--	--	111.7	133.8	197.1	197.1	202.5	170.9	216.8
Stamping, Spring, and Connector Manufacturing													
332612	Light gauge spring manufacturing	122.8	123.1	123.5	123.4	124.5	136.7	144	144.1	144.8	156.5	160.7	160
332116	Metal stamping	128.6	128.7	129.9	130.6	131.4	142	149.2	154.2	162.9	175.9	172.6	173.9
334417	Electronic connector manufacturing	156.3	158.3	159.6	160.3	160.9	162.5	165.8	166.5	172.8	176.7	180.5	182.2

Table VI-2, continued

NAICS Code[1]	Industry	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Time Series of Producer Prices for Industries Affected by the Proposed Beryllium Standard													
Dental Laboratories													
339116	Dental laboratories	--	--	--	--	--	--	--	--	--	--	--	--
621210	Offices of dentists	--	--	--	--	--	--	--	--	--	--	--	--
Arc and Gas Welding													
331111	Iron and steel mills	102	104.1	96.9	100.1	103.8	136.4	145.9	161.5	172	202.5	147.8	175.8
331221	Rolled steel shape manufacturing	110.3	113.6	107.5	114.5	118	148.8	168.6	168.9	171.7	222	183.7	187.5
331513	Steel foundries (except investment)	137.5	137.3	136.7	135.3	137.5	146.2	160.1	170.5	183.7	193.4	191.4	198.2
332117	Powder metallurgy part manufacturing	--	--	--	--	--	100.6	101.8	104.4	106.2	110.8	--	115.4
332212	Hand and edge tool manufacturing	157.7	158.4	162.5	164.7	165.1	168.8	177	183.7	188.9	197	203.1	204.1
332312	Fabricated structural metal manufacturing	--	--	--	--	--	114.4	122.8	128.4	135.2	152.3	139.8	133.7
332313	Plate work manufacturing	--	--	--	--	--	107.2	109.5	114.8	120.2	144.9	139.1	136.7
332322	Sheet metal work manufacturing	140.1	141.8	141.5	142.9	144.4	159.4	165.6	171.6	176.8	187.6	182.5	184.9
332323	Ornamental and architectural metal work manufacturing	139.4	143.4	145.5	147.7	150.5	173.3	185.1	191.9	199.6	224.4	230.8	230.3
332439	Other metal container manufacturing	--	--	--	--	--	111.7	120.2	127	128.1	145.1	138.8	135.7
332919	Other metal valve and pipe fitting manufacturing	154.6	156.8	163	164.8	168	173.6	187.6	205.4	216.5	225.9	235.9	235.2
332999	All other miscellaneous fabricated metal product manufacturing	--	--	--	--	--	102.5	106.1	111.1	114	118.8	123.4	125
333111	Farm machinery and equipment manufacturing	142.2	143.9	146.4	149	151.3	156.2	164.7	168.6	173.4	180.5	186.7	190.6
333911	Pump and pumping equipment manufacturing	156.2	158.6	162.4	167.1	174.6	179.5	190.1	199.5	210.7	219.8	224.6	227.4
333922	Conveyor and conveying equipment manufacturing	134.8	136.3	138.5	139.7	140.9	149.4	155.4	160.6	167.3	180.1	183.7	183.1
333924	Industrial truck, tractor, trailer, and stacker machinery manufacturing	152.4	154	155.3	155.3	156.8	161.2	168.9	175	179.8	192.6	205.9	205.4
333999	All other miscellaneous general purpose machinery manufacturing	153.8	156.8	159.1	161.4	162.2	165.5	169	173.5	178.6	187.3	195.5	197.8
336211	Motor vehicle body manufacturing	157	160.3	163.3	165.6	167.5	176.7	190.3	200	205	212	216.4	217.7
336214	Travel trailer and camper manufacturing	--	--	--	--	--	101.6	104.7	109.7	113.9	119.4	121.6	121.3
336399b	All other motor vehicle parts manufacturing	--	--	--	--	--	100.6	101.9	102.5	104.4	108.4	109.5	112.4
336510	Railroad rolling stock	128.1	128.6	128.2	127.7	128.9	135.7	150.3	158.2	165.4	169.2	171.4	173.9
336999	All other transportation equipment manufacturing	--	--	--	--	--	101.1	104.2	106.1	108.3	107.3	107.2	107.8
337215	Showcase, partition, shelving, and locker manufacturing	--	--	--	--	--	110.7	118.8	119.4	120.9	126	128.7	129.3
811310	Commercial and industrial machinery and equipment repair	--	--	--	--	--	--	--	--	102.3	105.4	106.9	109.6

Table VI-2, continued

Time Series of Producer Prices for Industries Affected by the Proposed Beryllium Standard

NAICS Code[1]	Industry	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Resistance Welding													
333411	Air purification equipment manufacturing	--	--	--	--	--	102.7	109.8	113.1	115.9	118.7	115.4	114.2
333412	Industrial and commercial fan and blower manufacturing	--	--	--	--	--	103.1	109.2	112.9	117.6	125.2	130	131.9
333414	Heating equipment (except warm air furnaces) manufacturing	191	192.8	195	196.3	199.8	206.2	215.4	222.3	231.2	245.7	255.3	257.2
333415	Air-conditioning, warm air heating, and industrial refrigeration equipment manufacturing	131.5	130.6	130.6	131.4	131.7	133.4	141.6	147.3	155.7	162.2	163.1	162.3
335211	Electric housewares and household fan manufacturing	110.5	109.6	110.3	110.4	110	110.3	114.8	117.3	122.2	122.8	127.8	127.5
335212	Household vacuum cleaner manufacturing	121.1	119.7	117	112.2	107.5	105.8	103.8	103	102.2	103	105.3	105.4
335221	Household cooking appliance manufacturing	111.4	111.4	109.9	110.8	108.1	105.7	108.5	111.1	112.4	115.9	122.7	122.9
335222	Household refrigerator and home freezer manufacturing	107.9	105.5	102	99.6	97.1	96.6	99.1	99.8	101.1	105.1	109.4	105.8
335224	Household laundry equipment manufacturing	132	130.7	127.7	131.1	129.1	129.2	130	128.8	126.7	127.4	130	130.6
335228	Other major household appliance manufacturing	139.9	139.9	139.4	139.2	144.4	150.2	163.4	169	174.5	187.3	201.6	205.1
336311	Carburetor, piston, piston ring, and valve manufacturing	126.5	127.8	128.5	129.1	128.7	129.8	131.7	137.4	141.9	147	147.1	149.7
336312	Gasoline engine and engine parts manufacturing	--	--	--	--	--	101.4	102.5	111.5	113.1	116	103.7	108.2
336321	Vehicular lighting equipment manufacturing	124.7	122.7	122.5	122.7	122.1	123	123.9	124.6	126.8	129.3	131.4	132.6
336322	Other motor vehicle electrical and electronic equipment manufacturing	--	--	--	--	--	99.8	101.7	102.5	103.7	102.9	102.9	103.4
336330	Motor vehicle steering and suspension components (except spring) manufacturing	--	--	--	--	--	101.7	104.9	106.1	104.8	106.3	105.1	105.7
336340	Motor vehicle brake system manufacturing	--	--	--	--	--	99.6	100.3	101.2	101.6	103.4	104.5	104.2
336350	Motor vehicle transmission and power train parts manufacturing	--	--	--	--	--	100.9	101.2	103.2	105.9	108.1	112.7	113.8
336360	Motor vehicle seating and interior trim manufacturing	--	--	--	--	--	99.1	99.5	99.8	100	99.3	99.9	99.1
336370	Motor vehicle metal stamping	110.4	110.6	110.1	110.3	113	118.5	120.4	120.9	124.2	128.1	131.3	129.2
336391	Motor vehicle air-conditioning manufacturing	--	--	--	--	--	100.3	99.8	99.7	100.9	100.2	100	100.5

[1] NAICS industries with "a" and "b" designations and appearing in multiple application groups in previous sections of this analysis only appear once in this table

Note: The "--" designates situations where no data were available

Source: BLS, 2010

Table VI-3

Year-to-Year Percentage Change in Producer Price Index for Industries Affected by the Proposed Beryllium Standard

NAICS Code[1]	Industry	1999 - 2000	2000 - 2001	2001 - 2002	2002 - 2003	2003- 2004	2004 - 2005	2005 - 2006	2006 - 2007	2007 - 2008	2008 - 2009	2009 - 2010	Average Change (Absolute Values)
Beryllium Production													
331419	Primary smelting and refining of nonferrous metals	0.1%	-0.9%	-8.2%	-1.5%	13.2%	20.4%	46.1%	21.9%	-6.7%	-5.2%	--	12.4%
Beryllium Oxide Ceramics and Composites													
327113	Porcelain electrical supply manufacturing	-1.0%	15.6%	-1.3%	0.2%	1.8%	0.9%	5.9%	2.6%	3.7%	3.3%	2.5%	3.5%
334220	Cellular telephones manufacturing	-2.5%	0.2%	-3.4%	-3.2%	-1.9%	-0.8%	-0.5%	0.4%	1.7%	0.5%	0.2%	1.4%
334310	Compact disc players manufacturing	-2.2%	-2.0%	-0.8%	-1.6%	-2.3%	-2.7%	-1.9%	-3.1%	-1.7%	-4.3%	-1.3%	2.2%
334411	Electron tube manufacturing	-1.4%	0.5%	-4.2%	-3.3%	-7.8%	-12.1%	-2.8%	-7.0%	-3.6%	1.1%	1.1%	4.1%
334415	Electronic resistor manufacturing	1.7%	1.7%	1.7%	-4.8%	-5.1%	-4.9%	0.4%	1.1%	2.5%	0.7%	0.3%	2.3%
334419	Other electronic component manufacturing	--	--	--	--	--	0.0%	6.9%	1.8%	1.8%	1.5%	-0.1%	2.0%
334510	Electromedical equipment manufacturing	-2.9%	-1.9%	-0.5%	-0.9%	-2.8%	-1.9%	-0.9%	-2.6%	-1.9%	-1.7%	-0.8%	1.7%
Nonferrous Foundries													
331521	Aluminum die-casting foundries	1.3%	0.1%	-0.4%	1.7%	2.3%	2.0%	7.5%	1.0%	5.2%	-10.2%	6.5%	3.5%
331522	Nonferrous (except aluminum) die-casting foundries	0.7%	0.5%	-0.9%	0.1%	1.8%	4.4%	12.2%	22.1%	12.5%	-4.8%	4.3%	5.8%
331524	Aluminum foundries (except die-casting)	2.0%	0.7%	0.8%	0.7%	2.9%	3.7%	7.1%	5.8%	6.9%	1.1%	2.4%	3.1%
331525	Copper foundries (except die-casting)	1.3%	1.1%	2.4%	0.8%	7.3%	11.1%	30.9%	11.1%	6.1%	-4.0%	14.5%	8.2%
Secondary Smelting, Refining, and Alloying													
331314	Secondary smelting & alloying of aluminum	--	--	--	--	--	3.0%	22.3%	5.0%	3.1%	-26.9%	22.9%	13.9%
331421	Copper rolling, drawing, and extruding	5.8%	-3.9%	-3.6%	1.7%	26.2%	17.1%	62.1%	5.5%	-1.4%	-14.8%	22.6%	15.0%
331423	Secondary smelting, refining, & alloying of copper	--	--	--	--	--	15.4%	59.6%	9.5%	6.9%	-23.2%	31.8%	24.4%
331492	Secondary smelting, refining, & alloying of nonferrous metal (except copper & aluminum)	--	--	--	--	--	12.5%	26.4%	21.0%	3.4%	-8.5%	13.7%	14.3%
Precision Machining													
332721	Precision turned product manufacturing	2.1%	-0.3%	0.2%	0.2%	3.2%	2.8%	11.3%	13.1%	2.8%	-1.8%	1.6%	3.6%
Copper Rolling, Drawing and Extruding													
331422	Copper wire (except mechanical) drawing	--	--	--	--	--	19.8%	47.3%	0.0%	2.7%	-15.6%	26.9%	18.7%
Stamping, Spring, and Connector Manufacturing													
332612	Light gauge spring manufacturing	0.2%	0.3%	-0.1%	0.9%	9.8%	5.3%	0.1%	0.5%	8.1%	2.7%	-0.4%	2.6%
332116	Metal stamping	0.1%	0.9%	0.5%	0.6%	8.1%	5.1%	3.4%	5.6%	8.0%	-1.9%	0.8%	3.2%
334417	Electronic connector manufacturing	1.3%	0.8%	0.4%	0.4%	1.0%	2.0%	0.4%	3.8%	2.3%	2.2%	0.9%	1.4%

Table VI-3, continued

Year-to-Year Percentage Change in Producer Price Index for Industries Affected by the Proposed Beryllium Standard

NAICS Code[1]	Industry	1999 - 2000	2000 - 2001	2001 - 2002	2002 - 2003	2003- 2004	2004 - 2005	2005 - 2006	2006 - 2007	2007 - 2008	2008 - 2009	2009 - 2010	Average Change (Absolute Values)
Dental Laboratories													
339116	Dental laboratories	--	--	--	--	--	--	--	--	--	--	--	--
621210	Offices of dentists	--	--	--	--	--	--	--	--	--	--	--	--
Arc and Gas Welding													
331111	Iron and steel mills	2.1%	-6.9%	3.3%	3.7%	31.4%	7.0%	10.7%	6.5%	17.7%	-27.0%	18.9%	12.3%
331221	Rolled steel shape manufacturing	3.0%	-5.4%	6.5%	3.1%	26.1%	13.3%	0.2%	1.7%	29.3%	-17.3%	2.1%	9.8%
331513	Steel foundries (except investment)	-0.1%	-0.4%	-1.0%	1.6%	6.3%	9.5%	6.5%	7.7%	5.3%	-1.0%	3.6%	3.9%
332117	Powder metallurgy part manufacturing	--	--	--	--	--	1.2%	2.6%	1.7%	4.3%	--	--	2.5%
332212	Hand and edge tool manufacturing	0.4%	2.6%	1.4%	0.2%	2.2%	4.9%	3.8%	2.8%	4.3%	3.1%	0.5%	2.4%
332312	Fabricated structural metal manufacturing	--	--	--	--	--	7.3%	4.6%	5.3%	12.6%	-8.2%	-4.4%	7.1%
332313	Plate work manufacturing	--	--	--	--	--	2.1%	4.8%	4.7%	20.5%	-4.0%	-1.7%	6.3%
332322	Sheet metal work manufacturing	1.2%	-0.2%	1.0%	1.0%	10.4%	3.9%	3.6%	3.0%	6.1%	-2.7%	1.3%	3.1%
332323	Ornamental and architectural metal work manufacturing	2.9%	1.5%	1.5%	1.9%	15.1%	6.8%	3.7%	4.0%	12.4%	2.9%	-0.2%	4.8%
332439	Other metal container manufacturing	--	--	--	--	--	7.6%	5.7%	0.9%	13.3%	-4.3%	-2.2%	5.7%
332919	Other metal valve and pipe fitting manufacturing	1.4%	4.0%	1.1%	1.9%	3.3%	8.1%	9.5%	5.4%	4.3%	4.4%	-0.3%	4.0%
332999	All other miscellaneous fabricated metal product manufacturing	--	--	--	--	--	3.5%	4.7%	2.6%	4.2%	3.9%	1.3%	3.4%
333111	Farm machinery and equipment manufacturing	1.2%	1.7%	1.8%	1.5%	3.2%	5.4%	2.4%	2.8%	4.1%	3.4%	2.1%	2.7%
333911	Pump and pumping equipment manufacturing	1.5%	2.4%	2.9%	4.5%	2.8%	5.9%	4.9%	5.6%	4.3%	2.2%	1.2%	3.5%
333922	Conveyor and conveying equipment manufacturing	1.1%	1.6%	0.9%	0.9%	6.0%	4.0%	3.3%	4.2%	7.7%	2.0%	-0.3%	2.9%
333924	Industrial truck, tractor, trailer, and stacker machinery manufacturing	1.0%	0.8%	0.0%	1.0%	2.8%	4.8%	3.6%	2.7%	7.1%	6.9%	-0.2%	2.8%
333999	All other miscellaneous general purpose machinery manufacturing	2.0%	1.5%	1.4%	0.5%	2.0%	2.1%	2.7%	2.9%	4.9%	4.4%	1.2%	2.3%
336211	Motor vehicle body manufacturing	2.1%	1.9%	1.4%	1.1%	5.5%	7.7%	5.1%	2.5%	3.4%	2.1%	0.6%	3.0%
336214	Travel trailer and camper manufacturing	--	--	--	--	--	3.1%	4.8%	3.8%	4.8%	1.8%	-0.2%	3.1%
336399	All other motor vehicle parts manufacturing	--	--	--	--	--	1.3%	0.6%	1.9%	3.8%	1.0%	2.6%	1.9%
336510	Railroad rolling stock	0.4%	-0.3%	-0.4%	0.9%	5.3%	10.8%	5.3%	4.6%	2.3%	1.3%	1.5%	3.0%
336999	All other transportation equipment manufacturing	--	--	--	--	--	3.1%	1.8%	2.1%	-0.9%	-0.1%	0.6%	1.4%
337215	Showcase, partition, shelving, and locker manufacturing	--	--	--	--	--	7.3%	0.5%	1.3%	4.2%	2.1%	0.5%	2.7%
811310	Commercial and industrial machinery and equipment repair	--	--	--	--	--	--	--	--	3.0%	1.4%	2.5%	2.3%

Table VI-3, continued

Year-to-Year Percentage Change in Producer Price Index for Industries Affected by the Proposed Beryllium Standard

NAICS Code[1]	Industry	1999 - 2000	2000 - 2001	2001 - 2002	2002 - 2003	2003- 2004	2004 - 2005	2005 - 2006	2006 - 2007	2007 - 2008	2008 - 2009	2009 - 2010	Average Change (Absolute Values)
Resistance Welding													
333411	Air purification equipment manufacturing	--	--	--	--	--	6.9%	3.0%	2.5%	2.4%	-2.8%	-1.0%	3.1%
333412	Industrial and commercial fan and blower manufacturing	--	--	--	--	--	5.9%	3.4%	4.2%	6.5%	3.8%	1.5%	4.2%
333414	Heating equipment (except warm air furnaces) manufacturing	0.9%	1.1%	0.7%	1.8%	3.2%	4.5%	3.2%	4.0%	6.3%	3.9%	0.7%	2.8%
333415	Air-conditioning, warm air heating, and industrial refrigeration equipment manufacturing	-0.7%	0.0%	0.6%	0.2%	1.3%	6.1%	4.0%	5.7%	4.2%	0.6%	-0.5%	2.2%
335211	Electric housewares and household fan manufacturing	-0.8%	0.6%	0.1%	-0.4%	0.3%	4.1%	2.2%	4.2%	0.5%	4.1%	-0.2%	1.6%
335212	Household vacuum cleaner manufacturing	-1.2%	-2.3%	-4.1%	-4.2%	-1.6%	-1.9%	-0.8%	-0.8%	0.8%	2.2%	0.1%	1.8%
335221	Household cooking appliance manufacturing	0.0%	-1.3%	0.8%	-2.4%	-2.2%	2.6%	2.4%	1.2%	3.1%	5.9%	0.2%	2.0%
335222	Household refrigerator and home freezer manufacturing	-2.2%	-3.3%	-2.4%	-2.5%	-0.5%	2.6%	0.7%	1.3%	4.0%	4.1%	-3.3%	2.4%
335224	Household laundry equipment manufacturing	-1.0%	-2.3%	2.7%	-1.5%	0.1%	0.6%	-0.9%	-1.6%	0.6%	2.0%	0.5%	1.3%
335228	Other major household appliance manufacturing	0.0%	-0.4%	-0.1%	3.7%	4.0%	8.8%	3.4%	3.3%	7.3%	7.6%	1.7%	3.7%
336311	Carburetor, piston, piston ring, and valve manufacturing	1.0%	0.5%	0.5%	-0.3%	0.9%	1.5%	4.3%	3.3%	3.6%	0.1%	1.8%	1.6%
336312	Gasoline engine and engine parts manufacturing	--	--	--	--	--	1.1%	8.8%	1.4%	2.6%	-10.6%	4.3%	4.8%
336321	Vehicular lighting equipment manufacturing	-1.6%	-0.2%	0.2%	-0.5%	0.7%	0.7%	0.6%	1.8%	2.0%	1.6%	0.9%	1.0%
336322	Other motor vehicle electrical and electronic equipment manufacturing	--	--	--	--	--	1.9%	0.8%	1.2%	-0.8%	0.0%	0.5%	0.9%
336330	Motor vehicle steering and suspension components (except spring) manufacturing	--	--	--	--	--	3.1%	1.1%	-1.2%	1.4%	-1.1%	0.6%	1.4%
336340	Motor vehicle brake system manufacturing	--	--	--	--	--	0.7%	0.9%	0.4%	1.8%	1.1%	-0.3%	0.9%
336350	Motor vehicle transmission and power train parts manufacturing	--	--	--	--	--	0.3%	2.0%	2.6%	2.1%	4.3%	1.0%	2.0%
336360	Motor vehicle seating and interior trim manufacturing	--	--	--	--	--	0.4%	0.3%	0.2%	-0.7%	0.6%	-0.8%	0.5%
336370	Motor vehicle metal stamping	0.2%	-0.5%	0.2%	2.4%	4.9%	1.6%	0.4%	2.7%	3.1%	2.5%	-1.6%	1.8%
336391	Motor vehicle air-conditioning manufacturing	--	--	--	--	--	-0.5%	-0.1%	1.2%	-0.7%	-0.2%	0.5%	0.5%

[1] NAICS industries with "a" and "b" designations and appearing in multiple application groups in previous sections of this analysis only appear once in this table

Note: The "--" indicates situations where no data were available

Source: OSHA Office of Regulatory Analysis calculation using BLS, 2010

Profit rates are also subject to the dynamics of the U.S. economy. A recession, a downturn in a particular industry, foreign competition, or the increased competitiveness of producers of close domestic substitutes are all easily capable of causing a decline in profit rates in an industry of well in excess of ten percent in one year or for several years in succession.

To demonstrate the normal year-to-year variation in profit rates for all the manufacturers affected by the proposed rule, OSHA developed Table VI-4 and Table VI-5, which show, respectively, year-to-year profit rates and year-to-year percentage changes in profit rates, by industry, for the years 2002–2009. For the industries that OSHA has estimated will be affected by this proposed standard over the 8-year period, the average change in profit rates is calculated to be 39 percent per year (average for all industries calculated from the per-NAICS averages shown in Table VI-5). For the industries with the largest estimated potential annual cost impacts as a percentage of profit—NAICS 331524: Aluminum foundries (except die-casting), (14 percent); NAICS 331525(a and b): Copper foundries (except die-casting) (16 percent); NAICS 332721a: Precision Turned Product Manufacturing of high content beryllium (8 percent);[418] and NAICS 811310 Commercial and Industrial Machinery and Equipment (Except Automotive and Electronic) Repair and Maintenance (10 percent)—the average annual changes in profit rates in these industries over the eight-year period were 35 percent, 35 percent, 11 percent, and 5 percent, respectively.

One complicating factor in analyzing how the proposed rule would affect the industries within the rule's scope is that the annualized costs of the proposed rule, if absorbed in lost profits, would involve not a temporary loss of profits but a longer-term negative effect on profits, relative to the baseline, over the annualization period. To address this issue, the Agency compared the effect of a longer-term reduction in profits to much larger reductions in profits but over shorter periods.

[418] By contrast, NAICS 332721b: Precision Turned Product Manufacturing of low content beryllium alloys has a cost to profit ratio of 6 percent.

Assuming a three-percent discount rate, the Agency determined a ten percent decline in profit rates relative to the original baseline, which remains constant at that lower level over a ten-year period, would be equivalent to:[419]

- an 88.5 percent decline in profit rates for one year;
- a 44.5 percent decline in profit rates that remains constant at the lower level for two years; or
- a 30 percent decline in profit rates that remains constant at the lower level for three years.[420]

Keep in mind that this exercise shows a reduction in profit rates, not the elimination of profits. Table VI-5, for the eight-year period from 2002 to 2009, clearly shows that short-run reductions in average industry profit rates of the above magnitudes—that is, that satisfy at least one of the three equivalent conditions described above—have occurred on numerous occasions in the industries affected by this proposed standard, presumably without threatening their economic viability.[421] For this reason, OSHA feels confident that potential profit rate impacts of 10 percent or less as a result of the proposed rule would not threaten the economic viability of the affected industries.

A longer-term loss of profits in excess of 10 percent a year could be more problematic for some affected industries and might conceivably, under sufficiently adverse circumstances, threaten an industry's economic viability. However, as previously discussed, OSHA's analysis indicates that

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[419] Note that the reduction in profits rates over time, as a result of the proposed rule, is being measured here relative to the baseline. If the reduction in profit rates were made relative to the previous year, as is done in Table VI-5 below, then there would be only a one-time reduction in the profit rate in Year 1 as a result of the proposed rule, after which the profit rate would reach a new (lower) level but would not change from year to year.

[420] Assuming a seven-percent discount rate, a 10-percent decline in profit rates over the 10-year annualization period would be equivalent to: a 75 percent decline in profit rates for one year; a 39 percent decline in profit rates that remains constant at the lower level for two years; or a 27 percent decline in profit rates that remains constant at the lower level for three years.

[421] Thus, for example, as shown in Table VI-5, the decline in profits for the years 2007-2009 in NAICS 331419: Primary smelting and refining of nonferrous metals, would qualify. Note that Table VI-5 is artificially constrained for this exercise in that it covers only 7 years of changes in profit rates relative to the 10 years of changes in profit rates that would occur over the annualization period.

affected industries would generally *not* absorb the costs of the proposed rule in reduced profits but, instead, would be able to pass on most or all of those costs in the form of higher prices (due to the relative price inelasticity of demand for beryllium and beryllium-containing inputs). It is possible that such price increases will result in some reduction in output, and the reduction in output might be met through the closure of a small percentage of the plants in the industry. The only realistic circumstance where an entire industry would be significantly affected by small potential price increases would be where there is a very close or perfect substitute product available not subject to OSHA regulation. In most cases where beryllium is used, there is no substitute product that could be used in place of beryllium and achieve the same level of performance. The main potential concern would be substitution by foreign competition, but the following discussion reveals why such competition is not likely.

International Trade Effects

World production of beryllium is a thin market, with only a handful of countries known to process beryllium ores and concentrates into beryllium products, and characterized by a high degree of variation and uncertainty. The United States accounts for approximately 65 percent of world beryllium deposits and 90 percent of world production, but there is also a significant stockpiling of beryllium materials in Kazakhstan, Russia, China, and possibly other countries (USGS, 2013a). For the individual years 2008-2012, the United States' net import reliance as a percentage of apparent consumption (that is, imports minus exports net of industry and government stock adjustments) ranged from 10 percent to 61 percent (USGS, 2013b). To assure an adequate stockpile of beryllium materials to support national defense interests, the U.S. Department of Defense, in 2005, under the Defense Production Act, Title III, invested in a public-private partnership with the leading U.S.

beryllium producer to build a new $90.4 million primary beryllium facility in Elmore, Ohio. Construction of that facility was completed in 2011 (USGS, 2013b).

One factor of importance to firms working with beryllium and beryllium alloys is to have a reliable supply of beryllium materials. U.S. manufacturers can have a relatively high confidence in the availability of beryllium materials relative to manufacturers in many foreign countries, particularly those that do not have economic or national security partnerships with the United States.

Firms using beryllium in production must consider not just the cost of the chemical itself but also the various regulatory costs associated with the use, transport, and disposal of the material. For example, for marine transport, metallic beryllium powder and beryllium compounds are classified by the International Maritime Organization (IMO) as poisonous substances, presenting medical danger. Beryllium is also classified as flammable. The United Nations classification of beryllium and beryllium compounds for the transport of dangerous goods is "poisonous substance" and, for packing, a "substance presenting medium danger" (World Health Organization, 1990). Because of beryllium’s toxicity, the material is subject to various workplace restrictions as well as international, national, and State requirements and guidelines regarding beryllium content in environmental media (USGS, 2013a).

As the previous discussion indicates, the production and use of beryllium and beryllium alloys in the United States and foreign markets appears to depend on the availability of production facilities; beryllium stockpiles; national defense and political considerations; regulations limiting the shipping of beryllium and beryllium products; international, national, and State regulations and guidelines regarding beryllium content in environmental media; and, of course, the special performance properties of beryllium and beryllium alloys in various applications. Relatively small changes in the price of beryllium would seem to have a minor effect on the location of beryllium production and use. In particular, as a result of this proposed rule, OSHA would expect that, if all compliance costs were passed through in the form of higher prices, a price increase of 0.11 percent, on average, for firms manufacturing or using beryllium in the United States—and not exceeding 1 percent in any affected industry—would have a negligible effect on foreign competition and would therefore not threaten the economic viability of any affected domestic industries.

Table VI-4

Time Series of Annual Profit Rates for Industries Affected by the Proposed Beryllium Standard

NAICS Code[1]	Industry	2002	2003	2004	2005	2006	2007	2008	2009	Average
Beryllium Production										
331419	Primary smelting and refining of nonferrous metals	2.68%	3.83%	4.88%	5.42%	7.32%	8.28%	4.31%	1.63%	4.79%
Beryllium Oxide Ceramics and Composites										
327113	Porcelain electrical supply manufacturing	2.68%	2.64%	4.55%	7.13%	5.70%	6.37%	6.04%	5.01%	5.01%
334220	Cellular telephones manufacturing	5.73%	2.01%	2.56%	7.22%	8.51%	5.53%	6.64%	10.46%	6.08%
334310	Compact disc players manufacturing	3.60%	4.10%	2.86%	8.90%	5.65%	3.74%	3.53%	2.77%	4.39%
334411	Electron tube manufacturing	2.05%	2.67%	6.83%	13.80%	10.00%	9.57%	9.82%	8.04%	7.85%
334415	Electronic resistor manufacturing	2.05%	2.67%	6.83%	13.80%	10.00%	9.57%	9.82%	8.04%	7.85%
334419	Other electronic component manufacturing	2.05%	2.67%	6.83%	13.80%	10.00%	9.57%	9.82%	8.04%	7.85%
334510	Electromedical equipment manufacturing	3.67%	3.70%	4.23%	12.08%	9.10%	7.42%	6.99%	6.78%	6.75%
Nonferrous Foundries										
331521	Aluminum die-casting foundries	2.74%	1.80%	3.24%	5.71%	6.65%	7.83%	7.50%	6.27%	5.22%
331522	Nonferrous (except aluminum) die-casting foundries	2.74%	1.80%	3.24%	5.71%	6.65%	7.83%	7.50%	6.27%	5.22%
331524	Aluminum foundries (except die-casting)	2.74%	1.80%	3.24%	5.71%	6.65%	7.83%	7.50%	6.27%	5.22%
331525	Copper foundries (except die-casting)	2.74%	1.80%	3.24%	5.71%	6.65%	7.83%	7.50%	6.27%	5.22%
Secondary Smelting, Refining, and Alloying										
331314	Secondary smelting & alloying of aluminum	2.40%	2.11%	4.88%	5.42%	7.32%	8.28%	4.31%	1.63%	4.54%
331421	Copper rolling, drawing, and extruding	2.68%	3.83%	4.88%	5.42%	7.32%	8.28%	4.31%	1.63%	4.79%
331423	Secondary smelting, refining, & alloying of copper	2.68%	3.83%	4.88%	5.42%	7.32%	8.28%	4.31%	1.63%	4.79%
331492	Secondary smelting, refining, & alloying of nonferrous metal (except copper & aluminum)	2.68%	3.83%	4.88%	5.42%	7.32%	8.28%	4.31%	1.63%	4.79%
Precision Machining										
332721	Precision turned product manufacturing	4.80%	4.41%	5.94%	6.83%	6.89%	6.24%	6.06%	5.39%	5.82%
Copper Rolling, Drawing and Extruding										
331422	Copper wire (except mechanical) drawing	2.68%	3.83%	4.88%	5.42%	7.32%	8.28%	4.31%	1.63%	4.79%
Stamping, Spring, and Connector Manufacturing										
332612	Light gauge spring manufacturing	3.98%	3.58%	5.94%	6.83%	6.89%	6.24%	6.06%	5.39%	5.61%
332116	Metal stamping	4.67%	3.79%	4.45%	5.38%	6.07%	6.34%	5.61%	4.66%	5.12%
334417	Electronic connector manufacturing	2.05%	2.67%	6.83%	13.80%	10.00%	9.57%	9.82%	8.04%	7.85%

Table VI-4, continued										
Time Series of Annual Profit Rates for Industries Affected by the Proposed Beryllium Standard										
NAICS Code[1]	**Industry**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**Average**
Dental Laboratories										
339116	Dental laboratories	9.15%	7.70%	8.88%	17.80%	13.52%	9.93%	7.92%	9.52%	10.55%
621210	Offices of dentists	6.81%	6.73%	8.30%	8.29%	8.11%	10.03%	9.23%	10.30%	8.47%
Arc and Gas Welding										
331111	Iron and steel mills	2.12%	1.13%	7.87%	8.05%	9.25%	7.06%	6.28%	1.51%	5.41%
331221	Rolled steel shape manufacturing	2.12%	1.13%	7.87%	8.05%	9.25%	7.06%	6.28%	1.51%	5.41%
331513	Steel foundries (except investment)	2.74%	1.80%	3.24%	5.71%	6.65%	7.83%	7.50%	6.27%	5.22%
332117	Powder metallurgy part manufacturing	4.67%	3.79%	4.45%	5.38%	6.07%	6.34%	5.61%	4.66%	5.12%
332212	Hand and edge tool manufacturing	3.98%	3.58%	5.94%	6.83%	6.89%	6.24%	6.06%	5.39%	5.61%
332312	Fabricated structural metal manufacturing	3.69%	3.21%	4.26%	5.57%	6.02%	6.18%	4.66%	4.32%	4.74%
332313	Plate work manufacturing	3.69%	3.21%	4.26%	5.57%	6.02%	6.18%	4.66%	4.32%	4.74%
332322	Sheet metal work manufacturing	3.69%	3.21%	4.26%	5.57%	6.02%	6.18%	4.66%	4.32%	4.74%
332323	Ornamental and architectural metal work manufacturing	3.69%	3.21%	4.26%	5.57%	6.02%	6.18%	4.66%	4.32%	4.74%
332439	Other metal container manufacturing	4.22%	2.20%	3.75%	6.51%	4.43%	4.81%	4.43%	4.08%	4.30%
332919	Other metal valve and pipe fitting manufacturing	5.52%	5.42%	7.23%	10.00%	7.37%	7.92%	6.61%	5.93%	7.00%
332999	All other miscellaneous fabricated metal product manufacturing	5.52%	5.42%	7.23%	10.00%	7.37%	7.92%	6.61%	5.93%	7.00%
333111	Farm machinery and equipment manufacturing	3.37%	2.29%	3.42%	8.51%	9.65%	9.33%	10.06%	4.28%	6.36%
333911	Pump and pumping equipment manufacturing	3.31%	2.91%	4.53%	6.75%	5.52%	8.67%	6.17%	5.02%	5.36%
333922	Conveyor and conveying equipment manufacturing	3.31%	2.91%	4.53%	6.75%	5.52%	8.67%	6.17%	5.02%	5.36%
333924	Industrial truck, tractor, trailer, and stacker machinery manufacturing	3.31%	2.91%	4.53%	6.75%	5.52%	8.67%	6.17%	5.02%	5.36%
333999	All other miscellaneous general purpose machinery manufacturing	3.31%	2.91%	4.53%	6.75%	5.52%	8.67%	6.17%	5.02%	5.36%
336211	Motor vehicle body manufacturing	1.91%	1.18%	1.38%	4.62%	1.77%	1.97%	0.77%	1.00%	1.83%
336214	Travel trailer and camper manufacturing	1.91%	1.18%	1.38%	4.62%	1.77%	1.97%	0.77%	1.00%	1.83%
336399	All other motor vehicle parts manufacturing	1.91%	1.18%	1.38%	4.62%	1.77%	1.97%	0.77%	1.00%	1.83%
336510	Railroad rolling stock	2.51%	1.48%	6.13%	6.54%	8.90%	8.29%	6.24%	3.69%	5.47%
336999	All other transportation equipment manufacturing	5.48%	7.24%	6.13%	6.54%	8.90%	8.29%	6.24%	3.69%	6.56%
337215	Showcase, partition, shelving, and locker manufacturing	4.13%	3.80%	4.08%	5.72%	5.70%	4.68%	2.74%	3.21%	4.26%
811310	Commercial and industrial machinery and equipment repair	4.98%	5.14%	5.45%	5.62%	5.46%	5.90%	5.34%	5.44%	5.42%

Table VI-4, continued

Time Series of Annual Profit Rates for Industries Affected by the Proposed Beryllium Standard

NAICS Code[1]	Industry	2002	2003	2004	2005	2006	2007	2008	2009	Average
Resistance Welding										
333411	Air purification equipment manufacturing	4.00%	3.90%	3.84%	6.22%	5.86%	6.07%	4.00%	3.55%	4.68%
333412	Industrial and commercial fan and blower manufacturing	4.00%	3.90%	3.84%	6.22%	5.86%	6.07%	4.00%	3.55%	4.68%
333414	Heating equipment (except warm air furnaces) manufacturing	4.00%	3.90%	3.84%	6.22%	5.86%	6.07%	4.00%	3.55%	4.68%
333415	Air-conditioning, warm air heating, and industrial refrigeration equipment manufacturing	4.00%	3.90%	3.84%	6.22%	5.86%	6.07%	4.00%	3.55%	4.68%
335211	Electric housewares and household fan manufacturing	3.28%	3.45%	5.88%	4.10%	3.64%	3.04%	4.65%	4.19%	4.03%
335212	Household vacuum cleaner manufacturing	3.28%	3.45%	5.88%	4.10%	3.64%	3.04%	4.65%	4.19%	4.03%
335221	Household cooking appliance manufacturing	3.28%	3.45%	5.88%	4.10%	3.64%	3.04%	4.65%	4.19%	4.03%
335222	Household refrigerator and home freezer manufacturing	3.28%	3.45%	5.88%	4.10%	3.64%	3.04%	4.65%	4.19%	4.03%
335224	Household laundry equipment manufacturing	3.28%	3.45%	5.88%	4.10%	3.64%	3.04%	4.65%	4.19%	4.03%
335228	Other major household appliance manufacturing	3.28%	3.45%	5.88%	4.10%	3.64%	3.04%	4.65%	4.19%	4.03%
336311	Carburetor, piston, piston ring, and valve manufacturing	1.91%	1.18%	1.38%	4.62%	1.77%	1.97%	0.77%	1.00%	1.83%
336312	Gasoline engine and engine parts manufacturing	1.91%	1.18%	1.38%	4.62%	1.77%	1.97%	0.77%	1.00%	1.83%
336321	Vehicular lighting equipment manufacturing	1.91%	1.18%	1.38%	4.62%	1.77%	1.97%	0.77%	1.00%	1.83%
336322	Other motor vehicle electrical and electronic equipment manufacturing	1.91%	1.18%	1.38%	4.62%	1.77%	1.97%	0.77%	1.00%	1.83%
336330	Motor vehicle steering and suspension components (except spring) manufacturing	1.91%	1.18%	1.38%	4.62%	1.77%	1.97%	0.77%	1.00%	1.83%
336340	Motor vehicle brake system manufacturing	1.91%	1.18%	1.38%	4.62%	1.77%	1.97%	0.77%	1.00%	1.83%
336350	Motor vehicle transmission and power train parts manufacturing	1.91%	1.18%	1.38%	4.62%	1.77%	1.97%	0.77%	1.00%	1.83%
336360	Motor vehicle seating and interior trim manufacturing	1.91%	1.18%	1.38%	4.62%	1.77%	1.97%	0.77%	1.00%	1.83%
336370	Motor vehicle metal stamping	1.91%	1.18%	1.38%	4.62%	1.77%	1.97%	0.77%	1.00%	1.83%
336391	Motor vehicle air-conditioning manufacturing	1.91%	1.18%	1.38%	4.62%	1.77%	1.97%	0.77%	1.00%	1.83%

[1] NAICS industries with "a" and "b" designations and appearing in multiple application groups in previous sections of this analysis only appear once in this table

Note: The "--" indicates situations where no data were available

Source:

Table VI-5									
Annual Percentage Change in Profit Rates for Industries Affected by the Proposed Beryllium Standard									
NAICS Code[1]	**Industry**	**2002-2003**	**2003-2004**	**2004-2005**	**2005-2006**	**2006-2007**	**2007-2008**	**2008-2009**	**Average Change (Absolute Values)**
Beryllium Production									
331419	Primary smelting and refining of nonferrous metals	43.3%	27.3%	10.9%	35.1%	13.2%	-48.0%	-62.2%	34.3%
Beryllium Oxide Ceramics and Composites									
327113	Porcelain electrical supply manufacturing	-1.3%	72.5%	56.5%	-20.1%	11.9%	-5.3%	-17.0%	26.4%
334220	Cellular telephones manufacturing	-65.0%	27.7%	181.8%	17.8%	-35.0%	20.0%	57.6%	57.8%
334310	Compact disc players manufacturing	14.1%	-30.2%	211.3%	-36.6%	-33.8%	-5.5%	-21.5%	50.4%
334411	Electron tube manufacturing	30.6%	155.4%	102.1%	-27.5%	-4.4%	2.7%	-18.1%	48.7%
334415	Electronic resistor manufacturing	30.6%	155.4%	102.1%	-27.5%	-4.4%	2.7%	-18.1%	48.7%
334419	Other electronic component manufacturing	30.6%	155.4%	102.1%	-27.5%	-4.4%	2.7%	-18.1%	48.7%
334510	Electromedical equipment manufacturing	0.8%	14.4%	185.4%	-24.7%	-18.4%	-5.8%	-3.0%	36.1%
Nonferrous Foundries									
331521	Aluminum die-casting foundries	-34.4%	80.3%	76.1%	16.3%	17.9%	-4.2%	-16.4%	35.1%
331522	Nonferrous (except aluminum) die-casting foundries	-34.4%	80.3%	76.1%	16.3%	17.9%	-4.2%	-16.4%	35.1%
331524	Aluminum foundries (except die-casting)	-34.4%	80.3%	76.1%	16.3%	17.9%	-4.2%	-16.4%	35.1%
331525	Copper foundries (except die-casting)	-34.4%	80.3%	76.1%	16.3%	17.9%	-4.2%	-16.4%	35.1%
Secondary Smelting, Refining, and Alloying									
331314	Secondary smelting & alloying of aluminum	-12.0%	130.9%	10.9%	35.1%	13.2%	-48.0%	-62.2%	44.6%
331421	Copper rolling, drawing, and extruding	43.3%	27.3%	10.9%	35.1%	13.2%	-48.0%	-62.2%	34.3%
331423	Secondary smelting, refining, & alloying of copper	43.3%	27.3%	10.9%	35.1%	13.2%	-48.0%	-62.2%	34.3%
331492	Secondary smelting, refining, & alloying of nonferrous metal (except copper & aluminum)	43.3%	27.3%	10.9%	35.1%	13.2%	-48.0%	-62.2%	34.3%
Precision Machining									
332721	Precision turned product manufacturing	-8.1%	34.7%	14.9%	0.9%	-9.4%	-3.0%	-11.0%	11.7%
Copper Rolling, Drawing and Extruding									
331422	Copper wire (except mechanical) drawing	43.3%	27.3%	10.9%	35.1%	13.2%	-48.0%	-62.2%	34.3%
Stamping, Spring, and Connector Manufacturing									
332612	Light gauge spring manufacturing	-10.0%	65.8%	14.9%	0.9%	-9.4%	-3.0%	-11.0%	16.4%
332116	Metal stamping	-18.9%	17.5%	20.9%	12.8%	4.5%	-11.6%	-16.9%	14.7%
334417	Electronic connector manufacturing	30.6%	155.4%	102.1%	-27.5%	-4.4%	2.7%	-18.1%	48.7%

Table VI-5, continued

Annual Percentage Change in Profit Rates for Industries Affected by the Proposed Beryllium Standard

NAICS Code[1]	Industry	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	Average Change (Absolute Values)
Dental Laboratories									
339116	Dental laboratories	-15.8%	15.3%	100.3%	-24.0%	-26.6%	-20.2%	20.2%	31.8%
621210	Offices of dentists	-1.2%	23.4%	-0.2%	-2.2%	23.6%	-7.9%	11.6%	10.0%
Arc and Gas Welding									
331111	Iron and steel mills	-46.5%	593.9%	2.3%	14.9%	-23.7%	-11.1%	-75.9%	109.7%
331221	Rolled steel shape manufacturing	-46.5%	593.9%	2.3%	14.9%	-23.7%	-11.1%	-75.9%	109.7%
331513	Steel foundries (except investment)	-34.4%	80.3%	76.1%	16.3%	17.9%	-4.2%	-16.4%	35.1%
332117	Powder metallurgy part manufacturing	-18.9%	17.5%	20.9%	12.8%	4.5%	-11.6%	-16.9%	14.7%
332212	Hand and edge tool manufacturing	-10.0%	65.8%	14.9%	0.9%	-9.4%	-3.0%	-11.0%	16.4%
332312	Fabricated structural metal manufacturing	-13.2%	32.8%	30.9%	8.0%	2.7%	-24.7%	-7.3%	17.1%
332313	Plate work manufacturing	-13.2%	32.8%	30.9%	8.0%	2.7%	-24.7%	-7.3%	17.1%
332322	Sheet metal work manufacturing	-13.2%	32.8%	30.9%	8.0%	2.7%	-24.7%	-7.3%	17.1%
332323	Ornamental and architectural metal work manufacturing	-13.2%	32.8%	30.9%	8.0%	2.7%	-24.7%	-7.3%	17.1%
332439	Other metal container manufacturing	-47.8%	70.3%	73.5%	-32.0%	8.6%	-7.9%	-7.9%	35.4%
332919	Other metal valve and pipe fitting manufacturing	-2.0%	33.5%	38.3%	-26.3%	7.5%	-16.5%	-10.3%	19.2%
332999	All other miscellaneous fabricated metal product manufacturing	-2.0%	33.5%	38.3%	-26.3%	7.5%	-16.5%	-10.3%	19.2%
333111	Farm machinery and equipment manufacturing	-32.0%	49.4%	148.7%	13.5%	-3.4%	7.9%	-57.5%	44.6%
333911	Pump and pumping equipment manufacturing	-11.9%	55.4%	49.2%	-18.2%	57.1%	-28.9%	-18.5%	34.2%
333922	Conveyor and conveying equipment manufacturing	-11.9%	55.4%	49.2%	-18.2%	57.1%	-28.9%	-18.5%	34.2%
333924	Industrial truck, tractor, trailer, and stacker machinery manufacturing	-11.9%	55.4%	49.2%	-18.2%	57.1%	-28.9%	-18.5%	34.2%
333999	All other miscellaneous general purpose machinery manufacturing	-11.9%	55.4%	49.2%	-18.2%	57.1%	-28.9%	-18.5%	34.2%
336211	Motor vehicle body manufacturing	-38.1%	17.0%	234.8%	-61.6%	11.0%	-60.7%	29.0%	64.6%
336214	Travel trailer and camper manufacturing	-38.1%	17.0%	234.8%	-61.6%	11.0%	-60.7%	29.0%	64.6%
336399	All other motor vehicle parts manufacturing	-38.1%	17.0%	234.8%	-61.6%	11.0%	-60.7%	29.0%	64.6%
336510	Railroad rolling stock	-41.0%	314.9%	6.6%	36.2%	-6.9%	-24.8%	-40.9%	67.3%
336999	All other transportation equipment manufacturing	32.1%	-15.3%	6.6%	36.2%	-6.9%	-24.8%	-40.9%	23.2%
337215	Showcase, partition, shelving, and locker manufacturing	-8.0%	7.4%	40.2%	-0.4%	-17.9%	-41.5%	17.3%	19.0%
811310	Commercial and industrial machinery and equipment repair	3.3%	6.1%	3.2%	-2.8%	8.1%	-9.6%	1.9%	5.0%

Table VI-5, continued									
Annual Percentage Change in Profit Rates for Industries Affected by the Proposed Beryllium Standard									
NAICS Code[1]	**Industry**	**2002-2003**	**2003-2004**	**2004-2005**	**2005-2006**	**2006-2007**	**2007-2008**	**2008-2009**	**Average Change (Absolute Values)**
Resistance Welding									
333411	Air purification equipment manufacturing	-2.6%	-1.5%	62.0%	-5.7%	3.5%	-34.0%	-11.3%	17.2%
333412	Industrial and commercial fan and blower manufacturing	-2.6%	-1.5%	62.0%	-5.7%	3.5%	-34.0%	-11.3%	17.2%
333414	Heating equipment (except warm air furnaces) manufacturing	-2.6%	-1.5%	62.0%	-5.7%	3.5%	-34.0%	-11.3%	17.2%
333415	Air-conditioning, warm air heating, and industrial refrigeration equipment manufacturing	-2.6%	-1.5%	62.0%	-5.7%	3.5%	-34.0%	-11.3%	17.2%
335211	Electric housewares and household fan manufacturing	5.4%	70.4%	-30.3%	-11.2%	-16.5%	52.9%	-9.9%	28.1%
335212	Household vacuum cleaner manufacturing	5.4%	70.4%	-30.3%	-11.2%	-16.5%	52.9%	-9.9%	28.1%
335221	Household cooking appliance manufacturing	5.4%	70.4%	-30.3%	-11.2%	-16.5%	52.9%	-9.9%	28.1%
335222	Household refrigerator and home freezer manufacturing	5.4%	70.4%	-30.3%	-11.2%	-16.5%	52.9%	-9.9%	28.1%
335224	Household laundry equipment manufacturing	5.4%	70.4%	-30.3%	-11.2%	-16.5%	52.9%	-9.9%	28.1%
335228	Other major household appliance manufacturing	5.4%	70.4%	-30.3%	-11.2%	-16.5%	52.9%	-9.9%	28.1%
336311	Carburetor, piston, piston ring, and valve manufacturing	-38.1%	17.0%	234.8%	-61.6%	11.0%	-60.7%	29.0%	64.6%
336312	Gasoline engine and engine parts manufacturing	-38.1%	17.0%	234.8%	-61.6%	11.0%	-60.7%	29.0%	64.6%
336321	Vehicular lighting equipment manufacturing	-38.1%	17.0%	234.8%	-61.6%	11.0%	-60.7%	29.0%	64.6%
336322	Other motor vehicle electrical and electronic equipment manufacturing	-38.1%	17.0%	234.8%	-61.6%	11.0%	-60.7%	29.0%	64.6%
336330	Motor vehicle steering and suspension components (except spring) manufacturing	-38.1%	17.0%	234.8%	-61.6%	11.0%	-60.7%	29.0%	64.6%
336340	Motor vehicle brake system manufacturing	-38.1%	17.0%	234.8%	-61.6%	11.0%	-60.7%	29.0%	64.6%
336350	Motor vehicle transmission and power train parts manufacturing	-38.1%	17.0%	234.8%	-61.6%	11.0%	-60.7%	29.0%	64.6%
336360	Motor vehicle seating and interior trim manufacturing	-38.1%	17.0%	234.8%	-61.6%	11.0%	-60.7%	29.0%	64.6%
336370	Motor vehicle metal stamping	-38.1%	17.0%	234.8%	-61.6%	11.0%	-60.7%	29.0%	64.6%
336391	Motor vehicle air-conditioning manufacturing	-38.1%	17.0%	234.8%	-61.6%	11.0%	-60.7%	29.0%	64.6%

[1] NAICS industries with "a" and "b" designations and appearing in multiple application groups in previous sections of this analysis only appear once in this table

Note: The "--" indicates situations where no data were available

Source:

Economic Feasibility Screening Analysis: Small and Very Small Businesses

The preceding discussion focused on the economic viability of the affected industries in their entirety. Even though OSHA found that the proposed standard did not threaten the survival of these industries, there is still the possibility that the competitive structure of these industries could be significantly altered such as by small entities exiting from the industry as a result of the proposed standard.

To address this possibility, OSHA examined the annualized costs of the proposed standard per affected small entity, and per affected very small entity, for each affected industry. Again, OSHA used a minimum threshold level of annualized compliance costs equal to one percent of annual revenues—and, secondarily, annualized compliance costs equal to ten percent of annual profits—below which the Agency has concluded that the costs are unlikely to threaten the survival of small entities or very small entities or, consequently, to alter the competitive structure of the affected industries.

Based on the results presented in Table VI-6, the annualized cost of compliance with the proposed rule for the average affected small entity is estimated to be $8,108 in 2010 dollars.[422] Based on the results presented in Table VI-7, the annualized cost of compliance with the proposed rule for the average affected very small entity is estimated to be $1,955 in 2010 dollars.[423] These tables also show that there are no industries in which the annualized costs of the proposed rule for small entities or very small entities exceed one percent of annual revenues. NAICS 331525b: Sand Copper Foundries (except die-casting) has the highest estimated cost

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[422] Tables VI-B-1 and VI-B-2 in Appendix VI-B show, per small entity, annualized costs and ratios of annualized cost to annual revenue and annualized costs to annual profit using discount rates of 7 percent and 0 percent, respectively.

[423] Tables VI-C-1 and VI-C-2 in Appendix VI-C show, per very small entity, annualized costs and ratios of annualized cost to annual revenue and annualized costs to annual profit using discount rates of 7 percent and 0 percent, respectively.

impact as a percentage of revenues for small entities, 0.95 percent, and NAICS 336322b: Other motor vehicle electrical and electronic equipment has the highest estimated cost impact as a percentage of revenues for very small entities, 0.70 percent.

Small entities in four industries—NAICS 331525: Sand and non-sand foundries (except die-casting); NAICS 331524(a and b): Aluminum foundries (except die-casting); NAICS 811310: Commercial and Industrial Machinery and Equipment; and NAICS 331522: Nonferrous (except aluminum) die-casting foundries—have annualized costs in excess of 10 percent of annual profits (17.45 percent, 16.12 percent, 11.68 percent, and 10.64 percent, respectively).[424] Very small entities in seven industries are estimated to have annualized costs in excess of 10 percent of annual profit: NAICS 336322b: Other motor vehicle electrical and electronic equipment (38.49 percent);[425] NAICS 336322a: Other motor vehicle electrical and electronic equipment, (18.18 percent); NAICS 327113: Porcelain electrical Supply Manufacturing (13.82 percent); NAICS 811310: Commercial and Industrial Machinery and Equipment (Except Automotive and Electronic) Repair and Maintenance (12.76 percent); NAICS 332721a: Precision turned product manufacturing (10.50 percent); NAICS 336214: Travel trailer and camper manufacturing (10.75 percent); and NAICS 336399: All other motor vehicle parts manufacturing (10.38 percent).[426]

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[424] Table VI-B-1 in Appendix VI-B shows that when applying a 7 percent discount rate the same industries are above the 10 percent cost-to-profit threshold as when applying the 3 percent discount rate. Table VI-B-2 shows that when applying a 0 percent discount rate NAICS 331522: Nonferrous (except aluminum) die-casting foundries (9.89 percent) drops below the 10 percent cost-to-profit threshold.

[425] NAICS 336322 contains entities that fall into three separate application groups. NAICS 336322b is in the Beryllium Oxide Ceramics and Composites application group. NAICS 336322a (which follows in the text) is in the Fabrication of Beryllium Alloy Products application group.

[426] Table VI-C-1 in Appendix VI-C shows that when applying the 7 percent discount rate two additional industries are above the 10 percent threshold; NAICS 337215: Showcase, partition, shelving, and locker manufacturing, increases from 9.96 to 10.25 percent and NAICS 332323: Ornamental and Architectural Metal Work Manufacturing, increases from 9.70 percent to 10.06 percent. Table VI-C-2 shows that when applying a 0 percent

In general, cost impacts for affected small entities or very small entities will tend to be somewhat higher, on average, than the cost impacts for the average business in those affected industries. That is to be expected. After all, smaller businesses typically suffer from diseconomies of scale in many aspects of their business, leading to less revenue per dollar of cost and higher unit costs. Small businesses are able to overcome these obstacles by providing specialized products and services, offering local service and better service, or otherwise creating a market niche for themselves. The higher cost impacts for smaller businesses estimated for this rule—other than very small entities in NAICS 336322b: Other motor vehicle electrical and electronic equipment—generally fall within the range observed in other OSHA regulations and, as verified by OSHA's lookback reviews, have not been of such a magnitude to lead to the economic failure of regulated small businesses.

The ratio of annualized costs to annual profit is a sizable 38.49 percent in NAICS 336322b: Other motor vehicle electrical and electronic equipment. However, OSHA believes that the actual ratio is significantly lower. There are 386 very small entities in NAICS 336322, of which only 6, or 1.5 percent, are affected entities using beryllium. When OSHA calculated the cost-to-profit ratio, it used the average profit per firm for the entire NAICs industry, not the average profit rate for firms working with beryllium. The profit rate for all establishments in NAICS 336322b was estimated at 1.83 percent. If, for example, the average profit rate for a very small entity in NAICS 336322b were equal to 5.95 percent, the average profit rate for its application group, Beryllium Oxide Ceramics and Composites, then the ratio of the very small entity's annualized cost of the proposed rule to its annual profit would actually be 11.77 percent. OSHA tentatively concludes the 6 establishments in the NAICS specializing in beryllium

discount rate the same industries are above the 10 percent cost-to-profit threshold as when applying the 3 percent discount rate.

production will have a higher than average profit rate and will be able to pass much of the cost onto the consumer for three main reasons: (1) the absence of substitutes containing the rare performance characteristics of beryllium; (2) the relative price insensitivity of (other) motor vehicles containing the special performance characteristics of beryllium and beryllium alloys; and (3) the fact that electrical and electronic components made of beryllium or beryllium-containing alloys typically account for only a small portion of the overall cost of the finished (other) motor vehicles. The annualized compliance cost to annual revenue ratio for NAICS 336332b is 0.70 percent, 0.30 percent below the 1 percent threshold. Based on OSHA's past experience, price increases of this magnitude have not historically been associated with the economic failure of small businesses.

Table VI-6

Screening Analysis for SBA-Defined Small Entities Affected by the Proposed Beryllium Standard
With Costs Calculated Using a Three Percent Discount Rate

				Revenues		Profit		Compliance Costs		
NAICS Code	Industry	Total Small Entities	Total Affected Small Entities	Total for SBA Entitities ($1,000)	Per Entity ($s)	Rate	Per Entity ($s)	Per Entity ($s)	As a Percent of Revenues	As a Percent of Profits
Beryllium Production										
331419	Primary smelting and refining of nonferrous metals	--	--	--	--	--	--	--	--	--
Beryllium Oxide Ceramics and Composites										
327113a	Porcelain electrical supply manufacturing (primary)	85	1	$326,127	--	--	--	--	--	--
327113b	Porcelain electrical supply manufacturing (secondary)	85	11	$326,127	$3,836,783	5.01%	$192,368	$12,979	0.34%	6.75%
334220	Cellular telephones manufacturing	724	9	$35,475,343	$48,999,093	6.08%	$2,980,355	$19,318	0.04%	0.65%
334310	Compact disc players manufacturing	460	5	$3,975,351	$8,642,068	4.39%	$379,730	$16,768	0.19%	4.42%
334411	Electron tube manufacturing	62	16	$1,220,476	19,685,102	7.85%	1,544,859	$21,598	0.11%	1.40%
334415	Electronic resistor manufacturing	46	9	$385,781	8,386,547	7.85%	658,164	$15,052	0.18%	2.29%
334419	Other electronic component manufacturing	990	8	$4,796,313	4,844,761	7.85%	380,210	$12,982	0.27%	3.41%
334510	Electromedical equipment manufacturing	494	7	$3,752,243	7,595,634	6.75%	512,503	$8,812	0.12%	1.72%
336322b	Other motor vehicle electrical and electronic equipment manufacturing	585	9	$12,152,053	20,772,740	1.83%	379,243	$18,415	0.09%	4.86%
Nonferrous Foundries										
331521	Aluminum die-casting foundries	209	6	$2,070,759	9,907,938	5.22%	517,103	$38,396	0.39%	7.43%
331522	Nonferrous (except aluminum) die-casting foundries	129	35	$813,444	6,305,771	5.22%	329,103	$35,014	0.56%	10.64%
331524	Aluminum foundries (except die-casting)	351	6	$1,690,008	4,814,839	5.22%	251,290	$40,517	0.84%	16.12%
331525a	Copper foundries (except die-casting) (non-sand casting foundries)	195	19	$925,667	4,747,008	5.22%	247,750	$41,295	0.87%	16.67%
331525b	Copper foundries (except die-casting) (sand casting foundries)	195	23	$925,667	4,747,008	5.22%	247,750	$45,131	0.95%	18.22%
Secondary Smelting, Refining, and Alloying										
331314	Secondary smelting & alloying of aluminum	98	1	$4,837,129	49,358,460	4.54%	2,243,316	$33,757	0.07%	1.50%
331421b	Copper rolling, drawing, and extruding	70	1	$12,513,425	178,763,215	4.79%	8,569,920	$34,206	0.02%	0.40%
331423	Secondary smelting, refining, & alloying of copper	23	3	$723,759	31,467,777	4.79%	1,508,567	$35,101	0.11%	2.33%
331492	Secondary smelting, refining, & alloying of nonferrous metal (except copper & aluminum)	217	26	$8,195,807	37,768,697	4.79%	1,810,634	$22,183	0.06%	1.23%
Precision Turned Products										
332721a	Precision turned product manufacturing (high beryllium content)	3,006	18	$11,393,081	3,790,113	5.82%	220,539	$19,481	0.51%	8.83%
332721b	Precision turned product manufacturing (low beryllium content)	3,006	283	$11,393,081	3,790,113	5.82%	220,539	$14,207	0.37%	6.44%
Copper Rolling, Drawing and Extruding										
331421a	Copper rolling, drawing, and extruding	70	11	$12,513,425	178,763,215	4.79%	8,569,920	$119,129	0.07%	1.39%
331422	Copper wire (except mechanical) drawing	84	43	$6,471,491	77,041,555	4.79%	3,693,377	$105,463	0.14%	2.86%
Fabrication of Beryllium Alloy Products										
332612	Light gauge spring manufacturing	262	262	$1,030,905	3,934,752	5.61%	220,868	$7,277	0.18%	3.29%
332116	Metal stamping	1,367	68	$7,693,541	5,628,048	5.12%	288,086	$8,395	0.15%	2.91%
334417	Electronic connector manufacturing	176	35	$1,556,871	8,845,860	7.85%	694,211	$5,765	0.07%	0.83%
336322a	Other motor vehicle electrical & electronic equipment	585	146	$12,152,053	20,772,740	1.83%	379,243	$10,048	0.05%	2.65%

Table VI-6, continued

Screening Analysis for SBA-Defined Small Entities Affected by the Proposed Beryllium Standard
With Costs Calculated Using a Three Percent Discount Rate

NAICS Code	Industry	Total Establishments	Total Affected Establishments	Revenues: Total ($1,000)	Revenues: Per Establishment ($s)	Profit: Rate	Profit: Per Establishment ($s)	Compliance Costs: Per Establishment ($s)	Compliance Costs: As a Percent of Revenues	Compliance Costs: As a Percent of Profits
Arc and Gas Welding										
331111	Iron and steel mills	461	5	$92,726,004	201,141,005	5.41%	10,877,459	$10,377	0.01%	0.10%
331221	Rolled steel shape manufacturing	134	1	$8,376,271	62,509,488	5.41%	3,380,437	$12,541	0.02%	0.37%
331513	Steel foundries (except investment)	188	1	$2,739,158	14,569,989	5.22%	760,419	$8,657	0.06%	1.14%
332117	Powder metallurgy part manufacturing	106	1	$841,084	7,934,752	5.12%	406,161	$8,278	0.10%	2.04%
332212	Hand and edge tool manufacturing	975	3	$3,072,300	3,151,077	5.61%	176,878	$7,037	0.22%	3.98%
332312	Fabricated structural metal manufacturing	3,001	49	$15,405,728	5,133,531	4.74%	243,251	$6,076	0.12%	2.50%
332313	Plate work manufacturing	1,220	20	$4,900,364	4,016,692	4.74%	190,330	$7,379	0.18%	3.88%
332322	Sheet metal work manufacturing	3,835	63	$12,607,305	3,287,433	4.74%	155,774	$7,010	0.21%	4.50%
332323	Ornamental and architectural metal work manufacturing	2,287	38	$4,118,512	1,800,836	4.74%	85,332	$6,548	0.36%	7.67%
332439	Other metal container manufacturing	302	5	$1,698,117	5,622,904	4.30%	242,034	$5,858	0.10%	2.42%
332919	Other metal valve and pipe fitting manufacturing	207	2	$2,028,451	9,799,278	7.00%	686,061	$6,301	0.06%	0.92%
332999	All other miscellaneous fabricated metal product manufacturing	3,111	32	$10,202,505	3,279,494	7.00%	229,602	$6,782	0.21%	2.95%
333111	Farm machinery and equipment manufacturing	941	18	$5,132,720	5,454,538	6.36%	347,100	$3,899	0.07%	1.12%
333414a	Heating equipment (except warm air furnaces) manufacturing	410	5	$2,583,472	6,301,151	4.68%	294,852	$5,769	0.09%	1.96%
333911	Pump and pumping equipment manufacturing	399	5	$3,348,262	8,391,635	5.36%	449,783	$4,457	0.05%	0.99%
333922	Conveyor and conveying equipment manufacturing	707	8	$4,768,668	6,744,933	5.36%	361,522	$6,809	0.10%	1.88%
333924	Industrial truck, tractor, trailer, and stacker machinery manufacturing	347	4	$7,444,451	21,453,748	5.36%	1,149,899	$9,122	0.04%	0.79%
333999	All other miscellaneous general purpose machinery manufacturing	1,385	16	$5,601,674	4,044,530	5.36%	216,783	$5,282	0.13%	2.44%
336211	Motor vehicle body manufacturing	652	13	$9,877,558	15,149,628	1.83%	276,583	$9,055	0.06%	3.27%
336214	Travel trailer and camper manufacturing	585	12	$2,513,608	4,296,766	1.83%	78,445	$4,404	0.10%	5.61%
336399a	All other motor vehicle parts manufacturing	1,156	6	$32,279,766	27,923,673	1.83%	509,796	$9,445	0.03%	1.85%
336510	Railroad rolling stock	157	2	$11,927,191	75,969,367	5.47%	4,156,603	$12,983	0.02%	0.31%
336999	All other transportation equipment manufacturing	349	3	$941,637	2,698,100	6.56%	177,073	$4,339	0.16%	2.45%
337215	Showcase, partition, shelving, and locker manufacturing	1,120	3	$3,688,129	3,292,972	4.26%	140,227	$6,966	0.21%	4.97%
811310	Commercial and industrial machinery and equipment repair	19,857	129	$17,088,964	860,601	5.42%	46,622	$5,445	0.63%	11.68%
Resistance Welding										
333411	Air purification equipment manufacturing	283	20	$1,327,014	4,689,095	4.68%	219,418	$8,363	0.18%	3.81%
333412	Industrial and commercial fan and blower manufacturing	118	8	$1,001,835	8,490,124	4.68%	397,281	$11,780	0.14%	2.97%
333414b	Heating equipment (except warm air furnaces) manufacturing	410	29	$2,583,472	6,301,151	4.68%	294,852	$10,186	0.16%	3.45%
333415	Air-conditioning, warm air heating, and industrial refrigeration equipment manufacturing	695	49	$25,454,383	36,625,012	4.68%	1,713,806	$18,247	0.05%	1.06%
335211	Electric housewares and household fan manufacturing	101	5	$2,209,657	21,877,797	4.03%	881,709	$15,789	0.07%	1.79%
335212	Household vacuum cleaner manufacturing	29	1	$891,600	30,744,844	4.03%	1,239,064	$17,638	0.06%	1.42%
335221	Household cooking appliance manufacturing	91	5	$3,757,849	41,295,040	4.03%	1,664,253	$15,870	0.04%	0.95%
335222	Household refrigerator and home freezer manufacturing	16	1	$4,489,845	280,615,299	4.03%	11,309,226	$16,548	0.01%	0.15%
335224	Household laundry equipment manufacturing	9	1	$3,720,514	413,390,395	4.03%	16,660,266	$8,274	0.00%	0.05%
335228	Other major household appliance manufacturing	24	1	$185,373	7,723,871	4.03%	311,284	$1,740	0.02%	0.56%

Table VI-6, continued
Screening Analysis for SBA-Defined Small Entities Affected by the Proposed Beryllium Standard
With Costs Calculated Using a Three Percent Discount Rate

NAICS Code	Industry	Total Establishments	Total Affected Establishments	Revenues: Total ($1,000)	Revenues: Per Establishment ($s)	Profit: Rate	Profit: Per Establishment ($s)	Compliance Costs: Per Establishment ($s)	Compliance Costs: As a Percent of Revenues	Compliance Costs: As a Percent of Profits
Resistance Welding										
336311	Carburetor, piston, piston ring, and valve manufacturing	89	4	$499,977	5,617,722	1.83%	102,562	$5,227	0.09%	5.10%
336312	Gasoline engine and engine parts manufacturing	697	35	$20,000,705	28,695,417	1.83%	523,886	$16,015	0.06%	3.06%
336321	Vehicular lighting equipment manufacturing	75	4	$671,947	8,959,292	1.83%	163,568	$6,084	0.07%	3.72%
336322c	Other motor vehicle electrical and electronic equipment manufacturing	585	29	$12,152,053	20,772,740	1.83%	379,243	$16,355	0.08%	4.31%
336330	Motor vehicle steering and suspension components (except spring) manufacturing	209	10	$8,856,584	42,376,000	1.83%	773,649	$17,707	0.04%	2.29%
336340	Motor vehicle brake system manufacturing	159	8	$8,147,826	51,244,189	1.83%	935,554	$18,828	0.04%	2.01%
336350	Motor vehicle transmission and power train parts manufacturing	397	20	$21,862,014	55,068,044	1.83%	1,005,365	$18,037	0.03%	1.79%
336360	Motor vehicle seating and interior trim manufacturing	273	14	$3,482,677	12,757,060	1.83%	232,903	$6,586	0.05%	2.83%
336370	Motor vehicle metal stamping	540	27	$7,262,381	13,448,854	1.83%	245,533	$8,894	0.07%	3.62%
336391	Motor vehicle air-conditioning manufacturing	72	4	$3,798,464	52,756,449	1.83%	963,163	$16,715	0.03%	1.74%
336399b	All other motor vehicle parts manufacturing	1,156	58	$32,279,766	27,923,673	1.83%	509,796	$17,568	0.06%	3.45%
Dental Laboratories										
339116	Dental laboratories	6,703	1,676	$3,156,130	470,853	10.55%	49,696	$1,394	0.30%	2.81%
621210	Offices of dentists	123,077	225	$94,120,777	764,731	8.47%	64,809	$1,630	0.21%	2.51%
	Total/Average	193,274	3,741	$687,134,666	7,300,515	7.55%	550,848	$8,108	0.11%	1.47%

"--" indicates areas where data are not available. (While the average revenues and implied profits for the Beryllium Production (NAICS 331419) and Beryllium Oxide (NAICS 327113a) industries can be calculated, they would in no way reflect the actual revenues and profits of the affected facilities

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis.

Table VI-7										
Screening Analysis for Very Small Entities (with fewer than 20 employees) Affected by the Proposed Beryllium Standard With Costs Calculated Using a Three Percent Discount Rate										
				Revenues		Profit		Compliance Costs		
NAICS Code	Industry	Total Small Entities	Total Affected Small Entities	Total for Very Small Entitities ($1,000)	Per Entity ($s)	Rate	Per Entity ($s)	Per Entity ($s)	As a Percent of Revenues	As a Percent of Profits
Beryllium Production										
331419	Primary smelting and refining of nonferrous me	--	--	--	--	--	--	--	--	--
Beryllium Oxide Ceramics and Composites										
327113a	Porcelain electrical supply manufacturing (prim	53	0	52,358	--	--	--	--	--	--
327113b	Porcelain electrical supply manufacturing (secc	53	7	52,358	$987,892	5.01%	$192,368	$6,846	0.69%	13.82%
334220	Cellular telephones manufacturing	445	4	576,956	$1,296,530	6.08%	$2,980,355	$6,273	0.48%	7.95%
334310	Compact disc players manufacturing	373	4	1,128,513	$3,025,503	4.39%	$379,730	$8,383	0.28%	6.31%
334411	Electron tube manufacturing	38	10	45,454	$1,196,149	7.85%	$1,544,859	$6,430	0.54%	6.85%
334415	Electronic resistor manufacturing	17	3	25,647	$1,508,662	7.85%	$658,164	$6,848	0.45%	5.78%
334419	Other electronic component manufacturing	624	5	639,599	$1,024,999	7.85%	$380,210	$6,962	0.68%	8.65%
334510	Electromedical equipment manufacturing	324	3	420,245	$1,297,053	6.75%	$512,503	$6,271	0.48%	7.17%
336322b	Other motor vehicle electrical and electronic eq	386	6	349,811	$906,246	1.83%	$379,243	$6,368	0.70%	38.49%
Nonferrous Foundries										
331521	Aluminum die-casting foundries	107	0	153,274	--	5.22%	$517,103	--	--	--
331522	Nonferrous (except aluminum) die-casting four	84	0	92,703	--	5.22%	$329,103	--	--	--
331524	Aluminum foundries (except die-casting)	217	0	204,397	--	5.22%	$251,290	--	--	--
331525a	Copper foundries (except die-casting) (non-sar	131	0	139,372	--	5.22%	$247,750	--	--	--
331525b	Copper foundries (except die-casting) (sand ca	131	0	139,372	--	5.22%	$247,750	--	--	--
Secondary Smelting, Refining, and Alloying										
331314	Secondary smelting & alloying of aluminum	45	0	306,390	--	4.54%	$2,243,316	--	--	--
331421b	Copper rolling, drawing, and extruding	26	0	48,421	--	4.79%	$8,569,920	--	--	--
331423	Secondary smelting, refining, & alloying of cop	11	1	85,353	$7,759,405	4.79%	$1,508,567	$21,589	0.28%	5.80%
331492	Secondary smelting, refining, & alloying of noi	121	15	388,603	$3,211,598	4.79%	$1,810,634	$11,055	0.34%	7.18%
Precision Turned Products										
332721a	Precision turned product manufacturing (high l	1,970	12	2,219,340	$1,126,568	5.82%	$220,539	$6,881	0.61%	10.50%
332721b	Precision turned product manufacturing (low b	1,970	185	2,219,340	$1,126,568	5.82%	$220,539	$5,045	0.45%	7.70%
Copper Rolling, Drawing and Extruding										
331421a	Copper rolling, drawing, and extruding	26	4	48,421	$1,862,347	4.79%	$8,569,920	$5,684	0.31%	6.37%
331422	Copper wire (except mechanical) drawing	35	18	254,426	$7,269,304	4.79%	$3,693,377	$7,682	0.11%	2.20%
Fabrication of Beryllium Alloy Products										
332612	Light gauge spring manufacturing	164	164	156,603	$954,897	5.61%	$220,868	$3,310	0.35%	6.18%
332116	Metal stamping	807	40	1,033,657	$1,280,864	5.12%	$288,086	$3,543	0.28%	5.40%
334417	Electronic connector manufacturing	106	11	129,405	$1,220,804	7.85%	$694,211	$3,014	0.25%	3.15%
336322a	Other motor vehicle electrical & electronic equi	386	60	349,811	$906,246	1.83%	$379,243	$3,007	0.33%	18.18%

Table VI-7, continued

Screening Analysis for Very Small Entities (with fewer than 20 employees) Affected by the Proposed Beryllium Standard
With Costs Calculated Using a Three Percent Discount Rate

NAICS Code	Industry	Total Small Entities	Total Affected Small Entities	Revenues: Total for Very Small Entitities ($1,000)	Revenues: Per Entity ($s)	Profit: Rate	Profit: Per Entity ($s)	Compliance Costs: Per Entity ($s)	Compliance Costs: As a Percent of Revenues	Compliance Costs: As a Percent of Profits
Arc and Gas Welding										
331111	Iron and steel mills	268	0	1,018,914	--	5.41%	$10,877,459	--	--	--
331221	Rolled steel shape manufacturing	50	0	208,799	--	5.41%	$3,380,437	--	--	--
331513	Steel foundries (except investment)	94	0	$112,227	--	5.22%	760,419	--	--	--
332117	Powder metallurgy part manufacturing	55	0	$100,643	--	5.12%	406,161	--	--	--
332212	Hand and edge tool manufacturing	751	2	$681,375	907,290	5.61%	176,878	$3,171	0.35%	6.23%
332312	Fabricated structural metal manufacturing	2,159	35	$3,182,459	1,474,043	4.74%	243,251	$2,299	0.16%	3.29%
332313	Plate work manufacturing	845	14	$1,007,308	1,192,080	4.74%	190,330	$2,891	0.24%	5.12%
332322	Sheet metal work manufacturing	2,778	46	$2,631,155	947,140	4.74%	155,774	$2,620	0.28%	5.84%
332323	Ornamental and architectural metal work manuf	1,957	32	$1,342,443	685,970	4.74%	85,332	$3,153	0.46%	9.70%
332439	Other metal container manufacturing	203	2	$187,607	924,174	4.30%	242,034	$2,471	0.27%	6.21%
332919	Other metal valve and pipe fitting manufacturin	115	1	$181,192	1,575,580	7.00%	686,061	$4,302	0.27%	3.90%
332999	All other miscellaneous fabricated metal produ	2,353	24	$2,117,303	899,831	7.00%	229,602	$2,560	0.28%	4.06%
333111	Farm machinery and equipment manufacturing	673	7	$785,460	1,167,103	6.36%	347,100	$2,299	0.20%	3.10%
333414a	Heating equipment (except warm air furnaces) r	283	2	$365,551	1,291,699	4.68%	294,852	$2,536	0.20%	4.20%
333911	Pump and pumping equipment manufacturing	251	1	$497,397	1,981,660	5.36%	449,783	$2,477	0.12%	2.33%
333922	Conveyor and conveying equipment manufact	407	4	$541,532	1,330,547	5.36%	361,522	$2,335	0.18%	3.27%
333924	Industrial truck, tractor, trailer, and stacker mac	195	1	$213,335	1,094,026	5.36%	1,149,899	$2,761	0.25%	4.71%
333999	All other miscellaneous general purpose machi	975	10	$1,151,152	1,180,669	5.36%	216,783	$2,298	0.19%	3.63%
336211	Motor vehicle body manufacturing	400	4	$535,923	1,339,807	1.83%	276,583	$2,298	0.17%	9.39%
336214	Travel trailer and camper manufacturing	410	5	$480,503	1,171,958	1.83%	78,445	$2,300	0.20%	10.75%
336399a	All other motor vehicle parts manufacturing	653	1	$835,261	1,279,114	1.83%	509,796	$2,424	0.19%	10.38%
336510	Railroad rolling stock	83	0	$189,164	--	5.47%	4,156,603	--	--	--
336999	All other transportation equipment manufactur	307	2	$253,916	827,087	6.56%	177,073	$2,938	0.36%	5.41%
337215	Showcase, partition, shelving, and locker manu	814	2	$582,654	715,791	4.26%	140,227	$3,035	0.42%	9.96%
811310	Commercial and industrial machinery and equip	18,714	122	$10,692,921	571,386	5.42%	46,622	$3,949	0.69%	12.76%
Resistance Welding										
333411	Air purification equipment manufacturing	189	13	$283,628	1,500,678	4.68%	219,418	$2,506	0.17%	3.57%
333412	Industrial and commercial fan and blower manu	60	4	$78,644	1,310,729	4.68%	397,281	$2,401	0.18%	3.92%
333414b	Heating equipment (except warm air furnaces) r	283	20	$365,551	1,291,699	4.68%	294,852	$2,321	0.18%	3.84%
333415	Air-conditioning, warm air heating, and industr	395	28	$806,994	2,043,023	4.68%	1,713,806	$1,094	0.05%	1.14%
335211	Electric housewares and household fan manufa	70	4	$99,219	1,417,419	4.03%	881,709	$1,151	0.08%	2.01%
335212	Household vacuum cleaner manufacturing	18	0	$21,745	--	4.03%	1,239,064	--	--	--
335221	Household cooking appliance manufacturing	57	2	$66,863	1,173,037	4.03%	1,664,253	$1,056	0.09%	2.23%
335222	Household refrigerator and home freezer manu	6	0	$8,833	--	4.03%	11,309,226	--	--	--
335224	Household laundry equipment manufacturing	4	0	$1,837	--	4.03%	16,660,266	--	--	--
335228	Other major household appliance manufacturin	15	0	$24,856	--	4.03%	311,284	--	--	--

Table VI-7, continued

Screening Analysis for Very Small Entities (with fewer than 20 employees) Affected by the Proposed Beryllium Standard
With Costs Calculated Using a Three Percent Discount Rate

				Revenues		Profit		Compliance Costs		
NAICS Code	Industry	Total Small Entities	Total Affected Small Entities	Total for Very Small Entitities ($1,000)	Per Entity ($s)	Rate	Per Entity ($s)	Per Entity ($s)	As a Percent of Revenues	As a Percent of Profits
Resistance Welding										
336311	Carburetor, piston, piston ring, and valve manu	59	3	$54,436	922,644	1.83%	102,562	$1,395	0.15%	8.28%
336312	Gasoline engine and engine parts manufacturin	545	27	$883,783	1,621,620	1.83%	523,886	$1,331	0.08%	4.49%
336321	Vehicular lighting equipment manufacturing	45	2	$59,894	1,330,971	1.83%	163,568	$1,056	0.08%	4.35%
336322c	Other motor vehicle electrical and electronic eq	386	19	$349,811	906,246	1.83%	379,243	$1,452	0.16%	8.78%
336330	Motor vehicle steering and suspension compo	116	5	$998,968	8,611,797	1.83%	773,649	$1,056	0.01%	0.67%
336340	Motor vehicle brake system manufacturing	82	3	$96,867	1,181,305	1.83%	935,554	$1,056	0.09%	4.90%
336350	Motor vehicle transmission and power train pa	240	9	$304,951	1,270,628	1.83%	1,005,365	$1,056	0.08%	4.55%
336360	Motor vehicle seating and interior trim manufa	167	7	$310,566	1,859,677	1.83%	232,903	$1,056	0.06%	3.11%
336370	Motor vehicle metal stamping	225	11	$478,984	2,128,816	1.83%	245,533	$1,329	0.06%	3.42%
336391	Motor vehicle air-conditioning manufacturing	34	1	$80,741	2,374,734	1.83%	963,163	$1,056	0.04%	2.44%
336399b	All other motor vehicle parts manufacturing	653	33	$835,261	1,279,114	1.83%	509,796	$1,267	0.10%	5.43%
Dental Laboratories										
339116	Dental laboratories	6,379	1,595	1,807,075	$283,285	10.55%	$49,696	$922	0.33%	3.09%
621210	Offices of dentists	119,544	219	81,995,117	$685,899	8.47%	$64,809	$1,464	0.21%	2.52%
	Total/Average	172,628	2,875	128,347,342	$679,421	8.27%	$56,189	$1,955	0.29%	3.48%

"--" indicates areas where data are not available. (While the average revenues and implied profits for the Beryllium Production (NAICS 331419) and Beryllium Oxide (NAICS 327113a) industries can be calculated, they would in no way reflect the actual revenues and profits of the affected facilities

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis.

Regulatory Flexibility Screening Analysis

To determine if the Assistant Secretary of Labor for OSHA can certify that the proposed beryllium standard will not have a significant economic impact on a substantial number of small entities, the Agency has developed screening tests to consider minimum threshold effects of the proposed standard on small entities. The minimum threshold effects for this purpose are annualized costs equal to one percent of annual revenues, and annualized costs equal to five percent of annual profits, applied to each affected industry. OSHA has applied these screening tests both to small entities and to very small entities. For purposes of certification, the threshold level cannot be exceeded for affected small entities or very small entities in any affected industry.

Tables VI-6 and Table VI-7, presented above, show that the annualized costs of the proposed standard do not exceed one percent of annual revenues for affected small entities or affected very small entities in any affected industry. These tables also show that the annualized costs of the proposed standard exceed five percent of annual profits for affected small entities in 12 industries and for affected very small entities in 30 industries.[427] OSHA is therefore unable to certify that the proposed standard will not have a significant economic impact on a substantial number of small entities and must prepare an Initial Regulatory Flexibility Analysis (IRFA). The IRFA is presented in Chapter IX of this PEA.

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[427] Tables VI-B-1 in Appendix VI-B shows that, when applying a 7 percent discount rate, 14 industries are above the 5 percent cost-to-profit threshold. Table VI-B-2 shows that, when applying a 0 percent discount rate, 11 industries are above the 5 percent cost-to-profit threshold.

Tables VI-C-1 in Appendix VI-C shows that, when applying a 7 percent discount rate, 31 industries are above the 5 percent cost to profit threshold. Table VI-C-2 shows that, when applying a 0 percent discount rate the same 29 industries are above the 5 percent cost to profit threshold.

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Appendix VI-A

Screening Analysis for Establishments Affected by the Proposed Beryllium Standard (Applying Alternative Discount Rates of 7% and 0%)

Table VI-A-2

Screening Analysis for Establishments Affected by the Proposed Beryllium Standard
With Costs Calculated Using a Zero Percent Discount Rate

NAICS Code	Industry	Total Establishments	Total Affected Establishments	Revenues: Total ($1,000)	Revenues: Per Establishment ($s)	Profit: Rate	Profit: Per Establishment ($s)	Compliance Costs: Per Establishment ($s)	Compliance Costs: As a Percent of Revenues	Compliance Costs: As a Percent of Profits
Beryllium Production										
331419	Primary smelting and refining of nonferrous metals	161	1	$8,524,863	--	--	--	$1,171,789	--	--
Beryllium Oxide Ceramics and Composites										
327113a	Porcelain electrical supply manufacturing (primary)	106	2	$789,731	--	--	--	$113,548	--	--
327113b	Porcelain electrical supply manufacturing (secondary)	106	14	$789,731	7,450,295	5.01%	373,542	$16,304	0.22%	4.36%
334220	Cellular telephones manufacturing	810	10	$35,475,343	43,796,720	6.08%	2,663,922	$16,804	0.04%	0.63%
334310	Compact disc players manufacturing	464	5	$3,975,351	8,567,567	4.39%	376,456	$16,160	0.19%	4.29%
334411	Electron tube manufacturing	79	21	$1,220,476	15,449,068	7.85%	1,212,421	$16,487	0.11%	1.36%
334415	Electronic resistor manufacturing	61	12	$560,967	9,196,181	7.85%	721,703	$16,480	0.18%	2.28%
334419	Other electronic component manufacturing	1,133	9	$10,013,730	8,838,244	7.85%	693,613	$16,315	0.18%	2.35%
334510	Electromedical equipment manufacturing	629	9	$27,480,966	43,689,930	6.75%	2,947,904	$16,867	0.04%	0.57%
336322b	Other motor vehicle electrical and electronic equipment manufacturing	636	10	$12,152,053	19,107,002	1.83%	348,832	$16,476	0.09%	4.72%
Nonferrous Foundries										
331521	Aluminum die-casting foundries	254	7	$4,310,021	16,968,585	5.22%	885,603	$43,707	0.26%	4.94%
331522	Nonferrous (except aluminum) die-casting foundries	140	38	$1,510,799	10,791,418	5.22%	563,212	$42,949	0.40%	7.63%
331524	Aluminum foundries (except die-casting)	394	7	$2,518,097	6,391,108	5.22%	333,557	$42,766	0.67%	12.82%
331525a	Copper foundries (except die-casting) (non-sand casting foundries)	208	20	$1,205,574	5,796,031	5.22%	302,499	$42,345	0.73%	14.00%
331525b	Copper foundries (except die-casting) (sand casting foundries)	208	25	$1,205,574	5,796,031	5.22%	302,499	$46,094	0.80%	15.24%
Secondary Smelting, Refining, and Alloying										
331314	Secondary smelting & alloying of aluminum	122	1	$4,837,129	39,648,599	4.54%	1,802,008	$32,709	0.08%	1.82%
331421b	Copper rolling, drawing, and extruding	96	1	$12,513,425	130,348,178	4.79%	6,248,900	$33,158	0.03%	0.53%
331423	Secondary smelting, refining, & alloying of copper	24	3	$723,759	30,156,619	4.79%	1,445,710	$32,594	0.11%	2.25%
331492	Secondary smelting, refining, & alloying of nonferrous metal (except copper & aluminum)	248	30	$8,195,807	33,047,610	4.79%	1,584,305	$18,811	0.06%	1.19%
Precision Turned Products										
332721a	Precision turned product manufacturing (high beryllium content)	3,124	18	$13,262,706	4,245,425	5.82%	247,032	$20,382	0.48%	8.25%
332721b	Precision turned product manufacturing (low beryllium content)	3,124	294	$13,262,706	4,245,425	5.82%	247,032	$14,943	0.35%	6.05%
Copper Rolling, Drawing and Extruding										
331421a	Copper rolling, drawing, and extruding	96	15	$12,513,425	130,348,178	4.79%	6,248,900	$85,267	0.07%	1.36%
331422	Copper wire (except mechanical) drawing	114	59	$6,471,491	56,767,462	4.79%	2,721,436	$76,296	0.13%	2.80%
Fabrication of Beryllium Alloy Products										
332612	Light gauge spring manufacturing	323	323	$2,167,977	6,712,003	5.61%	376,763	$8,509	0.13%	2.26%
332116	Metal stamping	1,484	74	$9,749,800	6,569,946	5.12%	336,300	$8,902	0.14%	2.65%
334417	Electronic connector manufacturing	231	46	$5,029,508	21,772,761	7.85%	1,708,696	$9,140	0.04%	0.53%
336322a	Other motor vehicle electrical & electronic equipment	636	159	$12,152,053	19,107,002	1.83%	348,832	$9,029	0.05%	2.59%

Table VI-A-2, continued

With Costs Calculated Using a Zero Percent Discount Rate

				Revenues		Profit		Compliance Costs		
NAICS Code	Industry	Total Establishments	Total Affected Establishments	Total ($1,000)	Per Establishment ($s)	Rate	Per Establishment ($s)	Per Establishment ($s)	As a Percent of Revenues	As a Percent of Profits
Arc and Gas Welding										
331111	Iron and steel mills	587	7	$92,726,004	157,965,934	5.41%	8,542,604	$7,946	0.01%	0.09%
331221	Rolled steel shape manufacturing	161	1	$8,376,271	52,026,531	5.41%	2,813,531	$10,226	0.02%	0.36%
331513	Steel foundries (except investment)	220	1	$4,251,852	19,326,599	5.22%	1,008,670	$10,274	0.05%	1.02%
332117	Powder metallurgy part manufacturing	133	1	$1,414,108	10,632,394	5.12%	544,246	$11,703	0.11%	2.15%
332212	Hand and edge tool manufacturing	1,066	3	$5,077,868	4,763,479	5.61%	267,387	$8,706	0.18%	3.26%
332312	Fabricated structural metal manufacturing	3,407	56	$26,119,614	7,666,455	4.74%	363,273	$7,754	0.10%	2.13%
332313	Plate work manufacturing	1,288	21	$6,023,356	4,676,519	4.74%	221,596	$7,754	0.17%	3.50%
332322	Sheet metal work manufacturing	4,173	69	$17,988,908	4,310,786	4.74%	204,266	$7,754	0.18%	3.80%
332323	Ornamental and architectural metal work manufacturing	2,354	39	$5,708,707	2,425,109	4.74%	114,913	$7,754	0.32%	6.75%
332439	Other metal container manufacturing	370	7	$3,565,875	9,637,500	4.30%	414,839	$7,939	0.08%	1.91%
332919	Other metal valve and pipe fitting manufacturing	265	3	$4,584,082	17,298,424	7.00%	1,211,086	$8,805	0.05%	0.73%
332999	All other miscellaneous fabricated metal product manufacturing	3,262	33	$13,963,184	4,280,559	7.00%	299,688	$7,754	0.18%	2.59%
333111	Farm machinery and equipment manufacturing	1,041	20	$24,067,145	23,119,255	6.36%	1,471,196	$7,754	0.03%	0.53%
333414a	Heating equipment (except warm air furnaces) manufacturing	460	6	$4,781,561	10,394,697	4.68%	486,402	$8,011	0.08%	1.65%
333911	Pump and pumping equipment manufacturing	571	7	$12,395,387	21,708,209	5.36%	1,163,538	$7,945	0.04%	0.68%
333922	Conveyor and conveying equipment manufacturing	776	9	$6,569,120	8,465,361	5.36%	453,735	$7,791	0.09%	1.72%
333924	Industrial truck, tractor, trailer, and stacker machinery manufacturing	374	4	$7,444,451	19,904,948	5.36%	1,066,885	$8,259	0.04%	0.77%
333999	All other miscellaneous general purpose machinery manufacturing	1,524	18	$10,972,258	7,199,644	5.36%	385,894	$7,754	0.11%	2.01%
336211	Motor vehicle body manufacturing	742	15	$9,877,558	13,312,072	1.83%	243,036	$7,754	0.06%	3.19%
336214	Travel trailer and camper manufacturing	683	14	$7,465,024	10,929,757	1.83%	199,542	$7,754	0.07%	3.89%
336399a	All other motor vehicle parts manufacturing	1,350	7	$32,279,766	23,910,938	1.83%	436,537	$7,884	0.03%	1.81%
336510	Railroad rolling stock	226	3	$11,927,191	52,775,180	5.47%	2,887,552	$8,813	0.02%	0.31%
336999	All other transportation equipment manufacturing	374	4	$5,250,368	14,038,417	6.56%	921,324	$8,454	0.06%	0.92%
337215	Showcase, partition, shelving, and locker manufacturing	1,194	3	$5,815,404	4,870,523	4.26%	207,405	$8,561	0.18%	4.13%
811310	Commercial and industrial machinery and equipment repair	21,960	143	$31,650,469	1,441,278	5.42%	78,080	$7,754	0.54%	9.93%
Resistance Welding										
333411	Air purification equipment manufacturing	358	25	$3,060,744	8,549,565	4.68%	400,062	$14,739	0.17%	3.68%
333412	Industrial and commercial fan and blower manufacturing	151	11	$1,681,585	11,136,327	4.68%	521,106	$14,739	0.13%	2.83%
333414b	Heating equipment (except warm air furnaces) manufacturing	460	32	$4,781,561	10,394,697	4.68%	486,402	$14,739	0.14%	3.03%
333415	Air-conditioning, warm air heating, and industrial refrigeration equipment manufacturing	843	59	$25,454,383	30,194,998	4.68%	1,412,924	$14,739	0.05%	1.04%
335211	Electric housewares and household fan manufacturing	106	5	$2,209,657	20,845,825	4.03%	840,119	$14,739	0.07%	1.75%
335212	Household vacuum cleaner manufacturing	34	2	$891,600	26,223,543	4.03%	1,056,849	$14,739	0.06%	1.39%
335221	Household cooking appliance manufacturing	96	5	$3,757,849	39,144,257	4.03%	1,577,573	$14,739	0.04%	0.93%
335222	Household refrigerator and home freezer manufacturing	22	1	$4,489,845	204,083,854	4.03%	8,224,892	$14,739	0.01%	0.18%
335224	Household laundry equipment manufacturing	11	1	$3,720,514	338,228,505	4.03%	13,631,126	$14,739	0.00%	0.11%
335228	Other major household appliance manufacturing	38	2	$3,499,273	92,086,126	4.03%	3,711,212	$14,739	0.02%	0.40%

Table VI-A-2, continued

With Costs Calculated Using a Zero Percent Discount Rate

NAICS Code	Industry	Total Establishments	Total Affected Establishments	Revenues		Profit		Compliance Costs		
				Total ($1,000)	Per Establishment ($s)	Rate	Per Establishment ($s)	Per Establishment ($s)	As a Percent of Revenues	As a Percent of Profits
Resistance Welding										
336311	Carburetor, piston, piston ring, and valve manufacturing	109	5	$1,715,429	15,737,881	1.83%	287,323	$14,739	0.09%	5.13%
336312	Gasoline engine and engine parts manufacturing	742	37	$20,000,705	26,955,128	1.83%	492,114	$14,739	0.05%	3.00%
336321	Vehicular lighting equipment manufacturing	93	5	$2,322,610	24,974,299	1.83%	455,950	$14,739	0.06%	3.23%
336322c	Other motor vehicle electrical and electronic equipment manufacturing	636	32	$12,152,053	19,107,002	1.83%	348,832	$14,739	0.08%	4.23%
336330	Motor vehicle steering and suspension components (except spring) manufacturing	246	12	$8,856,584	36,002,374	1.83%	657,287	$14,739	0.04%	2.24%
336340	Motor vehicle brake system manufacturing	199	10	$8,147,826	40,943,850	1.83%	747,503	$14,739	0.04%	1.97%
336350	Motor vehicle transmission and power train parts manufacturing	476	24	$21,862,014	45,928,600	1.83%	838,508	$14,739	0.03%	1.76%
336360	Motor vehicle seating and interior trim manufacturing	403	20	$15,168,862	37,639,856	1.83%	687,183	$14,739	0.04%	2.14%
336370	Motor vehicle metal stamping	736	37	$19,809,238	26,914,725	1.83%	491,376	$14,739	0.05%	3.00%
336391	Motor vehicle air-conditioning manufacturing	80	4	$3,798,464	47,480,804	1.83%	866,847	$14,739	0.03%	1.70%
336399b	All other motor vehicle parts manufacturing	1,350	68	$32,279,766	23,910,938	1.83%	436,537	$14,739	0.06%	3.38%
Dental Laboratories										
339116	Dental laboratories	6,995	1,749	$4,100,626	586,222	10.55%	61,873	$1,604	0.27%	2.59%
621210	Offices of dentists	129,830	238	$100,431,324	773,560	8.47%	65,557	$1,608	0.21%	2.45%
	Totals / Averages	207,586	4,088	$877,101,106	8,145,219	7.42%	604,340	$8,937	0.11%	1.48%

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis.

Appendix VI-B

Screening Analysis for Small Businesses Affected by the Proposed Beryllium Standard (Applying Alternative Discount Rates of 7% and 0%)

Table VI-B-1

Screening Analysis for SBA-Defined Small Entities Affected by the Proposed Beryllium Standard
With Costs Calculated Using a Seven Percent Discount Rate

				Revenues		Profit		Compliance Costs		
NAICS Code	Industry	Total Small Entities	Total Affected Small Entities	Total for SBA Entities ($1,000)	Per Entity ($s)	Rate	Per Entity ($s)	Per Entity ($s)	As a Percent of Revenues	As a Percent of Profits
Beryllium Production										
331419	Primary smelting and refining of nonferrous metals	140	0	$8,524,863	--	--	--	NA	--	--
Beryllium Oxide Ceramics and Composites										
327113a	Porcelain electrical supply manufacturing (primary)	85	1	$326,127	--	--	--	$105,269	--	--
327113b	Porcelain electrical supply manufacturing (secondary)	85	11	$326,127	3,836,783	5.01%	192,368	$13,566	0.35%	7.05%
334220	Cellular telephones manufacturing	724	9	$35,475,343	48,999,093	6.08%	2,980,355	$20,071	0.04%	0.67%
334310	Compact disc players manufacturing	460	5	$3,975,351	8,642,068	4.39%	379,730	$17,448	0.20%	4.59%
334411	Electron tube manufacturing	62	16	$1,220,476	19,685,102	7.85%	1,544,859	$22,456	0.11%	1.45%
334415	Electronic resistor manufacturing	46	9	$385,781	8,386,547	7.85%	658,164	$15,704	0.19%	2.39%
334419	Other electronic component manufacturing	990	8	$4,796,313	4,844,761	7.85%	380,210	$13,563	0.28%	3.57%
334510	Electromedical equipment manufacturing	494	7	$3,752,243	7,595,634	6.75%	512,503	$9,280	0.12%	1.81%
336322b	Other motor vehicle electrical and electronic equipment manufacturing	585	9	$12,152,053	20,772,740	1.83%	379,243	$19,147	0.09%	5.05%
Nonferrous Foundries										
331521	Aluminum die-casting foundries	209	6	$2,070,759	9,907,938	5.22%	517,103	$42,182	0.43%	8.16%
331522	Nonferrous (except aluminum) die-casting foundries	129	35	$813,444	6,305,771	5.22%	329,103	$38,629	0.61%	11.74%
331524	Aluminum foundries (except die-casting)	351	6	$1,690,008	4,814,839	5.22%	251,290	$44,440	0.92%	17.68%
331525a	Copper foundries (except die-casting) (non-sand casting foundries)	195	19	$925,667	4,747,008	5.22%	247,750	$45,226	0.95%	18.25%
331525b	Copper foundries (except die-casting) (sand casting foundries)	195	23	$925,667	4,747,008	5.22%	247,750	$49,455	1.04%	19.96%
Secondary Smelting, Refining, and Alloying										
331314	Secondary smelting & alloying of aluminum	98	1	$4,837,129	49,358,460	4.54%	2,243,316	$35,283	0.07%	1.57%
331421b	Copper rolling, drawing, and extruding	70	1	$12,513,425	178,763,215	4.79%	8,569,920	$35,732	0.02%	0.42%
331423	Secondary smelting, refining, & alloying of copper	23	3	$723,759	31,467,777	4.79%	1,508,567	$36,689	0.12%	2.43%
331492	Secondary smelting, refining, & alloying of nonferrous metal (except copper & aluminum)	217	26	$8,195,807	37,768,697	4.79%	1,810,634	$23,180	0.06%	1.28%
Precision Turned Products										
332721a	Precision turned product manufacturing (high beryllium content)	3,006	18	$11,393,081	3,790,113	5.82%	220,539	$20,288	0.54%	9.20%
332721b	Precision turned product manufacturing (low beryllium content)	3,006	283	$11,393,081	3,790,113	5.82%	220,539	$14,684	0.39%	6.66%
Copper Rolling, Drawing and Extruding										
331421a	Copper rolling, drawing, and extruding	70	11	$12,513,425	178,763,215	4.79%	8,569,920	$122,320	0.07%	1.43%
331422	Copper wire (except mechanical) drawing	84	43	$6,471,491	77,041,555	4.79%	3,693,377	$108,252	0.14%	2.93%
Fabrication of Beryllium Alloy Products										
332612	Light gauge spring manufacturing	262	262	$1,030,905	3,934,752	5.61%	220,868	$7,546	0.19%	3.42%
332116	Metal stamping	1,367	68	$7,693,541	5,628,048	5.12%	288,086	$8,690	0.15%	3.02%
334417	Electronic connector manufacturing	176	35	$1,556,871	8,845,860	7.85%	694,211	$5,984	0.07%	0.86%
336322a	Other motor vehicle electrical & electronic equipment	585	146	$12,152,053	20,772,740	1.83%	379,243	$10,387	0.05%	2.74%

Table VI-B-1, continued

With Costs Calculated Using a Seven Percent Discount Rate

NAICS Code	Industry	Total Small Entities	Total Affected Small Entities	Revenues		Profit		Compliance Costs		
				Total for SBA Entities ($1,000)	Per Entity ($s)	Rate	Per Entity ($s)	Per Entity ($s)	As a Percent of Revenues	As a Percent of Profits
Arc and Gas Welding										
331111	Iron and steel mills	461	5	$92,726,004	201,141,005	5.41%	10,877,459	$10,754	0.01%	0.10%
331221	Rolled steel shape manufacturing	134	1	$8,376,271	62,509,488	5.41%	3,380,437	$12,912	0.02%	0.38%
331513	Steel foundries (except investment)	188	1	$2,739,158	14,569,989	5.22%	760,419	$8,898	0.06%	1.17%
332117	Powder metallurgy part manufacturing	106	1	$841,084	7,934,752	5.12%	406,161	$8,477	0.11%	2.09%
332212	Hand and edge tool manufacturing	975	3	$3,072,300	3,151,077	5.61%	176,878	$7,268	0.23%	4.11%
332312	Fabricated structural metal manufacturing	3,001	49	$15,405,728	5,133,531	4.74%	243,251	$6,301	0.12%	2.59%
332313	Plate work manufacturing	1,220	20	$4,900,364	4,016,692	4.74%	190,330	$7,653	0.19%	4.02%
332322	Sheet metal work manufacturing	3,835	63	$12,607,305	3,287,433	4.74%	155,774	$7,270	0.22%	4.67%
332323	Ornamental and architectural metal work manufacturing	2,287	38	$4,118,512	1,800,836	4.74%	85,332	$6,791	0.38%	7.96%
332439	Other metal container manufacturing	302	5	$1,698,117	5,622,904	4.30%	242,034	$6,070	0.11%	2.51%
332919	Other metal valve and pipe fitting manufacturing	207	2	$2,028,451	9,799,278	7.00%	686,061	$6,502	0.07%	0.95%
332999	All other miscellaneous fabricated metal product manufacturing	3,111	32	$10,202,505	3,279,494	7.00%	229,602	$7,034	0.21%	3.06%
333111	Farm machinery and equipment manufacturing	941	18	$5,132,720	5,454,538	6.36%	347,100	$4,044	0.07%	1.16%
333414a	Heating equipment (except warm air furnaces) manufacturing	410	5	$2,583,472	6,301,151	4.68%	294,852	$5,976	0.09%	2.03%
333911	Pump and pumping equipment manufacturing	399	5	$3,348,262	8,391,635	5.36%	449,783	$4,617	0.06%	1.03%
333922	Conveyor and conveying equipment manufacturing	707	8	$4,768,668	6,744,933	5.36%	361,522	$7,060	0.10%	1.95%
333924	Industrial truck, tractor, trailer, and stacker machinery manufacturing	347	4	$7,444,451	21,453,748	5.36%	1,149,899	$9,443	0.04%	0.82%
333999	All other miscellaneous general purpose machinery manufacturing	1,385	16	$5,601,674	4,044,530	5.36%	216,783	$5,478	0.14%	2.53%
336211	Motor vehicle body manufacturing	652	13	$9,877,558	15,149,628	1.83%	276,583	$9,391	0.06%	3.40%
336214	Travel trailer and camper manufacturing	585	12	$2,513,608	4,296,766	1.83%	78,445	$4,568	0.11%	5.82%
336399a	All other motor vehicle parts manufacturing	1,156	6	$32,279,766	27,923,673	1.83%	509,796	$9,790	0.04%	1.92%
336510	Railroad rolling stock	157	2	$11,927,191	75,969,367	5.47%	4,156,603	$13,416	0.02%	0.32%
336999	All other transportation equipment manufacturing	349	3	$941,637	2,698,100	6.56%	177,073	$4,479	0.17%	2.53%
337215	Showcase, partition, shelving, and locker manufacturing	1,120	3	$3,688,129	3,292,972	4.26%	140,227	$7,199	0.22%	5.13%
811310	Commercial and industrial machinery and equipment repair	19,857	129	$17,088,964	860,601	5.42%	46,622	$5,647	0.66%	12.11%
Resistance Welding										
333411	Air purification equipment manufacturing	283	20	$1,327,014	4,689,095	4.68%	219,418	$8,616	0.18%	3.93%
333412	Industrial and commercial fan and blower manufacturing	118	8	$1,001,835	8,490,124	4.68%	397,281	$12,130	0.14%	3.05%
333414b	Heating equipment (except warm air furnaces) manufacturing	410	29	$2,583,472	6,301,151	4.68%	294,852	$10,491	0.17%	3.56%
333415	Air-conditioning, warm air heating, and industrial refrigeration equipment manufacturing	695	49	$25,454,383	36,625,012	4.68%	1,713,806	$18,785	0.05%	1.10%
335211	Electric housewares and household fan manufacturing	101	5	$2,209,657	21,877,797	4.03%	881,709	$16,254	0.07%	1.84%
335212	Household vacuum cleaner manufacturing	29	1	$891,600	30,744,844	4.03%	1,239,064	$18,158	0.06%	1.47%
335221	Household cooking appliance manufacturing	91	5	$3,757,849	41,295,040	4.03%	1,664,253	$16,338	0.04%	0.98%
335222	Household refrigerator and home freezer manufacturing	16	1	$4,489,845	280,615,299	4.03%	11,309,226	$17,036	0.01%	0.15%
335224	Household laundry equipment manufacturing	9	1	$3,720,514	413,390,395	4.03%	16,660,266	$8,518	0.00%	0.05%
335228	Other major household appliance manufacturing	24	1	$185,373	7,723,871	4.03%	311,284	$1,802	0.02%	0.58%

Table VI-B-1, continued

With Costs Calculated Using a Seven Percent Discount Rate

NAICS Code	Industry	Total Small Entities	Total Affected Small Entities	Revenues: Total for SBA Entities ($1,000)	Revenues: Per Entity ($s)	Profit: Rate	Profit: Per Entity ($s)	Compliance Costs: Per Entity ($s)	Compliance Costs: As a Percent of Revenues	Compliance Costs: As a Percent of Profits
Resistance Welding										
336311	Carburetor, piston, piston ring, and valve manufacturing	89	4	$499,977	5,617,722	1.83%	102,562	$5,390	0.10%	5.25%
336312	Gasoline engine and engine parts manufacturing	697	35	$20,000,705	28,695,417	1.83%	523,886	$16,487	0.06%	3.15%
336321	Vehicular lighting equipment manufacturing	75	4	$671,947	8,959,292	1.83%	163,568	$6,271	0.07%	3.83%
336322c	Other motor vehicle electrical and electronic equipment manufacturing	585	29	$12,152,053	20,772,740	1.83%	379,243	$16,838	0.08%	4.44%
336330	Motor vehicle steering and suspension components (except spring) manufacturing	209	10	$8,856,584	42,376,000	1.83%	773,649	$18,229	0.04%	2.36%
336340	Motor vehicle brake system manufacturing	159	8	$8,147,826	51,244,189	1.83%	935,554	$19,384	0.04%	2.07%
336350	Motor vehicle transmission and power train parts manufacturing	397	20	$21,862,014	55,068,044	1.83%	1,005,365	$18,569	0.03%	1.85%
336360	Motor vehicle seating and interior trim manufacturing	273	14	$3,482,677	12,757,060	1.83%	232,903	$6,787	0.05%	2.91%
336370	Motor vehicle metal stamping	540	27	$7,262,381	13,448,854	1.83%	245,533	$9,163	0.07%	3.73%
336391	Motor vehicle air-conditioning manufacturing	72	4	$3,798,464	52,756,449	1.83%	963,163	$17,208	0.03%	1.79%
336399b	All other motor vehicle parts manufacturing	1,156	58	$32,279,766	27,923,673	1.83%	509,796	$18,086	0.06%	3.55%
Dental Laboratories										
339116	Dental laboratories	6,703	1,676	$3,156,130	470,853	10.55%	49,696	$1,429	0.30%	2.88%
621210	Offices of dentists	123,077	225	$94,120,777	764,731	8.47%	64,809	$1,670	0.22%	2.58%
	Totals / Averages	193,274	3,741	$687,134,666	7,300,515	7.55%	550,848	$8,432	0.12%	1.53%

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis.

Table VI-B-2

Screening Analysis for SBA-Defined Small Entities Affected by the Proposed Beryllium Standard
With Costs Calculated Using a Zero Percent Discount Rate

				Revenues		Profit		Compliance Costs		
NAICS Code	Industry	Very Small Entities	Affected Very Small Entities	Total ($1,000)	Per Entity ($s)	Rate	Per Entity ($s)	Per Entity ($s)	As a Percent of Revenues	As a Percent of Profits
Beryllium Production										
331419	Primary smelting and refining of nonferrous metals	140	0	$8,524,863	--	--	--	NA	--	--
Beryllium Oxide Ceramics and Composites										
327113a	Porcelain electrical supply manufacturing (primary)	85	1	$326,127	--	--	--	$89,334	--	--
327113b	Porcelain electrical supply manufacturing (secondary)	85	11	$326,127	3,836,783	5.01%	192,368	$12,576	0.33%	6.54%
334220	Cellular telephones manufacturing	724	9	$35,475,343	48,999,093	6.08%	2,980,355	$18,800	0.04%	0.63%
334310	Compact disc players manufacturing	460	5	$3,975,351	8,642,068	4.39%	379,730	$16,301	0.19%	4.29%
334411	Electron tube manufacturing	62	16	$1,220,476	19,685,102	7.85%	1,544,859	$21,008	0.11%	1.36%
334415	Electronic resistor manufacturing	46	9	$385,781	8,386,547	7.85%	658,164	$14,604	0.17%	2.22%
334419	Other electronic component manufacturing	990	8	$4,796,313	4,844,761	7.85%	380,210	$12,583	0.26%	3.31%
334510	Electromedical equipment manufacturing	494	7	$3,752,243	7,595,634	6.75%	512,503	$8,491	0.11%	1.66%
336322b	Other motor vehicle electrical and electronic equipment manufacturing	585	9	$12,152,053	20,772,740	1.83%	379,243	$17,912	0.09%	4.72%
Nonferrous Foundries										
331521	Aluminum die-casting foundries	209	6	$2,070,759	9,907,938	5.22%	517,103	$35,799	0.36%	6.92%
331522	Nonferrous (except aluminum) die-casting foundries	129	35	$813,444	6,305,771	5.22%	329,103	$32,534	0.52%	9.89%
331524	Aluminum foundries (except die-casting)	351	6	$1,690,008	4,814,839	5.22%	251,290	$37,826	0.79%	15.05%
331525a	Copper foundries (except die-casting) (non-sand casting foundries)	195	19	$925,667	4,747,008	5.22%	247,750	$38,597	0.81%	15.58%
331525b	Copper foundries (except die-casting) (sand casting foundries)	195	23	$925,667	4,747,008	5.22%	247,750	$42,164	0.89%	17.02%
Secondary Smelting, Refining, and Alloying										
331314	Secondary smelting & alloying of aluminum	98	1	$4,837,129	49,358,460	4.54%	2,243,316	$32,709	0.07%	1.46%
331421b	Copper rolling, drawing, and extruding	70	1	$12,513,425	178,763,215	4.79%	8,569,920	$33,158	0.02%	0.39%
331423	Secondary smelting, refining, & alloying of copper	23	3	$723,759	31,467,777	4.79%	1,508,567	$34,011	0.11%	2.25%
331492	Secondary smelting, refining, & alloying of nonferrous metal (except copper & aluminum)	217	26	$8,195,807	37,768,697	4.79%	1,810,634	$21,499	0.06%	1.19%
Precision Turned Products										
332721a	Precision turned product manufacturing (high beryllium content)	3,006	18	$11,393,081	3,790,113	5.82%	220,539	$18,926	0.50%	8.58%
332721b	Precision turned product manufacturing (low beryllium content)	3,006	283	$11,393,081	3,790,113	5.82%	220,539	$13,879	0.37%	6.29%
Copper Rolling, Drawing and Extruding										
331421a	Copper rolling, drawing, and extruding	70	11	$12,513,425	178,763,215	4.79%	8,569,920	$116,937	0.07%	1.36%
331422	Copper wire (except mechanical) drawing	84	43	$6,471,491	77,041,555	4.79%	3,693,377	$103,545	0.13%	2.80%
Fabrication of Beryllium Alloy Products										
332612	Light gauge spring manufacturing	262	262	$1,030,905	3,934,752	5.61%	220,868	$7,092	0.18%	3.21%
332116	Metal stamping	1,367	68	$7,693,541	5,628,048	5.12%	288,086	$8,193	0.15%	2.84%
334417	Electronic connector manufacturing	176	35	$1,556,871	8,845,860	7.85%	694,211	$5,614	0.06%	0.81%
336322a	Other motor vehicle electrical & electronic equipment	585	146	$12,152,053	20,772,740	1.83%	379,243	$9,816	0.05%	2.59%

Table VI-B-2, continued

With Costs Calculated Using a Zero Percent Discount Rate

				Revenues		Profit		Compliance Costs		
NAICS Code	Industry	Very Small Entities	Affected Very Small Entities	Total ($1,000)	Per Entity ($s)	Rate	Per Entity ($s)	Per Entity ($s)	As a Percent of Revenues	As a Percent of Profits
Arc and Gas Welding										
331111	Iron and steel mills	461	5	$92,726,004	201,141,005	5.41%	10,877,459	$10,118	0.01%	0.09%
331221	Rolled steel shape manufacturing	134	1	$8,376,271	62,509,488	5.41%	3,380,437	$12,287	0.02%	0.36%
331513	Steel foundries (except investment)	188	1	$2,739,158	14,569,989	5.22%	760,419	$8,491	0.06%	1.12%
332117	Powder metallurgy part manufacturing	106	1	$841,084	7,934,752	5.12%	406,161	$8,142	0.10%	2.00%
332212	Hand and edge tool manufacturing	975	3	$3,072,300	3,151,077	5.61%	176,878	$6,879	0.22%	3.89%
332312	Fabricated structural metal manufacturing	3,001	49	$15,405,728	5,133,531	4.74%	243,251	$5,921	0.12%	2.43%
332313	Plate work manufacturing	1,220	20	$4,900,364	4,016,692	4.74%	190,330	$7,191	0.18%	3.78%
332322	Sheet metal work manufacturing	3,835	63	$12,607,305	3,287,433	4.74%	155,774	$6,832	0.21%	4.39%
332323	Ornamental and architectural metal work manufacturing	2,287	38	$4,118,512	1,800,836	4.74%	85,332	$6,381	0.35%	7.48%
332439	Other metal container manufacturing	302	5	$1,698,117	5,622,904	4.30%	242,034	$5,713	0.10%	2.36%
332919	Other metal valve and pipe fitting manufacturing	207	2	$2,028,451	9,799,278	7.00%	686,061	$6,163	0.06%	0.90%
332999	All other miscellaneous fabricated metal product manufacturing	3,111	32	$10,202,505	3,279,494	7.00%	229,602	$6,610	0.20%	2.88%
333111	Farm machinery and equipment manufacturing	941	18	$5,132,720	5,454,538	6.36%	347,100	$3,799	0.07%	1.09%
333414a	Heating equipment (except warm air furnaces) manufacturing	410	5	$2,583,472	6,301,151	4.68%	294,852	$5,628	0.09%	1.91%
333911	Pump and pumping equipment manufacturing	399	5	$3,348,262	8,391,635	5.36%	449,783	$4,347	0.05%	0.97%
333922	Conveyor and conveying equipment manufacturing	707	8	$4,768,668	6,744,933	5.36%	361,522	$6,636	0.10%	1.84%
333924	Industrial truck, tractor, trailer, and stacker machinery manufacturing	347	4	$7,444,451	21,453,748	5.36%	1,149,899	$8,902	0.04%	0.77%
333999	All other miscellaneous general purpose machinery manufacturing	1,385	16	$5,601,674	4,044,530	5.36%	216,783	$5,147	0.13%	2.37%
336211	Motor vehicle body manufacturing	652	13	$9,877,558	15,149,628	1.83%	276,583	$8,825	0.06%	3.19%
336214	Travel trailer and camper manufacturing	585	12	$2,513,608	4,296,766	1.83%	78,445	$4,291	0.10%	5.47%
336399a	All other motor vehicle parts manufacturing	1,156	6	$32,279,766	27,923,673	1.83%	509,796	$9,207	0.03%	1.81%
336510	Railroad rolling stock	157	2	$11,927,191	75,969,367	5.47%	4,156,603	$12,686	0.02%	0.31%
336999	All other transportation equipment manufacturing	349	3	$941,637	2,698,100	6.56%	177,073	$4,242	0.16%	2.40%
337215	Showcase, partition, shelving, and locker manufacturing	1,120	3	$3,688,129	3,292,972	4.26%	140,227	$6,806	0.21%	4.85%
811310	Commercial and industrial machinery and equipment repair	19,857	129	$17,088,964	860,601	5.42%	46,622	$5,306	0.62%	11.38%
Resistance Welding										
333411	Air purification equipment manufacturing	283	20	$1,327,014	4,689,095	4.68%	219,418	$8,190	0.17%	3.73%
333412	Industrial and commercial fan and blower manufacturing	118	8	$1,001,835	8,490,124	4.68%	397,281	$11,539	0.14%	2.90%
333414b	Heating equipment (except warm air furnaces) manufacturing	410	29	$2,583,472	6,301,151	4.68%	294,852	$9,977	0.16%	3.38%
333415	Air-conditioning, warm air heating, and industrial refrigeration equipment manufacturing	695	49	$25,454,383	36,625,012	4.68%	1,713,806	$17,878	0.05%	1.04%
335211	Electric housewares and household fan manufacturing	101	5	$2,209,657	21,877,797	4.03%	881,709	$15,469	0.07%	1.75%
335212	Household vacuum cleaner manufacturing	29	1	$891,600	30,744,844	4.03%	1,239,064	$17,280	0.06%	1.39%
335221	Household cooking appliance manufacturing	91	5	$3,757,849	41,295,040	4.03%	1,664,253	$15,549	0.04%	0.93%
335222	Household refrigerator and home freezer manufacturing	16	1	$4,489,845	280,615,299	4.03%	11,309,226	$16,213	0.01%	0.14%
335224	Household laundry equipment manufacturing	9	1	$3,720,514	413,390,395	4.03%	16,660,266	$8,106	0.00%	0.05%
335228	Other major household appliance manufacturing	24	1	$185,373	7,723,871	4.03%	311,284	$1,698	0.02%	0.55%

Table VI-B-2, continued

With Costs Calculated Using a Zero Percent Discount Rate

NAICS Code	Industry	Very Small Entities	Affected Very Small Entities	Revenues: Total ($1,000)	Revenues: Per Entity ($s)	Profit: Rate	Profit: Per Entity ($s)	Compliance Costs: Per Entity ($s)	Compliance Costs: As a Percent of Revenues	Compliance Costs: As a Percent of Profits
Resistance Welding										
336311	Carburetor, piston, piston ring, and valve manufacturing	89	4	$499,977	5,617,722	1.83%	102,562	$5,116	0.09%	4.99%
336312	Gasoline engine and engine parts manufacturing	697	35	$20,000,705	28,695,417	1.83%	523,886	$15,691	0.05%	3.00%
336321	Vehicular lighting equipment manufacturing	75	4	$671,947	8,959,292	1.83%	163,568	$5,956	0.07%	3.64%
336322c	Other motor vehicle electrical and electronic equipment manufacturing	585	29	$12,152,053	20,772,740	1.83%	379,243	$16,024	0.08%	4.23%
336330	Motor vehicle steering and suspension components (except spring) manufacturing	209	10	$8,856,584	42,376,000	1.83%	773,649	$17,348	0.04%	2.24%
336340	Motor vehicle brake system manufacturing	159	8	$8,147,826	51,244,189	1.83%	935,554	$18,447	0.04%	1.97%
336350	Motor vehicle transmission and power train parts manufacturing	397	20	$21,862,014	55,068,044	1.83%	1,005,365	$17,672	0.03%	1.76%
336360	Motor vehicle seating and interior trim manufacturing	273	14	$3,482,677	12,757,060	1.83%	232,903	$6,447	0.05%	2.77%
336370	Motor vehicle metal stamping	540	27	$7,262,381	13,448,854	1.83%	245,533	$8,710	0.06%	3.55%
336391	Motor vehicle air-conditioning manufacturing	72	4	$3,798,464	52,756,449	1.83%	963,163	$16,377	0.03%	1.70%
336399b	All other motor vehicle parts manufacturing	1,156	58	$32,279,766	27,923,673	1.83%	509,796	$17,213	0.06%	3.38%
Dental Laboratories										
339116	Dental laboratories	6,703	1,676	$3,156,130	470,853	10.55%	49,696	$1,370	0.29%	2.76%
621210	Offices of dentists	123,077	225	$94,120,777	764,731	8.47%	64,809	$1,602	0.21%	2.47%
	Totals / Averages	193,274	3,741	$687,134,666	7,300,515	7.55%	550,848	$7,886	0.11%	1.43%

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis.

Appendix VI-C

Screening Analysis for Very Small Businesses Affected by the Proposed Beryllium Standard (Applying Alternative Discount Rates of 7% and 0%)

Table VI-C-1

Screening Analysis for Very Small Entities (with fewer than 20 employees) Affected by the Proposed Beryllium Standard
With Costs Calculated Using a Seven Percent Discount Rate

				Revenues		Profit		Compliance Costs		
NAICS Code	Industry	Total Small Entities	Total Affected Small Entities	Total for Small Entities ($1,000)	Per Entity ($s)	Rate	Per Entity ($s)	Per Entity ($s)	As a Percent of Revenues	As a Percent of Profits
Beryllium Production										
331419	Primary smelting and refining of nonferrous metals	86	0	$399,861	--	--	--	--	--	--
Beryllium Oxide Ceramics and Composites										
327113a	Porcelain electrical supply manufacturing (primary)	53	0	$52,358	--	--	--	--	--	--
327113b	Porcelain electrical supply manufacturing (secondary)	53	7	$52,358	987,892	5.01%	192,368	$7,264	0.74%	14.67%
334220	Cellular telephones manufacturing	445	4	$576,956	1,296,530	6.08%	2,980,355	$6,675	0.51%	8.46%
334310	Compact disc players manufacturing	373	4	$1,128,513	3,025,503	4.39%	379,730	$8,841	0.29%	6.65%
334411	Electron tube manufacturing	38	10	$45,454	1,196,149	7.85%	1,544,859	$6,836	0.57%	7.28%
334415	Electronic resistor manufacturing	17	3	$25,647	1,508,662	7.85%	658,164	$7,266	0.48%	6.14%
334419	Other electronic component manufacturing	624	5	$639,599	1,024,999	7.85%	380,210	$7,382	0.72%	9.18%
334510	Electromedical equipment manufacturing	324	3	$420,245	1,297,053	6.75%	512,503	$6,672	0.51%	7.62%
336322b	Other motor vehicle electrical and electronic equipment manufacturing	386	6	$349,811	906,246	1.83%	379,243	$6,774	0.75%	40.94%
Nonferrous Foundries										
331521	Aluminum die-casting foundries	107	0	$153,274	--	5.22%	517,103	--	--	--
331522	Nonferrous (except aluminum) die-casting foundries	84	0	$92,703	--	5.22%	329,103	--	--	--
331524	Aluminum foundries (except die-casting)	217	0	$204,397	--	5.22%	251,290	--	--	--
331525a	Copper foundries (except die-casting) (non-sand casting foundries)	131	0	$139,372	--	5.22%	247,750	--	--	--
331525b	Copper foundries (except die-casting) (sand casting foundries)	131	0	$139,372	--	5.22%	247,750	--	--	--
Secondary Smelting, Refining, and Alloying										
331314	Secondary smelting & alloying of aluminum	45	0	$306,390	--	4.54%	2,243,316	--	--	--
331421b	Copper rolling, drawing, and extruding	26	0	$48,421	--	4.79%	8,569,920	--	--	--
331423	Secondary smelting, refining, & alloying of copper	11	1	$85,353	7,759,405	4.79%	1,508,567	$22,904	0.30%	6.16%
331492	Secondary smelting, refining, & alloying of nonferrous metal (except copper & aluminum)	121	15	$388,603	3,211,598	4.79%	1,810,634	$11,732	0.37%	7.62%
Precision Turned Products										
332721a	Precision turned product manufacturing (high beryllium content)	1,970	12	$2,219,340	1,126,568	5.82%	220,539	$7,171	0.64%	10.94%
332721b	Precision turned product manufacturing (low beryllium content)	1,970	185	$2,219,340	1,126,568	5.82%	220,539	$5,222	0.46%	7.97%
Copper Rolling, Drawing and Extruding										
331421a	Copper rolling, drawing, and extruding	26	4	$48,421	1,862,347	4.79%	8,569,920	$5,879	0.32%	6.59%
331422	Copper wire (except mechanical) drawing	35	18	$254,426	7,269,304	4.79%	3,693,377	$7,983	0.11%	2.29%
Fabrication of Beryllium Alloy Products										
332612	Light gauge spring manufacturing	164	164	$156,603	954,897	5.61%	220,868	$3,465	0.36%	6.46%
332116	Metal stamping	807	40	$1,033,657	1,280,864	5.12%	288,086	$3,704	0.29%	5.65%
334417	Electronic connector manufacturing	106	11	$129,405	1,220,804	7.85%	694,211	$3,160	0.26%	3.30%
336322a	Other motor vehicle electrical & electronic equipment	386	60	$349,811	906,246	1.83%	379,243	$3,154	0.35%	19.06%

Table VI-C-1, continued

With Costs Calculated Using a Seven Percent Discount Rate

NAICS Code	Industry	Total Small Entities	Total Affected Small Entities	Revenues: Total for Small Entities ($1,000)	Revenues: Per Entity ($s)	Profit: Rate	Profit: Per Entity ($s)	Compliance Costs: Per Entity ($s)	Compliance Costs: As a Percent of Revenues	Compliance Costs: As a Percent of Profits
Arc and Gas Welding										
331111	Iron and steel mills	268	0	$1,018,914	--	5.41%	10,877,459	--	--	--
331221	Rolled steel shape manufacturing	50	0	$208,799	--	5.41%	3,380,437	--	--	--
331513	Steel foundries (except investment)	94	0	$112,227	--	5.22%	760,419	--	--	--
332117	Powder metallurgy part manufacturing	55	0	$100,643	--	5.12%	406,161	--	--	--
332212	Hand and edge tool manufacturing	751	2	$681,375	907,290	5.61%	176,878	$3,262	0.36%	6.40%
332312	Fabricated structural metal manufacturing	2,159	35	$3,182,459	1,474,043	4.74%	243,251	$2,385	0.16%	3.41%
332313	Plate work manufacturing	845	14	$1,007,308	1,192,080	4.74%	190,330	$2,999	0.25%	5.31%
332322	Sheet metal work manufacturing	2,778	46	$2,631,155	947,140	4.74%	155,774	$2,718	0.29%	6.06%
332323	Ornamental and architectural metal work manufacturing	1,957	32	$1,342,443	685,970	4.74%	85,332	$3,270	0.48%	10.06%
332439	Other metal container manufacturing	203	2	$187,607	924,174	4.30%	242,034	$2,558	0.28%	6.43%
332919	Other metal valve and pipe fitting manufacturing	115	1	$181,192	1,575,580	7.00%	686,061	$4,411	0.28%	4.00%
332999	All other miscellaneous fabricated metal product manufacturing	2,353	24	$2,117,303	899,831	7.00%	229,602	$2,655	0.30%	4.22%
333111	Farm machinery and equipment manufacturing	673	7	$785,460	1,167,103	6.36%	347,100	$2,385	0.20%	3.21%
333414a	Heating equipment (except warm air furnaces) manufacturing	283	2	$365,551	1,291,699	4.68%	294,852	$2,624	0.20%	4.34%
333911	Pump and pumping equipment manufacturing	251	1	$497,397	1,981,660	5.36%	449,783	$2,564	0.13%	2.41%
333922	Conveyor and conveying equipment manufacturing	407	4	$541,532	1,330,547	5.36%	361,522	$2,421	0.18%	3.40%
333924	Industrial truck, tractor, trailer, and stacker machinery manufacturing	195	1	$213,335	1,094,026	5.36%	1,149,899	$2,850	0.26%	4.86%
333999	All other miscellaneous general purpose machinery manufacturing	975	10	$1,151,152	1,180,669	5.36%	216,783	$2,384	0.20%	3.77%
336211	Motor vehicle body manufacturing	400	4	$535,923	1,339,807	1.83%	276,583	$2,384	0.18%	9.75%
336214	Travel trailer and camper manufacturing	410	5	$480,503	1,171,958	1.83%	78,445	$2,386	0.20%	11.15%
336399a	All other motor vehicle parts manufacturing	653	1	$835,261	1,279,114	1.83%	509,796	$2,511	0.20%	10.75%
336510	Railroad rolling stock	83	0	$189,164	--	5.47%	4,156,603	--	--	--
336999	All other transportation equipment manufacturing	307	2	$253,916	827,087	6.56%	177,073	$3,027	0.37%	5.58%
337215	Showcase, partition, shelving, and locker manufacturing	814	2	$582,654	715,791	4.26%	140,227	$3,126	0.44%	10.25%
811310	Commercial and industrial machinery and equipment repair	18,714	122	$10,692,921	571,386	5.42%	46,622	$4,096	0.72%	13.23%
Resistance Welding										
333411	Air purification equipment manufacturing	189	13	$283,628	1,500,678	4.68%	219,418	$2,590	0.17%	3.69%
333412	Industrial and commercial fan and blower manufacturing	60	4	$78,644	1,310,729	4.68%	397,281	$2,483	0.19%	4.05%
333414b	Heating equipment (except warm air furnaces) manufacturing	283	20	$365,551	1,291,699	4.68%	294,852	$2,400	0.19%	3.97%
333415	Air-conditioning, warm air heating, and industrial refrigeration equipment manufacturing	395	28	$806,994	2,043,023	4.68%	1,713,806	$1,138	0.06%	1.19%
335211	Electric housewares and household fan manufacturing	70	4	$99,219	1,417,419	4.03%	881,709	$1,196	0.08%	2.09%
335212	Household vacuum cleaner manufacturing	18	0	$21,745	--	4.03%	1,239,064	--	--	--
335221	Household cooking appliance manufacturing	57	2	$66,863	1,173,037	4.03%	1,664,253	$1,099	0.09%	2.32%
335222	Household refrigerator and home freezer manufacturing	6	0	$8,833	--	4.03%	11,309,226	--	--	--
335224	Household laundry equipment manufacturing	4	0	$1,837	--	4.03%	16,660,266	--	--	--
335228	Other major household appliance manufacturing	15	0	$24,856	--	4.03%	311,284	--	--	--

Table VI-C-1, continued

With Costs Calculated Using a Seven Percent Discount Rate

NAICS Code	Industry	Total Small Entities	Total Affected Small Entities	Revenues: Total for Small Entities ($1,000)	Revenues: Per Entity ($s)	Profit: Rate	Profit: Per Entity ($s)	Compliance Costs: Per Entity ($s)	Compliance Costs: As a Percent of Revenues	Compliance Costs: As a Percent of Profits
Resistance Welding										
336311	Carburetor, piston, piston ring, and valve manufacturing	59	3	$54,436	922,644	1.83%	102,562	$1,447	0.16%	8.59%
336312	Gasoline engine and engine parts manufacturing	545	27	$883,783	1,621,620	1.83%	523,886	$1,381	0.09%	4.67%
336321	Vehicular lighting equipment manufacturing	45	2	$59,894	1,330,971	1.83%	163,568	$1,099	0.08%	4.52%
336322c	Other motor vehicle electrical and electronic equipment manufacturing	386	19	$349,811	906,246	1.83%	379,243	$1,506	0.17%	9.10%
336330	Motor vehicle steering and suspension components (except spring) manufacturing	116	5	$998,968	8,611,797	1.83%	773,649	$1,099	0.01%	0.70%
336340	Motor vehicle brake system manufacturing	82	3	$96,867	1,181,305	1.83%	935,554	$1,099	0.09%	5.10%
336350	Motor vehicle transmission and power train parts manufacturing	240	9	$304,951	1,270,628	1.83%	1,005,365	$1,099	0.09%	4.74%
336360	Motor vehicle seating and interior trim manufacturing	167	7	$310,566	1,859,677	1.83%	232,903	$1,099	0.06%	3.24%
336370	Motor vehicle metal stamping	225	11	$478,984	2,128,816	1.83%	245,533	$1,379	0.06%	3.55%
336391	Motor vehicle air-conditioning manufacturing	34	1	$80,741	2,374,734	1.83%	963,163	$1,099	0.05%	2.53%
336399b	All other motor vehicle parts manufacturing	653	33	$835,261	1,279,114	1.83%	509,796	$1,316	0.10%	5.64%
Dental Laboratories										
339116	Dental laboratories	6,379	1,595	$1,807,075	283,285	10.55%	49,696	$947	0.33%	3.17%
621210	Offices of dentists	119,544	219	$81,995,117	685,899	8.47%	64,809	$1,501	0.22%	2.58%
	Totals / Averages	172,628	2,875	$128,347,342	679,421	8.27%	56,189	$2,027	0.30%	3.61%

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis.

Table VI-C-2

Screening Analysis for Very Small Entities (with fewer than 20 employees) Affected by the Proposed Beryllium Standard
With Costs Calculated Using a Zero Percent Discount Rate

NAICS Code	Industry	Total Small Entities	Total Affected Small Entities	Revenues: Total for Small Entities ($1,000)	Revenues: Per Entity ($s)	Profit: Rate	Profit: Per Entity ($s)	Compliance Costs: Per Entity ($s)	Compliance Costs: As a Percent of Revenues	Compliance Costs: As a Percent of Profits
Beryllium Production										
331419	Primary smelting and refining of nonferrous metals	86	0	$399,861	--	--	--	--	--	--
Beryllium Oxide Ceramics and Composites										
327113a	Porcelain electrical supply manufacturing (primary)	53	0	$52,358	--	--	--	--	--	--
327113b	Porcelain electrical supply manufacturing (secondary)	53	7	$52,358	987,892	5.01%	192,368	$6,560	0.66%	13.24%
334220	Cellular telephones manufacturing	445	4	$576,956	1,296,530	6.08%	2,980,355	$5,997	0.46%	7.60%
334310	Compact disc players manufacturing	373	4	$1,128,513	3,025,503	4.39%	379,730	$8,069	0.27%	6.07%
334411	Electron tube manufacturing	38	10	$45,454	1,196,149	7.85%	1,544,859	$6,151	0.51%	6.55%
334415	Electronic resistor manufacturing	17	3	$25,647	1,508,662	7.85%	658,164	$6,563	0.43%	5.54%
334419	Other electronic component manufacturing	624	5	$639,599	1,024,999	7.85%	380,210	$6,673	0.65%	8.30%
334510	Electromedical equipment manufacturing	324	3	$420,245	1,297,053	6.75%	512,503	$5,995	0.46%	6.85%
336322b	Other motor vehicle electrical and electronic equipment manufacturing	386	6	$349,811	906,246	1.83%	379,243	$6,090	0.67%	36.81%
Nonferrous Foundries										
331521	Aluminum die-casting foundries	107	0	$153,274	--	5.22%	517,103	--	--	--
331522	Nonferrous (except aluminum) die-casting foundries	84	0	$92,703	--	5.22%	329,103	--	--	--
331524	Aluminum foundries (except die-casting)	217	0	$204,397	--	5.22%	251,290	--	--	--
331525a	Copper foundries (except die-casting) (non-sand casting foundries)	131	0	$139,372	--	5.22%	247,750	--	--	--
331525b	Copper foundries (except die-casting) (sand casting foundries)	131	0	$139,372	--	5.22%	247,750	--	--	--
Secondary Smelting, Refining, and Alloying										
331314	Secondary smelting & alloying of aluminum	45	0	$306,390	--	4.54%	2,243,316	--	--	--
331421b	Copper rolling, drawing, and extruding	26	0	$48,421	--	4.79%	8,569,920	--	--	--
331423	Secondary smelting, refining, & alloying of copper	11	1	$85,353	7,759,405	4.79%	1,508,567	$20,687	0.27%	5.56%
331492	Secondary smelting, refining, & alloying of nonferrous metal (except copper & aluminum)	121	15	$388,603	3,211,598	4.79%	1,810,634	$10,591	0.33%	6.88%
Precision Turned Products										
332721a	Precision turned product manufacturing (high beryllium content)	1,970	12	$2,219,340	1,126,568	5.82%	220,539	$6,682	0.59%	10.19%
332721b	Precision turned product manufacturing (low beryllium content)	1,970	185	$2,219,340	1,126,568	5.82%	220,539	$4,924	0.44%	7.51%
Copper Rolling, Drawing and Extruding										
331421a	Copper rolling, drawing, and extruding	26	4	$48,421	1,862,347	4.79%	8,569,920	$5,549	0.30%	6.22%
331422	Copper wire (except mechanical) drawing	35	18	$254,426	7,269,304	4.79%	3,693,377	$7,475	0.10%	2.15%
Fabrication of Beryllium Alloy Products										
332612	Light gauge spring manufacturing	164	164	$156,603	954,897	5.61%	220,868	$3,204	0.34%	5.98%
332116	Metal stamping	807	40	$1,033,657	1,280,864	5.12%	288,086	$3,432	0.27%	5.24%
334417	Electronic connector manufacturing	106	11	$129,405	1,220,804	7.85%	694,211	$2,914	0.24%	3.04%
336322a	Other motor vehicle electrical & electronic equipment	386	60	$349,811	906,246	1.83%	379,243	$2,907	0.32%	17.57%

Table VI-C-2, continued

With Costs Calculated Using a Zero Percent Discount Rate

NAICS Code	Industry	Total Small Entities	Total Affected Small Entities	Revenues: Total for Small Entities ($1,000)	Revenues: Per Entity ($s)	Profit: Rate	Profit: Per Entity ($s)	Compliance Costs: Per Entity ($s)	Compliance Costs: As a Percent of Revenues	Compliance Costs: As a Percent of Profits
Arc and Gas Welding										
331111	Iron and steel mills	268	0	$1,018,914	--	5.41%	10,877,459	--	--	--
331221	Rolled steel shape manufacturing	50	0	$208,799	--	5.41%	3,380,437	--	--	--
331513	Steel foundries (except investment)	94	0	$112,227	--	5.22%	760,419	--	--	--
332117	Powder metallurgy part manufacturing	55	0	$100,643	--	5.12%	406,161	--	--	--
332212	Hand and edge tool manufacturing	751	2	$681,375	907,290	5.61%	176,878	$3,108	0.34%	6.10%
332312	Fabricated structural metal manufacturing	2,159	35	$3,182,459	1,474,043	4.74%	243,251	$2,240	0.15%	3.21%
332313	Plate work manufacturing	845	14	$1,007,308	1,192,080	4.74%	190,330	$2,817	0.24%	4.99%
332322	Sheet metal work manufacturing	2,778	46	$2,631,155	947,140	4.74%	155,774	$2,553	0.27%	5.69%
332323	Ornamental and architectural metal work manufacturing	1,957	32	$1,342,443	685,970	4.74%	85,332	$3,072	0.45%	9.45%
332439	Other metal container manufacturing	203	2	$187,607	924,174	4.30%	242,034	$2,412	0.26%	6.06%
332919	Other metal valve and pipe fitting manufacturing	115	1	$181,192	1,575,580	7.00%	686,061	$4,228	0.27%	3.83%
332999	All other miscellaneous fabricated metal product manufacturing	2,353	24	$2,117,303	899,831	7.00%	229,602	$2,494	0.28%	3.96%
333111	Farm machinery and equipment manufacturing	673	7	$785,460	1,167,103	6.36%	347,100	$2,240	0.19%	3.02%
333414a	Heating equipment (except warm air furnaces) manufacturing	283	2	$365,551	1,291,699	4.68%	294,852	$2,476	0.19%	4.10%
333911	Pump and pumping equipment manufacturing	251	1	$497,397	1,981,660	5.36%	449,783	$2,417	0.12%	2.28%
333922	Conveyor and conveying equipment manufacturing	407	4	$541,532	1,330,547	5.36%	361,522	$2,276	0.17%	3.19%
333924	Industrial truck, tractor, trailer, and stacker machinery manufacturing	195	1	$213,335	1,094,026	5.36%	1,149,899	$2,700	0.25%	4.60%
333999	All other miscellaneous general purpose machinery manufacturing	975	10	$1,151,152	1,180,669	5.36%	216,783	$2,239	0.19%	3.54%
336211	Motor vehicle body manufacturing	400	4	$535,923	1,339,807	1.83%	276,583	$2,239	0.17%	9.15%
336214	Travel trailer and camper manufacturing	410	5	$480,503	1,171,958	1.83%	78,445	$2,241	0.19%	10.47%
336399a	All other motor vehicle parts manufacturing	653	1	$835,261	1,279,114	1.83%	509,796	$2,365	0.18%	10.13%
336510	Railroad rolling stock	83	0	$189,164	--	5.47%	4,156,603	--	--	--
336999	All other transportation equipment manufacturing	307	2	$253,916	827,087	6.56%	177,073	$2,876	0.35%	5.30%
337215	Showcase, partition, shelving, and locker manufacturing	814	2	$582,654	715,791	4.26%	140,227	$2,973	0.42%	9.75%
811310	Commercial and industrial machinery and equipment repair	18,714	122	$10,692,921	571,386	5.42%	46,622	$3,849	0.67%	12.43%
Resistance Welding										
333411	Air purification equipment manufacturing	189	13	$283,628	1,500,678	4.68%	219,418	$2,449	0.16%	3.49%
333412	Industrial and commercial fan and blower manufacturing	60	4	$78,644	1,310,729	4.68%	397,281	$2,346	0.18%	3.82%
333414b	Heating equipment (except warm air furnaces) manufacturing	283	20	$365,551	1,291,699	4.68%	294,852	$2,267	0.18%	3.75%
333415	Air-conditioning, warm air heating, and industrial refrigeration equipment manufacturing	395	28	$806,994	2,043,023	4.68%	1,713,806	$1,064	0.05%	1.11%
335211	Electric housewares and household fan manufacturing	70	4	$99,219	1,417,419	4.03%	881,709	$1,120	0.08%	1.96%
335212	Household vacuum cleaner manufacturing	18	0	$21,745	--	4.03%	1,239,064	--	--	--
335221	Household cooking appliance manufacturing	57	2	$66,863	1,173,037	4.03%	1,664,253	$1,027	0.09%	2.17%
335222	Household refrigerator and home freezer manufacturing	6	0	$8,833	--	4.03%	11,309,226	--	--	--
335224	Household laundry equipment manufacturing	4	0	$1,837	--	4.03%	16,660,266	--	--	--
335228	Other major household appliance manufacturing	15	0	$24,856	--	4.03%	311,284	--	--	--

Table VI-C-2, continued

With Costs Calculated Using a Zero Percent Discount Rate

				Revenues		Profit		Compliance Costs		
NAICS Code	Industry	Total Small Entities	Total Affected Small Entities	Total for Small Entities ($1,000)	Per Entity ($s)	Rate	Per Entity ($s)	Per Entity ($s)	As a Percent of Revenues	As a Percent of Profits
Resistance Welding										
336311	Carburetor, piston, piston ring, and valve manufacturing	59	3	$54,436	922,644	1.83%	102,562	$1,359	0.15%	8.07%
336312	Gasoline engine and engine parts manufacturing	545	27	$883,783	1,621,620	1.83%	523,886	$1,296	0.08%	4.38%
336321	Vehicular lighting equipment manufacturing	45	2	$59,894	1,330,971	1.83%	163,568	$1,027	0.08%	4.23%
336322c	Other motor vehicle electrical and electronic equipment manufacturing	386	19	$349,811	906,246	1.83%	379,243	$1,415	0.16%	8.55%
336330	Motor vehicle steering and suspension components (except spring) manufacturing	116	5	$998,968	8,611,797	1.83%	773,649	$1,027	0.01%	0.65%
336340	Motor vehicle brake system manufacturing	82	3	$96,867	1,181,305	1.83%	935,554	$1,027	0.09%	4.76%
336350	Motor vehicle transmission and power train parts manufacturing	240	9	$304,951	1,270,628	1.83%	1,005,365	$1,027	0.08%	4.43%
336360	Motor vehicle seating and interior trim manufacturing	167	7	$310,566	1,859,677	1.83%	232,903	$1,027	0.06%	3.03%
336370	Motor vehicle metal stamping	225	11	$478,984	2,128,816	1.83%	245,533	$1,294	0.06%	3.33%
336391	Motor vehicle air-conditioning manufacturing	34	1	$80,741	2,374,734	1.83%	963,163	$1,027	0.04%	2.37%
336399b	All other motor vehicle parts manufacturing	653	33	$835,261	1,279,114	1.83%	509,796	$1,234	0.10%	5.28%
Dental Laboratories										
339116	Dental laboratories	6,379	1,595	$1,807,075	283,285	10.55%	49,696	$906	0.32%	3.03%
621210	Offices of dentists	119,544	219	$81,995,117	685,899	8.47%	64,809	$1,439	0.21%	2.48%
	Totals / Averages	172,628	2,875	$128,347,342	679,421	8.27%	56,189	$1,905	0.28%	3.39%

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis.

CHAPTER VII: BENEFITS AND NET BENEFITS

INTRODUCTION

In this chapter, OSHA estimates the benefits and net benefits of the proposed beryllium rule.

This chapter proceeds in five steps. The first step estimates the numbers of diseases and deaths prevented by comparing the current (baseline) situation to a world in which the proposed PEL is adopted in a final standard to which employees are exposed throughout their working lives. The second step also assumes that the proposed PEL is adopted, but uses the results from the first step to estimate what would happen under a more realistic scenario in which employees have been exposed for varying periods of time to the baseline situation and will thereafter be exposed to the new PEL.

The third step covers the monetization of benefits. Then, in the fourth step, OSHA estimates the net benefits and incremental benefits of the proposed rule by comparing the monetized benefits to the costs presented in Chapter V of this PEA. The models underlying each step inevitably need to make a variety of assumptions based on limited data. In the fifth step, OSHA provides a sensitivity analysis to explore the robustness of the estimates of net benefits with respect to many of the assumptions made in developing and applying the underlying models. OSHA invites comments on each aspect of the data and methods used in this chapter. Because dental labs constitute a significant source of both costs and benefits to the rule (over 40 percent), OSHA is particularly interested in comments regarding the appropriateness of the model, assumptions, and data to estimating the benefits to workers in that industry.

OSHA has added to the docket the spreadsheets used to calculate the estimates of benefits outlined below (OSHA, 2015a). Those interested in exploring the details and methodology of

OSHA benefits analysis, such as how the life table referred to below was developed and applied, should consult those spreadsheets.

STEP 1 - ESTIMATION OF THE STEADY-STATE NUMBER OF BERYLLIUM-RELATED DISEASES AVOIDED

Methods of Estimation

This section covers the first step in OSHA's development of the benefits analysis—comparing the situation in which employees continue to be at baseline exposure levels for their entire working lives to the situation in which all employees have been exposed at a given PEL for their entire working lives. This is a comparison of two steady-state situations. To do this, OSHA must estimate both the risk associated with the baseline exposure levels and the risk following the promulgation of a new beryllium standard. OSHA's approach assumes for inputs such as the turnover rate and the exposure response function that they are similar across all workers exposed to beryllium, regardless of industry.

An exposure-response model, discussed below, is used to estimate a worker's risk of beryllium-related disease based on the worker's cumulative beryllium exposure. The Agency used a lifetime risk model to estimate the baseline risk and the associated number of cases for the various disease endpoints. A lifetime risk model explicitly follows a worker each year, from work commencement onwards, accumulating the worker's beryllium exposure in the workplace and estimating outcomes each year for the competing risks that can occur. To go from exposure to number of cases, the Agency needs to estimate an exposure-response relationship, and this is discussed below. The possible outcomes are no change, or the various health endpoints OSHA has considered (beryllium sensitization, CBD, lung cancer, and the mortality associated with these endpoints). As part of the estimation discussion, OSHA will mention specific parameters used in some of the estimation methods, but will further discuss how these parameters were derived later in this section.

The baseline lifetime risk model is the most complicated part of the analysis. The Agency only needs to make relatively simple adjustments to this model to reflect changes in activities and conditions due to the standard, which, working through the model, then lead to changes in relevant health outcomes. There are three channels by which the standard generates benefits. First are estimated benefits due to the lowering of the PEL. Second are estimated benefits with further exposure reductions from the substitution of non-beryllium for beryllium-containing materials, ending workers' beryllium exposures entirely. This potential source of benefits is particularly significant with respect to OSHA' s assumptions for how dental labs are likely to reduce exposures (see below). Finally, the model estimates benefits due to the ancillary programs that are required by the proposed standard. The last channel affects CBD and sensitization, endpoints which may be mitigated or prevented with the help of ancillary provisions such as dermal protection and medical surveillance for early detection, and for which the Agency has some information on the effects on risk of ancillary provisions. The benefits of ancillary provisions are not estimated for lung cancer because the benefits from reducing lung cancer are considered to be the result of reducing airborne exposure only and thus the ancillary provisions will have no separable effect on airborne exposures. The discussion here will concentrate on CBD as being the most important and complex endpoint, and most illustrative of other endpoints: the structure for other endpoints is the same; only the exposure response functions are different. Here OSHA will discuss first the exposure-response model, then the structure of the year-to-year changes for a worker, then the estimated exposure distribution in the affected population and the risk model with the lowering of the PEL, and, last, the other adjustments for the ancillary benefits and the substitution benefits.

The exposure response model is designed to translate beryllium exposure to risk of adverse health endpoints. In the case of beryllium sensitization and CBD, the Agency uses the cumulative exposure data from a beryllium manufacturing facility. Specifically, OSHA uses the quartile data from the Cullman plant that are presented in Table VI-7 of the Preliminary Risk Assessment in the preamble. The raw data from this study show cases of CBD with cumulative exposures that would represent an average exposure level of less than 0.1 μg/m^3 if exposed for ten years; show cases of CBD with exposures lasting less than one year; and show cases of CBD with actual average exposure of less than 0.1 μg/m^3.

Prevalence is defined as the percentage of persons with a condition in a population at a given point in time. The quartile data in Table VI-7 are prevalence percentages (the number of cases of illness documented over several years in the 319 person cohort from the Cullman plant) at different cumulative exposure levels. The Cullman data do not cover persons who left the work force or what happened to persons who remained in the workforce after the study was completed. For the lifetime risk model, the prevalence percentages will be translated into incidence percentages—the estimated number of new cases predicted to occur each year. For this purpose OSHA assumed that the incidence for any given cumulative exposure level is constant from year to year and continues after exposure ceases.

To calculate incidence from prevalence, OSHA assumed a steady state in which both the size of the beryllium-exposed affected population, exposure concentrations during employment and prevalence are constant over time. If these conditions are met, and turnover among workers with a condition is equal to turnover for workers without a condition, then the incidence rate will be equal to the turnover rate multiplied by the prevalence rate. If the turnover rate among persons with a condition is higher than the turnover rate for workers without the condition, then this assumption will underestimate incidence. This might happen if, in addition to other reasons for leaving work, persons with a condition leave a place of employment more frequently because their disabilities cause them to have difficulty continuing to do the work. If the turnover rate among persons with a condition is lower than the turnover rate for workers without the condition, then this assumption will overestimate incidence. This could happen if an employer provides special benefits to workers with the condition, and the employer would cease to provide these benefits if the employee left work.

To illustrate, if 10 percent of the work force (including 10 percent of those with the condition) leave each year and if the overall prevalence is at 20 percent, then a 2 percent (10 percent times 20 percent) incidence rate will be needed in order to keep a steady 20 percent group prevalence rate each year. OSHA's model assumes a constant 10 percent turnover rate (see later in this chapter for the rationale for this particular turnover rate). While turnover rates are not available for the specific set of employees in question, for manufacturing as a whole, the turnover rates are greater than 20 percent, and greater than 30 percent for the economy as a whole (BLS, 2013). For this analysis, OSHA assumed an effective turnover rate of 10 percent. Different turnover rates will result in different incidence rates. The lower the turnover rate the lower the estimated incidence rate. This is a conservative assumption for the industries where turnover rates may be higher. However, some occupations/industries, such as dental lab technicians, may have lower turnover rates than manufacturing workers. Additionally, the typical dental technician even if leaving one workplace, has significant likelihood of continuing to work as a dental technician and going to another workplace that uses beryllium. OSHA welcomes comments on its turnover estimates and on sectors, such as dental laboratories, where turnover may be lower than ten percent.

Using Table VI-7 of the preliminary risk assessment, when a worker's cumulative exposure is below 0.147 ($\mu g/m^3$-years), the prevalence of CBD is 2.5 percent and so the derived annual risk would be 0.25 percent (0.10 x 2.5 percent). It will stay at this level until the worker has reached a cumulative exposure of 1.468, where it will rise to 0.80 percent.

The model assumes a maximum 45-year (250 days per year) working life (ages 20 through 65 or age of death or onset of CBD, whichever is earlier) and follows workers after retirement through age 80. The 45-year working life is based on OSHA's legal requirements and is longer than the working lives of most exposed workers. A shorter working life will be examined later in this section. While employed, the worker accumulates beryllium exposure at a rate depending on where the worker is in the empirical exposure profile presented in Chapter IV (i.e., OSHA calculates a general risk model which depends on the exposure level and then plug in our empirical exposure distribution to estimate the final number of cases of various health outcomes). Following a worker's retirement, there is no increased exposure, just a constant annual risk resulting from the worker's final cumulative exposure.

OSHA's model follows the population of workers each year, keeping track of cumulative exposure and various health outcomes. Explicitly, each year the model calculates: the increased cumulative exposure level for each worker versus last year, the incidence at the new exposure level, the survival rate for this age bracket, and the percentage of workers who have not previously developed CBD in earlier years.

For any individual year, the equation for predicting new cases of CBD for workers at age t is:

new CBD cases rate(t) = modeled incidence rate(t) * survival rate(t) * (1- currently have CBD rate(t)), where the variables used are:

new CBD cases rate(t) is the output variable to be calculated;

cumulative exposure(t) = cumulative exposure(t-1) + current exposure;

modeled incidence rate(t) is a function of cumulative exposure; and

survival rate(t) is the background survival rate from mortality due to other causes in the national population.

Then for the next year the model updates the survival rate (due to an increase in the worker's age), incidence rate (due to any increased cumulative exposure), and the rate of those currently having CBD, which increases due to the new CBD case rate of the year before. This process then repeats for all 60 years.

It is important to note that this model is based on the assumption that prevalence is explained by an underlying constant incidence, and as a result, prevalence will be different depending on the average number of years of exposure in the population examined and (though a sensitivity analysis is provided later) on the assumption of a maximum of 45 years of exposure. OSHA also examined (OSHA 2015c) a model in which prevalence is constant at the levels shown in Table VI-7 of the preliminary risk assessment, with a population age (and thus exposure) distribution estimated based on an assumed constant turnover rate.[428] OSHA solicits

[428] As an example of how population age distribution is a function of the length of working life and the turnover rate, consider an example in which employees begin working at age 20 and uniformly continue until age 65 (in other words, there is no turnover apart from retirement); this pattern is consistent with a turnover rate of 2.2 percent (=1/45) because one forty-fifth of employees reach retirement age each year. Therefore, turnover higher than 2.2 percent would be an indication that employee population is not equal across all ages between 20 and 65. If turnover is 10 percent, then at any given time, 10 percent of employees must be in their first year of work (which we assume, consistent with OSHA's standard practice, to occur at age 20). Also consistent with OSHA's standard practice, we assume retirement occurs by age 65; in other words, turnover amongst employees in their forty-fifth year of work will be 100 percent. This necessitates a turnover rate of slightly less than 10 percent for younger employees in order for the overall turnover rate to equal 10 percent. We assume that the turnover rate is equal for all employees in their first through forty-fourth years of work and find that a turnover rate of approximately 9.9086 percent, when combined with the 100 percent turnover rate for employees in their forty-fifth year of work, yields an overall turnover rate of 10 percent and also satisfies the numerical requirement that the percentages of workers of each age sum to a total of 100 percent. The result of this approach is to estimate that 9.0091 percent (=10 percent - 10 percent * 9.9086 percent) of employees are in their second year of work, 8.1165 percent (=9.0091 percent - 9.0091 percent * 9.9086 percent) are in their third year of work, etc., steadily declining to an estimate of 0.1014 percent being in their forty-fifth year of work. These estimates can then be multiplied by the exposed population estimates from chapter III's Table III-15. For example, Table III-15 shows 1,610 (=(2,834-1,417)+(385-192)) dental employees with exposures between 0.5 and 1.0 $\mu g/m^3$. This model yields estimates of 161 of these employees being in their first year of work, 145 in their second year of work, etc., with approximately 15.9 (=1,610 *10 percent * 9.9086 percent) separating from their jobs after one year of exposure, approximately 14.4 (=1,610 * 9.0091 percent * 9.9086 percent) separating from their jobs after two years of exposure, etc. To capture the total number of exposures in the first 45 years of the rule's implementation, we sum 44 years' worth of turnover with the full population of workers in year 45. For dental exposure between 0.5 and 1.0 $\mu g/m^3$, there are an estimated 862.7 (=44*15.9 + 161) employees having experienced one year's worth of exposure, 777.2 (=44*14.4 + 145) having experienced two years' worth of exposure, etc. As with the primary benefits model, we set exposures to 0.1 $\mu g/m^3$ for exposures shown in Table III-15 as <0.1 $\mu g/m^3$, to 2.0 $\mu g/m^3$ for exposures shown in Table III-15 as ≥2.0 $\mu g/m^3$, and to the midpoint for all other ranges. It is then possible to directly apply the cumulative exposure prevalence estimates from the quartile analysis (e.g., 2.5 percent for the 862.7 dental employees with one year's worth of exposure at an average of 0.75 $\mu g/m^3$ and 8 percent for the 777.2 with two years' worth of exposure at the average of 0.75 $\mu g/m^3$). Summing across employees in all exposure ranges yields estimates of 8,903 CBD cases (2,903

comment on this and other alternative approaches to using the available prevalence data to develop an exposure-response function for this benefits analysis.

In the next step, OSHA uses its model to take into account the adoption of the lower proposed PEL. OSHA uses the exposure profile for workers as estimated in Chapter IV of this PEA for each of the various application groups. These exposure profiles estimate the number of workers at various exposure levels, specifically the ranges less than 0.1 μg/m^3, 0.1 to 0.2, 0.2 to 0.5, 0.5 to 1.0, 1.0 to 2.0, and greater than 2.0 μg/m^3. Translating these ranges into exposure levels for the risk model, the model assumes an average exposure equal to the midpoint of the range, except for the lower end, where it was assumed to be equal to 0.1 μg/m^3, and the upper end, where it was assumed to be equal to 2.0 μg/m^3.

The model increases the workers' cumulative exposure each year by these midpoints and then plugs these new values into the new case equation. This alters the incidence rate as cumulative exposure crosses a threshold of the quartile data. So then using the exposure profiles by application group from Chapter IV of this PEA, the baseline exposure flows through the life time risk model to give us a baseline number of cases. Next OSHA calculated the number of cases estimated to occur after the implementation of the proposed PEL of 0.2 μg/m^3. Here OSHA simply takes the number of workers with current average exposure above 0.2 μg/m^3 and set their exposure level at 0.2 μg/m^3; all exposures for workers exposed below 0.2 μg/m^3 stay the same. After adjusting the worker exposure profile in this way, OSHA goes through all the same calculations and obtains a post-standard number of CBD cases. Subtracting estimated post-

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amongst dental employees and 6,000 amongst non-dental employees) in the baseline and 6,092 CBD cases (471 amongst dental employees and 5,621 amongst non-dental employees) with the proposed PEL reduction. With a 5 percent turnover rate, analogous calculations yield estimates of 6,787 CBD cases (2,033 dental and 4,754 non-dental) in the baseline and 5,002 CBD cases (395 dental and 4,606 non-dental) with the proposed PEL reduction. With a 20 percent turnover rate, analogous calculations yield estimates of 12,608 CBD cases (4,387 dental and 8,221 non-dental) in the baseline and 7,978 CBD cases (622 dental and 7,356 non-dental) with the proposed PEL reduction.

standard CBD cases from estimated pre-standard CBD cases gives us the number of CBD cases that would be averted due to the proposed change in the PEL.

Based on these methods, OSHA's estimate of benefits associated with the proposed rule does not include benefits associated with current compliance that have already been achieved with regard to the new requirements, or benefits obtained from future compliance with existing beryllium requirements. However, available exposure data indicate that few employees are currently exposed above the existing standard's PEL of 2.0 $\mu g/m^3$. To achieve consistency with the cost estimation method in chapter V, all employees in the exposure profile that are above 2.0 $\mu g/m^3$ are assumed to be at the 2.0 $\mu g/m^3$ level.

There is also a component that applies only to dental labs. OSHA has preliminarily assumed, based on the estimates of higher costs for engineering controls than using substitutes presented in the cost chapter, that rather than incur the costs of compliance with the proposed standard, many dental labs are likely to stop using beryllium-containing materials after the promulgation of the proposed standard.[429] OSHA estimated earlier in this PEA that, for the baseline, only 25 percent of dental lab workers still work with beryllium. OSHA estimates that, if OSHA adopts the proposed rule, 75 percent of the 25 percent still using beryllium will stop working with beryllium; their beryllium exposure level will therefore drop to zero. OSHA estimates that the 75 percent of workers will not be a random sample of the dental lab exposure profile but instead will concentrate among workers who are currently at the highest exposure levels because it would cost more to reduce those higher exposures into compliance with the proposed PEL. Under this judgment OSHA is estimating that the rule would eliminate all cases of CBD in the 75 percent of dental lab workers with the highest exposure levels. As discussed in the sensitivity analysis below, dental labs constitute a significant source of both costs and

[429] In the cost chapter, OSHA explored the cost of putting in LEV instead of substitution. The Agency costed an enclosure for 2 technicians: the Powder Safe Type A Enclosure, 32 inch wide with HEPA filter, AirClean Systems (2011), which including operating and maintenance, was annualized at $411 per worker. This is significantly higher than the annual cost for substitution of $166 per worker, shown later in this section.

benefits to the rule (over 40 percent), and the extent to which dental laboratories substitute other materials for beryllium has significant effects on the benefits and costs of the rule. To derive its baseline estimate of cases of CBD in dental laboratories, OSHA 1) estimated baseline cases of CBD using the existing rate of beryllium use in dental labs without a projection of further substitution; 2) estimated cases of CBD with the proposed regulation using an estimate that 75 percent of the dental labs with higher exposure would switch to other materials and thus eliminate exposure to beryllium; and 3) the turnover rate in the industry is 10 percent. OSHA welcomes comments on all aspects of the analysis of substitution away from beryllium in the dental laboratories sector.

Estimation results for both dental labs and non-dental workplaces appear in Table VII-0.

Table VII-0. CBD case estimates, 45-year totals, baseline and with PEL of 0.2 μg/m^3

		Current beryllium exposure (μg/m^3)						Total
		< 0.1	0.1 – 0.2	0.2 – 0.5	0.5 – 1.0	1.0 – 2.0	> 2.0	
Baseline	Dental labs	827	636	432	608	155	466	3,124
	Non-dental	5,912	631	738	287	112	214	7,893
	Total	6,739	1,267	1,171	895	267	679	11,017
PEL = 0.2 μg/m^3	Dental labs	679	0	0	0	0	0	679
	Non-dental	5,912	631	693	255	98	186	7,774
	Total	6,591	631	693	255	98	186	8,454
Prevented by PEL reduction	Dental labs	148	636	432	608	155	466	2,444
	Non-dental	0	0	45	32	14	27	119
	Total	148	636	478	640	169	493	2,563

In contrast to this PEL component of the benefits, both the ancillary program benefits calculation and the substitution benefits calculation are relatively simple. Both are percentages of the lifetime-risk-model CBD cases that still occur in the post-standard world. OSHA notes that in the context of existing CBD prevention programs, some ancillary-provision programs similar to those included in OSHA's proposal have eliminated a significant percentage of the remaining CBD cases (discussed later in this chapter). If the ancillary provisions reduce remaining CBD cases by 90 percent for example, and if the estimated baseline contains 120 cases of CBD, and post-standard compliance with a lower PEL reduces the total to 100 cases of CBD, then 90 of those remaining 100 cases of CBD would be averted due to the ancillary programs.

OSHA assumed, based on the clinical experience discussed further below, that approximately 65 percent of CBD cases ultimately result in death. Later in this chapter, OSHA provides a sensitivity analysis of the effects of different values for assuming this percentage at 50% and 80% on the number of CBD deaths prevented. OSHA welcomes comment on this assumption. OSHA's exposure-response model for lung cancer is based on lung cancer mortality data. Thus, all of the estimated cases of lung cancer in the benefits analysis are cases of premature death from beryllium-related lung cancer.

Finally, in recognition of the uncertainty in this aspect of these models, OSHA presents a "high" estimate, a "low" estimate, and uses the midpoint of these two as our "primary" estimate. The low estimate is simply those CBD fatalities prevented due to everything except the ancillary provisions, i.e., both the reduction in the PEL and the substitution by dental labs. The high estimate includes both of these factors plus all the ancillary benefits calculated at an effectiveness rate of 90 percent in preventing cases of CBD not averted by the reduction of the PEL. The midpoint is the combination of reductions attributed to adopting the proposed PEL, substitution by dental labs, and the ancillary provisions calculated at an effectiveness rate of only 45 percent.

<u>Chronic Beryllium Disease and Sensitization</u>

CBD is a respiratory disease in which the body's immune system reacts to the presence of beryllium in the lung, causing a progression of pathological changes including chronic inflammation and tissue scarring. Immunological sensitization to beryllium (BeS) is a precursor that occurs before early-stage CBD. Only sensitized individuals can go on to develop CBD. In early, asymptomatic stages of CBD, small granulomatous lesions and mild inflammation occur in the lungs. As CBD progresses, the capacity and function of the lungs decrease, which eventually affects other organs and bodily functions as well. Over time the spread of lung fibrosis (scarring) and loss of pulmonary function cause symptoms such as: a persistent dry cough, shortness of breath, fatigue, night sweats, chest and join pain, clubbing of fingers due to impaired oxygen exchange, and loss of appetite. In these later stages CBD can also impair the liver, spleen, and kidneys, and cause health effects such as granulomas of the skin and lymph nodes, and cor pulmonale. The speed and extent of disease progression may be influenced by the level and duration of exposure, treatment with corticosteroids, and genetics, but these effects are not fully understood.

Corticosteroid therapy, in workers whose beryllium exposure has ceased, has been shown to control inflammation, ease symptoms, and in some cases prevent the development of fibrosis. However, corticosteroid use can have adverse effects, including increased risk of infections; accelerated bone loss or osteoporosis; psychiatric effects such as depression, sleep disturbances, and psychosis; adrenal suppression; ocular effects; glucose intolerance; excessive weight gain; increased risk of cardiovascular disease; and poor wound healing. The effects of CBD, and the common treatments for CBD, are discussed in detail in the preamble at Section V, Health Effects, and Section VIII, Significance of Risk.

OSHA's review of the literature on CBD suggests three broad types of CBD progression (see the preamble to the proposed standard at Section V, Health Effects). In the first, individuals progress relatively directly toward death related to CBD. They suffer rapidly advancing disability and their death is significantly premature. Medical intervention is not applied, or if it is, does little to slow the progression of disease. In the second type, individuals live with CBD for an extended period of time. The progression of CBD in these individuals is naturally slow, or may be medically stabilized. They may suffer significant disability, in terms of loss of lung function—and quality of life—and require medical oversight their remaining years. They would be expected to lose some years of normal lifespan—see discussion below. As discussed previously, advanced CBD can involve organs and systems beyond the respiratory system; thus, CBD can contribute to premature death from other causes. Finally, individuals with the third type of CBD progression do not die prematurely from causes related to CBD. The disease is stabilized and may never progress to a debilitating state. These individuals nevertheless may experience some disability or loss of lung function, as well as side effects from medical treatment, and may be affected by the disease in many areas of their lives: work, recreation, family, etc.[430]

In the analysis that follows, OSHA assumes, based on the clinical experience discussed below, that 35 percent of workers who develop CBD experience the third type of progression and do not die prematurely from CBD. The remaining 65 percent were estimated to die prematurely, whether from rapid disease progression (type 1) or slow (type 2). Although the proportion of CBD patients who die prematurely as a result of the disease is not well understood or documented at this time, OSHA believes this assumption is consistent with the information submitted in response to the RFI. Newman et al. (2003) presented a scenario for what they considered to be the "typical" CBD patient:

> We have included an example of a life care plan for a typical clinical case of CBD. In this example, the hypothetical case is diagnosed at age 40 and assumed to live an additional 33.7 years (approximately 5% reduced life expectancy in this model). In this hypothetical example, this individual would be considered to have moderate severity of chronic beryllium disease at the time of initial diagnosis. They require treatment with prednisone and treatment for early cor pulmonale secondary to CBD. They have experienced some, but not all, of the side effects of treatment and only the most common CBD-related health effects.

In short, *most* workers diagnosed with CBD are expected to have shortened life expectancy, even if they do not progress rapidly and directly to death. It should be emphasized that this represents

[430] As indicated in the Health Effects section of the preamble: "It should be noted, however, that treatment with corticosteroids has side-effects of their own that need to be measured against the possibility of progression of disease (Gibson *et al.*, 1996; Zaki *et al.*, 1987). Alternative treatments such as azathioprine and infliximab, while successful at treating symptoms of CBD, have been demonstrated to have side-effects as well (Pallavicino *et al.*, 2013; Freeman, 2012)".

the Agency's best estimate of the mortality related to CBD based upon the current available evidence. As described here and in Section V, Health Effects, there is a substantial degree of uncertainty as to the prognosis for those contracting CBD, particularly as the relatively less severe cases are likely not to be studied closely for the remainder of their lives.

As mentioned previously, OSHA used the Cullman data set for empirical estimates of beryllium sensitization and CBD prevalence in its exposure response model, which translates beryllium exposure to risk of adverse health endpoints for the purpose of determining the benefits that could be achieved by preventing those adverse health endpoint .

OSHA chose the cumulative exposure quartile data as the basis for this benefits analysis. The choice of cumulative quartiles was based in part on the need to use the cumulative exposure forecast developed in the model, and in part on the fact that in statistically fitted models for CBD, the cumulative exposure tended to fit the CBD data better than other exposure variables. OSHA also chose the quartile model because the outside expert who examined the logistic and proportional hazards models believed statistical modeling of the data set to be unreliable due to its small size. In addition, the proportional hazards model with its dummy variables by year of detection is difficult to interpret for purposes of this section. Of course regression analyses are often useful in empirical analysis. They can be a useful compact representation of a set of data, allow investigations of various variable interactions and possible causal relationships, have added flexibility due to covariate transformations, and under certain conditions can be shown to be statistically "optimal." However, they are only useful when used in the proper setting. The possibility of misspecification of functional form, endogeneity, or incorrect distributional assumptions are just three reasons to be cautious about using regression analyses.

On the other hand, the use of results produced by a quartile analysis as inputs in a benefits assessment implies that the analytic results are being interpreted as evidence of an exposure-response causal relationship. Regression analysis is a more sophisticated approach to estimating causal relationships (or even correlations) than quartile or other quantile analysis, and any data limitations that may apply to a particular regression-based exposure-response estimation also apply to exposure-response estimation conducted with a quartile analysis using the same data set. In this case, OSHA adopted the quartile analysis because the logistic regression analysis yielded extremely high prevalence rates for higher level of exposure over long time periods that some might not find credible. Use of the quartile analysis serves to show that there are significant benefits even without using an extremely high estimate of prevalence for long periods of exposure at high levels. As a check on the quartile model, the Agency performed the same benefits calculation using the logit model estimated by the Agency's outside expert, and these benefit results are presented in a separate OSHA background document (OSHA, 2015b). The difference in benefits between the two models is slight, and there is no qualitative change in final outcomes. The Agency solicits comment on these issues.

To examine the effect of simply changing the PEL, including the effect of the standard on some dental labs to discontinue their use of beryllium, OSHA compared the number of CBD-related deaths (mortality) and cases of non-fatal CBD (morbidity) that would occur if workers were exposed for a working life to PELs of 0.1, 0.2, or 0.5 $\mu g/m^3$ to the number of cases that would occur at current levels of exposure at or below the current PEL. The number of avoided cases over a hypothetical working life of exposure for the current population at a lower PEL is then equal to the difference between the number of cases at levels of exposure at or below the current PEL for that population minus the number of cases at the lower PEL. This approach represents a steady-state comparison based on what would hypothetically happen to workers who received a specific average level of occupational exposure to beryllium during an entire working life. Later in this chapter, OSHA modifies this approach by introducing a model that takes into account the timing of benefits before steady state is reached.

As indicated in Table VII-1, the Agency estimates that there would be 16,240 cases of beryllium sensitization, from which there would be 11,017, or about 70 percent, progressing to CBD. The Agency arrived at these estimates by using the CBD and BeS prevalence values from the Agency's preliminary risk analysis, the exposure profile at current exposure levels (under an assumption of full, or fixed, compliance with the existing beryllium PEL), and the model outlined in the previous methods of estimation section after a working lifetime of exposure. Applying the prior midpoint estimate, as explained above, that 65 percent of CBD cases cause, or contribute to, premature death, the Agency predicts a total of 7,161 cases of mortality and 3,856 cases of morbidity from exposure at current levels; this translates, annually, to 165 cases of mortality and 86 cases of morbidity. At the proposed PEL, OSHA's base model estimates that, due to the airborne factor only, a total of 2,563 CBD cases would be avoided from exposure at current levels, including 1,666 cases of mortality and 897 cases of morbidity—or an average of 37 cases of mortality and 20 cases of morbidity annually. OSHA has not estimated the quantitative benefits of sensitization cases avoided.

OSHA requests comment on this analysis, including feedback on the data relied on and the approach and assumptions used. As discussed earlier, based on information submitted in response to the RFI, the Agency estimates that most of the workers with CBD will progress to an early death, even if it comes after retirement, and has quantified those cases prevented. However, given the evolving nature of science and medicine, the Agency invites public comment on the current state of CBD-related mortality.

The proposed standard also includes provisions for medical surveillance and removal. The Agency believes that to the extent the proposal provides medical surveillance sooner and to more workers than would have been the case in the absence of the proposed standard, workers will be more likely to receive appropriate treatment and, where necessary, removal from beryllium exposure. These interventions may lessen the severity of beryllium-related illnesses, and possibly prevent premature death. The Agency requests public comment on this issue.

CBD Cases Prevented by the Ancillary Provisions of the Proposed Standard

The nature of the chronic beryllium disease process should be emphasized. As discussed in the preamble to the Proposed Standard at section V, Heath Effects, the chronic beryllium disease process involves two steps. First, workers become sensitized to beryllium. In most epidemiological studies of CBD conducted to date, a large percentage of sensitized workers have progressed to CBD. A certain percentage of the population has an elevated risk of this occurring, even at very low exposure levels, and sensitization can occur from dermal as well as inhalation exposure to beryllium.[431] For this reason, the threat of beryllium sensitization and CBD persist to a substantial degree, even at very low levels of airborne beryllium exposure. It is therefore desirable not only to significantly reduce airborne beryllium exposure, but to avoid nearly any source of beryllium exposure, so as to prevent beryllium sensitization.

The analysis presented above accounted only for CBD-prevention benefits associated with the proposed reduction of the PEL, from 2 ug/m^3 to 0.2 ug/m^3. However, the proposed standard also includes a variety of ancillary provisions—including requirements for respiratory protection, other personal protective equipment (PPE), housekeeping procedures, hygiene areas, medical surveillance, medical removal, and training—that the Agency believes would further reduce workers' risk of disease from beryllium exposure. These provisions were described in Chapter I of this PEA and discussed extensively in Section XVIII of the preamble, Summary and Explanation of the Proposed Standard.

The leading manufacturer of beryllium in the U.S., Materion Corporation (Materion), has implemented programs including these types of provisions in several of its plants and has worked

[431] The population characteristics referred to here are genetically based. There is additional discussion of this in the Health Effects section of the preamble.

with NIOSH to publish peer-reviewed studies of their effectiveness in reducing workers' risk of BeS and CBD. The Agency used the results of these studies to estimate the health benefits associated with a comprehensive standard for beryllium.

The best available evidence on comprehensive beryllium programs comes from studies of programs introduced at Materion plants in Reading, PA; Tucson, AZ; and Elmore, OH. These studies are discussed in detail in the preamble at Section VI, Preliminary Risk Assessment, and Section VIII, Significance of Risk. All three facilities were in compliance with the current PEL prior to instituting comprehensive programs, and had taken steps to reduce airborne levels of beryllium below the PEL, but their medical surveillance programs continued to identify cases of BeS and CBD among their workers. Beginning around 2000, these facilities introduced comprehensive beryllium programs that used a combination of engineering controls, dermal and respiratory PPE, and stringent housekeeping measures to reduce workers' dermal exposures and airborne exposures. These comprehensive beryllium programs have substantially lowered the risk of BeS among workers. At the times that studies of the programs were published, insufficient follow-up time had elapsed to report directly on the results for CBD. However, since only sensitized workers can develop CBD, reduction of BeS risk necessarily reduces CBD risk as well.

In the Reading, PA copper beryllium plant, full-shift airborne exposures in all jobs were reduced to a median of 0.1 ug/m^3 or below, and dermal protection was required for production-area workers, beginning in 2000-2001 (Thomas et al., 2009). In 2002, the process with the highest exposures (with a median of 0.1 ug/m^3) was enclosed, and workers involved in that process were required to use respiratory protection. Among 45 workers hired after the enclosure was built and respiratory protection instituted, one was found to be sensitized (2.2 percent). This is more than an 80 percent reduction in BeS from a previous group of 43 workers hired after 1992, 11.5 percent of whom had been sensitized by the time of testing in 2000.

In the Tucson beryllium ceramics plant, respiratory and skin protection was instituted for all workers in production areas in 2000 (Cummings et al., 2007). BeLPT testing in 2000-2004 showed that only 1 (1 percent) of 97 workers hired during that time period was sensitized to beryllium. This is a 90 percent reduction from the prevalence of sensitization in a 1998 BeLPT screening, which found that six (9 percent) of 69 workers hired after 1992 were sensitized.

In the Elmore, OH beryllium production and processing facility, all new workers were required to wear loose-fitting powered air-purifying respirators (PAPRs) in manufacturing buildings, beginning in 1999 (Bailey et al., 2010). Skin protection became part of the protection program for new workers in 2000, and glove use was required in production areas and for handling work boots, beginning in 2001. Bailey et al. (2010) found that 23 (8.9 percent) of 258 workers hired between 1993 and 1999, before institution of respiratory and dermal protection, were sensitized to beryllium. The prevalence of BeS among the 290 workers who were hired after the respiratory protection and PPE measures were put in place was about 2 percent, close to an 80 percent reduction in beryllium sensitization.

In a response to OSHA's 2002 Request for Information (RFI), Lee Newman et al. from National Jewish Medical and Research Center (NJMRC) summarized results of beryllium program effectiveness from several sources. Said Dr. Newman (in response to Question #33, (Newman et al., 2003)):

> *Q. 33. What are the potential impacts of reducing occupational exposures to beryllium in terms of costs of controls, costs for training, benefits from reduction in the number or severity of illnesses, effects on revenue and profit, changes in worker productivity, or any other impact measures than you can identify?*
>
> A: From experience in [the Tucson, AZ facility discussed above], one can infer that approximately 90% of beryllium sensitization can be eliminated. Furthermore, the preliminary data would suggest that potentially 100% of CBD can be eliminated with appropriate workplace control measures.
>
> In a study by Kelleher 2001, Martyny 2000, Newman, JOEM 2001 in a plant that previously had rates of sensitization as high as 9.7%, the data suggests that when lifetime

> weighted average exposures were below 0.02 µg per cu meter that the rate of sensitization fell to zero and the rate of CBD fell to zero as well.
>
> In an unpublished study, we have been conducting serial surveillance including testing new hires in a precision machining shop that handles beryllium and beryllium alloys in the Southeast United States. At the time of the first screening with the blood BeLPT of people tested within the first year of hire, we had a rate of 6.7% (4/60) sensitization and with 50% of these individuals showing CBD at the time of initial clinical evaluation. At that time, the median exposures in the machining areas of the plant was 0.47 µg per cu meter. Subsequently, efforts were made to reduce exposures, further educate the workforce, and increase monitoring of exposure in the plant. Ongoing testing of newly hired workers within the first year of hire demonstrated an incremental decline in the rate of sensitization and in the rate of CBD. For example, at the time of most recent testing when the median airborne exposures in the machining shop were 0.13 µg per cu meter, the percentage of newly hired workers found to have beryllium sensitization or CBD was now 0% (0/55). Notably, we also saw an incremental decline in the percentage of longer term workers being detected with sensitization and disease across this time period of exposure reduction and improved hygiene practices.
>
> Thus, in calculating the potential economic benefit, it’s reasonable to work with the assumption that with appropriate efforts to control exposures in the work place, rates of sensitization can be reduced by over 90%.

OSHA has reviewed these papers and is in agreement with Dr. Newman's testimony. OSHA judges Dr. Newman’s estimate to be an upper bound of the effectiveness of ancillary programs and examined the results of using Dr. Newman’s estimate that beryllium ancillary programs can reduce BeS by 90 percent, and potentially eliminate CBD where sensitization is reduced, because CBD can only occur where there is sensitization. OSHA applied this 90 percent reduction factor to all cases of CBD remaining after application of the reductions due to lowering the PEL alone. OSHA applied this reduction broadly because the proposed standard would require housekeeping and PPE related to skin exposure (18,000 of 28,000 employees will need PPE because of possible skin exposure) to apply to all or most employees likely to come in contact with beryllium and not just those with exposure above the action level. Table VII-1 shows that there are 11,017 baseline cases of CBD and that the proposed PEL of 0.2 ug/m^3 would prevent 2,563 cases through airborne prevention alone. The remaining number of cases of CBD is then 8,454 (11,017 minus 2,563). If OSHA applies the full ninety percent reduction factor to account for prevention of skin exposure (“non-airborne” protections), then 7,609 (90 percent of 8,454 cases) additional cases of CBD would be prevented.

The Agency recognizes that there are significant differences between the comprehensive programs discussed above and the proposed standard. While the proposed standard includes many of the same elements, it is generally less stringent. For example, the proposed standard’s requirements for respiratory protection and other PPE are narrower, and many provisions of the standard apply only to workers exposed above the proposed TWA PEL or STEL. However, many provisions, such as housekeeping and beryllium work areas, apply to all employers. To account for these differences, OSHA has provided a range of benefits estimates (shown in Table VII-1), first, assuming that there are no ancillary provisions to the standard, and, second, assuming that the comprehensive standard achieves the full 90-percent reduction in risk documented in existing programs. The Agency is taking the midpoint of these two numbers as its main estimate of the benefits of avoided CBD due to the ancillary provisions of the proposed standard.[432] The results in Table VII-1 suggest that approximately 60 percent of the beryllium sensitization cases and the CBD cases avoided would be attributable to the ancillary provisions of the standard. OSHA solicits comment on all aspects of this approach to analyzing ancillary provisions and solicits additional data that might serve to make more accurate estimates of the effects of ancillary provisions. OSHA is interested in the extent of the effects of ancillary provisions and whether these apply to all exposed employees or only those exposed above or below a given exposure level.

[432] This averaging procedure also reflects the lack of data on the effectiveness of these programs at a higher PEL than 0.2 μg/m^3. While there is undoubtedly a positive effect of these additional programmatic measures even at higher ambient exposures, the Agency has assigned a lower effectiveness value, or 45 percent, half of what is assumed for levels where the effect has been documented. As with the effect of these measures at lower ambient exposures, the Agency welcomes public comment on this issue.

Morbidity Only Cases

As previously indicated, the Agency does not believe that all CBD cases will ultimately result in premature death. While strong empirical data on this are currently lacking, the Agency estimates that approximately 35 percent of cases would not ultimately be fatal, but would result in some pain and suffering related to having CBD, and possible side effects from steroid treatment, as well as the dread of not knowing whether the disease will ultimately lead to premature death.[433] These would be described as "mild" cases of CBD relative to the others. These are the residual cases of CBD after cases with premature mortality have been counted. However, the Agency notes that some of these residual cases could involve more severe forms of CBD where the workers would have died from CBD if they had not died from other causes first. As indicated in Table VII-1, the Agency estimates the standard will prevent 2,228 morbidity cases not preceding death (midpoint) over 45 years, or an estimated 50 cases annually.

Lung Cancer

In addition to the Agency's determinations with respect to the risk of chronic beryllium disease, the Agency has also preliminarily determined that chronic beryllium exposure at the current PEL can lead to a significantly elevated risk of lung cancer. OSHA used the estimation methodology outlined at the beginning of this section. However, unlike with chronic beryllium disease, the underlying data were based on incidence of lung cancer and thus there was no need to address the possible limitations of prevalence data. The Agency used lifetime excess risk estimates of lung cancer mortality, presented in Table VI-20 in Section VI of the preamble, Preliminary Risk Assessment, to estimate the benefits of avoided lung cancer mortality. The lung cancer risk estimates are derived from one of the models a recent NIOSH lung cancer study, and are based on average exposure levels. The estimates of excess lifetime risk of lung cancer were taken from the line in Table VI-20 in the risk assessment labeled PWL (piecewise log-linear) not including professional and asbestos workers. This model avoids possible

[433] The 35 percent estimate parallels the 15-30 percent of CBD cases that are currently presumed to proceed more directly toward death, and the perhaps 35-50 percent of cases Newman, et al. (2003) described as "typical"—ones can be stabilized for an extended period, but ultimately result in premature death.

confounding from asbestos exposure and reduces the potential for confounding due to smoking, as smoking rates and beryllium exposures can be correlated via professional worker status. Of the three estimates in the NIOSH study that excluded professional workers and those with asbestos exposure, this model was chosen because it was at the midpoint of risk results.

As indicated previously in the context of CBD, this benefits analysis assumes that exposures currently below 0.1 $\mu g/m^3$ are equal to 0.1 $\mu g/m^3$. While the risk assessment section does not provide data on cancer risk below 0.1 $\mu g/m^3$, this assumption may theoretically result in an overestimate of baseline cancers if in fact the risk below 0.1 $\mu g/m^3$ is lower than at an exposure of 0.1 $\mu g/m^3$. However, it would have no bearing on the incremental effects of lowering the PEL to 0.2 $\mu g/m^3$, or the alternative of a 0.1 $\mu g/m^3$ PEL.

Combining the two major fatal health endpoints—for lung cancer and CBD-related mortality—OSHA estimates that the proposed PEL would prevent between 1,846 and 6,791 premature fatalities over the lifetime of the current worker population, with a midpoint estimate of 4,318 fatalities prevented. This is the equivalent of between 41 and 151 premature fatalities avoided annually, with a midpoint estimate of 96 premature fatalities avoided annually, given a 45-year working life of exposure.

Table VII-1 Prevented Mortality and Morbidity by PEL Option (45-Year Working Life Case) (Quartile Model)									
Airborne Factor Only									
	Baseline Total Cases	**PEL Option (µg/m^3)**				**Baseline Annual Cases**	**PEL Option (µg/m^3)**		
		Total Number of Avoided Cases					**Annual Number of Avoided Cases**		
		0.1	**0.2**	**0.5**			**0.1**	**0.2**	**0.5**
Total Cases									
Be S	16,240	3,826	3,594	3,503		361	85.0	79.9	77.9
CBD	11,017	2,763	2,563	2,463		245	61.4	56.9	54.7
Mortality									
Lung Cancer	279	192	180	163		6.2	4.3	4.0	3.6
CBD-Related	7,161	1,796	1,666	1,601		159	39.9	37.0	35.6
Total Mortality	7,440	1,988	1,846	1,764		165	44.2	41.0	39.2
Morbidity	3,856	967	897	862		86	21.5	19.9	19.2
Non-Airborne Factor Included									
	Baseline Total Cases	**PEL Option (µg/m^3)**				**Baseline Annual Cases**	**PEL Option (µg/m^3)**		
		Total Number of Avoided Cases					**Annual Number of Avoided Cases**		
		0.1	**0.2**	**0.5**			**0.1**	**0.2**	**0.5**
Total Cases									
Be S	16,240	14,998	14,975	9,235		361	333.3	332.8	205.2
CBD	11,017	10,191	10,171	6,312		245	226.5	226.0	140.3
Mortality									
Lung Cancer	279	192	180	163		6	4.3	4.0	3.6
CBD-Related	7,161	6,624	6,611	4,103		159	147.2	146.9	91.2
Total Mortality	7,440	6,816	6,791	4,266		165	151.5	150.9	94.8
Morbidity	3,856	3,567	3,560	2,209		86	79.3	79.1	49.1
Midpoint Estimates									
	Baseline Total Cases	**PEL Option (µg/m^3)**				**Baseline Annual Cases**	**PEL Option (µg/m^3)**		
		Total Number of Avoided Cases					**Annual Number of Avoided Cases**		
		0.1	**0.2**	**0.5**			**0.1**	**0.2**	**0.5**
Total Cases									
Be S - Total	16,240	9,412	9,284	6,369		361	209.2	206.3	141.5
CBD	11,017	6,477	6,367	4,387		245	143.9	141.5	97.5
Mortality									
Lung Cancer	279	192	180	163		6	4.3	4.0	3.6
CBD-Related	7,161	4,210	4,139	2,852		159	93.6	92.0	63.4
Total Mortality	7,440	4,402	4,318	3,015		165	97.8	96.0	67.0
Morbidity	3,856	2,267	2,228	1,536		86	50.4	49.5	34.1
Source: Office of Regulatory Analysis, Directorate of Standards and Guidance									

An Alternate Assumption of Exposure History

Note that the Agency based its estimates of reductions in the number of beryllium-related diseases over a working life of constant exposure for workers who are employed in a beryllium-exposed occupation for their entire working lives, from ages 20 to 65. In other words, workers are assumed not to enter or exit jobs with beryllium exposure mid-career or to switch to other exposure groups during their working lives. While the Agency is legally obligated to examine the effect of exposures from a working lifetime of exposure and set its standard accordingly,[434] in an alternative analysis purely for informational purposes, using the same underlying risk model for CBD, the Agency examined, in Table VII-2, the effect of assuming that workers are exposed for a maximum of only 25 working years, as opposed to the 45 years assumed in the main analysis. While all workers are assumed to have less cumulative exposure under the 25-years-of-exposure assumption, the effective exposed population over time is proportionately increased.

A comparison of Table VII-2 to Table VII-1, reflecting exposures over a maximum of 25 working years versus over a potentially 45-year working life, shows variations in the number of estimated prevented cases by health outcome. For chronic beryllium disease, there is a substantial increase in the number of estimated baseline and prevented cases if one assumes that the typical maximum exposure period is 25 years, as opposed to 45. This reflects the relatively flat CBD risk function within the relevant exposure range, given varying levels of airborne beryllium exposure—shortening the average tenure and increasing the exposed population over time translates into larger total numbers of people sensitized to beryllium. This, in turn, results in

[434] Section (6)(b)(5) of the OSH Act states: "The Secretary, in promulgating standards dealing with toxic materials or harmful physical agents under this subsection, shall set the standard which most adequately assures, to the extent feasible, on the basis of the best available evidence, that no employee will suffer material impairment of health or functional capacity even if such employee has regular exposure to the hazard dealt with by such standard for the period of his working life." Given that it is necessary for OSHA to reach a determination of significant risk over a working life, it is a logical extension to estimate what this translates into in terms of estimated benefits for the affected population over the same period.

larger populations of individuals contracting CBD. Since the lung cancer model itself is based on average, as opposed to cumulative, exposure, it is not adaptable to estimate exposures over a shorter period of time. As a practical matter, however, over 90 percent of illness and mortality attributable to beryllium exposure in this analysis comes from CBD.

Overall, the 45-year-maximum-working-life assumption yields smaller estimates of the number of cases of avoided fatalities and illnesses than does the maximum-25-years-of-exposure assumption. For example, the midpoint estimates of the number of avoided fatalities and illnesses related to CBD under the proposed PEL of 0.2 $\mu g/m^3$ increases from 92 and 50, respectively, under the 45-year-maximum-working-life assumption to 147 and 79, respectively, under the 25-year-maximum-working-life assumption—or approximately a 60 to 63 percent increase.[435]

[435] Technically, this analysis assumes that workers receive up to 25 years' worth of beryllium exposure, but that they receive it over 45 working years, as is assumed by the risk models in the risk assessment. It also accounts for the turnover implied by 25, as opposed to 45, maximum years of work. However, it is possible that an alternate analysis, which accounts for the larger number of post-exposure worker-years implied by workers departing their jobs before the end of their working lifetime, might find even larger health effects for workers receiving up to 25 years' worth of beryllium exposure.

Table VII-2

Prevented Mortality and Morbidity by PEL Option (25-Year Working Life Case)

Airborne Factor Only

	Baseline Total Cases	PEL Option (μg/m^3) Total Number of Avoided Cases			PEL Option (μg/m^3) Annual Number of Avoided Cases		
		0.1	**0.2**	**0.5**	**0.1**	**0.2**	**0.5**
Total Cases							
Be S	25,425	7,133	6,345	5,976	158.5	141.0	132.8
CBD	17,133	5,000	4,470	4,179	111.1	99.3	92.9
Mortality							
Lung Cancer	NA	NA	NA	NA	NA	NA	NA
CBD-Related	11,136	3,250	2,905	2,716	72.2	64.6	60.4
Total Mortality	NA	NA	NA	NA	NA	NA	NA
Morbidity	5,996	1,750	1,564	1,463	38.9	34.8	32.5

Non-Airborne Factor Included

	Baseline Total Cases	PEL Option (μg/m^3) Total Number of Avoided Cases			PEL Option (μg/m^3) Annual Number of Avoided Cases		
		0.1	**0.2**	**0.5**	**0.1**	**0.2**	**0.5**
Total Cases							
Be S	25,425	16,462	44,373	31,891	365.8	986.1	708.7
CBD	17,133	15,919	15,866	10,008	353.8	352.6	222.4
Mortality							
Lung Cancer	NA	NA	NA	NA	NA	NA	NA
CBD-Related	11,136	10,348	10,313	6,505	229.9	229.2	144.6
Total Mortality	NA	NA	NA	NA	NA	NA	NA
Morbidity	5,996	5,572	5,553	3,503	123.8	123.4	77.8

idpoint Estimates

	Baseline Total Cases	PEL Option (μg/m^3) Total Number of Avoided Cases			PEL Option (μg/m^3) Annual Number of Avoided Cases		
		0.1	**0.2**	**0.5**	**0.1**	**0.2**	**0.5**
Total Cases							
Be S - Total	25,425	11,798	25,359	18,933	262.2	563.5	420.7
CBD	17,133	10,460	10,168	7,094	232.4	226.0	157.6
Mortality							
Lung Cancer	NA	NA	NA	NA	NA	NA	NA
CBD-Related	11,136	6,799	6,609	4,611	151.1	146.9	102.5
Total Mortality	NA	NA	NA	NA	NA	NA	NA
Morbidity	5,996	3,661	3,559	2,483	81.4	79.1	55.2

Source: Office of Regulatory Analysis, Directorate of Standards & Guidance

STEP 2 - ESTIMATING THE STREAM OF BENEFITS OVER TIME

Risk assessments in the occupational environment are generally designed to estimate the risk of an occupationally related illness over the course of an individual worker's lifetime. As demonstrated previously in this chapter, the current occupational exposure profile for a particular substance for the current cohort of workers can be matched up against the expected profile after the proposed standard takes effect, creating a "steady state" estimate of benefits. However, in order to annualize the benefits for the period of time after the beryllium rule takes effect, it is necessary to create a timeline of benefits for an entire active workforce over that period.

In order to estimate the benefits of the standard over time, one has to consider that workers currently being exposed to beryllium are going to vary considerably in age and past exposure level Since the calculated health risks from beryllium exposure depend on a worker's cumulative exposure over a working lifetime, the overall benefits of the proposed standard will phase in over several decades, as the cumulative exposure gradually falls for all age groups, until those now entering the workforce reach retirement and the annual stream of beryllium-related illnesses reaches a new, significantly lowered "steady state."[436] That said, the near-term impact of the proposed rule estimated for those workers with similar current levels of cumulative exposure will be greater for workers who are now middle-aged or older. This conclusion follows in part from the structure of

[436] Technically, the RA lung cancer model is based on average exposure, Nonetheless, as noted in the RA, the underlying studies found lung cancer to be significantly related to cumulative exposure. Particularly since the large majority of the benefits are related to CBD, the Agency considers this fairly descriptive of the overall phase-in of benefits from the standard.

the relative risk model used for lung cancer in this analysis and the fact that the background mortality rates for lung cancer increase with age.[437]

In order to characterize the magnitude of benefits before the steady state is reached, OSHA created a linear phase-in model to reflect the potential timing of benefits. Specifically, OSHA estimated that, for all non-cancer cases, while the number of cases of beryllium-related disease would gradually decline as a result of the proposed rule, they would not reach the steady-state level until 45 years had passed. The reduction in cases estimated to occur in any given year in the future was estimated to be equal to the steady-state reduction (the number of cases in the baseline minus the number of cases in the new steady state) times the ratio of the number of years since the standard was implemented and a working life of 45 years. Expressed mathematically:

$$N_t = (C - S) \times (t / 45),$$

where N_t is the number of non-malignant beryllium-related diseases avoided in year t; C is the current annual number of non-malignant beryllium-related diseases; S is the steady-state annual number of non-malignant beryllium-related diseases; and t represents the number of years after the proposed standard takes effect, with $t \leq 45$.

In the case of lung cancer, the function representing the decline in the number of beryllium-related cases as a result of the proposed rule is similar, but there would be a 10-year lag before any reduction in cancer cases would be achieved. Expressed mathematically, for lung cancer:

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[437] As previously discussed, the CBD estimate is based on an empirical analysis of exposures and disease in industry (the quartile analysis), as opposed to a relative risk model. This was necessary as CBD is almost entirely occupational in nature and has no meaningful background rate. Nonetheless, previously exposed workers would still benefit from reduced future exposure.

$$L_t = (C_m - S_m) \times ((t\text{-}10) / 45)),$$

where $10 \leq t \leq 55$ and L_t is the number of lung cancer cases avoided in year t as a result of the proposed rule; C_m is the current annual number of beryllium-related lung cancers; and S_m is the steady-state annual number of beryllium-related lung cancers.

This model was extended to 60 years for all the health effects previously discussed in order to incorporate the 10 year lag, in the case of lung cancer, and a maximum 45-year working life, as well as to capture some occupationally-related disease that manifests itself after retirement. (The left-hand columns in the tables in Appendix VII-A provide estimates using this model of the stream of prevented fatalities and illnesses due to the proposed beryllium rule.) Because the rule, if finalized, will be in effect indefinitely, stopping the benefits analysis at 60 years is arbitrary; however, the longer into the future the analysis extends, the more subject it is to uncertainty, but the greater the benefits if conditions hold constant.[438] An internal analysis by OSHA indicated that, both in terms of cases prevented, and even with regard to monetized benefits, particularly when lower discount rates are used, the estimated benefits of the standard are larger on an annualized basis if the analysis extends further into the future. The Agency welcomes comment on the merit of choosing some time horizon other than the 60 years analyzed in the PEA.

In order to compare costs to benefits, OSHA assumes that economic conditions remain constant and that annualized costs—and the underlying costs—will repeat for the entire 60-year time horizon used for the benefits analysis (as discussed in Chapter V of

[438] A longer time horizon allows for greater probability that new cures or treatments for beryllium-related illnesses could be developed or that changes could occur in the affected industries (e.g., manufacturing activity could move to foreign locations out of OSHA's jurisdiction or new uses of beryllium could be found). These and many other difficult-to-project phenomena would change the costs and benefits attributable to the proposed rule.

this PEA). OSHA welcomes comments on the assumption for both the benefit and cost analysis that economic conditions remain constant for sixty years. OSHA is particularly interested in what assumptions and time horizon should be used instead and why.

Separating the Timing of Mortality

In previous sections, OSHA modeled the timing and incidence of morbidity. OSHA's benefit estimates are based on an underlying CBD-related mortality rate of 65 percent. However, this mortality is not simultaneous with the onset of morbidity. Although mortality from CBD has not been well studied, OSHA believes, based on discussions with experienced clinicians, that the average lag for a larger population has a range of 10 to 30 years between morbidity and mortality. The Agency's review of Workers Compensation data related to beryllium exposure from the Office of Worker Compensation Programs (OWCP)'s Division of Energy Employees Occupational Illness Compensation is consistent with this range. . Hence, for the purposes of this proposal, OSHA estimates that mortality occurs on average 20 years after the onset of CBD morbidity. Thus, for example, the prevented deaths that would have occurred in year 21 after the promulgation of the rule are associated with the CBD morbidity cases prevented in year 1. OSHA requests comment on this estimate and range.

The Agency invites comment on each of these elements of the analysis, particularly on the estimates of the expected life expectancy of a patient with CBD.

STEP 3 - MONETIZING THE BENEFITS OF THE PROPOSED RULE

OSHA has also provided estimates of the monetary value of the benefits associated with the proposed rule. These estimates are for informational purposes only because OSHA cannot use benefit-cost analysis as a basis for determining the PEL for a health standard. The Agency's methodology for monetizing benefits was based on both the relevant academic literature and on the approaches OSHA and other regulatory agencies have taken in the past for similar regulatory actions.

Placing a Monetary Value on Individual Beryllium-Related Fatalities Avoided

To estimate the monetary value of the reductions in the number of beryllium-related fatalities, OSHA relied, as OMB recommends, on estimates developed from the willingness of affected individuals to pay to avoid a marginal increase in the risk of fatality. [439] While a willingness-to-pay (WTP) approach clearly has theoretical merit, it should be noted that an *individual's* willingness to pay to reduce the risk of fatality may tend to underestimate the total willingness to pay, which could include the willingness of others—particularly the immediate family—to pay to reduce that individual's risk of fatality.[440] For estimates using the willingness-to-pay concept, OSHA relied on existing studies of the imputed value of fatalities avoided based on the theory of compensating wage differentials in the labor market. These studies rely on certain critical assumptions

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[439] See (OMB, 2003), pp. 18-19.

[439] See, for example, Thaler and Rosen (1976, pp. 265-266), Sunstein (2004, p. 433); or Viscusi, Magat and Forrest (1988), the last of whom write that benefits from improvement in public health "consist of two components, the private valuation consumers attach to their own health, plus the altruistic valuation other members of society place on their health." This paper uses contingent valuation methods to suggest that the effect of altruism could alter willingness-to-pay estimates for some kinds of health improvement. There are, however, many questions concerning how to measure this and the conditions under which it might matter.

for their accuracy, particularly that workers understand the risks to which they are exposed and that workers have legitimate choices between high- and low-risk jobs. These assumptions are far from obviously met in actual labor markets.[441] A number of academic studies, as summarized in Viscusi and Aldy (2003), have shown a correlation between higher job risk and higher wages, suggesting that employees demand monetary compensation in return for a greater risk of injury or fatality. The estimated trade-off between lower wages and marginal reductions in fatal occupational risk—that is, workers' willingness to pay for marginal reductions in such risk—yields an imputed value of an avoided fatality: the willingness-to-pay amount for a reduction in risk divided by the reduction in risk.[442]

OSHA has used this approach in many recent proposed and final rules. (See, for example, the preambles for the proposed and final hexavalent chromium rule (OSHA, 2004; OSHA, 2006), and the preamble for the proposed respirable crystalline silica rule (OSHA, 2013).) This approach has been criticized for yielding results that are less than statistically robust (see, for example: (Hintermann, Alberini, and Markandya, 2010).) A more recent WTP analysis, by Kniesner et al. (2012), of the trade-off between fatal job risks and wages, using panel data, seems to address many of the earlier econometric criticisms by controlling for measurement error, endogeneity, and heterogeneity. In conclusion, the Agency views the WTP approach as the best available and will rely on it

[441] On the former assumption, see the discussion in Chapter II of this PEA on imperfect information. On the latter, see, for example, the discussion of wage compensation for risk for union versus nonunion workers in Dorman and Hagstrom (1998).

[442] For example, if workers are willing to pay $90 each for a 1/100,000 reduction in the probability of dying on the job, then the imputed value of an avoided fatality would be $90 divided by 1/100,000, or $9,000,000. Another way to consider this result would be to assume that 100,000 workers made this trade-off. On average, one life would be saved at a cost of $9,000,000.

to monetize benefits.[443] OSHA welcomes comments on the use of willingness-to-pay measures and estimates based on compensating wage differentials.

Viscusi and Aldy (2003) conducted a meta-analysis of studies in the economics literature that use a willingness-to-pay methodology to estimate the imputed value of life-saving programs and found that each fatality avoided was valued at approximately $7 million in 2000 dollars. Using the GDP Deflator (BEA, 2010), this $7 million base number in 2000 dollars yields an estimate of $8.7 million in 2010 dollars for each fatality avoided.[444, 445]

<u>Placing a Monetary Value on Individual Beryllium-Related Diseases Avoided</u>

In addition to the benefits that are based on the implicit value of fatalities avoided, workers also place an implicit value on occupational injuries or illnesses avoided, which reflect their willingness to pay to avoid monetary costs (for medical expenses and lost wages) and quality-of-life losses as a result of occupational illness. Chronic beryllium disease and lung cancer can adversely affect individuals for years, or even decades, in

[443] Note that, consistent with the economics literature, most of the available VSL estimates are for reducing the risk of an acute (immediate) fatality. They do not include an individual's willingness to pay to avoid a higher risk of illness prior to fatality, which is separately estimated in the following section.

[444] The Agency notes that two recent studies mentioned in this chapter—Kniesner et al. (2010) and Kniesner et al. (2012)—report similar estimates. The median quintile estimate of the imputed value of an avoided fatality in Kniesner et al. (2010) is $9.2 million in 2010 dollars, while Kniesner et al. (2012) provide a range of estimates between approximately $5 million and $12 million in 2012 dollars. For the purpose of this PEA, OSHA has chosen to rely on the Viscusi and Aldy (2003) meta-analysis rather than the two more recent individual studies.

[445] An alternative approach to valuing an avoided fatality is to monetize, for each year that a life is extended, an estimate from the economics literature of the value of that statistical life-year (VSLY). See, for instance, (Aldy and Viscusi, 2007) for discussion of VSLY theory and (FDA, 2003), pp. 41488-9, for an application of VSLY in rulemaking. The VSL and VSLY approaches may yield more similar results for this beryllium rulemaking than they would in some other regulatory contexts because deaths from CBD are frequently not delayed until old age. OSHA welcomes comment on the issue.

non-fatal cases, or before ultimately proving fatal. Because measures of the benefits of avoiding these illnesses are rare and difficult to find, OSHA has included a range based on a variety of estimation methods.

For both CBD and lung cancer, there is typically some permanent loss of lung function and disability, on-going medical treatments, side effects of medicines, and major impacts on one's ability to work, marry, enjoy family life, and quality of life.

While diagnosis with CBD is evidence of material impairment of health, placing a precise monetary value on this condition is difficult, in part because the severity of symptoms may vary significantly among individuals. For that reason, for this preliminary analysis, the Agency employed a broad range of valuation, which should encompass the range of severity these individuals may encounter.

Using the willingness-to-pay approach, discussed in the context of the imputed value of fatalities avoided, OSHA has estimated a range in valuations (updated and reported in 2010 dollars) that runs from approximately $62,000 per case—which reflects estimates developed by Viscusi and Aldy (2003), based on a series of studies primarily describing simple accidents—to upwards of $5 million per case—which reflects work developed by Magat, Viscusi, and Huber (1996) for non-fatal cancer. The latter number is based on an approach that places a willingness-to-pay value to avoid serious illness that is calibrated relative to the value of an avoided fatality. OSHA previously used this approach in the Preliminary Economic Analysis (PEA) supporting its respirable crystalline silica proposal (OSHA, 2013) and in the Final Economic Analysis (FEA) supporting its hexavalent chromium final rule (OSHA, 2006), and EPA (EPA, 2003) used this approach in its Stage 2 Disinfection and Disinfection Byproducts Rule concerning regulation of primary drinking water. Based on Magat, Viscusi, and Huber (1996), EPA used studies on the willingness to pay to avoid nonfatal lymphoma and chronic bronchitis as a basis for valuing a case of nonfatal cancer at 58.3 percent of the value of a fatal cancer. OSHA's estimate of $5 million for an avoided case of non-fatal cancer is based on this 58.3 percent figure.

There are several indirect benchmarks for valuation of health impairment due to beryllium exposure, using a variety of techniques, which provide a number of mid-range estimates between OSHA's high and low estimates, by looking at other forms of lung impairment. For example, EPA (2008) recently estimated a cost of approximately $460,000, in 2008 dollars, per case of chronic bronchitis, which OSHA (2009) used as the basis for comparison with less severe lung impairments from diacetyl exposure.

Another approach is to employ a cost-of-injury model. Combining estimates of loss of income, medical cost, and loss of quality-of-life components, Miller (2005), using an enhanced cost-of-injury model, estimated the average silicosis disease cost the equivalent of $317,000 per case, in 2009 dollars.[446] While different conditions, silicosis and CBD have several similarities: both are progressive diseases; both are a form of pneumoconiosis; and both cause fibrosis. Disease progression can last decades in both cases. Both cause debilitative conditions—shortness of breath to loss of pulmonary function, loss of appetite, and cor pulmonale. Miller (2005) also estimated the morbidity costs of several different pneumoconioses other than silicosis and found the other cases to be even more costly to society than silicosis. This suggests that a more precise WTP estimate of CBD would produce an estimate well above the $62,000 estimate of injuries

[446] Miller (2005) estimated the cost of a silicosis case, using an enhanced direct cost approach—including a quality-adjusted-life-years (QALY) component—to be $265,808 in 2002 dollars.

in (Viscusi and Aldy, 2003). Moreover, several studies (e.g., Alberini and Krupnick, 2000) have found that the cost of injury approach tends to significantly underestimate the true economic cost of an injury or illness, relative to the willingness to pay approach, which tends to include quality of life impacts and psychic costs as well as lost income and the portion of medical costs patients themselves pay.

Specifically, for chronic beryllium disease, an estimate of $1.45 million was proposed in 2000 to account for direct morbidity and medical costs (Bartell, et al., 2000). The authors noted that while a willingness to pay estimate specific to CBD is not available, it would likely run substantially higher than $1.45 million. Adjusted to 2010 dollars, the direct cost estimate would be about $1.8 million. This appears to be generally consistent with the midpoint (between $62,000 and $5 million) willingness-to-pay estimate of $2.58 million that OSHA is using.

Therefore, as discussed, the various studies presented in this section suggest that the imputed value of avoided morbidity associated with beryllium exposure, for cases preceding death, ranges between $62,000 and $5 million. The Agency believes this range of estimates is descriptive of the value of preventing morbidity associated with the trauma of CBD that ultimately results in premature death. As discussed previously, the Agency has estimated that 65 percent of CBD cases would hypothetically result in premature mortality. However, the Agency acknowledges that it is possible there have been new developments in medicine and industrial hygiene related to the benefits of early detection, medical intervention, and greater control of exposure achieved within the past decade. For that reason, as elsewhere, the Agency requests comment on these issues.

Also not clear are the negative effects of the illness in terms of lost productivity, medical costs, and potential side-effects of a lifetime of immunosuppressive medication. Nonetheless, the Agency is assigning a valuation of $62,000 per case, to reflect the WTP value of a prevented injury not estimated to precede premature mortality. The Agency believes this is conservative, in part because, with any given case of CBD, the outcome is not known in advance, certainly not at the point of discovery; indeed much of the psychic value of preventing the cases may come from removing the threat of premature mortality. In addition, as previously noted, some of these cases could involve relatively severe forms of CBD where the worker died of other causes; however, in those cases, the duration of the disease would be shortened. While beryllium sensitization is a critical precursor of CBD, this preliminary analysis does not attempt to assign a separate value to sensitization itself.

Particularly given the uncertainties in valuation on these questions, the Agency is interested in public input on the issue of valuing the cost to society of morbidity associated with CBD, both in cases preceding mortality, and those that may not result in premature mortality. The Agency is also interested in comments on whether it is appropriate to assign a separate valuation to prevented sensitization cases in their own right, and if so, how such cases should be valued.

Summary of Monetized Benefits

Table VII-3 presents the estimated annualized (over 60 years, using a 0 percent discount rate) benefits from each of these components of the valuation, and the range of estimates, based on uncertainty of the prevention factor (i.e., the estimated range of prevented cases, depending on how large an impact the rule has on cases beyond an airborne-only effect), and the range of uncertainty regarding valuation of morbidity. Mid-point estimates of the undiscounted benefits for each of the first 60 years are provided in the middle columns of Table VII-A-1 in Appendix VII-A at the end of this chapter. For the period examined, the estimates reach a peak of $3.5 billion in the 60th year. Note that, by using a 60-year time-period, OSHA is not including any monetized fatality benefits associated with reduced worker CBD cases originating after year 40 because the 20-year lag takes these CBD fatalities beyond the 60-year time horizon. To this extent, OSHA will have underestimated benefits.

As shown in Table VII-3, the full range of monetized benefits, undiscounted, for the proposed PEL of 0.2 $\mu g/m^3$ runs from $291 million annually, in the case of the lowest estimated of prevented cases of CBD, and the lowest valuation for morbidity, up to $2.1 billion annually, for the highest of both. Note that the value of total benefits is more sensitive to the prevention factor used (ranging from $430 million to $1.6 billion, given estimates at the midpoint of the morbidity valuation) than to the valuation of morbidity (ranging from $666 million to $1.3 billion, given estimates at the midpoint of prevention factor).[447]

Also, the analysis illustrates that most of the morbidity benefits are related to CBD and lung cancer cases that are ultimately fatal. At the valuation and case frequency midpoint, $653 million in benefits are related to mortality, $226 million are related to

[447] As previously indicated, these valuations include all the various estimated health endpoints. In the case of mortality this includes lung cancer and CBD. The Agency highlighted uncertainty about the percentage of CBD cases that would be prevented by the proposal. In calculating the monetized benefits from this point on in the PEA, the Agency is typically referring to the midpoint of the high and low ends of potential valuation, assuming the midpoint of CBD cases prevented—in this case, the undiscounted midpoint of $665 million and $1.3 billion, or $995 million, if benefits are undiscounted, as shown in Table VII-3.

severe morbidity preceding mortality, and $4.3 million are related to “mild” cases of morbidity not preceding mortality.

TABLE VII-3

Estimated Annualized Undiscounted Monetized Benefits of the Beryllium Proposal for Morbidity and Mortality

PEL	0.1 μg/m^3			0.2 μg/m^3			0.5 μg/m^3		
	Valuation			Valuation			Valuation		
	Low	Midpoint	High	Low	Midpoint	High	Low	Midpoint	High
Cases									
Fatalities - Total									
Low	$308,027,593	$308,027,593	$308,027,593	$285,909,109	$285,909,109	$285,909,109	$272,760,749	$272,760,749	$272,760,749
Midpoint	$666,610,424	$666,610,424	$666,610,424	$653,373,439	$653,373,439	$653,373,439	$458,581,095	$458,581,095	$458,581,095
High	$1,025,193,255	$1,025,193,255	$1,025,193,255	$1,020,660,530	$1,020,660,530	$1,020,660,530	$644,401,440	$644,401,440	$644,401,440
Morbidity Preceding Mortality - CBD and lung cancer deaths									
Low	$3,765,360	$153,711,707	$303,658,053	$3,495,142	$142,680,735	$281,866,327	$3,343,232	$136,479,355	$269,615,478
Midpoint	$8,431,448	$344,193,474	$679,955,500	$8,274,496	$337,786,267	$667,298,039	$5,761,234	$235,188,453	$464,615,672
High	$13,097,537	$534,675,242	$1,056,252,947	$13,053,849	$532,891,800	$1,052,729,751	$8,179,237	$333,897,551	$659,615,865
Morbidity Not Preceding Mortality									
Low	$1,869,166	$1,869,166	$1,869,166	$1,733,636	$1,733,636	$1,733,636	$1,665,847	$1,665,847	$1,665,847
Midpoint	$4,381,675	$4,381,675	$4,381,675	$4,307,133	$4,307,133	$4,307,133	$2,967,849	$2,967,849	$2,967,849
High	$7,320,735	$7,320,735	$7,320,735	$7,306,343	$7,306,343	$7,306,343	$4,321,800	$4,321,800	$4,321,800
TOTAL									
Low	$313,662,119	$463,608,465	$613,554,812	$291,137,887	$430,323,479	$569,509,072	$277,769,829	$410,905,952	$544,042,075
Midpoint	$679,423,547	$1,015,185,573	$1,350,947,599	$665,955,068	$995,466,840	$1,324,978,612	$467,310,178	$696,737,396	$926,164,615
High	$1,045,611,526	$1,567,189,232	$2,088,766,937	$1,041,020,722	$1,560,858,673	$2,080,696,625	$656,902,477	$982,620,791	$1,308,339,106

Source: Office of Regulatory Analysis, Directorate of Standards & Guidance

Adjustment of WTP Estimates to Reflect Rising Real Income over Time

OSHA's estimates of the monetized benefits of the proposed rule are based on the imputed value of each avoided fatality and each avoided beryllium-related disease. As previously discussed, these, in turn, are derived from a worker's willingness to pay to avoid a fatality (with an imputed value per fatality avoided of $8.7 million in 2010 dollars) and to avoid a beryllium-related disease (with an imputed value per disease avoided of between $62,000 and $5 million in 2010 dollars). To this point, these imputed values have been assumed to remain constant over time. However, two related factors suggest that these values will tend to increase over time.

First, economic theory indicates that the value of reducing life-threatening and health-threatening risks—and correspondingly the willingness of individuals to pay to reduce these risks—will increase as real per capita income increases.[448] With increased income, an individual's health and life becomes more valuable relative to other goods because, unlike most other goods, they are without close substitutes. Expressed differently, as income increases, consumption will increase but the marginal utility of consumption will decrease. In contrast, added years of life (in good health) is, in the model of Hall and Jones (2007), not subject to the same type of diminishing returns—implying that an effective way to increase lifetime utility is by extending one's life and maintaining one's good health.

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[448] Simple modeling can show this directly. For example, Rosen (1988) demonstrates that the value of life can be expressed as the marginal rate of substitution between wealth and the probability of survival. An increase in wealth or income will therefore increase the value of life (except perhaps for persons whose welfare increases directly with increased risk).

Second, real per capita income has broadly been increasing throughout U.S. history, including recent periods.[449] For example, for the period 1950 through 2000, real per capita income grew at an average rate of 2.31 percent a year (Hall and Jones, 2007),[450] although real per capita income for the recent 25 year period 1983 through 2008 grew at an average rate of only 1.3 percent a year (U.S. Census Bureau, 2010). More important is the fact that real U.S. per capita income is projected to grow significantly in future years. For example, the Annual Energy Outlook (AEO) projections, prepared by the Energy Information Administration (EIA) in the Department of Energy (DOE), show an average annual growth rate of per capita income in the United States of 2.7 percent for the period 2011-2035.[451] The U.S. Environmental Protection Agency prepared its economic analysis of the Clean Air Act using the AEO projections. OSHA believes that it is reasonable to use the same AEO projections employed by DOE and EPA, and correspondingly projects that per capita income in the United States will increase by 2.7 percent a year.

On the basis of the predicted increase in real per capita income in the United States over time and the expected resulting increase in the value of avoided fatalities and

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[449] In addition, as Costa (1998) and Costa and Kahn (2004) point out, elderly health, longevity, and well-being in the United States have historically been improving, which also has the effect of increasing the imputed value of life. Of course, improvements in elderly health, longevity, and well-being are not independent of increases in per capita income over the same period.

[450] The results are similar if the historical period includes a major economic downturn (such as the United States has recently experienced). From 1929 through 2003, a period in U.S. history that includes the Great Depression, real per capita income still grew at an average rate of 2.22 percent a year (Gomme and Rupert, 2004).

[451] The EIA used DOE's National Energy Modeling System (NEMS) to produce the AEO projections (EIA, 2011). Future per capita GDP was calculated by dividing the projected real gross domestic product each year by the projected U.S. population for that year.

diseases, OSHA has adjusted its estimates of the benefits of the proposed rule to reflect the anticipated increase in their value over time. This type of adjustment has been supported by EPA's Science Advisory Board (EPA, 2000) and by EPA (2010) and Department of Transportation (2014) guidelines, and applied by EPA[452]. OSHA proposes to carry out this adjustment by modifying benefits in year i from [B_i] to [$B_i * (1 + k)^i$], where "k" is the estimated annual increase in the magnitude of the benefits of the proposed rule.[453]

What remains is to estimate a value for "k" with which to increase benefits annually in response to annual increases in real per capita income., where "k" is equal to "g * (η)", "g" is the expected annual percentage increase in real per capita income, and "η" is the income elasticity of the value of a statistical life. Probably the most direct evidence of the value of "k" comes from the work of Costa and Kahn (2003, 2004). They estimate repeated labor market compensating wage differentials from cross-sectional hedonic regressions using census and fatality data from the Bureau of Labor Statistics for 1940, 1950, 1960, 1970, and 1980. In addition, with the imputed income elasticity of the value of life on per capita GNP of 1.7 derived from the 1940-1980 data, they then predict the value of an avoided fatality in 1900, 1920, and 2000. Given the change in the value of an avoided fatality over time, it is possible to estimate a value of "k" of 3.4 percent a year from 1900-2000; of 4.3 percent a year from 1940-1980; and of 2.5 percent a year from 1980-2000.[454]

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[452] See, for example, EPA (2003, 2008).

[453] This precise methodology was suggested in Ashford and Caldart (1996).

[454] These estimates for "k" were not reported in Costa and Kahn (2003, 2004) but were derived by OSHA from the data presented. The changes in the value of "k" for the different time periods mainly reflect different growth rates of per capita income during those periods.

Other, more indirect evidence comes from estimates in the economics literature of "η", the income elasticity of the value of a statistical life. Viscusi and Aldy (2003) performed a meta-analysis on 49 wage-risk studies and concluded that the confidence interval upper bound on the income elasticity did not exceed 1.0 and that the point estimates across a variety of model specifications ranged between 0.5 and 0.6.[455] Applied to a long-term increase in per capita income of about 2.7 percent a year, this would suggest a value of "k" of about 1.5 percent a year.

More recently, Kniesner, Viscusi, and Ziliak (2010), using panel data quintile regressions, developed an estimate of the overall income elasticity of the value of a statistical life of 1.44. Applied to a long-term increase in per capita income of about 2.7 percent a year, this would suggest a value of "k" of about 3.9 percent a year.

Based on the preceding discussion of these three approaches for estimating the annual increase in the value of the benefits of the proposed rule and the fact that the projected increase in real per capita income in the United States has flattened in recent years and could remain so, OSHA suggests a conservative value for "k" of approximately 2 percent a year. The Agency invites comment on this estimate and on estimates of the income elasticity of the value of a statistical life.

The Agency believes that the rising value, over time, of health benefits is a real phenomenon that should be taken into account in estimating the annualized benefits of the proposed rule.[456] Table VII-IV, in the following section, shows estimates of the

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[455] These results conflict with the more recent work by Hall and Jones (2007), which concludes that the income elasticity of the value of life should be larger than 1.

[456] As noted above in the text, this adjustment to the value of health benefits, in response to increases in real income over time, has been supported in the economic literature and by other Federal agencies. However, two issues may merit consideration. First, materials and services (e.g., respirators,

monetized benefits of the proposed rule (under alternative discount rates) with this estimated increase in monetized benefits over time. The Agency invites comment on this adjustment to monetized benefits and has conducted a sensitivity analysis later in this chapter of the effects on the benefits and net benefits of the proposed rule in the absence of this real income adjustment.

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medical check-ups) used to achieve compliance with the proposed standard would also help improve health and increase longevity, and would likely be characterized by a positive income elasticity. However, OSHA believes that it would be a mistake to make an analogous adjustment to these rule-induced costs. The rising value of health benefits over time is derived from demand (willingness-to-pay) considerations. Costs to comply with a regulation reflect the intersection of market demand and supply. In the case of respirators, for example, long-run supply may be close to perfectly elastic, and thus the cost of respirators would remain approximately unchanged, though total purchases of respirators would increase.

A second issue is whether the application of available empirical estimates of society's discount rate implicitly captures the effect of income growth over time, at least as an average across goods and services, thus making more detailed income growth accounting unnecessary. OSHA invites comment on these issues.

The Discounting Of Monetized Benefits

As previously noted, the estimated stream of benefits arising from the proposed beryllium rule is not constant from year to year, both because of the 45-year delay after the rule takes effect until all active workers obtain reduced beryllium exposure over their entire working lives and because of, in the case of lung cancer, a 10-year latency period between reduced exposure and a reduction in the probability of disease.

<u>Alternative Discount Rates for Annualizing Benefits</u>

An appropriate discount rate is needed to reflect the timing of benefits over the 60-year period after the rule takes effect and to allow conversion to an equivalent steady stream of annualized benefits. Following OMB (2003) guidelines, OSHA has estimated the annualized benefits of the proposed rule using separate discount rates of 3 percent and 7 percent.

Consistent with the Agency's own practices in recent rulemakings,[457] OSHA has also estimated, for benchmarking purposes, undiscounted benefits—that is, benefits using a zero percent discount rate.

The question remains, what is the "appropriate" or "preferred" discount rate to use to monetize health benefits? The choice of discount rate is a controversial topic, one that has been the source of scholarly economic debate for several decades.[458] However,

[457] See, for example, (OSHA, 2004, p. 59429), the preamble for the proposed hexavalent chromium rule, and (OSHA, 2013, p. 56390), the preamble for the proposed silica rule.

[458] For a more detailed discussion of the major issues, see, for example, (Lind,1982b; Lind, 1990; EPA, 2010, Chapter 6; and OMB, 2003, pp. 31-37).

in simplest terms, the basic choices involve a social opportunity cost of capital approach or social rate of time preference approach.[459]

The social opportunity cost of capital approach reflects the fact that private funds spent to comply with government regulations have an opportunity cost in terms of foregone private investments that could otherwise have been made. The relevant discount rate in this case is the pre-tax rate of return on the foregone investments (Lind, 1982a, pp. 24-32).

The rate of time preference approach is intended to measure the tradeoff between current consumption and future consumption, or in the context of the proposed rule, between current benefits and future benefits. The *individual* rate of time preference is influenced by uncertainty about the availability of the benefits at a future date and whether the individual will be alive to enjoy the delayed benefits. By comparison, the *social* rate of time preference takes a broader view over a longer time horizon—ignoring individual mortality and the riskiness of individual investments (which can be accounted for separately).

A usual method for estimating the social rate of time preference is to calculate the post-tax real rate of return on long-term, risk-free assets, such as U.S. Treasury securities

[459] Ignored here are the various possible methods to adjust or to override the discounting of benefits to address the special problems arising from intergenerational impacts (such as from global climate change or other environmental consequences capable of lasting tens of thousands of years or more). The proposed beryllium rule, and OSHA regulations in general, do not have intergenerational impacts, as that term is usually understood and used. Other, more complicated approaches—not immediately relevant here—are also possible (see, for example, (EPA, 2010).

(OMB, 2003, p. 33). A variety of studies have estimated these rates of return over time and reported them to be in the range of approximately 1 - 4 percent.[460]

In accordance with OMB Circular A-4 (OMB, 2003), OSHA presents benefits and net benefits estimates using discount rates of 3 percent (representing the social rate of time preference) and 7 percent (a rate estimated using the social cost of capital approach). The Agency is interested in any evidence, theoretical or applied, that would inform the application of discount rates to the costs and benefits of a regulation.

Summary of Annualized Benefits under Alternative Discount Rates

Table VII-4 presents OSHA's estimates of the sum of the annualized benefits of the proposed rule, using alternative discount rates of 0, 3, and 7 percent, with the suggested adjustment for increasing monetized benefits in response to annual increases in per capita income over time.

Given that the stream of benefits extends out 60 years, the value of future benefits is sensitive to the choice of discount rate. As previously established in Table VII-3, the undiscounted benefits range from $291 million to $2.1 billion annually. Using a 7 percent discount rate, the annualized benefits range from $60 million to $591 million. As can be seen, going from undiscounted benefits to a 7 percent discount rate has the effect of cutting the annualized benefits of the proposed rule by about 74 percent.

[460] For example, the Congressional Budget Office (CBO, 1988) has estimated the cost of government borrowing to be 2 percent. Farber and Hemmersbaugh (1993) cite rates of return on long-term government securities ranging from approximately 0.5 percent to 3.0 percent. OMB (2003) calculates that the pre-tax yield on 10-year Treasury notes has averaged 3.1 percent in real terms over the 30 years prior to publication of its Circular A-4 in 2003. Newell and Pizer (2003) report real rates of return of nearly 4 percent on 30-year Treasury securities. Nordhaus (2008, page 170), cites a real rate of return of 2.7 percent in 2007 on 20-year Treasury securities.

Tables VII-A-1 and VII-A-2, in Appendix VII-A, demonstrate how annualized benefits are derived (over the 60 years after the beryllium rule becomes effective), using the midpoint value of annualized benefits for alternate discount rates of 3 and 7 percent (with the annualized undiscounted benefits—using a 0 percent discount rate—derived in the middle columns of each table in Appendix VII-A).

Taken as a whole, the Agency's best preliminary estimate of the total annualized benefits of the proposed rule—using a 3 percent discount rate with an adjustment for the increasing value of health benefits over time—is between $158 million and $1.2 billion, with a mid-point value of $576 million.

Table VII-4

Total Annualized Monitized Benefits - Midpoint Estimates ($Millions)

(Quartile Model)

		PEL Option (μg/m³)		
		0.1	**0.2**	**0.5**
	Discount Rate			
Low Estimates				
	Undiscounted (0%)	$313.7	$291.1	$277.8
	Discounted at 3%	$170.3	$158.0	$150.7
	Discounted at 7%	$64.9	$60.2	$57.4
High Estimates				
	Undiscounted (0%)	$2,088.8	$2,080.7	$1,308.3
	Discounted at 3%	$1,250.0	$1,245.2	$782.8
	Discounted at 7%	$593.3	$591.1	$371.3
Midpoint Estimates				
	Undiscounted (0%)	$1,015.2	$995.5	$696.7
	Discounted at 3%	$587.3	$575.8	$403.1
	Discounted at 7%	$260.4	$255.3	$178.8

Source: Office of Regulatory Analysis, Directorate of Standards and Guidance

STEP 4 - NET BENEFITS OF THE PROPOSED RULE

OSHA has estimated, in Table VII-5, the monetized and annualized net benefits of the proposed rule (with a PEL of 0.2 $\mu g/m^3$), based on the benefits and costs previously presented in this chapter and in Chapter V of this PEA. Table VII-5 also provides estimates of annualized net benefits for alternative PELs of 0.1 and 0.5 $\mu g/m^3$. Both the proposed rule and the alternatives PEL options have the same ancillary provisions and an action level equal to half of the PEL in both cases.

Table VII-5 is being provided for informational purposes only. As previously noted, the OSH Act requires the Agency to set standards based on eliminating significant risk to the extent feasible. An alternative criterion of maximizing net (monetized) benefits may result in very different regulatory outcomes. Thus, this analysis of net benefits has not been used by OSHA as the basis for its decision concerning the choice of a PEL or of other ancillary requirements for the proposed beryllium rule.

Table VII-5 shows net benefits using alternative discount rates of 0, 3, and 7 percent for benefits and costs, having previously included an adjustment to monetized benefits to reflect increases in real per capita income over time. OSHA has relied on a uniform discount rate applied to both costs and benefits. The Agency is interested in any evidence, theoretical or applied, that would support or refute the application of differential discount rates to the costs and benefits of a regulation.

As previously noted in this chapter, the choice of discount rate for annualizing benefits has a significant effect on annualized benefits. The same is true for net benefits. For example, the net benefits using a 7 percent discount rate for benefits are considerably smaller than the net benefits using a 3 percent discount rate, declining by almost half under all scenarios. (Conversely, as noted in Chapter V of this PEA, the choice of discount rate for annualizing costs has a relatively minor effect on annualized costs.)

Based on the results presented in Table VII-5, OSHA finds:

- While the net benefits of the proposed rule vary considerably—depending on the choice of discount rate used to annualize benefits and on whether the benefits being used are in the high, midpoint, or low range—benefits exceed costs for the proposed 0.2 $\mu g/m^3$ PEL in all cases that OSHA considered.

- The Agency's best estimate of the net annualized benefits of the proposed rule—using a uniform discount rate for both benefits and costs of 3 percent—is between $2120 million and $1.2 billion, with a midpoint value of $538 million.

- The alternative of a 0.5 $\mu g/m^3$ PEL has lower net benefits under all assumptions, except for the low-end benefits at 7%, whereas the effect on net benefits of the 0.1 $\mu g/m^3$ PEL is somewhat more mixed, relative to the proposed 0.2 $\mu g/m^3$ PEL. However, for these alternative PELs, benefits were also found to exceed costs in all cases that OSHA considered.

STEP 4 - INCREMENTAL BENEFITS OF THE PROPOSED RULE

Incremental costs and benefits are those that are associated with increasing the stringency of the standard. A comparison of incremental benefits and costs provides an indication of the relative efficiency of the proposed PEL and the alternative PELs. Again, OSHA has conducted these calculations for informational purposes only and has not used these results as the basis for selecting the PEL for the proposed rule.

OSHA provided, in Table VII-5, estimates of the net benefits of the alternative 0.1and 0.5 μg/m^3 PELs. The incremental costs, benefits, and net benefits of meeting a 0.5μg/m^3 PEL and then going to a 0.2 μg/m^3 PEL (as well as meeting a 0.2 μg/m^3 PEL and then going to a 0.1 μg/m^3 PEL—which the Agency has not yet determined is feasible), for alternative discount rates of 3 and 7 percent, are presented in Table VII-6. Table VII-6 breaks out costs by provision and benefits by type of disease and by morbidity/mortality. As Table VII-6 shows, at a discount rate of 3 percent, a PEL of 0.2 μg/m^3, relative to a PEL of 0.5 μg/m^3, imposes additional costs of $4.4 million per year; additional benefits of $172 million per year; and additional net benefits of $168 million per year. The proposed PEL of 0.2 μg/m^3 also has higher net benefits, relative to a PEL of 0.5 μg/m^3, using a 7 percent discount rate.

Table VII-6 demonstrates that, regardless of discount rate, there are net benefits to be achieved by lowering exposures from the current PEL of 2.0 μg/m^3 to 0.5 μg/m^3 and then, in turn, lowering them further to 0.2 μg/m^3. However, the majority of the benefits and costs attributable to the proposed rule are from the initial effort to lower exposures to 0.5 μg/m^3. Consistent with the previous analysis, net benefits decline across all increments as the discount rate for annualizing benefits increases. As also shown in Table VII-6, there is a small positive net incremental benefit from going from a PEL of 0.2 μg/m^3 to 0.1 μg/m^3, at 3 percent, but is slightly negative at 7 percent. (Note that this result reflects OSHA's midpoint estimate of benefits, although as indicated in Table VII-5, this is not universal across all estimation parameters.)

In addition to examining alternative PELs, OSHA also examined alternatives to other provisions of the standard. These alternatives are discussed in the following Regulatory Alternatives chapter.

Table VII-5

Annual Monetized Net Benefits Resulting from a Reduction in Exposure to Beryllium to Proposed PEL of 0.2 μg/m^3 and Alternative PELS of 0.1 μg/m^3 and 0.5 μg/m3

($Millions)

PEL		**0.1**	**0.2**	**0.5**
Discount Rate	**Range**			
Undiscounted (0%)	Low	$271.1	$254.6	$245.5
	Midpoint	$972.6	$958.9	$664.4
	High	$2,046.2	$2,044.2	$1,276.0
Discounted at 3%	Low	$126.5	$120.4	$117.6
	Midpoint	$543.5	$538.2	$370.0
	High	$1,206.3	$1,207.6	$749.6
Discounted at 7%	Low	$19.5	$21.0	$23.0
	Midpoint	$214.9	$216.2	$144.4
	High	$547.8	$552.0	$336.9

Source: Office of Regulatory Analysis, Directorate of Standards & Guidance

Table VII-6: Annualized Costs, Benefits and Incremental Benefits of OSHA's Proposed Beryllium Standard of of 0.1 μg/m3 and 0.5 μg/m3 PEL Alternative
Millions ($2010)

	Alternative 4 (PEL = 0.1 μg/m^3, AL = 0.05 μg/m^3)			Alternative 4 Incremental Costs/Benefits			Proposed PEL			Alternative 5 Incremental Costs/Benefits			Alternative 5 (PEL = 0.5 μg/m^3, AL = 0.25 μg/m^3)		
Discount Rate		3%	7%		3%	7%		3%	7%		3%	7%		3%	7%
Annualized Costs															
Control Costs		$12.9	$13.9		$3.3	$3.5		$9.5	$10.3		$3.6	$3.9		$6.0	$6.5
Respirators		$0.7	$0.7		$0.4	$0.5		$0.2	$0.3		$0.1	$0.1		$0.1	$0.1
Exposure Assessment		$3.8	$3.9		$1.6	$1.5		$2.2	$2.4		$0.3	$0.3		$1.9	$2.1
Regulated Areas		$0.9	$0.9		$0.3	$0.3		$0.6	$0.7		$0.3	$0.3		$0.3	$0.4
Medical Surveillance		$3.0	$3.1		$0.1	$0.1		$2.9	$3.0		$0.1	$0.1		$2.8	$2.9
Medical Removal		$0.4	$0.5		$0.3	$0.3		$0.1	$0.2		$0.1	$0.1		$0.1	$0.1
Exposure Control Plan		$1.8	$1.8		$0.0	$0.0		$1.8	$1.8		$0.0	$0.0		$1.8	$1.8
Protective Clothing and Equipment		$1.4	$1.4		$0.0	$0.0		$1.4	$1.4		$0.0	$0.0		$1.4	$1.4
Hygiene Areas and Practices		$0.6	$0.6		$0.2	$0.2		$0.4	$0.4		$0.0	$0.0		$0.4	$0.4
Housekeeping		$12.6	$12.9		$0.0	$0.0		$12.6	$12.9		$0.0	$0.0		$12.6	$12.9
Training		$5.8	$5.8		$0.0	$0.0		$5.8	$5.8		$0.0	$0.0		$5.8	$5.8
Total Annualized Costs (point estimate)		**$43.7**	**$45.5**		**$6.1**	**$6.3**		**$37.6**	**$39.1**		**$4.4**	**$4.8**		**$33.2**	**$34.4**
Annual Benefits: Number of Cases Prevented	**Cases**			**Cases**			**Cases**			**Cases**			**Cases**		
Fatal Lung Cancers (midpoint estimate)	4			0			4			0			4		
Fatal Chronic Beryllium Disease	94			2			92			29			63		
Beryllium-Related Mortality	98	$584.4	$258.8	2	$11.1	$4.9	96	$573.0	$253.7	29	$171.8	$76.1	67	$401.2	$177.7
Beryllium Morbidity	50	$2.9	$1.6	1	$0.0	$0.0	50	$2.8	$1.6	15	$0.9	$0.5	34	$2.0	$1.1
Monetized Annual Benefits (midpoint estimate)		**$587.3**	**$260.4**		**$11.2**	**$5.1**		**$575.8**	**$255.3**		**$172.7**	**$76.6**		**$403.1**	**$178.8**
Net Benefits		**$543.5**	**$214.9**		**$5.3**	**-$1.3**		**$538.2**	**$216.2**		**$168.2**	**$71.8**		**$370.0**	**$144.4**

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis

** Benefits are assessed over a 60-year time horizon, during which it is assumed that economic conditions remain constant. Costs are annualized over ten years, with the exception of equipment expenditures, which are annualized over the life of the equipment. Annualized costs are assumed to continue at the same level for sixty years, which is consistent with assuming that economic conditions remain constant for the sixty-year time horizon.*

STEP 5 - SENSITIVITY ANALYSIS

In this section, OSHA presents the results of two different types of sensitivity analysis to demonstrate how robust the estimates of net benefits are to changes in various cost and benefit parameters. In the first type of sensitivity analysis, OSHA made a series of isolated changes to individual cost and benefit input parameters in order to determine their effects on the Agency's estimates of annualized costs, annualized benefits, and annualized net benefits. In the second type of sensitivity analysis—a so-called "break-even" analysis—OSHA also investigated isolated changes to individual cost and benefit input parameters, but with the objective of determining how much they would have to change for annualized costs to equal annualized benefits. For both types of sensitivity analyses, OSHA used the annualized costs and benefits obtained from a three-percent discount rate as the reference point.

Again, the Agency has conducted these calculations for informational purposes only and has not used these results as the basis for selecting the PEL for the proposed rule.

Analysis of Isolated Changes to Inputs

The methodology and calculations underlying the estimation of the costs and benefits associated with this rulemaking are generally linear and additive in nature. Thus, the sensitivity of the results and conclusions of the analysis will generally be proportional to isolated variations in a particular input parameter. For example, if the estimated time that employees need to travel to (and from) medical screenings were doubled, the corresponding labor costs would double as well.

OSHA evaluated a series of such changes in input parameters to test whether and to what extent the general conclusions of the economic analysis held up. OSHA first considered changes to input parameters that affected only costs and then changes to input parameters that affected only benefits. Each of the sensitivity tests on cost parameters had only a very minor effect on total costs or net costs. Much larger effects were observed when the benefits parameters were modified; however, in all cases, net benefits remained significantly positive. On the whole, OSHA found that the conclusions of the analysis are reasonably robust, as changes in any of the cost or benefit input parameters still show significant net benefits for the proposed rule. The results of the individual sensitivity tests are summarized in Table VII-7 and are described in more detail below.

In the first of these sensitivity tests, where OSHA doubled the estimated portion of employees in need of protective clothing and equipment (PPE), essentially doubling the estimated baseline non-compliance rate (e.g., from 10 to 20 percent), and estimates of other input parameters remained unchanged, Table VII-7 shows that the estimated total costs of compliance would increase by $1.4 million annually, or by about 3.7 percent, while net benefits would also decline by $1.4 million annually, from $538.2 million to $536.8 million annually.

In a second sensitivity test, OSHA increased the estimated unit cost of ventilation from $13.18 per cfm for most sectors to $25 per cfm for most sectors. As shown in Table VII-7, if OSHA's estimates of other input parameters remained unchanged, the total estimated costs of compliance would increase by $2.0 million annually, or by about 5.3 percent, while net benefits would also decline by $2.0 million annually, from $538 million to $536 million annually.

Table VII-7 Sensitivity Tests

Uncertainty Scenarios	Change from OSHA's Primary Estimate	Difference From Primary Estimate	Percentage Impact on Costs or Benefits	Total Annualized Cost or Benefit	Net Benefit
Cost Scenarios					
Proposed Rule - OSHA's best estimate	NA	$0	0.0%	$37,597,325	$538,229,309
Reduced PPE Compliance Rates	Double PPE non-compliance rates	$1,385,575	3.7%	$38,982,900	$536,843,733
Increased CFM Unit Cost	Increase CFM Unit Cost to $25 for most sectors	$1,993,863	5.3%	$39,591,188	$536,235,445
Increased share of workers showing signs and symptoms	Increase share of workers showing signs and symtoms to 25%	$1,545,310	4.1%	$39,142,635	$536,683,999
Increased housekeeping	Increase the estimated incremental time per worker for housekeeping by 50%	$5,429,113	14.4%	$43,026,437	$532,800,196
Increased establishment-based costs	For establishment-based costs, increased the number of affected establishments by up to 100%	$4,483,148	11.9%	$42,080,472	$533,746,161
Benefit Scenarios					
Proposed Rule - OSHA's best estimate	NA	$0	0.0%	$575,826,633	$538,229,309
Low morbidity valuation	Benefits estimated using low morbidity value	-$216,839,627	-37.7%	$358,987,006	$321,389,682
High morbidity valuation	Benefits estimated using high morbidity value	$443,411,757	77.0%	$1,019,238,390	$981,641,066
Remove adjustment for future valuation of benefits (due to positive income elasticity of health benefits)	Set the growth in future benefits to 0.0%	-$314,319,477	-54.6%	$261,507,156	$223,909,831

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis

** Benefits are assessed over a 60-year time horizon, during which it is assumed that economic conditions remain constant. Costs are annualized over ten years, with the exception of equipment expenditures, which are annualized over the life of the equipment. Annualized costs are assumed to continue at the same level for sixty years, which is consistent with assuming economic conditions remain constant for the sixty-year time horizon.*

In a third sensitivity test, OSHA increased the estimated share of workers showing signs and symptoms of CBD from 15 to 25 percent, thereby adding these workers to the group eligible for medical surveillance and assuming that they would not be otherwise eligible for another reason (working in a regulated area, exposed during an emergency, etc.)[461] As shown in Table VII-7, if OSHA's estimates of other input parameters remained unchanged, the total estimated costs of compliance would increase by $1.5 million annually, or by about 4.1 percent, while net benefits would also decline by $1.5 million annually, from $538 million to $537 million annually.

In a fourth sensitivity test, OSHA increased its estimated incremental time per workers for housekeeping by 50 percent. As shown in Table VII-7, if OSHA's estimates of other input parameters remained unchanged, the total estimated costs of compliance would increase by $5 million annually, or by about 14.4 percent, while net benefits would also decline by $5.4 million annually, from $538 million to $533 million annually.

In a fifth sensitivity test, OSHA increased the estimated number of establishments needing engineering controls. For this sensitivity test, if 50 percent or less of the establishments in an industry needed engineering controls, OSHA increased the percentage of establishments needing engineering controls by 100 percent. If more than 50 percent of establishments in an industry needed engineering controls, then OSHA estimated that all establishments in that industry would need engineering controls. The purpose of this sensitivity analysis was to check the importance of using a methodology that treated 50 percent of workers in a given occupation exposed above the PEL as equivalent to 50 percent of facilities lacking adequate exposure controls. As shown in

[461] Chapter V of this PEA factors in overlap between those with signs and symptoms of CBD and those for other reasons. This assumes a simple additional 10 percent of symptomatic employees (as opposed to 9 percent implied if the same approach were used here).

Table VII-7, if OSHA's estimates of other input parameters remained unchanged, the total estimated costs of compliance would increase by $4.5 million, or by about 11.9 percent, while net benefits would also decline by $4.5 million, from $538 million to $534 million annually.

The Agency also performed sensitivity tests on several input parameters used to estimate the benefits of the proposed rule. In the first two tests, in an extension of results previously presented in Table VII-3, the Agency examined the effect on annualized net benefits of employing the high-end estimate of the benefits, as well as the low-end estimate, specifically examining the effect on undiscounted benefits of varying the valuation of individual morbidity cases. Table VII-7 presents the effect on annualized net benefits of using the extreme values of these ranges: the high morbidity valuation case and the low morbidity valuation case. For the low estimate of valuation, the benefits decline by 37.7 percent, to $359 million annually, yielding net benefits of $322 million annually. As shown, using the high estimate of morbidity valuation, the benefits rise by 77 percent to $1.0 billion annually, yielding net benefits of $982 million annually.

In a third sensitivity test of benefits, the Agency examined the effect of removing the component for the estimated rising value of health and safety over time. This would reduce the benefits by 54.6 percent, or $262 million annually, lowering the net benefits to $224 million annually.

Not part of this table, because it is reported elsewhere (e.g., in Table VII-6), the Agency examined the effect of raising the discount rate for costs and benefits to 7 percent. Raising the discount rate to 7 percent would increase costs by $1.6 million annually and lower benefits by $321 million annually, yielding annualized net benefits of $216 million.

<u>Sensitivity Analysis of Dental Lab Substitution</u>

As discussed in the Industry Profile (Chapter III), OSHA estimates that 75 percent of the dental laboratory industry will react to a new standard on beryllium by substituting away from using beryllium to the use of other materials. The basis for the estimated changes in the industry profile and cost estimates are described in the PEA in Profile Of Affected Industries (Chapter III), Costs of Compliance (Chapter V), and earlier in this chapter on benefits. However, because of uncertainties about the extent to which dental laboratories will substitute out of beryllium use in the future and the extent to which the future substitution is attributable to the OSHA beryllium rule, and because of the substantial portion of the net benefits accounted for by this sector, OSHA has provided a sensitivity analysis of the effect on benefits and costs of alternative substitution rates away from beryllium use in the dental laboratory sector.

Substitution is not costless, and Chapter V estimates the increased cost due to the higher costs of using non-beryllium alloys. But these costs are smaller than the avoided costs of the ancillary provisions and engineering controls. Regardless, the net cost effect is swamped by the benefits to thousands of workers having their baseline beryllium exposures completely eliminated. Thus, as indicated in Table VII-8, the benefits of the proposal would be lower and the costs higher if there were less substitution out of beryllium in dental labs. The lowest net benefits would occur if labs were unable to substitute out beryllium-containing materials at all, and had to use ventilation to control exposures. In this case, the proposal would yield only $420 million in net benefits. The highest net benefits, larger than assumed for OSHA's primary estimate, would be if *all* dental labs substituted out of beryllium-containing materials as a result of the proposal; as a result, the proposal would yield $573 million in net benefits.

Another possibility is a scenario is which technology and the market move along rapidly away from using beryllium-containing materials, independently of an OSHA rule, and the proposal itself would therefore produce neither costs nor benefits in this sector. If dental labs are removed from the PEA, the net benefits for the proposal—for the remaining industry sectors—decline to $284 million. Critically, however, this analysis demonstrates that regardless of any assumption regarding substitution in dental labs, the proposal would generate substantially more monetized benefits than costs.

Table VII-8

Laboratories Substituting Away From Beryllium Alloys ($Millions)

Share of Dental Labs Substiuting	Benefits	Costs	Net Benefits
0.0%	$462.7	$42.7	$420.0
25.0%	$501.9	$41.0	$460.8
50.0%	$540.7	$39.3	$501.4
75.0%	$575.8	$37.6	$538.2
100.0%	$609.1	$35.9	$573.2

Baseline Benefits and Costs by Sector ($Millions)

Sector	Benefits	Costs	Net Benefits
Non Dental Labs	$318.2	$34.4	$283.9
Dental Labs	$257.6	$3.2	$254.4
Total	$575.8	$37.6	$538.2

Source: OSHA, DSG, Office of Regulatory Analysis

“Break-Even” Analysis

OSHA also performed sensitivity tests on several other parameters used to estimate the net costs and benefits of the proposed rule. However, for these, the Agency performed a “break-even” analysis, asking how much the various cost and benefits inputs would have to vary in order for the costs to equal, or break even with, the benefits. The results are shown in Table VII-9.

In one break-even test on cost estimates, OSHA examined how much total costs would have to increase in order for costs to equal benefits. As shown in Table VII-9, this point would be reached if costs increased by $538 million, or by 1,432 percent.

In a second test, looking specifically at the estimated engineering control costs, the Agency found that these costs would need to increase by $567 million, or 6,240 percent, for costs to equal benefits.

In a third sensitivity test, on benefits, OSHA examined how much its estimated monetary valuation of an avoided illness or an avoided fatality would need to be reduced in order for the costs to equal the benefits. Since the total valuation of prevented mortality and morbidity are each estimated to exceed the estimated costs of $38 million, an independent break-even point for each is impossible. In other words, for example, if no value is attached to an avoided illness associated with the rule, but the estimated value of an avoided fatality is held constant, the rule still has substantial net benefits. Only through a reduction in the estimated net value of both components is a break-even point possible.

The Agency, therefore, examined how large an across-the-board reduction in the monetized value of all avoided illnesses and fatalities would be necessary for the benefits to equal the costs. As shown in Table VII-9, a 94 percent reduction in the monetized value of all avoided illnesses and fatalities would be necessary for costs to equal benefits, reducing the estimated value to $733,303 per fatality prevented, and an equivalent percentage reduction to about $4,048 per illness prevented.

In a fourth break-even sensitivity test, OSHA estimated how many fewer beryllium-related fatalities and illnesses would be required for benefits to equal costs. Paralleling the previous discussion, eliminating either the prevented mortality or morbidity cases alone would be insufficient to lower benefits to the break-even point. The Agency therefore examined them as a group. As shown in Table VII-9, a reduction of 94 percent, for both simultaneously, is required to reach the break-even point—90 fewer fatalities prevented annually, and 46 fewer beryllium-related illnesses-only cases prevented annually.

Taking into account both types of sensitivity analysis the Agency performed on its point estimates of the annualized costs and annualized benefits of the proposed rule, the results demonstrate that net benefits would be positive in all cases tested. In particular, this finding would hold even with relatively large variations in individual input parameters. Alternately, one would have to imagine extremely large changes in costs or benefits for the rule to fail to produce net benefits. OSHA concludes that its finding of significant net benefits resulting from the proposed rule is a robust one.

OSHA welcomes input from the public regarding all aspects of this sensitivity analysis, including any data or information regarding the accuracy of the preliminary estimates of compliance costs and benefits and how the estimates of costs and benefits may be affected by varying assumptions and methodological approaches. OSHA also invites comment on the risk analysis and risk estimates from which the benefits estimates were derived.

CBD Prevalence/Incidence and Mortality Ratio Sensitivity Analysis

Finally, the Agency examined the effects of changes in two important inputs to the benefits analysis: the factor that transforms CBD prevalence rates into incidence rates, needed for the equilibrium lifetime risk model, and the percentage of CBD cases that eventually lead to a fatality.

From the Cullman dataset the Agency has estimated the prevalence of CBD cases at any point in time as a function of cumulative beryllium exposure. In order to utilize the lifetime risk model, which tracks workers over their working life in a job, OSHA has turned these prevalence rates into an incidence rate, which is the rate of contracting CBD at a point in time. OSHA's baseline estimate of the turnover rate in the model is 10%. OSHA also presents alternative turnover rates of 5% and 20% in the top panel of Table VII-10. A higher turnover rate translates into a higher incidence rate, and the table shows that, from a baseline midpoint estimate with 10% turnover the number of CBD cases prevented is 6,367, while raising the turnover rate to 20% causes this midpoint estimate to rise to 11,751. Conversely, a rate of 5% lowers the number of CBD cases prevented to 3,321. Translated into monetary benefits, the table shows that the baseline midpoint estimate of $575.8m now ranges from $314.4m to $1,038m.

Second, the Agency looks at the effects of varying the percentage of CBD cases that eventuate in fatality. The Agency's baseline estimate of this outcome is 65%, with half of this occurring relatively soon, and the other half after an extended debilitating condition. The Agency judged that a reasonable range to investigate was a low of 50% and a high of 80%, while maintaining the shares of short-term and long-term endpoint fatality. The lower panel of Table VII-10 presents these results, here for CBD fatalities, versus the upper panel which is for overall CBD cases. At a baseline of 65%, the midpoint estimate of total CBD cases prevented is 4,139. At the low end of 50% mortality this estimate lowers to 3,183 while at the high end of 80% mortality this estimate rises to 5,094. Translated into monetary benefits, the table shows that the baseline midpoint estimate of $575.8m now ranges from $500.1m to $651.5m.

Table VII-9

Break-Even Sensitivity Analysis

	OSHA's Best Estimate of Annualized Cost or Benefit Factor	Factor Value at Which Benefits Equal Costs	Required Factor Dollar/Number Change	Percentage Factor Change
Total Costs	$37,597,325	$575,826,633	$538,229,309	1431.6%
Engineering Control Costs	$9,082,884	$575,826,633	$566,743,749	6239.7%
Benefits Valuation per Case Avoided				
Monetized Benefit per Fatality Avoided	$11,231,000	$733,303	-$10,497,697	-93.5%
Monetized Benefit per Illness Avoided	$62,000	$4,048	-$57,952	-93.5%
Cases Avoided				
Deaths Avoided	96	6	-90	-93.5%
Illnesses Avoided	50	3	-46	-93.5%

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis

Table VII-10

Sensitivity of the Benefits Estimates to the Incidence-Prevalence Ratio

	Number of CBD Cases	Prevented			Monetized Benefits ($millions)		
	Baseline	Low Estimate	High Estimate	Midpoint Estimate	Low Estimate	High Estimate	Midpoint Estimate
Incidence-Prevalence Ratio = 10.0% (base case)	11,017	2,563	10,171	6,367	$158.0	$1,245.2	$575.8
Incidence-Prevalence Ratio = 5.0%	5,735	1,347	5,296	3,321	$93.9	$665.3	$314.4
Incidence-Prevalence Ratio = 20.0%	20,409	4,668	18,835	11,751	$268.9	$2,276.1	$1,038.0

Sensitivity of Benefits Estimates to the Mortality Ratio

	Number of CBD-Related Deaths	Prevented			Monetized Benefits ($millions)		
	Baseline	Low Estimate	High Estimate	Midpoint Estimate	Low Estimate	High Estimate	Midpoint Estimate
Mortality Ratio = 65% (base case)	7,161	1,666	6,611	4,139	$158.0	$1,245.2	$575.8
Mortality Ratio = 50%	5,508	1,281	5,086	3,183	$127.6	$1,124.2	$500.1
Mortality Ratio = 80%	8,813	2,050	8,137	5,094	$188.3	$1,366.3	$651.5

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis

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Appendix VII-A Estimated Benefits of the Standard by Year* **

TABLE VII-A-1

Benefits by Year After Promulgation of the Beryllium Standard (60-Year Time Horizon): Cases, Undiscounted Values and Values at a 3% Discount Rate

	Cases Prevented by Year After Promulgation				Undiscounted Value of Cases Prevented by Year After Promuglation ($M)						Present Value by Year After Promugations - 3% Discount Rate ($M)					
Year After Promugation	Lung Cancer	Fatal CBD (except lung cancer)	Total	Morbidity Cases Prevented	Fatal Lung Cancer	Fatal CBD (except lung cancer) - Morbidity before Death Valuation	Fatal CBD (except lung cancer) - Mortality Valuation	Fatality Total	Value of Morbidity Cases Prevented	Grand Total	Fatal Lung Cancer	Fatal CBD (except lung cancer) - Morbidity before Death Valuation	Fatal CBD (except lung cancer) - Mortality Valuation	Fatality Total	Value of Morbidity Cases Prevented	Grand Total
1	0	2	2	1	$0.0	$5.2	$0.0	$5.2	$0.1	5.2	$0.0	$5.0	$0.0	$5.0	$0.1	$5.1
2	0	4	4	2	$0.0	$10.6	$0.0	$10.6	$0.1	10.7	$0.0	$9.9	$0.0	$9.9	$0.1	$10.1
3	0	6	6	3	$0.0	$16.1	$0.0	$16.1	$0.2	16.4	$0.0	$14.8	$0.0	$14.8	$0.2	$15.0
4	0	8	8	4	$0.0	$22.0	$0.0	$22.0	$0.3	22.2	$0.0	$19.5	$0.0	$19.5	$0.3	$19.8
5	0	10	10	6	$0.0	$28.0	$0.0	$28.0	$0.4	28.4	$0.0	$24.1	$0.0	$24.1	$0.3	$24.5
6	0	12	12	7	$0.0	$34.3	$0.0	$34.3	$0.5	34.7	$0.0	$28.7	$0.0	$28.7	$0.4	$29.1
7	0	14	14	8	$0.0	$40.8	$0.0	$40.8	$0.5	41.3	$0.0	$33.2	$0.0	$33.2	$0.4	$33.6
8	0	16	16	9	$0.0	$47.5	$0.0	$47.5	$0.6	48.2	$0.0	$37.5	$0.0	$37.5	$0.5	$38.0
9	0	18	18	10	$0.0	$54.5	$0.0	$54.5	$0.7	55.3	$0.0	$41.8	$0.0	$41.8	$0.6	$42.4
10	0	20	20	11	$0.0	$61.8	$0.0	$61.8	$0.8	62.6	$0.0	$46.0	$0.0	$46.0	$0.6	$46.6
11	0	22	23	12	$1.2	$69.4	$0.0	$70.6	$0.9	71.5	$0.9	$50.1	$0.0	$51.0	$0.7	$51.6
12	0	25	25	13	$2.5	$77.2	$0.0	$79.7	$1.0	80.7	$1.7	$54.1	$0.0	$55.9	$0.7	$56.6
13	0	27	27	14	$3.8	$85.3	$0.0	$89.1	$1.1	90.2	$2.6	$58.1	$0.0	$60.7	$0.8	$61.4
14	0	29	29	15	$5.2	$93.7	$0.0	$98.8	$1.2	100.1	$3.4	$61.9	$0.0	$65.3	$0.8	$66.2
15	0	31	31	17	$6.6	$102.4	$0.0	$109.0	$1.4	110.3	$4.2	$65.7	$0.0	$69.9	$0.9	$70.8
16	1	33	33	18	$8.1	$111.4	$0.0	$119.4	$1.5	120.9	$5.0	$69.4	$0.0	$74.4	$0.9	$75.4
17	1	35	35	19	$9.6	$120.7	$0.0	$130.3	$1.6	131.9	$5.8	$73.0	$0.0	$78.8	$1.0	$79.8
18	1	37	37	20	$11.2	$130.4	$0.0	$141.6	$1.7	143.3	$6.6	$76.6	$0.0	$83.1	$1.0	$84.2
19	1	39	40	21	$12.8	$140.4	$0.0	$153.2	$1.9	155.0	$7.3	$80.0	$0.0	$87.4	$1.1	$88.4
20	1	41	42	22	$14.5	$150.7	$0.0	$165.3	$2.0	167.2	$8.1	$83.4	$0.0	$91.5	$1.1	$92.6
21	1	43	44	23	$16.3	$161.4	$26.4	$204.1	$2.1	206.3	$8.8	$86.8	$14.2	$109.7	$1.1	$110.9
22	1	45	46	24	$18.2	$172.5	$53.9	$244.5	$2.3	246.8	$9.5	$90.0	$28.1	$127.6	$1.2	$128.8
23	1	47	48	25	$20.1	$183.9	$82.5	$286.4	$2.4	288.9	$10.2	$93.2	$41.8	$145.1	$1.2	$146.4
24	1	49	50	26	$22.0	$195.8	$112.2	$329.9	$2.6	332.5	$10.8	$96.3	$55.2	$162.3	$1.3	$163.6
25	1	51	52	28	$24.1	$208.0	$143.0	$375.1	$2.7	377.8	$11.5	$99.3	$68.3	$179.1	$1.3	$180.4
26	1	53	55	29	$26.2	$220.6	$175.0	$421.9	$2.9	424.8	$12.1	$102.3	$81.2	$195.6	$1.3	$197.0
27	2	55	57	30	$28.4	$233.7	$208.3	$470.4	$3.1	473.5	$12.8	$105.2	$93.8	$211.8	$1.4	$213.1
28	2	57	59	31	$30.7	$247.2	$242.8	$520.7	$3.3	523.9	$13.4	$108.1	$106.1	$227.6	$1.4	$229.0
29	2	59	61	32	$33.0	$261.2	$278.6	$572.8	$3.4	576.2	$14.0	$110.8	$118.2	$243.1	$1.5	$244.5
30	2	61	63	33	$35.4	$275.6	$315.8	$626.8	$3.6	630.4	$14.6	$113.5	$130.1	$258.2	$1.5	$259.7
31	2	63	65	34	$38.0	$290.5	$354.3	$682.7	$3.8	686.5	$15.2	$116.2	$141.7	$273.1	$1.5	$274.6
32	2	65	67	35	$40.6	$305.8	$394.2	$740.6	$4.0	744.6	$15.8	$118.8	$153.1	$287.6	$1.6	$289.2
33	2	67	69	36	$43.3	$321.7	$435.6	$800.5	$4.2	804.8	$16.3	$121.3	$164.2	$301.8	$1.6	$303.4
34	2	69	72	37	$46.0	$338.1	$478.5	$862.6	$4.5	867.1	$16.9	$123.7	$175.1	$315.7	$1.6	$317.4
35	2	72	74	39	$48.9	$355.0	$522.9	$926.8	$4.7	931.5	$17.4	$126.1	$185.8	$329.4	$1.7	$331.0
36	2	74	76	40	$51.9	$372.4	$568.9	$993.2	$4.9	998.2	$17.9	$128.5	$196.3	$342.7	$1.7	$344.4
37	2	76	78	41	$55.0	$390.4	$616.6	$1,062.0	$5.1	1,067.1	$18.4	$130.8	$206.5	$355.7	$1.7	$357.5
38	2	78	80	42	$58.1	$409.0	$665.9	$1,133.0	$5.4	1,138.4	$18.9	$133.0	$216.6	$368.5	$1.8	$370.2
39	3	80	82	43	$61.4	$428.1	$717.0	$1,206.5	$5.6	1,212.2	$19.4	$135.2	$226.4	$381.0	$1.8	$382.7
40	3	82	84	44	$64.8	$447.9	$769.8	$1,282.5	$5.9	1,288.4	$19.9	$137.3	$236.0	$393.2	$1.8	$395.0

TABLE VII-A-1, Continued

Benefits by Year After Promulgation of the Beryllium Standard (60-Year Time Horizon): Cases, Undiscounted Values and Values at a 3% Discount Rate

	Cases Prevented by Year After Promulgation				Undiscounted Value of Cases Prevented by Year After Promuglation ($M)						Present Value by Year After Promugations - 3% Discount Rate ($M)					
Year After Promugation	Lung Cancer	Fatal CBD (except lung cancer)	Total	Morbidity Cases Prevented	Fatal Lung Cancer	Fatal CBD (except lung cancer) - Morbidity before Death Valuation	Fatal CBD (except lung cancer) - Mortality Valuation	Fatality Total	Value of Morbidity Cases Prevented	Grand Total	Fatal Lung Cancer	Fatal CBD (except lung cancer) - Morbidity before Death Valuation	Fatal CBD (except lung cancer) - Mortality Valuation	Fatality Total	Value of Morbidity Cases Prevented	Grand Total
41	3	84	87	45	$68.3	$468.3	$824.5	$1,361.0	$6.2	1,367.2	$20.3	$139.4	$245.4	$405.1	$1.8	$406.9
42	3	86	89	46	$71.9	$489.3	$881.0	$1,442.2	$6.5	1,448.7	$20.8	$141.4	$254.6	$416.7	$1.9	$418.6
43	3	88	91	47	$75.7	$511.0	$939.5	$1,526.1	$6.7	1,532.8	$21.2	$143.3	$263.6	$428.1	$1.9	$430.0
44	3	90	93	48	$79.5	$533.3	$999.9	$1,612.7	$7.0	1,619.8	$21.7	$145.3	$272.3	$439.3	$1.9	$441.2
45	3	92	95	50	$83.5	$556.3	$1,062.4	$1,702.2	$7.3	1,709.6	$22.1	$147.1	$280.9	$450.1	$1.9	$452.1
46	3	92	95	50	$87.6	$567.5	$1,127.0	$1,782.0	$7.5	1,789.5	$22.5	$145.7	$289.3	$457.5	$1.9	$459.4
47	3	92	95	50	$91.8	$578.8	$1,193.7	$1,864.4	$7.6	1,872.0	$22.9	$144.3	$297.6	$464.7	$1.9	$466.6
48	3	92	95	50	$96.2	$590.4	$1,262.7	$1,949.3	$7.8	1,957.1	$23.3	$142.9	$305.6	$471.7	$1.9	$473.6
49	3	92	95	50	$100.7	$602.2	$1,334.0	$2,036.9	$7.9	2,044.8	$23.7	$141.5	$313.4	$478.6	$1.9	$480.4
50	4	92	96	50	$105.3	$614.2	$1,407.6	$2,127.1	$8.1	2,135.2	$24.0	$140.1	$321.1	$485.2	$1.8	$487.1
51	4	92	96	50	$110.1	$626.5	$1,483.6	$2,220.2	$8.3	2,228.5	$24.4	$138.8	$328.6	$491.7	$1.8	$493.5
52	4	92	96	50	$115.1	$639.0	$1,562.1	$2,316.2	$8.4	2,324.6	$24.7	$137.4	$335.9	$498.0	$1.8	$499.8
53	4	92	96	50	$120.2	$651.8	$1,643.1	$2,415.1	$8.6	2,423.7	$25.1	$136.1	$343.0	$504.2	$1.8	$505.9
54	4	92	96	50	$125.4	$664.9	$1,726.7	$2,517.0	$8.8	2,525.8	$25.4	$134.7	$350.0	$510.1	$1.8	$511.9
55	4	92	96	50	$130.9	$678.2	$1,813.1	$2,622.1	$8.9	2,631.0	$25.7	$133.4	$356.8	$515.9	$1.8	$517.7
56	4	92	96	50	$133.5	$691.7	$1,902.2	$2,727.4	$9.1	2,736.5	$25.5	$132.1	$363.4	$521.0	$1.7	$522.8
57	4	92	96	50	$136.1	$705.6	$1,994.1	$2,835.8	$9.3	2,845.1	$25.3	$130.9	$369.9	$526.0	$1.7	$527.7
58	4	92	96	50	$138.9	$719.7	$2,089.0	$2,947.5	$9.5	2,957.0	$25.0	$129.6	$376.2	$530.8	$1.7	$532.5
59	4	92	96	50	$141.6	$734.1	$2,186.8	$3,062.5	$9.7	3,072.2	$24.8	$128.3	$382.3	$535.4	$1.7	$537.1
60	4	92	96	50	$144.5	$748.7	$2,287.8	$3,181.0	$9.9	3,190.8	$24.5	$127.1	$388.3	$539.9	$1.7	$541.6
Totals - 60 years			3,607	1,882				$59,470	$258	$59,728				$15,857.6	$78.7	$15,936

* Notes to Table VII-A-1: (a) all cases prevented in the left columns appear as rounded integers, but the actual value is used in all calculations—this is also true for some values that appear as 0 (i.e., other than those described in (d) below); (b) the number of fatal CBD cases prevented in year *i* represents the number of (ultimately) fatal CBD cases that are diagnosed in year *i*—the actual fatality is estimated to occur 20 years later; (c) the undiscounted value of prevented fatal lung cancers in year *i* is equal to the number of cases of lung cancer prevented in that year x $8.7 million x (1.02)^*i*; (d) because of the 10-year lag from exposure to disease for lung cancer, there are no fatal lung cancer benefits for years 1-10; (e) the undiscounted value of morbidity before death for fatal CBD in year *i* is equal to the number of cases of fatal CBD prevented in that year x $2.58 million x (1.02)^*i*; (f) the undiscounted mortality value of fatal CBD in year *i* is equal to [the number of cases of fatal CBD prevented in year (*i* - 20)] x $8.7 million x (1.02)^*i*—for example, the $26.4 million of undiscounted CBD mortality benefits reported in year 21 is based on the 2 fatal CBD cases diagnosed in year 1; (g) because of the estimated 20-year lag from diagnosis of CBD to death, there are no mortality benefits for CBD estimated for years 1-20 and no mortality benefits were taken for CBD cases diagnosed in years 41-60 (since death would occur beyond the 60-year time horizon selected for the estimation of benefits); (h) the undiscounted fatality total value is equal to the sum of the three columns to the left; (i) the undiscounted grand total value is equal to the sum of the two columns to the left; and (j) every cell in the "Present Value by Year After Promulgation – 3% Discount Rate ($M)" columns is equal to the corresponding cell in the "Undiscounted Value of Cases Prevented by Year After Promulgation ($M)" columns multiplied by 1/(1.03)^*i*.

TABLE VII-A-2

Benefits by Year After Promulgation of the Berylium Standard (60-Year Time Horizon): Cases, Undiscounted Values and Values at a 7% Discount Rate

	Cases Prevented by Year After Promulgation				Undiscounted Value of Cases Prevented by Year After Promulgation ($M)						Present Value by Year After Promugations - 7% Discount Rate ($M)					
Year After Promugation	Lung Cancer	Fatal CBD (except lung cancer)	Total	Morbidity Cases Prevented	Fatal Lung Cancer	Fatal CBD (except lung cancer) - Morbidity before Death Valuation	Fatal CBD (except lung cancer) - Mortality Valuation	Fatality Total	Value of Morbidity Cases Prevented	Grand Total	Fatal Lung Cancer	Fatal CBD (except lung cancer) - Morbidity before Death Valuation	Fatal CBD (except lung cancer) - Mortality Valuation	Fatality Total	Value of Morbidity Cases Prevented	Grand Total
1	0	2	2	1	$0.0	$5.2	$0.0	$5.2	$0.1	5.2	$0.0	$4.8	$0.0	$4.8	$0.1	$4.9
2	0	4	4	2	$0.0	$10.6	$0.0	$10.6	$0.1	10.7	$0.0	$9.2	$0.0	$9.2	$0.1	$9.3
3	0	6	6	3	$0.0	$16.1	$0.0	$16.1	$0.2	16.4	$0.0	$13.2	$0.0	$13.2	$0.2	$13.4
4	0	8	8	4	$0.0	$22.0	$0.0	$22.0	$0.3	22.2	$0.0	$16.8	$0.0	$16.8	$0.2	$17.0
5	0	10	10	6	$0.0	$28.0	$0.0	$28.0	$0.4	28.4	$0.0	$20.0	$0.0	$20.0	$0.3	$20.2
6	0	12	12	7	$0.0	$34.3	$0.0	$34.3	$0.5	34.7	$0.0	$22.8	$0.0	$22.8	$0.3	$23.1
7	0	14	14	8	$0.0	$40.8	$0.0	$40.8	$0.5	41.3	$0.0	$25.4	$0.0	$25.4	$0.3	$25.7
8	0	16	16	9	$0.0	$47.5	$0.0	$47.5	$0.6	48.2	$0.0	$27.7	$0.0	$27.7	$0.4	$28.0
9	0	18	18	10	$0.0	$54.5	$0.0	$54.5	$0.7	55.3	$0.0	$29.7	$0.0	$29.7	$0.4	$30.1
10	0	20	20	11	$0.0	$61.8	$0.0	$61.8	$0.8	62.6	$0.0	$31.4	$0.0	$31.4	$0.4	$31.8
11	0	22	23	12	$1.2	$69.4	$0.0	$70.6	$0.9	71.5	$0.6	$33.0	$0.0	$33.5	$0.4	$34.0
12	0	25	25	13	$2.5	$77.2	$0.0	$79.7	$1.0	80.7	$1.1	$34.3	$0.0	$35.4	$0.5	$35.8
13	0	27	27	14	$3.8	$85.3	$0.0	$89.1	$1.1	90.2	$1.6	$35.4	$0.0	$37.0	$0.5	$37.4
14	0	29	29	15	$5.2	$93.7	$0.0	$98.8	$1.2	100.1	$2.0	$36.3	$0.0	$38.3	$0.5	$38.8
15	0	31	31	17	$6.6	$102.4	$0.0	$109.0	$1.4	110.3	$2.4	$37.1	$0.0	$39.5	$0.5	$40.0
16	1	33	33	18	$8.1	$111.4	$0.0	$119.4	$1.5	120.9	$2.7	$37.7	$0.0	$40.5	$0.5	$41.0
17	1	35	35	19	$9.6	$120.7	$0.0	$130.3	$1.6	131.9	$3.0	$38.2	$0.0	$41.3	$0.5	$41.8
18	1	37	37	20	$11.2	$130.4	$0.0	$141.6	$1.7	143.3	$3.3	$38.6	$0.0	$41.9	$0.5	$42.4
19	1	39	40	21	$12.8	$140.4	$0.0	$153.2	$1.9	155.0	$3.5	$38.8	$0.0	$42.4	$0.5	$42.9
20	1	41	42	22	$14.5	$150.7	$0.0	$165.3	$2.0	167.2	$3.8	$38.9	$0.0	$42.7	$0.5	$43.2
21	1	43	44	23	$16.3	$161.4	$26.4	$204.1	$2.1	206.3	$3.9	$39.0	$6.4	$49.3	$0.5	$49.8
22	1	45	46	24	$18.2	$172.5	$53.9	$244.5	$2.3	246.8	$4.1	$38.9	$12.2	$55.2	$0.5	$55.7
23	1	47	48	25	$20.1	$183.9	$82.5	$286.4	$2.4	288.9	$4.2	$38.8	$17.4	$60.4	$0.5	$60.9
24	1	49	50	26	$22.0	$195.8	$112.2	$329.9	$2.6	332.5	$4.3	$38.6	$22.1	$65.0	$0.5	$65.6
25	1	51	52	28	$24.1	$208.0	$143.0	$375.1	$2.7	377.8	$4.4	$38.3	$26.3	$69.1	$0.5	$69.6
26	1	53	55	29	$26.2	$220.6	$175.0	$421.9	$2.9	424.8	$4.5	$38.0	$30.1	$72.6	$0.5	$73.1
27	2	55	57	30	$28.4	$233.7	$208.3	$470.4	$3.1	473.5	$4.6	$37.6	$33.5	$75.7	$0.5	$76.2
28	2	57	59	31	$30.7	$247.2	$242.8	$520.7	$3.3	523.9	$4.6	$37.2	$36.5	$78.3	$0.5	$78.8
29	2	59	61	32	$33.0	$261.2	$278.6	$572.8	$3.4	576.2	$4.6	$36.7	$39.2	$80.5	$0.5	$81.0
30	2	61	63	33	$35.4	$275.6	$315.8	$626.8	$3.6	630.4	$4.7	$36.2	$41.5	$82.3	$0.5	$82.8
31	2	63	65	34	$38.0	$290.5	$354.3	$682.7	$3.8	686.5	$4.7	$35.7	$43.5	$83.8	$0.5	$84.3
32	2	65	67	35	$40.6	$305.8	$394.2	$740.6	$4.0	744.6	$4.7	$35.1	$45.2	$85.0	$0.5	$85.4
33	2	67	69	36	$43.3	$321.7	$435.6	$800.5	$4.2	804.8	$4.6	$34.5	$46.7	$85.8	$0.5	$86.3
34	2	69	72	37	$46.0	$338.1	$478.5	$862.6	$4.5	867.1	$4.6	$33.9	$48.0	$86.4	$0.4	$86.9
35	2	72	74	39	$48.9	$355.0	$522.9	$926.8	$4.7	931.5	$4.6	$33.2	$49.0	$86.8	$0.4	$87.2
36	2	74	76	40	$51.9	$372.4	$568.9	$993.2	$4.9	998.2	$4.5	$32.6	$49.8	$86.9	$0.4	$87.4
37	2	76	78	41	$55.0	$390.4	$616.6	$1,062.0	$5.1	1,067.1	$4.5	$31.9	$50.4	$86.9	$0.4	$87.3
38	2	78	80	42	$58.1	$409.0	$665.9	$1,133.0	$5.4	1,138.4	$4.4	$31.3	$50.9	$86.6	$0.4	$87.0
39	3	80	82	43	$61.4	$428.1	$717.0	$1,206.5	$5.6	1,212.2	$4.4	$30.6	$51.2	$86.2	$0.4	$86.6
40	3	82	84	44	$64.8	$447.9	$769.8	$1,282.5	$5.9	1,288.4	$4.3	$29.9	$51.4	$85.6	$0.4	$86.0

TABLE VII-A-2, Continued

Benefits by Year After Promulgation of the Berylium Standard (60-Year Time Horizon): Cases, Undiscounted Values and Values at a 7% Discount Rate

	Cases Prevented by Year After Promulgation				Undiscounted Value of Cases Prevented by Year After Promulgation ($M)						Present Value by Year After Promugations - 7% Discount Rate ($M)					
Year After Promugation	Lung Cancer	Fatal CBD (except lung cancer)	Total	Morbidity Cases Prevented	Fatal Lung Cancer	Fatal CBD (except lung cancer) - Morbidity before Death Valuation	Fatal CBD (except lung cancer) - Mortality Valuation	Fatality Total	Value of Morbidity Cases Prevented	Grand Total	Fatal Lung Cancer	Fatal CBD (except lung cancer) - Morbidity before Death Valuation	Fatal CBD (except lung cancer) - Mortality Valuation	Fatality Total	Value of Morbidity Cases Prevented	Grand Total
41	3	84	87	45	$68.3	$468.3	$824.5	$1,361.0	$6.2	1,367.2	$4.3	$29.2	$51.5	$84.9	$0.4	$85.3
42	3	86	89	46	$71.9	$489.3	$881.0	$1,442.2	$6.5	1,448.7	$4.2	$28.5	$51.4	$84.1	$0.4	$84.5
43	3	88	91	47	$75.7	$511.0	$939.5	$1,526.1	$6.7	1,532.8	$4.1	$27.9	$51.2	$83.2	$0.4	$83.6
44	3	90	93	48	$79.5	$533.3	$999.9	$1,612.7	$7.0	1,619.8	$4.1	$27.2	$50.9	$82.2	$0.4	$82.5
45	3	92	95	50	$83.5	$556.3	$1,062.4	$1,702.2	$7.3	1,709.6	$4.0	$26.5	$50.6	$81.0	$0.3	$81.4
46	3	92	95	50	$87.6	$567.5	$1,127.0	$1,782.0	$7.5	1,789.5	$3.9	$25.3	$50.1	$79.3	$0.3	$79.6
47	3	92	95	50	$91.8	$578.8	$1,193.7	$1,864.4	$7.6	1,872.0	$3.8	$24.1	$49.6	$77.5	$0.3	$77.9
48	3	92	95	50	$96.2	$590.4	$1,262.7	$1,949.3	$7.8	1,957.1	$3.7	$22.9	$49.1	$75.8	$0.3	$76.1
49	3	92	95	50	$100.7	$602.2	$1,334.0	$2,036.9	$7.9	2,044.8	$3.7	$21.9	$48.5	$74.0	$0.3	$74.3
50	4	92	96	50	$105.3	$614.2	$1,407.6	$2,127.1	$8.1	2,135.2	$3.6	$20.9	$47.8	$72.2	$0.3	$72.5
51	4	92	96	50	$110.1	$626.5	$1,483.6	$2,220.2	$8.3	2,228.5	$3.5	$19.9	$47.1	$70.4	$0.3	$70.7
52	4	92	96	50	$115.1	$639.0	$1,562.1	$2,316.2	$8.4	2,324.6	$3.4	$18.9	$46.3	$68.7	$0.2	$68.9
53	4	92	96	50	$120.2	$651.8	$1,643.1	$2,415.1	$8.6	2,423.7	$3.3	$18.1	$45.5	$66.9	$0.2	$67.2
54	4	92	96	50	$125.4	$664.9	$1,726.7	$2,517.0	$8.8	2,525.8	$3.2	$17.2	$44.7	$65.2	$0.2	$65.4
55	4	92	96	50	$130.9	$678.2	$1,813.1	$2,622.1	$8.9	2,631.0	$3.2	$16.4	$43.9	$63.5	$0.2	$63.7
56	4	92	96	50	$133.5	$691.7	$1,902.2	$2,727.4	$9.1	2,736.5	$3.0	$15.6	$43.0	$61.7	$0.2	$61.9
57	4	92	96	50	$136.1	$705.6	$1,994.1	$2,835.8	$9.3	2,845.1	$2.9	$14.9	$42.2	$60.0	$0.2	$60.1
58	4	92	96	50	$138.9	$719.7	$2,089.0	$2,947.5	$9.5	2,957.0	$2.7	$14.2	$41.3	$58.2	$0.2	$58.4
59	4	92	96	50	$141.6	$734.1	$2,186.8	$3,062.5	$9.7	3,072.2	$2.6	$13.6	$40.4	$56.6	$0.2	$56.7
60	4	92	96	50	$144.5	$748.7	$2,287.8	$3,181.0	$9.9	3,190.8	$2.5	$12.9	$39.5	$54.9	$0.2	$55.1
Totals - 60 years			3,607	1,882				$59,470	$258	$59,728.0				$3,562.3	$22.3	$3,584.7

** Notes to Table VII-A-2: (a) all cases prevented in the left columns appear as rounded integers, but the actual value is used in all calculations—this is also true for some values that appear as 0 (i.e., other than those described in (d) below); (b) the number of fatal CBD cases prevented in year i represents the number of (ultimately) fatal CBD cases that are diagnosed in year i—the actual fatality is estimated to occur 20 years later; (c) the undiscounted value of prevented fatal lung cancers in year i is equal to the number of cases of lung cancer prevented in that year x $8.7 million x (1.02)^i; (d) because of the 10-year lag from exposure to disease for lung cancer, there are no fatal lung cancer benefits for years 1-10; (e) the undiscounted value of morbidity before death for fatal CBD in year i is equal to the number of cases of fatal CBD prevented in that year x $2.58 million x (1.02)^i; (f) the undiscounted mortality value of fatal CBD in year i is equal to [the number of cases of fatal CBD prevented in year (i - 20)] x $8.7 million x (1.02)^i—for example, the $26.4 million of undiscounted CBD mortality benefits reported in year 21 is based on the 2 fatal CBD cases diagnosed in year 1; (g) because of the estimated 20-year lag from diagnosis of CBD to death, there are no mortality benefits for CBD estimated for years 1-20 and no mortality benefits were taken for CBD cases diagnosed in years 41-60 (since death would occur beyond the 60-year time horizon selected for the estimation of benefits); (h) the undiscounted fatality total value is equal to the sum of the three columns to the left; (i) the undiscounted grand total value is equal to the sum of the two columns to the left; and (j) every cell in the "Present Value by Year After Promulgation – 7% Discount Rate ($M)" columns is equal to the corresponding cell in the "Undiscounted Value of Cases Prevented by Year After Promulgation ($M)" columns multiplied by 1/(1.07)^i.

CHAPTER VIII: REGULATORY ALTERNATIVES

This chapter discusses various regulatory alternatives to the proposed OSHA beryllium standard. Executive Order 12866 instructs agencies to "select those approaches that maximize net benefits (including potential economic, environmental, public health and safety, and other advantages; distributive impacts; and equity), unless a statute requires another regulatory approach." The OSH Act, as interpreted by the courts, requires health regulations to reduce significant risk to the extent feasible. Nevertheless OSHA has examined possible regulatory alternatives that may not meet its statutory requirements.

Each regulatory alternative presented here is described and analyzed relative to the proposed rule. Where appropriate, the Agency notes whether the regulatory alternative, to be a legitimate candidate for OSHA consideration, requires evidence contrary to the Agency's preliminary findings of significant risk and feasibility. To facilitate comment, OSHA has organized some two dozen specific regulatory alternatives into five categories: (1) scope; (2) exposure limits; (3) methods of compliance; (4) ancillary provisions; and (5) timing.

SCOPE ALTERNATIVES

The first set of regulatory alternatives would alter scope of the proposed standard—that is, the groups of employees and employers covered by the proposed standard. The scope of the current beryllium proposal applies only to general industry work, and does not apply to employers when engaged in construction or maritime activities. In addition, the proposed rule provides an exemption for those working with materials that contain beryllium only as a trace contaminant (less than 0.1% composition by weight).[462]

As discussed in the explanation of paragraph (a) in Section XVIII of the preamble, Summary and Explanation of the Proposed Standard, OSHA is considering alternatives to the proposed scope that would increase the range of employers and employees covered by the standard. OSHA's review of several industries indicates that employees in some construction and maritime industries, as well as some employees who deal with materials containing less than 0.1% beryllium, may be at significant risk of CBD and lung cancer as a result of their occupational exposures. Regulatory Alternatives #1a, #1b, #2a, and #2b would increase the scope of the proposed standard to provide additional protection to these workers.

Regulatory Alternative #1a would expand the scope of the proposed standard to also include all operations in general industry where beryllium exists only as a trace contaminant; that is, where the materials used contain less than 0.1% beryllium by weight. **Regulatory Alternative #1b** offers an exemption for operations where beryllium exists only as a trace contaminant and the employer can show that employees' exposures will not meet or exceed the action level or exceed the STEL. Either through initial monitoring or where the employer has objective data demonstrating that a material containing beryllium or a specific process, operation, or activity involving beryllium cannot release beryllium in concentrations at or above the proposed action level or above

[462] Employers engaged in general industry activities exempted from the proposed rule must still ensure that their employees are protected from beryllium exposure above the current PEL, as listed in 29 CFR 1910.1000 Table Z-2.

the proposed STEL under any expected conditions of use, that employer would be exempt from the proposed standard except for recordkeeping requirements pertaining to the objective data. Alternative #1a and Alternative #1b, like the proposed rule, would not cover employers or employees in construction or shipyards.

OSHA has identified two industries with workers engaged in general industry work that would be excluded under the proposed rule but would fall within the scope of the standard under Regulatory Alternatives #1a and #1b: primary aluminum production and coal-fired power generation.

Beryllium exists as a trace contaminant in aluminum ore and may result in exposures above the proposed permissible exposure limits (PELs) during aluminum refining and production. In primary aluminum production, OSHA's exposure data indicate that some jobs, mostly pot room-related, have exposures to beryllium that may exceed the proposed TWA PEL (see Appendix VIII-A at the end of this chapter). Drawing on the information presented in Appendix IV-A at the end of Chapter IV of this PEA, all feasible engineering controls and work practices for this industry were analyzed and then applied to the industrial profile to calculate engineering and work practice costs associated with this alternative ($1.9 million, presented in Appendix VIII-A at the end of this chapter).

Coal fly ash in coal-powered utility facilities also contains trace amounts of beryllium, which may become airborne and result in worker exposures. OSHA's exposure profile shows that most exposure samples collected in these facilities after the 1980s do not exceed the proposed action level of 0.1 ug/m^3 (see Appendix VIII-B at the end of this chapter). On occasion, workers performing maintenance activities such as baghouse cleaning and boiler rebuilding may be exposed to levels of beryllium that exceed the proposed PELs. These maintenance activities also involve potential exposures to arsenic and other contaminants present in fly ash. Coal-fired power plants must ensure that they are in compliance with OSHA's Inorganic Arsenic standard (29 CFR 1910.1018) . As discussed in Appendix IV-B, beryllium exposures from fly ash high enough to exceed the proposed PEL would usually be coupled with arsenic exposures exceeding the arsenic PEL. Employers would in that case be required to implement all feasible engineering controls, work practices, and necessary PPE (including respirators) to comply with the OSHA Inorganic Arsenic standard (29 CFR 1910.1018)—which would be sufficient to comply with those aspects of the proposed beryllium standard as well. Therefore, OSHA has judged that a reduction of the beryllium PEL would not impose costs for additional engineering controls or respiratory protection in coal-fired utilities. The arsenic standard also contains ancillary provisions similar to some of the proposed provisions for beryllium, such as requirements for personal protective equipment, housekeeping, and hygiene practices; but it does not contain all requirements in the proposed beryllium standard, such as requirements for a written exposure control plan, a medical surveillance program, and medical removal protection specific to beryllium. The degree of overlap between the applicability of the two standards and, hence, the increment of costs attributable to this alternative are difficult to gauge. To account for this uncertainty, the Agency at this time is presenting a range of costs for Regulatory Alternative #1a: from no costs being taken for ancillary provisions under Regulatory Alternative #1a to all such costs being included. At the low end, the only additional costs under Regulatory Alternative #1a are due to the engineering control costs incurred by the aluminum smelters (see Appendix VIII-A).

Similarly, the proposed beryllium standard would not result in additional benefits from a reduction in the beryllium PEL or from ancillary provisions similar to those already in place for the arsenic standard, but OSHA does anticipate some benefits will flow from ancillary provisions unique to the proposed beryllium standard. To account for significant uncertainty in the benefits that would result from the proposed beryllium standard for workers in primary aluminum production and coal-fired power generation, OSHA estimated a range of benefits for Regulatory Alternative #1a. The Agency estimated that the proposed ancillary provisions would avert between 0 and 45 percent[463] of those baseline CBD cases not averted by the proposed PEL. Though the Agency is presenting a range for both costs and benefits for this alternative, the Agency judges the degree of overlap with the arsenic standard is likely to be substantial, so that the actual costs and benefits are more likely to be found at the low end of this range. The Agency invites comment on all these issues.

Table VIII-1 presents, for informational purposes, the estimated costs, benefits, and net benefits of Regulatory Alternative #1a using alternative discount rates of 3 percent and 7 percent. In addition, this table presents the incremental costs, incremental benefits, and incremental net benefits of this alternative relative to the proposed rule. Table VIII-1 also breaks out costs by provision, and benefits by type of disease and by morbidity/mortality. (Note: “morbidity” cases are cases where health effects are limited to non-fatal illness; in these cases there is no further disease progression to fatality).

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[463] As discussed in Chapter VII of this PEA, OSHA used 45 percent to develop its best estimate .

As shown in Table VIII-1, Regulatory Alternative #1a would increase the annualized cost of the rule from $37.6 million to somewhere between $39.6 and $56.0 million using a 3 percent discount rate and from $39.1 million to somewhere between $41.3 and $58.1 million using a 7 percent discount rate. OSHA estimates that Regulatory Alternative #1a would prevent as few as an additional 0.3 (i.e., almost one fatality every 3 years) or as many as an additional 31.8 beryllium-related fatalities annually, relative to the proposed rule. OSHA also estimates that Regulatory Alternative #1a would prevent as few as an additional 0.002 or as many as an additional 9 beryllium-related non-fatal illnesses annually, relative to the proposed rule. As a result, annualized benefits in monetized terms would increase from $575.8 million to somewhere between $578 million and $765.2 million, using a 3 percent discount rate, and from $255.3 million to somewhere between $256.3 and $339.3 million using a 7 percent discount rate. Net benefits would change from $538.2 million to somewhere between $538.4 and $709.2 million using a 3 percent discount rate and from $216.2 million to somewhere between $215.1 and $281.2 million using a 7 percent discount rate.

OSHA estimates that the costs and the benefits of Regulatory Alternative #1b would be somewhat lower than those of Regulatory Alternative #1a, because most—but not all—of the provisions of the proposed standard are triggered only by exposures at the action level, 8-hour time-weighted average (TWA) PEL, or STEL. For example, where exposures exist but are below the action level and at or below the STEL, Regulatory Alternative #1a would require employers to establish work areas; develop, maintain, and implement a written exposure control plan; provide medical surveillance to employees who show signs or symptoms of CBD; and provide PPE in some instances. Regulatory

Alternative #1b would not require employers to take these measures in operations where they can show, either through monitoring or objective data, that exposures are below the action level and at or below the STEL under any expected conditions of use. And, of course, like Regulatory Alternative #1a, these changes would only affect the two industries of aluminum production and coal-fired utilities.

ERG estimated the share of aluminum smelters and coal-fired power plants that would be exempt using objective data and reduced the ancillary provision, respirator, and engineering control costs of Regulatory Alternative #1a by this exemption share. Given that aluminum smelters have some workers above the PEL and will need to install engineering controls (see Appendix VIII-A), ERG set the smelter exemption share at zero. For coal-fired power plants, Appendix VIII-B estimates that 75 percent of all production workers are below the action level. With these relatively low levels of beryllium exposures at coal-fired power plants, ERG set the exemption share for this sector using objective data to meet the Alternative #1b exemption at 50 percent. The Agency invites comment on these estimates. OSHA only analyzed costs, not benefits, for this alternative, consistent with the Agency's treatment of Regulatory Alternatives in the past. The costs are presented in Table VIII-7. Total costs for Regulatory Alternative #1b versus #1a, assuming full ancillary costs, drop from to $56.0 million to $49.9 million using a 3 percent discount rate, and from $58.1 million to $51.8 million using a 7 percent discount rate.

Table VIII-I: Annualized Costs, Benefits and Incremental Benefits of OSHA's Proposed Beryllium Standard of Alternative Scope
Millions ($2010)

	Alternative 1a (Include trace contaminants)			Alternative 1a Incremental Costs/Benefits			Proposed PEL (PEL = 0.2 μg/m³, AL = 0.10 μg/m³)		
Discount Rate		**3%**	**7%**		**3%**	**7%**		**3%**	**7%**
Annualized Costs									
Control Costs		$10.8 - $10.8	$11.7 - $11.7		$1.3 - $1.3	$1.3 - $1.3		$9.5	$10.3
Respirators		$0.3 - $0.3	$0.3 - $0.3		$0.0 - $0.0	$0.0 - $0.0		$0.2	$0.3
Exposure Assessment		$2.3 - $3.8	$2.5 - $4.1		$0.1 - $1.5	$0.1 - $2.1		$2.2	$2.4
Regulated Areas and Beryllium Work Areas		$0.7 - $0.7	$0.7 - $0.7		$0.0 - $0.1	$0.0 - $0.1		$0.6	$0.7
Medical Surveillance		$3.0 - $4.3	$3.1 - $4.5		$0.1 - $1.5	$0.7 - $2.7		$2.9	$3.0
Medical Removal		$0.2 - $0.3	$0.2 - $0.3		$0.0 - $0.1	$0.0 - $0.1		$0.1	$0.2
Exposure Control Plan		$1.8 - $2.8	$1.8 - $2.8		$0.0 - $1.0	$0.0 - $1.3		$1.8	$1.8
Protective Clothing and Equipment		$1.4 - $1.4	$0.0 - $0.0		$0.0 - $0.0	$0.2 - $0.2		$1.4	$1.4
Hygiene Areas and Practices		$0.4 - $0.4	$0.4 - $0.4		$0.0 - $0.0	$0.0 - $0.0		$0.4	$0.4
Housekeeping		$12.9 - $21.4	$13.3 - $22.0		$0.4 - $8.8	$0.4 - $10.9		$12.6	$12.9
Training		$6.0 - $9.9	$6.0 - $9.9		$0.2 - $4.1	$0.2 - $4.9		$5.8	$5.8
Total Annualized Costs (point estimate)		$39.6 - $56.0	$41.3 - $58.1		$2.0 - $18.4	$0.1 - $17.9		**$37.6**	**$39.1**
Annual Benefits: Number of Cases Prevented	**Cases**			**Cases**			**Cases**		
Fatal Lung Cancers (midpoint estimate)	4.1 - 4.1			0.1 - 0.1			4		
Fatal Chronic Beryllium Disease	92.1 - 123.7			0.2 - 31.7			92		
Beryllium-Related Mortality	96.3 - 127.8	$575.0 - $761.4	$254.6 - $337.2	0.3 - 31.8	$2.0 - $188.4	$0.9 - $83.4	96	$573.0	$253.7
Beryllium Morbidity	49.5 - 58.5	$3.0 - $3.8	$1.7 - $2.1	0.0 - 9.0	$0.2 - $1.0	$0.1 - $0.5	50	$2.8	$1.6
Monetized Annual Benefits (midpoint estimate)		**$578.0 - $765.2**	**$256.3 - $339.3**		**$2.2 - $189.4**	**$1.0 - $84.0**		**$575.8**	**$255.3**
Net Benefits		**$538.4 - $709.2**	**$215.1 - $281.2**		**$0.2 - $171.0**	**$-1.1 - $65.0**		**$538.2**	**$216.2**

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis

* Benefits are assessed over a 60-year time horizon, during which it is assumed that economic conditions remain constant. Costs are annualized over ten years, with the exception of equipment expenditures, which are annualized over the life of the equipment. Annualized costs are assumed to continue at the same level for sixty years, which is consistent with assuming that economic conditions remain constant for the sixty year time horizon.

Regulatory Alternative #2a would expand the scope of the proposed standard to also include employers in construction and maritime. For example, this alternative would cover abrasive blasters, pot tenders, and cleanup staff working in construction and shipyards who have the potential for airborne beryllium exposure during blasting operations and during cleanup of spent media. **Regulatory Alternative #2b** would, in addition to the proposed beryllium standard for general industry, update 29 CFR 1910.1000 Tables Z-1 and Z-2, 1915.1000 Table Z, and 1926.55 Appendix A so that the proposed TWA PEL and STEL would apply to all employers and employees in general industry, shipyards, and construction, including occupations where beryllium exists only as a trace contaminant. Thus, under Regulatory Alternative #2b, the changes to the Z tables would apply to workers exposed to beryllium during aluminum refining and production and workers exposed in coal-powered utility facilities, in addition to workers in construction and shipyards. All provisions of the standard other than the PELs, such as exposure monitoring, medical removal, and PPE, would be in effect only for employers and employees that fall within the scope of the proposed rule. Alternative #2b would not extend ancillary provisions to construction, to maritime, or to those operations in general industry where beryllium is present only as a trace contaminant, such as aluminum smelting and coal-fired utilities.[464]

As discussed in the explanation of proposed paragraph (a) in this preamble at Section XVIII, Summary and Explanation of the Proposed Standard, abrasive blasting is

[464] However, many of the occupations excluded from the scope of the proposed beryllium standard receive some ancillary provision protections from other rules, such as Personal Protective Equipment (29 CFR 1910 Subpart I, 1915 Subpart I, 1926.28, also 1926 Subpart E), Ventilation (including abrasive blasting) (1926.57, 1915.34), Hazard Communication (1910.1200), and specific provisions for welding (1910 Subpart Q, 1915 Subpart D, 1926 Subpart J).

the primary application group in construction and maritime industries where workers may be exposed to beryllium. OSHA has judged that abrasive blasters and their helpers in construction and maritime industries have the potential for significant airborne exposure during blasting operations and during cleanup of spent media. Airborne concentrations of beryllium have been measured above the current TWA PEL of 2 μg/m^3 when blast media containing beryllium are used as intended (see Appendix IV- C in this PEA for details). As discussed in Appendix VIII-C of this PEA, national employment statistics only estimate total employees in the abrasive blasting sector, not a breakdown between operators and various helpers, and provide no information on which workers use blasting materials that contain beryllium. To supplement these total figures, interviews were conducted with members of industry (ERG, 2014). From these conversations OSHA preliminarily estimates that 50 percent of operators and helpers in construction and 80 percent in shipyards use blast media containing beryllium. OSHA also estimates an average of 1.5 helpers per operator for both sectors (ERG, 2014). The Agency requests comment on these estimates.

To address high concentrations of various hazardous chemicals in abrasive blasting material, employers must already be using engineering and work practice controls to limit workers' exposures and must be supplementing these controls with respiratory protection when necessary. For example, abrasive blasters in the construction industry fall under the protection of the Ventilation standard (29 CFR 1926.57), as well as OSHA standards regulating other toxic substances found in coal slag (e.g., nickel (29 CFR 1926.55 App. A)). The Ventilation standard includes an abrasive blasting subsection (29 CFR 1926.57(f)), which requires that abrasive blasting respirators be worn by all abrasive blasting operators when working inside blast-cleaning rooms (29 CFR 1926.57(f)(5)(ii)(A)), or when using silica sand in manual blasting operations where the nozzle and blast are not physically separated from the operator in an exhaust-ventilated enclosure (29 CFR 1926.57(f)(5)(ii)(B)), or when needed to protect workers from exposures to hazardous substances in excess of the limits set in §1926.55 (29 CFR 1926.57(f)(5)(ii)(C); ACGIH, 1970). For maritime, standard 29 CFR 1915.34(c) covers similar requirements for respiratory protection needed in blasting operations. Due to these requirements, OSHA believes that abrasive blasting operators already have required controls in place and wear appropriate respiratory protection during blasting operations. Pot tenders, cleanup workers, and other helpers in blasting operations do not have similarly stringent protections. However, beryllium exposure due to blasting materials (coal slag) is associated with large amounts of dust; therefore OSHA judges that helpers would already be wearing the level of PPE that would be required by the proposed beryllium standard. An earlier NIOSH study (NIOSH, 1995; Table 1) found a very high percentage of pot tenders used respirators while performing their duties. OSHA requests comment on whether employers in abrasive blasting operations using blast material that contain beryllium as a trace contaminant are already using all feasible engineering and work practice controls, and ensuring the use of respiratory protection and PPE that would be required by Regulatory Alternative #2a. OSHA also requests comment on the type and frequency of use of respirators among abrasive blasting operators and helpers, as well as the numbers of blasting operators and helpers employed in construction and shipyards.

In the estimation of benefits for Regulatory Alternative #2a, OSHA has estimated a range to account for significant uncertainty in the benefits to this population from some of the ancillary provisions of the proposed beryllium standard. It is unclear how many of the workers associated with abrasive blasting work would benefit from dermal protection, as comprehensive dermal protection may already be used by most blasting operators. It is also unclear whether the housekeeping requirements of the proposed standard would be feasible to implement in the context of abrasive blasting work, and to what extent they would benefit blasting helpers, who are themselves exposed while performing cleanup activities. OSHA estimated that the proposed ancillary provisions would avert between 0 and 45 percent of those baseline CBD cases not averted by the proposed PEL.

These considerations also lead the Agency to present a range for the costs of this alternative: from no costs being taken for ancillary provisions under Regulatory Alternative #2a to including all such costs. Based on the considerations discussed above, the Agency judges that costs and benefits at the low end of this range are more likely to be correct. The Agency invites comment on these issues.

In addition to abrasive blasters, OSHA believes that a small number of welders in the maritime industry may be exposed to beryllium via arc and gas welding (and none through resistance welding). The number of maritime welders was estimated using the same methodology as was used to estimate the number of general industry welders. Brush Wellman's customer survey estimated 2,000 total welders on beryllium-containing products (Kolanz, 2001). Based on ERG's assumption of 4 welders per establishment, ERG estimated that a total of 500 establishments would be affected. These affected establishments were then distributed among the 26 NAICS industries with the highest number of IMIS samples for welders that were positive for beryllium. To do this, ERG first consulted the BLS OES survey to determine what share of establishments in each of the 26 NAICS employed welders and estimated the total number of establishments that perform welding regardless of beryllium exposure (BLS, 2010). Then ERG distributed the 500 affected beryllium welding facilities among the 26 NAICS based on the relative share of the total number of establishments performing welding. Finally, to estimate the number of welders, ERG again used the assumption of 4 welders per establishment. Based on the information from ERG, OSHA estimated that 30 welders would be covered in the maritime industry under this regulatory alternative. For these welders, OSHA used the same controls and exposure profile that were used to estimate costs for arc and gas welders in Chapter V of this PEA. ERG judged there to be no construction welders exposed to beryllium because there is no evidence indicating that construction welders performing arc or gas welding work to a significant degree with beryllium-containing metals; nor is resistance welding with beryllium alloy electrodes likely to be done in a construction setting. OSHA solicits comment and any relevant data on beryllium exposures for welders in construction and maritime employment.

Table VIII-2 presents the estimated costs, benefits, and net benefits of Regulatory Alternatives #2a using alternative discount rates of 3 percent and 7 percent. In addition, this table presents the incremental costs, incremental benefits, and incremental net benefits of these alternatives relative to the proposed rule. Table VIII-2 also breaks out costs by provision and benefits by type of disease and by morbidity/mortality. Because the small group of welders in maritime has exposures over the PEL, has different working conditions than blasting operations, and is not subject to the same blasting OSHA standards, even the low range of costs and benefits is non-zero for this group, and hence for this alternative.

As shown in Table VIII-2, Regulatory Alternative #2a would increase costs from $37.6 million to between $37.7 and $55.3 million, using a 3 percent discount rate, and from $39.1 million to between $39.2 and $57.3 million using a 7 percent discount rate. Annualized benefits would increase from $575.8 million to between $575.9 and $675.3 million using a 3 percent discount rate, and from $255.3 million to between $255.4 and $675.3 million using a 7 percent discount rate. Net benefits would change from $538.2 million to between $538.2 and $620.0 million using a 3 percent discount rate, and from $216.2 million to between $216.1 and $242.1 million using a 7 percent discount rate.

As shown in Table VIII-3, Regulatory Alternative #2b would increase the annualized cost of the rule from $37.6 million to $39.6 million using a 3 percent discount rate, and would increase the annualized cost of the rule from $39.1 to $41.1 million using a 7 percent discount rate. Regulatory Alternative #2b would prevent less than one additional beryllium-related fatality and less than one additional beryllium-related illness annually relative to the proposed rule. As a result, annualized benefits would increase from $575.8 million to $578.1 million using a 3 percent discount rate, and from $255.3 million to $256.3 million using a 7 percent discount rate. Net benefits would increase from $538.2 million to $538.5 million using a 3 percent discount rate, and decrease from $216.2 million to $215.2 million using a 7 percent discount rate.

Table VIII-2: Annualized Costs, Benefits and Incremental Benefits of OSHA's Proposed Beryllium Standard of Alternative Scope Including Maritime and Construction
Millions ($2010)

	Alternative 2a Include Maritime and Construction Sectors			Alternative 2a Include Maritime and Construction Sectors (incremental costs and benefits)			Proposed PEL (PEL = 0.2 μg/m^3, AL = 0.10 μg/m^3)		
Discount Rate		3%	7%		3%	7%		3%	7%
Annualized Costs									
Control Costs		$9.6 - $9.6	$10.4 - $10.4		$0.0 - $0.0	$0.0 - $0.0		$9.5	$10.3
Respirators		$0.3 - $0.3	$0.3 - $0.3		$0.0 - $0.0	$0.0 - $0.0		$0.2	$0.3
Exposure Assessment		$2.2 - $3.8	$2.4 - $4.0		$0.0 - $1.5	$0.0 - $1.6		$2.2	$2.4
Regulated areas and Beryllium Work Areas		$0.6 - $1.4	$0.7 - $1.4		$0.0 - $0.7	$0.0 - $0.7		$0.6	$0.7
Medical Surveillance		$2.9 - $6.2	$3.0 - $6.4		$0.0 - $3.3	$0.0 - $3.3		$2.9	$3.0
Medical Removal		$0.1 - $0.5	$0.2 - $0.6		$0.0 - $0.4	$0.0 - $0.4		$0.1	$0.2
Exposure Control Plan		$1.8 - $2.7	$1.8 - $2.8		$0.0 - $1.0	$0.0 - $1.0		$1.8	$1.8
Protective Clothing and Equipment		$1.4 - $1.4	$1.4 - $1.4		$0.0 - $0.0	$0.0 - $0.0		$1.4	$1.4
Hygiene Areas and Practices		$0.4 - $1.6	$0.4 - $1.6		$0.0 - $1.2	$0.0 - $1.1		$0.4	$0.4
Housekeeping		$12.6 - $19.1	$12.9 - $19.6		$0.0 - $6.6	$0.0 - $6.7		$12.6	$12.9
Training		$5.8 - $8.8	$5.8 - $8.9		$0.0 - $3.0	$0.0 - $3.0		$5.8	$5.8
		$37.7 - $55.3	$39.2 - $57.3		$0.1 - $17.7	$0.1 - $17.9			
Total Annualized Costs (point estimate)								**$37.6**	**$39.1**
Annual Benefits: Number of Cases Prevented	Cases			Cases			Cases		
Fatal Lung Cancers (midpoint estimate)	4.0 - 4.0			0.0 - 0.0			4		
Fatal Chronic Beryllium Disease	92.0 - 108.7			0.0 - 16.7			92		
Beryllium-Related Mortality	96.0 - 112.7	$573.0 - $671.9	$253.8 - $297.6	0.0 - 16.7	$0.0 - $99.0	$0.0 - $43.8	96	$573.0	$253.7
Beryllium Morbidity	49.5 - 58.5	$2.8 - $3.4	$1.6 - $1.9	0.0 - 9.0	$0.0 - $0.5	$0.0 - $0.3	50	$2.8	$1.6
Monetized Annual Benefits (midpoint estimate)		**$575.9 - $675.3**	**$255.4 - $299.4**		**$0.0 - $99.0**	**$0.0 - $44.1**		**$575.8**	**$255.3**
Net Benefits		**$538.2 - $620.0**	**$216.1 - $242.1**		**$0.0 - $81.8**	**$0.0 - $25.9**		**$538.2**	**$216.2**

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis

* Benefits are assessed over a 60-year time horizon, during which it is assumed that economic conditions remain constant. Costs are annualized over ten years, with the exception of equipment expenditures, which are annualized over the life of the equipment. Annualized costs are assumed to continue at the same level for sixty years, which is consistent with assuming that economic conditions remain constant for the sixty year time horizon.

Table VIII-3: Annualized Costs, Benefits and Incremental Benefits of OSHA's Proposed Beryllium Standard of Updating Z Tables 1910.1000, 1915.1000, and 1926.55 and Requiring Control Costs for Industries with Trace Contaminants
Millions ($2010)

	Alternative 2b: Update Z Tables 1910.1000, 1915.1000, and 1926.55 and Require Control Costs for Industries with Trace Contaminants			Alternative 2b: Update Z Tables 1910.1000, 1915.1000, and 1926.55 and Require Control Costs for Industries with Trace Contaminants (incremental costs and benefits)			Proposed PEL (PEL = 0.2 μg/m³, AL = 0.10 μg/m³)		
Discount Rate		**3%**	**7%**		**3%**	**7%**		**3%**	**7%**
Annualized Costs									
Control Costs		$11.5	$12.3		$2.0	$2.0		$9.5	$10.3
Respirators		$0.2	$0.3		$0.0	$0.0		$0.2	$0.3
Exposure Assessment		$2.2	$2.4		$0.0	$0.0		$2.2	$2.4
Regulated areas and Beryllium Work Areas		$0.6	$0.7		$0.0	$0.0		$0.6	$0.7
Medical Surveillance		$2.9	$3.0		$0.0	$0.0		$2.9	$3.0
Medical Removal		$0.1	$0.2		$0.0	$0.0		$0.1	$0.2
Exposure Control Plan		$1.8	$1.8		$0.0	$0.0		$1.8	$1.8
Protective Clothing and Equipment		$1.4	$1.4		$0.0	$0.0		$1.4	$1.4
Hygiene Areas and Practices		$0.4	$0.4		$0.0	$0.0		$0.4	$0.4
Housekeeping		$12.6	$12.9		$0.0	$0.0		$12.6	$12.9
Training		$5.8	$5.8		$0.0	$0.0		$5.8	$5.8
Total Annualized Costs (point estimate)		**$39.6**	**$41.1**		**$2.0**	**$2.0**		**$37.6**	**$39.1**
Annual Benefits: Number of Cases Prevented	**Cases**			**Cases**			**Cases**		
Fatal Lung Cancers (midpoint estimate)	4.1			0.1			4.0		
Fatal Chronic Beryllium Disease	92.1			0.2			92.0		
Beryllium-Related Mortality	96.3	$575.0	$254.6	0.3	$2.02	$0.90	96.0	$573.0	$253.7
Beryllium Morbidity	49.6	$3.0	$1.7	0.1	$0.20	$0.11	49.5	$2.8	$1.6
Monetized Annual Benefits (midpoint estimate)		**$578.1**	**$256.3**		**$2.2**	**$1.0**		**$575.8**	**$255.3**
Net Benefits		**$538.5**	**$215.2**		**$0.3**	**-$1.0**		**$538.2**	**$216.2**

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis

* Benefits are assessed over a 60-year time horizon, during which it is assumed that economic conditions remain constant. Costs are annualized over ten years, with the exception of equipment expenditures, which are annualized over the life of the equipment. Annualized costs are assumed to continue at the same level for sixty years, which is consistent with assuming that economic conditions remain constant for the sixty year time horizon.

EXPOSURE LIMIT (TWA PEL, STEL, AND ACTION LEVEL) ALTERNATIVES

OSHA is proposing a new TWA PEL for beryllium of 0.2 μg/m^3 and a STEL of 2.0 μg/m^3 for all application groups covered by the rule. OSHA's proposal is based on the requirements of the Occupational Safety and Health Act (OSH Act) and court interpretations of the Act. For health standards issued under section 6(b)(5) of the OSH Act, OSHA is required to promulgate a standard that reduces significant risk to the extent that it is technologically and economically feasible to do so. See Section II of the preamble, Pertinent Legal Authority, for a full discussion of OSHA legal requirements.

Paragraph (c) of the proposed standard establishes two PELs for beryllium in all forms, compounds, and mixtures: an 8-hour TWA PEL of 0.2 μg/m^3 (proposed paragraph (c)(1)), and a 15-minute short-term exposure limit (STEL) of 2.0 μg/m^3 (proposed paragraph (c)(2)). OSHA has defined the action level for the proposed standard as an airborne concentration of beryllium of 0.1 μg/m^3 calculated as an eight-hour TWA (proposed paragraph (b)). In this proposal, as in other standards, the action level has been set at one-half of the TWA PEL.

As discussed in the preamble explanation of paragraph (c) in Section XVIII, Summary and Explanation of the Proposed Standard, OSHA is considering three regulatory alternatives that would modify the PELs for the proposed standard.

Regulatory Alternative #3 would modify the proposed STEL to be five times the TWA PEL, as is typical for OSHA standards that have STELs. A STEL five times the TWA PEL has more practical effect because a STEL ten times the TWA PEL will rarely be exceeded without also driving exposures above the TWA PEL. For example, assuming a background exposure level of 0.1 μg/m^3, a STEL ten times the TWA PEL could only be exceeded once in a work shift for 15 minutes without driving exposures above the TWA PEL, whereas a STEL five times the TWA PEL could be exceeded three times before driving exposures above the TWA PEL.

OSHA's standards for methylene chloride (29 CFR 1910.1052), acrylonitrile (29 CFR 1910.1045), benzene (29 CFR 1910.1028), ethylene oxide (29 CFR 1910.1047), and 1,3-Butadiene (29 CFR 1910.1051) all set STELs at five times the TWA PEL. Thus, if OSHA promulgates the proposed TWA PEL of 0.2 μg/m^3, the accompanying STEL under this regulatory alternative would be set at 1 μg/m^3.

As discussed in the preamble at Section V of the preamble, Health Effects, immunological sensitization can be triggered by short-term exposures. OSHA believes a STEL for beryllium will help reduce the risk of sensitization and CBD in beryllium-exposed employees. For instance, without a STEL, workers' exposures could be as high as 6.4 μg/m^3 (32 x 0.2 μg/m^3) for 15 minutes under the proposed TWA PEL, if exposures during the remainder of the 8-hour work shift are non-detectable. A STEL serves to minimize high task-based exposures by requiring feasible controls in these situations, and has the added effect of further reducing the TWA exposure.

OSHA requests comment on the range of short-term exposures in covered industries, the types of operations where these are occurring, and on the proposed and alternative STELs, including any data or information that may help OSHA choose between them.

OSHA identified two job categories where workers would be expected to have short-term exposures in the range between the proposed STEL and the STEL under Regulatory Alternative #3 (that is, between 2.0 and 1.0 μg/m^3): furnace operators in nonferrous foundries and material preparation operators in the beryllium oxide ceramics application group. To estimate the costs for this alternative, OSHA assumed that all workers in these job categories would need to wear respirators to meet a STEL of 1.0, though exposures might not actually warrant respirator use for all such workers. OSHA also estimated costs for additional regulated areas and medical surveillance for workers in these two job categories. The costs for this alternative are presented in Table VIII-4. Total costs rise from $37.6 million to $37.7 million using a 3 percent discount rate and from $39.1 million to $39.3 million using a 7 percent discount rate.

Table VIII-4: Cost of Regulatory Alternatives, Alternative 3
(Proposed PEL=0.2, STEL=2.0, AL=0.1)

3% Discount Rate	Total Cost	Incremental Cost Relative to Proposal
Proposed Rule	$37,597,325	——
Alternative 3: STEL=1.0, all else the same	$37,742,714	$145,389

7% Discount Rate	Total Cost	Incremental Cost Relative to Proposal
Proposed Rule	$39,147,434	——
Alternative 3: STEL=1.0, all else the same	$39,294,987	$147,553

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis

Under **Regulatory Alternative #4**, the TWA PEL would be 0.1 μg/m^3 with an action level of 0.05 μg/m^3. The Agency's preliminary risk assessment indicates that the risks remaining at the proposed TWA PEL of 0.2 μg/m^3—while lower than risks at the current TWA PEL—are still significant (see the preamble at Section VIII, Significance of Risk). A TWA PEL of 0.1 μg/m^3 would reduce some of the remaining risks to workers at the proposed PEL. The OSH Act requires the Agency to set its standards to address significant risks of harm to the extent economically and technologically feasible, so OSHA would have very limited flexibility to adopt a higher PEL if a lower PEL is technologically and economically feasible.

While OSHA's preliminary analysis indicates that the proposed TWA PEL of 0.2 μg/m^3 is economically and technologically feasible, OSHA has less confidence in the feasibility of a TWA PEL of 0.1 μg/m^3. In some industry sectors it is difficult to determine whether a TWA

PEL of 0.1 μg/m^3 could be achieved in most operations most of the time (see Section IX.D of the preamble, Technological Feasibility). OSHA believes that one way this uncertainty could be resolved would be with additional information on exposure control technologies and the exposure levels that are currently being achieved in these industry sectors. OSHA requests additional data and information to inform its final determinations on feasibility (see Section IX.D of the preamble, Technological Feasibility) and the alternative PELs under consideration.

Regulatory Alternative #5, which would set a TWA PEL at 0.5 μg/m^3 and an action level at 0.25 μg/m^3, both higher than in the proposal, responds to an issue raised during the Small Business Advocacy Review (SBAR) process conducted in 2007 to consider a draft OSHA beryllium proposed rule that culminated in an SBAR Panel report (SBAR, 2008). That report included a recommendation that OSHA consider both the economic impact of a low TWA PEL and regulatory alternatives that would ease cost burden for small entities. OSHA has provided a full analysis of the economic impact of its proposed PELs (see Chapter VI of this PEA), and Regulatory Alternative #5 addresses the second half of that recommendation. However, the higher 0.5 μg/m^3 TWA PEL does not appear to be consistent with the Agency's mandate under the OSH Act to promulgate a lower PEL if it is feasible and could prevent additional fatalities and non-fatal illnesses. The data presented in Table VIII-5 below indicate that the lower TWA PEL would prevent additional fatalities and non-fatal illnesses, but nevertheless the Agency solicits comments on this alternative and OSHA's analysis of the costs and benefits associated with it.

Table VIII-5 below presents, for informational purposes, the estimated costs, benefits, and net benefits of the proposed rule under the proposed TWA PEL of 0.2 μg/m^3 and for the regulatory alternatives of a TWA PEL of 0.1 μg/m^3 and a TWA PEL of 0.5 μg/m^3 (Regulatory Alternatives #4 and #5, respectively), using alternative discount rates of 3 percent and 7 percent. In addition, the table presents the incremental costs, the incremental benefits, and the incremental net benefits, of going from a TWA PEL of 0.5 μg/m^3 to the proposed TWA PEL of 0.2 μg/m^3 and then of going from the proposed TWA PEL of 0.2 μg/m^3 to a TWA PEL of 0.1 μg/m^3. Table VIII-5 also breaks out costs by provision and benefits by type of disease and by morbidity/mortality.

OSHA has not made a determination that a TWA PEL of 0.1 μg/m^3 would be feasible for all application groups (that is, engineering and work practices would be sufficient to reduce and maintain beryllium exposures to a TWA PEL of 0.1 μg/m^3 or below in most operations most of the time in the affected industries). For Regulatory Alternative #4, the Agency attempted to identify engineering controls and their costs for those affected application groups where the technology feasibility analysis in Chapter IV of this PEA indicated that a TWA PEL of 0.1 μg/m^3 could be achieved. For those application groups, OSHA costed out the set of feasible controls necessary to meet this alternative PEL. For the rest of the affected application groups, OSHA assumed that all workers exposed between 0.2 μg/m^3 and 0.1 μg/m^3 would have to wear respirators to achieve compliance with the 0.1 μg/m^3 TWA PEL and estimated the associated additional costs for respiratory protection. For all affected industries, OSHA also estimated the costs to satisfy the ancillary requirements specified in the proposed rule for all affected workers under the alternative TWA PEL of 0.1 μg/m^3. For both controls and respirators, the unit costs were the same as presented in Chapter V of this PEA.

The estimated benefits for Regulatory Alternative #4 were calculated based on the number of workers identified with exposures between 0.1 and 0.2 μg/m^3, using the methods and unit benefit values developed in Chapter VII of this PEA.

As Table VIII-5 shows, going from a TWA PEL of 0.5 μg/m^3 to a TWA PEL of 0.2 μg/m^3 would prevent, annually, an additional 29 beryllium-related fatalities and an additional 15 non-fatal illnesses. This is consistent with OSHA's preliminary risk assessment, which indicates significant risk to workers exposed at a TWA PEL of 0.5 μg/m^3; furthermore, OSHA's preliminary feasibility analysis indicates that a lower TWA PEL than 0.5 μg/m^3 is feasible. Net benefits of this regulatory alternative versus the proposed TWA PEL of 0.2 μg/m^3 would decrease from $538.2 million to $370.0 million using a 3 percent discount rate and from $216.2 million to $144.4 million using 7 percent discount rate.

Table VIII-5 also shows the costs and benefits of going from the proposed TWA PEL of 0.2 μg/m^3 to a TWA PEL of 0.1 μg/m^3. As shown there, going from a TWA PEL of 0.2 μg/m^3 to a TWA PEL of 0.1 μg/m^3 would prevent an additional 2 beryllium-related fatalities and one additional non-fatal illness. Net benefits of this regulatory alternative versus the proposed TWA PEL of 0.2 μg/m^3 would increase from $538.2 million to $543.5 million using a 3 percent discount rate and decrease from $216.2 million to $214.9 million using a 7 percent discount rate.

Table VIII-5: Annualized Costs, Benefits and Incremental Benefits of OSHA's Proposed Beryllium Standard of 0.1 μg/m3 and 0.5 μg/m3 PEL Alternative
Millions ($2010)

	Alternative 4 (PEL = 0.1 μg/m^3, AL = 0.05 μg/m^3)			Alternative 4 Incremental Costs/Benefits			Proposed PEL (PEL = 0.2 μg/m^3, AL = 0.10 μg/m^3)			Alternative 5 Incremental Costs/Benefits			Alternative 5 (PEL = 0.5 μg/m^3, AL = 0.25 μg/m^3)		
Discount Rate		3%	7%		3%	7%		3%	7%		3%	7%		3%	7%
Annualized Costs															
Control Costs		$12.9	$13.9		$3.3	$3.5		$9.5	$10.3		$3.6	$3.9		$6.0	$6.5
Respirators		$0.7	$0.7		$0.4	$0.5		$0.2	$0.3		$0.1	$0.1		$0.1	$0.1
Exposure Assessment		$3.8	$3.9		$1.6	$1.5		$2.2	$2.4		$0.3	$0.3		$1.9	$2.1
Regulated areas and Beryllium Work Areas		$0.9	$0.9		$0.3	$0.3		$0.6	$0.7		$0.3	$0.3		$0.3	$0.4
Medical Surveillance		$3.0	$3.1		$0.1	$0.1		$2.9	$3.0		$0.1	$0.1		$2.8	$2.9
Medical Removal		$0.4	$0.5		$0.3	$0.3		$0.1	$0.2		$0.1	$0.1		$0.1	$0.1
Exposure Control Plan		$1.8	$1.8		$0.0	$0.0		$1.8	$1.8		$0.0	$0.0		$1.8	$1.8
Protective Clothing and Equipment		$1.4	$1.4		$0.0	$0.0		$1.4	$1.4		$0.0	$0.0		$1.4	$1.4
Hygiene Areas and Practices		$0.6	$0.6		$0.2	$0.2		$0.4	$0.4		$0.0	$0.0		$0.4	$0.4
Housekeeping		$12.6	$12.9		$0.0	$0.0		$12.6	$12.9		$0.0	$0.0		$12.6	$12.9
Training		$5.8	$5.8		$0.0	$0.0		$5.8	$5.8		$0.0	$0.0		$5.8	$5.8
Total Annualized Costs (point estimate)		**$43.7**	**$45.5**		**$6.1**	**$6.3**		**$37.6**	**$39.1**		**$4.4**	**$4.8**		**$33.2**	**$34.4**
Annual Benefits: Number of Cases Prevented	Cases			Cases			Cases			Cases			Cases		
Fatal Lung Cancers (midpoint estimate)	4			0			4			0			4		
Fatal Chronic Beryllium Disease	94			2			92			29			63		
Beryllium-Related Mortality	98	$584.4	$258.8	2	$11.4	$5.0	96	$573.0	$253.7	29	$171.8	$76.1	67	$401.2	$177.7
Beryllium Morbidity	50	$2.9	$1.6	1	$0.0	$0.0	50	$2.8	$1.6	15	$0.9	$0.5	34	$2.0	$1.1
Monetized Annual Benefits (midpoint estimate)		**$587.3**	**$260.4**		**$11.4**	**$5.1**		**$575.8**	**$255.3**		**$172.7**	**$76.6**		**$403.1**	**$178.8**
Net Benefits		**$543.5**	**$214.9**		**$5.3**	**-$1.3**		**$538.2**	**$216.2**		**$168.2**	**$71.9**		**$370.0**	**$144.4**

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis

* Benefits are assessed over a 60-year time horizon, during which it is assumed that economic conditions remain constant. Costs are annualized over ten years, with the exception of equipment expenditures, which are annualized over the life of the equipment. Annualized costs are assumed to continue at the same level for sixty years, which is consistent with assuming that economic conditions remain constant for the sixty year time horizon.

Regulatory Alternative Featuring Unchanged PEL but Full Ancillary Provisions

An Informational Analysis: This proposed regulation has the somewhat unusual feature for an OSHA substance-specific health standard that most of the quantified benefits would come from the ancillary provisions rather than from meeting the PEL with engineering controls. OSHA decided to analyze for informational purposes the effect of retaining the existing PEL but applying all of the ancillary provisions, including respiratory protection. Under this approach, the TWA PEL would remain at 2.0 micrograms per cubic meter, but all of the other proposed provisions (including respiratory protection, which OSHA does not consider an ancillary provision) would be required with their triggers remaining the same as in the proposed rule—either the presence of airborne beryllium at any level (e.g., initial monitoring, written exposure control plan), at certain kinds of dermal exposure (PPE), at the action level of 0.1 $\mu g/m^3$ (e.g., periodic monitoring, medical removal), or at 0.2 $\mu g/m^3$ (e.g., regulated areas, respiratory protection, medical surveillance).

Given the record regarding beryllium exposures, this approach is not one OSHA could legally adopt because the absence of a more protective requirement for engineering controls would not be consistent with section 6(b)(5) of the OSH Act, which requires OSHA to "set the standard which most adequately assures, to the extent feasible, on the basis of the best available evidence, that no employee will suffer material impairment of health or functional capacity even if such employee has regular exposure to the hazard dealt with by such standard for the period of his working life." For that reason, this additional analysis is provided strictly for informational purposes. EO 12866 and EO

13563 direct agencies to identify approaches that maximize net benefits, and this analysis is purely for the purpose of exploring whether this approach would hold any real promise to maximize net benefits if it was permissible under the OSH Act. It does not appear to hold such promise because an ancillary-provisions-only approach would not be as protective and thus offers fewer benefits than one that includes a lower PEL and engineering controls, and we estimate the costs would be about the same (or slightly lower, depending on certain assumptions) under that approach as under the traditional proposed approach.

When examined on an industry by industry basis, OSHA found that some industries would have lower costs if they could adopt the ancillary provision only approach. Some employers would use engineering controls where they are cheaper, even if they are not mandatory. OSHA does not have sufficient information to do an analysis of the employer-by-employer situations in which there exist some employers for whom the ancillary-provisions-only approach might be cheaper. In the majority of affected industries, the Agency estimates there are no costs saving to the ancillary-provisions-only approach. However, OSHA estimates a total of $2,675,828 per year in costs saving for entire industries where the ancillary-provisions-only approach would be less expensive.

The above discussion does not account for the possibility that the lack of engineering controls would result in higher beryllium exposures for workers in adjacent (non-production) work areas due to the increased level of beryllium in the air. Because of a lack of data, and because the issue did not arise in the other regulatory alternatives OSHA considered (all of which have a PEL of less than 2.0 $\mu g/m^3$), OSHA did not carefully examine exposure levels in non-production areas for either cost or benefit purposes. To the extent such exposure levels would be above the action level, there would be additional costs for respiratory protection.

If respirators were as effective as engineering controls, the ancillary provisions only approach would have benefits comparable to the benefits of the rule as proposed. However, in this alternative most exposed individuals would be required to use respirators, which OSHA considers less effective than engineering controls in preventing employee exposure to beryllium. OSHA last did an extensive review of the evidence on effectiveness of respirators for its APFs rulemaking in 2006 (71 FR 50128-45 Aug 24, 2006). As a result, OSHA also examined what the benefits would be if respirators were not required, were not worn, or were ineffective. OSHA found that, if all of the other aspects of the benefits analysis remain the same, the benefits would be reduced by from $22.4 to $33.2 million (using discount rates of 7 percent and 3 percent, respectively), largely as a result of failing to reduce deaths from lung cancer, which are unaffected by the ancillary provisions. However, there are also other reasons to believe that benefits may be even lower:

1) As noted above, in the proposal OSHA did not consider benefits caused by reductions in exposure in non-production areas. Unless employers act to reduce exposures in the production areas, the absence of a requirement for such controls would largely negate such benefits from reductions in exposure in the non-productions areas.

2) OSHA believes that there is a strong possibility that the benefits of the ancillary provisions (a midpoint estimate of eliminating 45 percent of all remaining cases of CBD) would be partially or wholly negated in the absence of engineering controls that would reduce both airborne and surface dust levels. The measured reduction in benefits

from ancillary provision was in a facility with average exposure levels of less than 0.2 $\mu g/m^3$.

Based on these considerations, OSHA believes that the ancillary-provisions-only approach is not one that is likely to maximize net benefits. The costs saving, if any, are estimated to be small, and the difficult-to-measure declines in benefits could be substantial.

A METHODS-OF-COMPLIANCE ALTERNATIVE

Paragraph (f)(2) of the proposed rule contains requirements for the implementation of engineering and work practice controls to minimize beryllium exposures in beryllium work areas. For each operation in a beryllium work area, employers must ensure that one or more of the following engineering and work practice controls are in place to minimize employee exposure: material and/or process substitution; ventilated enclosures; local exhaust ventilation; or process controls, such as wet methods and automation. Employers are exempt from using engineering and work practice controls only when they can show that such controls are not feasible or where exposures are below the action level based on two exposure samples taken seven days apart.

These requirements, which are based on the stakeholders' recommended beryllium standard that beryllium industry and union stakeholders submitted to OSHA in 2012 (Materion and United Steelworkers, 2012), address a concern associated with the proposed TWA PEL. OSHA expects that day-to-day changes in workplace conditions, such as workers' positioning or patterns of airflow, may cause frequent exposures above the TWA PEL in workplaces where periodic sampling indicates exposures are between the action level and the TWA PEL. As a result, the default under the standard is that the controls are required until the employer can demonstrate that exposures have not exceeded the action level from at least two separate measurements taken seven days apart.

OSHA believes that substitution or engineering controls such as those outlined in paragraph (f)(2)(i) provide the most reliable means to control variability in exposure levels. However, OSHA also recognizes that the requirements of paragraph (f)(2)(i) are not typical of OSHA standards, which usually require engineering controls only where exposures exceed the TWA PEL or STEL. The Agency is therefore considering **Regulatory Alternative #6**, which would drop the provisions of (f)(2)(i) from the proposed standard and make conforming edits to paragraphs (f)(2)(ii) and (iii). This regulatory alternative does not eliminate the need for engineering controls to comply with the proposed TWA PEL and STEL, but does eliminate the requirement to use one or more of the specified engineering or work practice controls where exposures equal or exceed the action level. As shown in Table VIII-6, Regulatory Alternative #6 would decrease the annualized cost of the proposed rule by about $457,000 using a discount rate of 3 percent and by about $480,000 using a discount rate of 7 percent. OSHA has not been able to estimate the change in benefits resulting from Regulatory Alternative #6 at this time and invites public comment on this issue.

Table VIII-6: Cost of Regulatory Alternatives, Alternative 6
(Proposed PEL=0.2, STEL=2.0, AL=0.1)

3% Discount Rate	Total Cost	Incremental Cost Relative to Proposal
Proposed Rule	$37,597,325	——
Alternative 6: Eliminate (f)(2) controls	$37,140,020	-$457,304

7% Discount Rate	Total Cost	Incremental Cost Relative to Proposal
Proposed Rule	$39,147,434	——
Alternative 6: Eliminate (f)(2) controls	$38,667,896	-$479,538

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis

REGULATORY ALTERNATIVES THAT AFFECT ANCILLARY PROVISIONS

The proposed standard contains several ancillary provisions (provisions other than the exposure limits), including requirements for exposure assessment, medical surveillance, medical removal, training, and regulated areas or access control. As reported in Chapter V of this PEA, these ancillary provisions account for $27.8 million (about 74 percent) of the total annualized costs of the rule ($37.6 million) using a 3 percent discount rate, or $28.6 million (about 73 percent) of the total annualized costs of the rule ($39.1 million) using a 7 percent discount rate. The most expensive of the ancillary provisions are the requirements for housekeeping and training, with annualized costs of $12.6 million and $5.8 million, respectively, at a 3 percent discount rate ($12.9 million and $5.8 million, respectively, at a 7 percent discount rate).

OSHA's reasons for including each of the proposed ancillary provisions are explained in Section XVIII of the preamble, Summary and Explanation of the Standards.

In particular, OSHA is proposing the requirements for exposure assessment to provide a basis for ensuring that appropriate measures are in place to limit worker exposures. Medical surveillance is especially important because workers exposed above the proposed TWA PEL, as well as many workers exposed below the proposed TWA PEL, are at significant risk of death and illness. Medical surveillance would allow for identification of beryllium-related adverse health effects at an early stage so that appropriate intervention measures can be taken. OSHA is proposing regulated areas and access control because they serve to limit exposure to beryllium to as few employees as possible. OSHA is proposing worker training to ensure that employers inform employees of the hazards to which they are exposed, along with associated protective measures, so that employees understand how they can minimize their exposure to beryllium. Worker training on beryllium-related work practices is particularly important in controlling beryllium exposures because engineering controls frequently require action on the part of workers to function effectively.

OSHA has examined a variety of regulatory alternatives involving changes to one or more of the proposed ancillary provisions. The incremental cost of each of these regulatory alternatives and its impact on the total costs of the proposed rule is summarized in Table VIII-7 at the end of this section. OSHA has preliminarily determined that several of these ancillary provisions will increase the benefits of the proposed rule, for example, by helping to ensure the TWA PEL is not exceeded or by lowering the risks to workers given the significant risk remaining at the proposed TWA PEL. However, except for Regulatory Alternative #7 (involving the elimination of all ancillary provisions), OSHA did not estimate changes in monetized benefits for the regulatory alternatives that affect ancillary provisions. Two regulatory alternatives that involve all ancillary provisions are presented below (#7 and #8), followed by regulatory alternatives for exposure monitoring (#9, #10, and #11), for regulated areas (#12), for personal protective clothing and equipment (#13), for medical surveillance (#14 through #21), and for medical removal (#22).

<u>All Ancillary Provisions</u>

The SBAR Panel recommended that OSHA analyze a PEL-only standard as a regulatory alternative. The Panel also recommended that OSHA consider not applying ancillary provisions of the standard where exposure levels are low so as to minimize costs for small businesses (SBAR, 2008). In response to these recommendations, OSHA analyzed Regulatory Alternative #7, a PEL-only standard, and Regulatory Alternative #8, which would apply ancillary provisions of the beryllium standard only where exposures exceed the proposed TWA PEL of 0.2 $\mu g/m^3$ or the proposed STEL of 2 $\mu g/m^3$.

Regulatory Alternative #7 would solely update 1910.1000 Tables Z-1 and Z-2, so that the proposed TWA PEL and STEL would apply to all workers in general industry. This alternative would eliminate all of the ancillary provisions of the proposed rule, including exposure assessment, medical surveillance, medical removal, PPE, housekeeping, training, and regulated areas or access control. Under this regulatory alternative, OSHA estimates that the costs for the proposed ancillary provisions of the rule (estimated at $27.8 million annually at a 3 percent discount rate) would be eliminated. In order to meet the PELs, employers would still commonly need to do monitoring, train workers on the use of controls, and set up some kind of regulated areas to indicate where respirator use would be required. It is also likely that, under this alternative, many employers would follow the recommendations of Materion and the United Steelworkers to provide medical surveillance, PPE, and other protective measures for their workers (Materion and United Steelworkers, 2012). OSHA has not attempted to estimate the extent to which these ancillary-provision costs would be incurred if they were not formally required or whether any of these costs under Regulatory Alternative #7 would reasonably be attributable to the proposed rule. OSHA welcomes comment on the issue.

OSHA has also estimated the effect of this regulatory alternative on the benefits of the rule, presented in Table VIII-7. As a result of eliminating all of the ancillary provisions, annualized benefits are estimated to decrease 56 percent, relative to the proposed rule, from $575.8 million to $249.1 million, using a 3 percent discount rate, and from $255.3 million to $110.4 million using a 7 percent discount rate. This estimate follows from OSHA's analysis of benefits in Chapter VII of this PEA, which found that about 56 percent of the benefits of the proposed rule, evaluated at their mid-point value, were attributable to the combination of the ancillary provisions. As these estimates show, OSHA expects that the benefits estimated under the proposed rule will not be fully achieved if employers do not implement the ancillary provisions of the proposed rule.

Both industry and worker groups have recognized that a comprehensive standard is needed to protect workers exposed to beryllium. The stakeholders' recommended standard that representatives of the primary beryllium manufacturing industry and the United Steelworkers union provided to OSHA confirms the importance of ancillary provisions in protecting workers from the harmful effects of beryllium exposure (Materion and United Steelworkers, 2012). Ancillary provisions such as personal protective clothing and equipment, regulated areas, medical surveillance, hygiene areas, housekeeping requirements, and hazard communication all serve to reduce the risks to beryllium-exposed workers beyond that which the proposed TWA PEL alone could achieve.

Moreover, where there is continuing significant risk at the TWA PEL, the decision in the Asbestos case (Bldg. and Constr. Trades Dep't, AFL-CIO v. Brock, 838 F.2d 1258, 1274 (D.C. Cir. 1988)) indicated that OSHA should use its legal authority to impose additional requirements on employers to further reduce risk when those requirements will result in a greater than de minimis incremental benefit to workers' health. Nevertheless, OSHA requests comment on this alternative.

Under **Regulatory Alternative #8**, several ancillary provisions that the current proposal would require under a variety of exposure conditions (e.g., dermal contact, any airborne exposure, exposure at or above the action level) would instead only apply where exposure levels exceed the TWA PEL or STEL. Regulatory Alternative #8 affects the following provisions of the proposed standard:

- Exposure monitoring: Whereas the proposed standard requires annual monitoring when exposure levels are at or above the action level and at or below the TWA PEL, Regulatory Alternative #8 would require annual exposure monitoring only where exposure levels exceed the TWA PEL or STEL;
- Written exposure control plan: Whereas the proposed standard requires written exposure control plans to be maintained in any facility covered by the

standard, Regulatory Alternative #8 would require only facilities with exposures above the TWA PEL or STEL to maintain a plan;

- Housekeeping: Whereas the proposed standard's housekeeping requirements apply across a wide variety of beryllium exposure conditions, Alternative #8 would limit housekeeping requirements to areas and employees with exposures above the TWA PEL or STEL;
- PPE: Whereas the proposed standard requires PPE for employees under a variety of conditions, such as exposure to soluble beryllium or visible contamination with beryllium, Alternative #8 would require PPE only for employees exposed above the TWA PEL or STEL;
- Medical Surveillance: Whereas the proposed standard's medical surveillance provisions require employers to offer medical surveillance to employees with signs or symptoms of beryllium-related health effects regardless of their exposure level, Alternative #8 would require surveillance only for those employees exposed above the TWA PEL or STEL.

To estimate the cost savings for this alternative, OSHA re-estimated the group of workers that would fall under the above provisions and the changes to their scope, presenting results in Table VIII-7. Combining these various adjustments along with associated unit costs, OSHA estimates that, under this regulatory alternative, the costs for the proposed rule would decline from $37.6 million to $18.9 million using a 3 percent discount rate and from $39.1 million to $20.0 million using a 7 percent discount rate.

The Agency has not quantified the impact of this alternative on the benefits of the rule. However, ancillary provisions that offer protective measures to workers exposed below the proposed TWA PEL, such as personal protective clothing and equipment, beryllium work areas, hygiene areas, housekeeping requirements, and hazard communication, all serve to reduce the risks to beryllium-exposed workers beyond that which the proposed TWA PEL and STEL could achieve. OSHA's preliminary conclusion is that the requirements triggered by the action level and other exposures below the proposed PELs will result in very real and necessary, but difficult to quantify, further reduction in risk beyond that provided by the PELs alone.

The remainder of this chapter discusses additional regulatory alternatives that apply to individual ancillary provisions. At this time, OSHA is not able to quantify the effects of these regulatory alternatives on benefits. The Agency solicits comment on the effects of these regulatory alternatives on the benefits of the proposed rule.

Exposure Monitoring

Paragraph (d) of the proposed standard, Exposure Monitoring, requires annual monitoring where exposures are at or above the action level and at or below the TWA PEL. It does not require periodic monitoring where exposure levels have been determined to be below the action level, or above the TWA PEL. The rationale for this provision is provided in the preamble discussion of paragraph (a) in Section XVIII, Summary and Explanation of the Proposed Standard. Below is a brief summary, followed by a discussion of three alternatives.

Because of the variable nature of employee exposures to airborne concentrations of beryllium, maintaining exposures below the action level provides reasonable assurance that employees will not be exposed to beryllium at levels above the TWA PEL on days when no exposure measurements are made. Even when all measurements on a given day fall at or below the TWA PEL, if those measurements are still at or above the action level, there is a smaller safety margin and a greater chance that on another day, when exposures are not measured, the employee's exposure may exceed the TWA PEL. When exposure measurements are at or above the action level, the employer cannot be reasonably confident that employees have not been exposed to beryllium concentrations in excess of the TWA PEL during at least some part of the work week. Therefore, requiring periodic exposure measurements when the action level is met or exceeded provides the employer with a reasonable degree of confidence in the results of the exposure monitoring. The proposed action level that would trigger the exposure monitoring is one-half of the TWA PEL, which reflects the Agency's typical approach to setting action levels (see, e.g., Inorganic arsenic (29 CFR 1910.1018), Ethylene oxide (29 CFR 1910.1047), Benzene (29 CFR 1910.1028), and Methylene Chloride (29 CFR 1910.1052)).

Certain other aspects of the proposed periodic monitoring requirements, which the Agency based on the stakeholders' recommended standard submitted by Materion and the United Steelworkers (Materion and United Steelworkers, 2012), depart significantly from OSHA's usual exposure monitoring requirements. The proposed standard only requires annual monitoring, and does not require periodic monitoring when exposures are recorded above the TWA PEL, whereas most OSHA standards require monitoring at least every 6 months when exposure levels exceed the action level, and every 3 months when exposures are above the TWA PEL. For example, the standards for vinyl chloride (29 CFR 1910.1017), inorganic arsenic (29 CFR 1910.1018), lead (29 CFR 1910.1025), cadmium (29 CFR 1910.1027), methylene chloride (29 CFR 1910.1052), acrylonitrile (29

CFR 1910.1045), ethylene oxide (29 CFR 1910.1047), and formaldehyde (29 CFR 1910.1048), all specify periodic monitoring at least every six months when exposures are at, or above, the action level. Monitoring is required every three months when exposures exceed the TWA PEL in the standards for methylene chloride, ethylene oxide, acrylonitrile, inorganic arsenic, lead, and vinyl chloride. In the standards for cadmium, 1,3-Butadiene, formaldehyde, benzene and asbestos (29 CFR 1910.1001), monitoring is required every six months when exposures exceed the TWA PEL. In these standards, monitoring workers exposed above the TWA PEL ensures that employers know workers' exposure levels in order to select appropriate respirators and other PPE, and that records of their exposures are available if needed for medical, legal, or epidemiological purposes.

OSHA has examined three regulatory alternatives that would modify the requirements of paragraph (d) to be more similar to OSHA's typical periodic monitoring requirements. Under **Regulatory Alternative #9**, employers would be required to perform periodic exposure monitoring every 180 days when exposures are at or above the action level or above the STEL, but at or below the TWA PEL. As shown in Table VIII-7, Regulatory Alternative #9 would increase the annualized cost of the proposed rule by about $773,000 using either a 3 percent or 7 percent discount rate.

Under **Regulatory Alternative #10**, employers would be required to perform periodic exposure monitoring every 180 days when exposures are at or above the action level or above the STEL, including where exposures exceed the TWA PEL. As shown in Table VIII-7, Regulatory Alternative #10 would increase the annualized cost of the proposed rule by about $929,000 using either a 3 percent or 7 percent discount rate.

Under **Regulatory Alternative #11**, employers would be required to perform periodic exposure monitoring every 180 days when exposures are at or above the action level, and every 90 days where exposures exceed the TWA PEL or STEL. This alternative is similar to the periodic monitoring requirements in the draft proposed rule presented to the SERs during the 2007 OSHA beryllium SBAR Panel process. Of the exposure monitoring alternatives, it is also the most similar to the exposure monitoring provisions of most other 6(b)(5) standards. As shown in Table VIII-7, Regulatory Alternative #11 would increase the annualized cost of the proposed rule by about $1.07 million using either a 3 percent or 7 percent discount rate.

Regulated Areas

Proposed paragraph (e) requires employers to establish and maintain beryllium work areas wherever employees are exposed to airborne beryllium, regardless of the level of exposure, and regulated areas wherever airborne concentrations of beryllium exceed the TWA PEL or STEL. Employers are required to demarcate beryllium work areas and regulated areas and limit access to regulated areas to authorized persons.

The SBAR Panel report recommended that OSHA consider dropping or limiting the provision for regulated areas (SBAR, 2008). In response to this recommendation, OSHA examined **Regulatory Alternative #12**, which would eliminate the requirement that employers establish regulated areas. This alternative is meant only to eliminate the requirement to set up and demarcate specific physical areas: all ancillary provisions would be triggered by the same conditions as under the standard's definition of a "regulated area." For example, under the current proposal, employees who work in regulated areas for at least 30 days annually are eligible for medical surveillance. If

OSHA were to remove the requirement to establish regulated areas, the medical surveillance provisions would be altered so that employees who work more than 30 days annually in jobs or areas with exposures that exceed the TWA PEL or STEL are eligible for medical surveillance. This alternative would not eliminate the proposed requirement to establish beryllium work areas. As shown in Table VIII-7, Regulatory Alternative #12 would decrease the annualized cost of the proposed rule by about $522,000 using a 3 percent discount rate, and by about $523,000 using a 7 percent discount rate.

Personal Protective Clothing and Equipment

Regulatory Alternative #13 would modify the requirements for personal protective equipment (PPE) by requiring appropriate PPE whenever there is potential for skin contact with beryllium or beryllium-contaminated surfaces. This alternative would be broader, and thus more protective, than the PPE requirement in the proposed standard, which requires PPE to be used in three circumstances: (1) where exposure exceeds the TWA PEL or STEL; (2) where employees' clothing or skin may become visibly contaminated with beryllium; and (3) where employees may have skin contact with soluble beryllium compounds. These PPE requirements were based on the stakeholders' recommended standard that Materion and the United Steelworkers submitted to the Agency (Materion and USW, 2012).

The proposed rule's requirement to use PPE where work clothing or skin may become "visibly contaminated" with beryllium differs from prior standards, which do not require contamination to be visible in order for PPE to be required. While OSHA's language regarding PPE requirements varies somewhat from standard to standard, previous standards tend to emphasize potential for contact with a substance that can trigger health effects via dermal exposure, rather than "visible contamination" with the substance. For example, the standard for chromium (VI) requires the employer to provide appropriate PPE where a hazard is present or is likely to be present from skin or eye contact with chromium (VI) (29 CFR 1910.1026). The lead and cadmium standards require PPE where employees are exposed above the PEL or where there is potential for skin or eye irritation, regardless of airborne exposure level. Under the Methylenedianiline (MDA) standard (29 CFR 1910.1050), PPE must be provided where employees are subject to dermal exposure to MDA, where liquids containing MDA can be splashed into the eyes, or where airborne concentrations of MDA are in excess of the PEL.

OSHA requests comment on the proposed PPE requirements in Regulatory Alternative #13, which would modify the proposed PPE requirements to be similar to the chromium (VI), lead, cadmium, and MDA standards. Because small beryllium particles can pass through intact or broken skin and cause sensitization, limiting the requirements for PPE based on surfaces that are "visibly contaminated" may not adequately protect workers from beryllium exposure. Submicron particles (less than 1 μg in diameter) are not visible to the naked eye and yet may pass through the skin and cause beryllium sensitization. Although solubility may play a role in the level of sensitization risk, the available evidence suggests that contact with insoluble, as well as soluble, beryllium can cause sensitization via dermal contact (see the preamble at Section V, Health Effects). Sensitized workers are at significant risk of developing CBD (see the preamble at Section V, Health Effects, and Section VIII, Significance of Risk).

To estimate the cost of Regulatory Alternative #13, OSHA assumed that all at-risk workers, except administrative occupations, would require protective clothing and a pair of work gloves that would need to be replaced annually. The economic analysis of the proposed standard already contained costs for protective clothing for all employees whose clothing might be contaminated by beryllium (the analysis assumed that all clothing contamination would be visible, or the clothing is already provided even if not required by this standard) and gloves for many jobs where workers were expected to be exposed to visible contamination or soluble beryllium; thus OSHA estimated the cost of this alternative as the cost of providing gloves for the remainder of the jobs where workers have potential for skin exposure even in the absence of visible contamination. As shown in Table VIII-7, Regulatory Alternative #13 would increase the annualized cost of the proposed rule by about $138,000 using either a 3 percent or 7 percent discount rate.

Medical Surveillance

The proposed requirements for medical surveillance include: (1) medical examinations, including a test for beryllium sensitization, for employees who are exposed to beryllium in a regulated area (i.e., above the proposed TWA PEL or STEL) for 30 days or more per year, who are exposed to beryllium in an emergency, or who show signs or symptoms of CBD; and (2) CT scans for employees who were exposed above the proposed TWA PEL or STEL for more than 30 days in a 12-month period for 5 years or more. The proposed standard would require annual medical exams to be provided for employees exposed in a regulated area for 30 days or more per year and for employees showing signs or symptoms of CBD, while tests for beryllium sensitization and CT scans would be provided to eligible employees biennially.

OSHA estimated in Chapter V of this PEA that the medical surveillance requirements would apply to 4,528 workers in general industry, of whom 387 already receive that surveillance.[465] In Chapter V, OSHA estimated the costs of medical surveillance for the remaining 4,141 workers who would now have such protection due to the proposed standard. The Agency's preliminary analysis indicates that 4 workers with beryllium sensitization and 6 workers with CBD will be referred to pulmonary specialists annually as a result of this medical surveillance. Medical surveillance is particularly important for this rule because beryllium-exposed workers, including many workers exposed below the proposed PELs, are at significant risk of illness. OSHA did not estimate, and the benefits analysis does not include, monetized benefits resulting from early discovery of illness.

OSHA has examined eight regulatory alternatives (#14 through #21) that would modify the proposed rule's requirements for employee eligibility, the tests that must be offered, and the frequency of periodic exams. Medical surveillance was a subject of special concern to SERs during the SBAR Panel process, and the SBAR Panel offered many comments and recommendations related to medical surveillance for OSHA's consideration. Some of the Panel's concerns have been partially addressed in this proposal, which was modified since the SBAR Panel was convened (see the preamble at Section XVIII, Summary and Explanation of the Proposed Standard, for more detailed discussion). Several of the regulatory alternatives presented here (#16, #18, and #20) also respond to recommendations by the SBAR Panel to reduce burdens on small businesses by dropping or reducing the frequency of medical surveillance requirements. OSHA is also considering several additional regulatory alternatives that would increase

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[465] See current compliance rates for medical surveillance in Chapter V of this PEA, Table V-15.

the frequency of surveillance or the range of employees covered by medical surveillance (#14, #15, #17, #19, and #21).

OSHA has preliminarily determined that a significant risk of beryllium sensitization, CBD, and lung cancer exists at exposure levels below the proposed TWA PEL and that there is evidence that beryllium sensitization can occur even from short-term exposures (see the preamble at Section V, Health Effects, and Section VIII, Significance of Risk). The Agency therefore anticipates that more employees would develop adverse health effects without receiving the benefits of early intervention in the disease process because they are not eligible for medical surveillance (see the preamble at Section V, Health Effects).

OSHA is considering three regulatory alternatives that would expand eligibility for medical surveillance to a broader group of employees than those eligible under the proposed standard. Under **Regulatory Alternative #14**, medical surveillance would be available to employees who are exposed to beryllium above the proposed TWA PEL or STEL, including employees exposed for fewer than 30 days per year. **Regulatory Alternative #15** would expand eligibility for medical surveillance to employees who are exposed to beryllium above the proposed action level, including employees exposed for fewer than 30 days per year. **Regulatory Alternative #21** would extend eligibility for medical surveillance as set forth in proposed paragraph (k) to all employees in shipyards, construction, and general industry who meet the criteria of proposed paragraph (k)(1). However, all other provisions of the standard would be in effect only for employers and employees that fall within the scope of the proposed rule. Each of these alternatives would provide surveillance to fewer workers (and cost less to employers) than the draft proposed rule presented to SERs during the SBAR Panel process, which included skin contact as a trigger and would therefore cover most beryllium-exposed workers in general industry, construction, and maritime. These alternatives would provide more surveillance (and cost more to employers) than the medical surveillance requirements in the current proposal.

To estimate the cost of Regulatory Alternative #14, OSHA assumed that 1 person would enter regulated areas for less than 30 days a year for every 4 people working in regulated areas on a regular basis. Thus, this alternative includes costs for an incremental number of annual medical exams equal to 25 percent of the number of workers estimated to be working in regulated areas after the standard is promulgated. As shown in Table VIII-7, Regulatory Alternative #14 would increase the annualized cost of the proposed rule by about $38,000 using either a 3 percent or 7 percent discount rate.

To estimate the cost of Regulatory Alternative #15, OSHA assumed that all workers exposed above the action level before the standard would continue to be exposed after the standard is promulgated. OSHA also assumed that 1 person would enter areas exceeding the action level for fewer than 30 days a year for every 4 people working in an area exceeding the action level on a regular basis. Thus, this alternative includes costs for medical exams for the number of workers exposed between the action level and the TWA PEL as well as an incremental 25 percent of all workers exposed above the action level. As shown in Table VIII-7, Regulatory Alternative #15 would increase the annualized cost of the proposed rule by about $3.9 million using a discount rate of 3 percent, and by about $4.0 million using a discount rate of 7 percent.

For Alternative #21, OSHA is considering two different scenarios to estimate costs: one where the TWA PEL for the groups outside the scope of the proposed standard changes from 2 μg/m^3 to 0.2 μg/m^3, as in Regulatory Alternative #2b; and one where the TWA PEL remains at the current level of 2.0 μg/m^3. For costing purposes, these have been designated as Regulatory Alternative #21a and Regulatory Alternative #21b, respectively.

For Regulatory Alternative #21a, medical surveillance above the proposed TWA PEL of 0.2 μg/m^3, OSHA estimated the cost of extending medical surveillance to workers in aluminum production, abrasive blasting in construction, maritime abrasive blasting, maritime welding, and coal fired power plants, assuming that all feasible controls are in place to reduce exposures to the proposed TWA PEL of 0.2 μg/m^3 or lower. OSHA did not include control costs to achieve compliance with a TWA PEL of 0.2 μg/m^3, as these costs were addressed in Regulatory Alternative #2b. (For a summary of the estimates of affected workers and the exposure profile, see the discussion accompanying Regulatory Alternative # 2b.) As shown in Table VIII-7, Regulatory Alternative #21a would increase the annualized cost of the proposed rule by about $4.4 million using a 3-percent discount rate and $4.5 million using a 7-percent discount rate.

For Regulatory Alternative #21b, medical surveillance above the current TWA PEL of 2.0 μg/m^3, OSHA estimated that all abrasive blasters in construction and shipyards who are currently above the current TWA PEL of 2.0 μg/m^{3}would be eligible for medical surveillance. As discussed under Regulatory Alternative #2b, outside of abrasive blasting, OSHA has identified a small group of maritime welders who may be exposed to beryllium above the current TWA PEL in their work. Of these workers, 90 percent would be below the current TWA PEL if their employers instituted all feasible engineering and work practice controls to meet the existing standard. If they came into compliance with the current PELs, they would not be required to offer employees medical surveillance under Regulatory Alternative #21b. OSHA estimated that the other 10 percent of these maritime welders, and 10 percent of workers in primary aluminum production and coal-fired power generation, with all feasible engineering controls and work practices in place, would still be exposed above the current TWA PEL and would be eligible for medical surveillance under Regulatory Alternative #21b. OSHA's customary method in preparing an economic analysis of a new standard is to cost out the incremental cost of the new standard assuming full compliance with existing standards. Finally, OSHA estimated that 15 percent of the workers excluded from the scope of the proposed standard absent the alternative would show signs and symptoms of CBD or be exposed in emergencies, and so would be eligible for medical surveillance. As shown in Table VIII-7, under these assumptions Regulatory Alternative #21b would increase the annualized cost of the proposed rule by about $3.0 million using r a 3-percent discount rate and $3.1 million using a7-percent discount rate. The Agency notes that, as abrasive blasters are the primary application group with beryllium exposure in construction and shipyards, it is unlikely that as many as 15 percent of other workers would show signs and symptoms of beryllium exposure or be exposed to beryllium in an emergency. Thus, OSHA believes the stated cost of about $3.0 million may overestimate the true costs for this alternative and invites comment on this issue.

In response to concerns raised during the SBAR Panel process about testing requirements, OSHA is considering two regulatory alternatives that would provide greater flexibility in the program of tests provided as part of an employer's medical surveillance program. Under **Regulatory Alternative #16**, employers would not be required to offer employees testing for beryllium sensitization. As shown in Table VIII-7, this alternative would decrease the annualized cost of the proposed rule by about $710,000 using a discount rate of 3 percent, and by about $724,000 using a discount rate of 7 percent.

Regulatory Alternative #18 would eliminate the CT scan requirement from the proposed rule. This alternative would decrease the annualized cost of the proposed rule by about $472,000 using a discount rate of 3 percent, and by about $481,000 using a discount rate of 7 percent.

OSHA is considering several alternatives to the proposed frequency of sensitization testing, CT scans, and general medical examinations. The frequency of periodic medical surveillance is an important factor in the efficacy of the surveillance in protecting worker health. Regular, appropriately frequent medical surveillance promotes awareness of beryllium-related health effects and early intervention in disease processes among workers. In addition, the longer the time interval between when a worker becomes sensitized and when the worker's case is identified in the surveillance program, the more difficult it will be to identify and address the exposure conditions that led to sensitization. Therefore, reducing the frequency of sensitization testing would reduce the usefulness of the surveillance information in identifying problem areas and reducing risks to other workers. These concerns must be weighed against the costs and other burdens of surveillance.

Regulatory alternative #17 would require employers to offer annual testing for beryllium sensitization to eligible employees, as in the draft proposal presented to the SBAR Panel. As shown in Table VIII-7, this alternative would increase the annualized cost of the proposed rule by about $392,000 using a discount rate of 3 percent, and by about $381,000 using a discount rate of 7 percent.

Regulatory Alternative #19 would similarly increase the frequency of periodic CT scans from biennial to annual scans, increasing the annualized cost of the proposed rule by about $459,000 using a discount rate of 3 percent, and by about $450,000 using a discount rate of 7 percent.

Finally, under **Regulatory Alternative #20**, employers would only have to provide all periodic components of the medical surveillance exams biennially to eligible employees. This alternative would decrease the annualized cost of the proposed rule by about $446,000 using a discount rate of 3 percent and by about $433,000 using a discount rate of 7 percent.

Medical Removal

Under paragraph (l) of the proposed standard, Medical Removal, employees in jobs with exposure at or above the action level become eligible for medical removal when they are diagnosed with CBD or confirmed positive for beryllium sensitization. When an employee chooses removal, the employer is required to remove the employee to comparable work in an environment where beryllium exposure is below the action level if such work is available and the employee is either already qualified or can be trained within one month. If comparable work is not available, paragraph (l) would require the employer to place the employee on paid leave for six months or until comparable work becomes available (whichever comes first). Or, rather than choosing removal, an eligible employee could choose to remain in a job with exposure at or above the action level and wear a respirator. The proposed medical removal protection (MRP) requirements are based on the stakeholders' recommended stakeholders' recommended beryllium standard that representatives of the beryllium production industry and the United Steelworkers union submitted to OSHA in 2012 (Materion and United Steelworkers, 2012).

The scientific information on effects of exposure cessation is limited at this time, but the available evidence suggests that removal from exposure can be beneficial for individuals who are sensitized or have early-stage CBD (see the preamble at Section VIII, Significance of Risk). As CBD progresses, symptoms become serious and debilitating. Steroid treatment is less effective at later stages, once fibrosis has developed (see the preamble at Section VIII, Significance of Risk). Given the progressive nature of the disease, OSHA believes it is reasonable to conclude that removal from exposure to beryllium will benefit sensitized employees and those with CBD. Physicians at National Jewish Health, one of the main CBD research and treatment sites in the US, "consider it important and prudent for individuals with beryllium sensitization and CBD to minimize their exposure to airborne beryllium," and "recommend individuals diagnosed with beryllium sensitization and CBD who continue to work in a beryllium industry to have exposure of no more than 0.01 micrograms per cubic meter of beryllium as an 8-hour time-weighted average" (National Jewish Health, 2013). However, OSHA is aware that MRP may prove costly and burdensome for some employers and that the scientific literature on the effects of exposure cessation on the development of CBD among sensitized individuals and the progression from early-stage to late-stage CBD is limited.

The SBAR Panel report included a recommendation that OSHA give careful consideration to the impacts that an MRP requirement could have on small businesses (SBAR, 2008). In response to this recommendation, OSHA analyzed **Regulatory Alternative #22**, which would remove the proposed requirement that employers offer MRP. As shown in Table VIII-7, this alternative would decrease the annualized cost of the proposed rule by about $149,000 using a discount rate of 3 percent, and by about $166,000 using a discount rate of 7 percent.

Table VIII-7: Cost of Regulatory Alternatives Affecting Ancillary Provisions (Proposed PEL=0.2, STEL=2.0, AL=0.1)

3% Discount Rate	Total Cost	Incremental Cost Relative to Proposal	Benefits	Incremental Benefits Relative to the Proposal
Proposed Rule	$37,597,325	——	$575,826,633	——
Alternative 1b: Include Trace Contaminants; Offer Opt Out for Trace Contaminant Industries with Objective Data	$49,863,812	$12,266,488		
Alternative 7: Update Z table 1910.1000 only, (No ancillary provisions)	$9,789,873	-$27,807,451	$249,099,326	-$326,727,308
Alternative 8: Ancillary provisions apply only when exposure above PEL/STEL	$18,917,028	-$18,680,297		
Alternative 9: semiannual monitoring when exposure between AL/STEL and PEL	$38,370,615	$773,291		
Alternative 10: semiannual monitoring when exposure above AL/STEL	$38,526,658	$929,333		
Alternative 11: semiannual monitoring when exposure above AL/STE, quarterly monitoring when exposure above PEL	$38,670,043	$1,072,719		
Alternative 12: No regulated areas, ancillary provisions triggered by PEL or STEL	$37,075,072	-$522,252		
Alternative 13: PPE wherever there is contact with beryllium or beryllium contaminated surfaces	$37,735,352	$138,027		
Alternative 14: No 30 day minimum for medical surveillance in regulated areas	$37,635,572	$38,248		
Alternative 15: No 30 day minimum for medical surveillance and triggered by AL	$41,466,339	$3,869,014		
Alternative 16: No BeLPTs in medical surveillance	$36,887,307	-$710,018		
Alternative 17: BeLPTs part of annual exam, rather than biannually.	$37,989,639	$392,314		
Alternative 18: No CT Scans	$37,124,958	-$472,367		
Alternative 19: Annual CT scans rather than biannual	$38,056,056	$458,732		
Alternative 20: All periodic components of medical surveillance are biannual	$37,150,975	-$446,349		
Alternative 21a: Medical Surveillance (PEL 0.2)	$42,042,633	$4,445,308		
Alternative 21b: Medical Surveillance (PEL 2.0)	$40,573,150	$2,975,826		
Alternative 22: No medical removal protection	$37,448,499	-$148,826		

Table VIII-7: Cost of Regulatory Alternatives Affecting Ancillary Provisions , Continued
(Proposed PEL=0.2, STEL=2.0, AL=0.1)

7% Discount Rate	Total Cost	Incremental Cost Relative to Proposal	Benefits	Incremental Benefits Relative to the Proposal
Proposed Rule	$39,147,434	——	$255,334,295	——
Alternative 1b: Include Trace Contaminants; Offer Opt Out for Trace Contaminant Industries with Objective Data	$51,781,738	$12,634,305		
Alternative 7: Update Z table 1910.1000 only, (No ancillary provisions)	$10,586,317	-$28,561,116	$110,383,499	-$144,950,796
Alternative 8: Ancillary provisions apply only when exposure above PEL/STEL	$19,986,867	-$19,160,567		
Alternative 9: semiannual monitoring when exposure between AL/STEL and PEL	$39,920,724	$773,291		
Alternative 10: semiannual monitoring when exposure above AL/STEL	$40,076,767	$929,333		
Alternative 11: semiannual monitoring when exposure above AL/STE, quarterly monitoring when exposure above PEL	$40,220,152	$1,072,719		
Alternative 12: No regulated areas, ancillary provisions triggered by PEL or STEL	$38,624,295	-$523,139		
Alternative 13: PPE wherever there is contact with beryllium or beryllium contaminated surfaces	$39,285,461	$138,027		
Alternative 14: No 30 day minimum for medical surveillance in regulated areas	$39,185,910	$38,477		
Alternative 15: No 30 day minimum for medical surveillance and triggered by AL	$43,162,902	$4,015,468		
Alternative 16: No BeLPTs in medical surveillance	$38,423,316	-$724,117		
Alternative 17: BeLPTs part of annual exam, rather than biannually.	$39,528,226	$380,793		
Alternative 18: No CT Scans	$38,666,205	-$481,229		
Alternative 19: Annual CT scans rather than biannual	$39,597,303	$449,870		
Alternative 20: All periodic components of medical surveillance are biannual	$38,714,200	-$433,233		
Alternative 21a: Medical Surveillance (PEL 0.2)	$43,708,041	$4,560,608		
Alternative 21b: Medical Surveillance (PEL 2.0)	$42,198,735	$3,051,301		
Alternative 22: No medical removal protection	$38,981,379	-$166,054		

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis

Timing

As proposed, the new standard would become effective 60 days following publication in the Federal Register. The majority of employer duties in the standard would become enforceable 90 days following the effective date. Change rooms, however, would not be required until one year after the effective date, and the deadline for engineering controls would be no later than two years after the effective date.

OSHA invites suggestions for alternative phase-in schedules for engineering controls, medical surveillance, and other provisions of the standard. Although OSHA did not explicitly develop or quantitatively analyze any other regulatory alternatives involving longer-term or more complex phase-ins of the standard (possibly involving more delayed implementation dates for small businesses), some general outcomes are likely. For example, a longer phase-in time would have several advantages, such as reducing initial costs of the standard or allowing employers to coordinate their environmental and occupational safety and health control strategies to minimize potential costs. However, a longer phase-in would also postpone and reduce the benefits of the standard. Suggestions for alternatives may apply to specific industries (e.g., industries where first-year or annualized cost impacts are highest), specific size-classes of employers (e.g., employers with fewer than 20 employees), combinations of these factors, or all firms covered by the rule.

OSHA requests comments on all these regulatory alternatives, including the Agency's regulatory alternatives presented above, the Agency's analysis of these alternatives, and whether there are other regulatory alternatives the Agency should consider.

REFERENCES

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National Jewish Health, 2013. webpage on Chronic Beryllium Disease: Work Environment Management, from http://www.nationaljewish.org/healthinfo/conditions/beryllium-disease/environment-management/, accessed May 2013.

NIOSH (National Institute for Occupational Safety and Health), 1995. "Abrasive Blasters, Parma and Akron, Ohio," HETA 95-0225-2596.

SBAR, 2008. Report of the Small Business Advocacy Review (SBAR) Panel on the OSHA Draft Proposed Standard for Occupational Exposure to Beryllium. Small Business Advisory Review Panel Report with Appendices A, B, C, and D. Final version, January 15, 2008. OSHA Beryllium Docket Document ID Number: OSHA-H005C-2006-0870-0345.

Appendix VIII-A

Primary Aluminum Production

Based on a review of the primary aluminum production industry, OSHA found that 10 such primary aluminum producers are currently operating in the United States, employing 8,750 workers. Of these employees, an estimated 6,956 employees work in production occupations.[466] While comprehensive exposure data are not available, the evidence suggests that some workers in pot room-related jobs are currently exposed to beryllium, with some at levels exceeding the proposed TWA PEL. These jobs include pot room workers, crane operators, pot repair workers, and other maintenance workers involved in cleaning operations in the pot room. Based on data from the BLS Occupational Employment Statistics survey, OSHA estimated the numbers of such workers as shown below:[467]

Pot room workers: 805

Crane operators: 331

Pot room maintenance workers: 270

Pot repair workers: 260

Total affected workers: 1,665[468]

As described in Appendix IV-A, existing exposure data for primary aluminum production workers are only available on an aggregated basis and are not disaggregated

[466] See Appendix IV-A, for a description of the sources indicating occupations with exposure.
[467] OSHA used the distribution of employment by occupation for NAICS 331300, Alumina and Aluminum Production and Processing, as shown in the 2012 BLS Occupational Employment Statistics database, to estimate the shares and associated numbers of primary aluminum production workers in the at-risk job categories.
[468] Total may not precisely sum from underlying elements due to rounding.

by specific job task. Based on the information that is presented in this appendix, OSHA preliminarily estimates that for workers with current exposure, 70 percent are below 0.1 $\mu g/m^3$, 10 percent are between 0.1 $\mu g/m^3$ and 0.2 $\mu g/m^3$, and 20 percent are above 0.2 $\mu g/m^3$. In Appendix IV-A of the PEA, OSHA identifies controls available to reduce exposure to beryllium in primary aluminum production.[469] These controls and their unit and total costs are shown in the following table. Overall, OSHA estimates annual control costs of $1.3 million for the primary aluminum production industry to achieve compliance with the proposed TWA PEL for beryllium. Employers would also incur costs to comply with the ancillary provisions for affected workers (as would be required by Regulatory Alternatives #1a and #1b).

Engineering and Work Practice Controls for Primary Aluminum Producers

Control	**Annualized Unit Cost**	**Applicability**	**Establishments/Workers Needing Controls**	**Total Annual Cost**
Improved pot room ventilation	$546,119	Pot room per establishment	2	$1,092,239
Wet methods	$1,369	Per cleaning maintenance worker	54	$73,945
Ventilated hand tools	$572	Per pot repair worker	52	$29,741
All Controls				$1,195,925

[469] Some controls mentioned in Appendix IV-A are not included in the chart below because OSHA did not consider them to be the lowest cost means to comply with the proposed TWA PEL in primary aluminum production.

References

BLS (Bureau of Labor Statistics), 2012. Occupational Employment Statistics Survey.

Appendix VIII-B

Coal-Fired Power Generation

Because beryllium occurs as a trace element in coal, workers in coal-fired power plants are at risk of beryllium exposure (see Appendix IV-B of this PEA). Based on data collected by the Department of Energy, Energy Information Administration, OSHA estimates that currently 562 such facilities are in operation under OSHA's purview (DOE, 2013). These include 433 operated by utilities and 129 operated by establishments in other industries. Census data indicate that average employment for utility facilities is 52 workers per establishment (U.S. Census Bureau, 2012). Applying this number to the entire set of coal-fired power plants suggests a total employment of 29,417. While reliable exposure information is not available for this sector, OSHA believes that potential beryllium exposures are limited to workers engaged in production occupations. Based on data from the BLS Occupational Employment Statistics Survey, OSHA estimates that 50.5 percent of the workers at coal-fired power plant facilities fall into this category (BLS, 2012). These estimates are shown in following table.

Employment in Coal Fired Power Plant Facilities		
	Total	Average Per Facility
Total Employment	29,417	52.3
Non Production Occupations	14,558	25.9
All Production Workers	14,859	26.4
Construction and Extraction Occupations	1,108	2.0
Installation, Maintenance, and Repair Occupations	8,864	15.8
Production Occupations - Operators	4,405	7.8
Transportation and Material Moving Occupations	482	0.9

As the exposure profile data presented in Appendix IV-B of this PEA indicate, most workers are not exposed above the proposed TWA PEL. OSHA preliminarily estimates that, of the 14,859 production workers, 75 percent have exposures below the proposed action level of 0.1 $\mu g/m^3$ and that the vast majority of the rest are below the proposed TWA PEL of 0.2 $\mu g/m^3$. As described in Appendix IV-B, there is the possibility of intermittent exposure above the proposed TWA PEL in a few maintenance occupations, such as baghouse cleaning. These high-exposure maintenance activities occur infrequently and probably would not require the use of additional engineering controls under Regulatory Alternatives #1a, #1b, or #2 because OSHA believes all feasible controls are already required by existing standards (e.g., Inorganic arsenic (29 CFR 1910.1018)).

References

BLS (Bureau of Labor Statistics), 2012. Occupational Employment Statistics Survey.

DOE (U.S. Department of Energy), 2013. Energy Information Administration. Form EIA-860, Annual Electric Generator Report, 2013.

U.S. Census Bureau, 2012. County Business Patterns: 2012.

Appendix VIII-C

Abrasive Blasting

Because of the presence of beryllium as a trace contaminant of certain types of media used for abrasive blasting of buildings and structures (e.g., bridges) as well as for blasting-related surface cleaning of ships in maritime sector shipyards, workers performing these operations, including blaster operators, pot tenders, and helpers, might be exposed to beryllium. Blast media that contain beryllium include commonly-used coal slag as well as other slag-derived media such as copper or nickel slags.

OSHA developed estimates of the numbers of workers who might perform abrasive blasting. These included workers in the construction sector engaged in blasting ancillary to painting of bridges, tunnels, and related highways; ships; and other non-building construction. Other workers perform blasting of building exteriors. Shipyard and boatyard workers in the maritime sector might perform blasting as part of ship surface cleaning and preparation prior to painting or other surface coating. Occupational employment data collected by the BLS Occupational Employment Statistics Survey (BLS, 2011), however, are not sufficiently disaggregated to provide statistics of employees who perform such blasting tasks. Most of these workers are, however, presumably subsumed in the broad occupational classifications "painters, construction, and maintenance" or "painters, transportation equipment."

Blasting in the Construction Sector

First, OSHA used data from the 1997 Economic Census (U.S. Census Bureau, 1997) to estimate the share of construction investment per worker by painting contractors for construction work on bridges, tunnels, and related highways; ships; and other non-building construction where abrasive blasting is most likely to occur. OSHA used the same method to estimate the share of construction investment by "other special trade contractors" for work involving abrasive blasting of building exteriors. Because such detailed construction investment data were not collected as part of the subsequent Economic Censuses, OSHA used these investment share estimates to project the revenues as reported in the 2007 Economic Census (U.S. Census Bureau, 2007) for blasting-related work and then extrapolated the total number of workers who might be engaged in these activities based on overall ratios, by industry, of receipts to employees.[470] Also, for painting contractors, BLS occupation employment data (BLS, 2011) indicate that about 65 percent of painting contractor employees are classified as "painters, construction and maintenance" workers. Applying this percentage to the total employment estimate for relevant work by painting contractors suggests that about 21,300 employees might work on painting activities for bridge, tunnel, and other non-building construction work. Assuming one half of these workers might perform abrasive blasting yields an estimate for 2007 of about 10,650 abrasive blasters employed by painting contractors.

Similarly, OSHA estimated that in 2007 about 5,200 employees might perform abrasive blasting-related surface preparation work on building exteriors. Combined, these estimates suggest a total of 15,850 abrasive blasting workers in 2007. Since then, however, construction employment has declined significantly. If these estimates are benchmarked to the 2011 employment totals for NAICS 23820: Painting and Wall Covering Contractors, and NAICS 238990: Other Special Trade Contractors (U.S. Census Bureau, 2011), the estimated number of blasters in construction declines to about 11,200.

[470] 2007 is the most recent year for which receipts data are available from the Economic Census.

Blasting in the Maritime Sector

To estimate the number of abrasive blasting workers in the maritime sector, OSHA also assumed that painters were the occupational category most likely to include blasters, although production helpers and general laborers might also participate in abrasive blasting. Based on 2011 BLS occupational employment data, transportation equipment and construction and maintenance painters account for 3.85 percent of total employment in ship-building and boat-yard industries (BLS, 2011). Using this percentage together with 2011 County Business Patterns industry employment totals (U.S. Census Bureau, 2011), OSHA estimates that 4,910 employees work as painters in ship and boat yards and might perform abrasive blasting as part of their work. But not all painters would be expected to be engaged in blasting operations. Based on estimates of the extent of maritime abrasive blasting activities developed for OSHA's silica rulemaking (ERG, 2007), OSHA estimates that approximately 3 percent of the total ship and boat yard worker population performs abrasive blasting. Applying this percentage to the total number of workers involved in shipbuilding and repair and boat building and repair generates an estimate of 3,825 maritime workers performing abrasive blasting in maritime operations.

Beryllium-Containing Abrasive Material and Number of Helpers Per Operator

National employment statistics only estimate total employees in the abrasive blasting sector, not a breakdown between operators and various helpers, and give no information on which workers use blasting materials that contain beryllium. To supplement these total figures, interviews were conducted with members of industry (ERG, 2014). From these conversations OSHA preliminarily estimates that 50 percent of operators and helpers in construction and 80 percent in shipyards use blast media containing beryllium. OSHA also estimates an average of

1.5 helpers per operator for both sectors (ERG, 2014). This results in an estimate of 2,240 operators and 3,360 helpers using blasting materials containing beryllium in construction, and 1,224 operators and 1,836 helpers using blasting materials containing beryllium in maritime. The Agency requests comment on these estimates.

Exposure Profile

As described in Appendix IV-C in Chapter IV of this PEA (and using the data underlying Table 3 of that Appendix), beryllium exposure data for abrasive blaster operators, pot tenders and helpers indicates the following exposure profile for blasting workers.

Abrasive Blaster Exposure Profile

		Beryllium Exposures (μg/m³)						Total
		≤ 0.1	> 0.1 to ≤ 0.2	> 0.2 to ≤ 0.5	> 0.5 to ≤ 1.0	> 1.0 to ≤ 2.0	> 2.0	
Abrasive Blasting Workers	**Samples**	**81**	**24**	**16**	**9**	**6**	**19**	**155**
	Percent	**(52%)**	**(16%)**	**(10%)**	**(6%)**	**(4%)**	**(12%)**	**(100%)**
Source: See Table 3, Appendix IV-C of Chapter IV of this PEA, and the discussion in Appendix IV-C of the data underlying that table.								

As discussed in Appendix IV-C of Chapter IV of this PEA, existing OSHA regulations mandate the use of respirators by blasting operators when performing the types of open-air blasting considered here, and when (as OSHA believes is currently required) all feasible engineering and work practice controls have been implemented. Since beryllium is only one of a number of toxic substances that can be released during abrasive blasting, and because most or all of these toxic substances (such as chromium and nickel) are currently regulated by OSHA, the Agency believes that abrasive blasting operators already have required controls in place and wear appropriate respiratory protection during blasting operations. OSHA regulations for other workers in blasting operations, such as pot tenders, cleanup workers, and other helpers, are not similarly stringent. However, beryllium exposure due to blasting materials (coal slag) is associated with large amounts of total dust and so OSHA judges that helpers would already be wearing the level of PPE that would be required by the proposed beryllium standard. OSHA requests comment on these issues.

References

BLS (Bureau of Labor Statistics), 2011. Occupation Employment Statistics Survey.

ERG (Eastern Research Group), 2007. Rulemaking Support for Supplemental Economic Feasibility Data for a Preliminary Economic Impact Analysis of a Proposed Crystalline Silica Standard; Updated Cost and Impact Analysis of the Draft Crystalline Silica Standard for General Industry. Task Report. Submitted to Occupational Safety And Health Administration, Directorate of Evaluation and Analysis, Office of Regulatory Analysis under Task Order 11, Contract No. DOLJ049F10022. April 20, 2007.

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CHAPTER IX: INITIAL REGULATORY FLEXIBILITY ANALYSIS

The Regulatory Flexibility Act, as amended in 1996, requires the preparation of an Initial Regulatory Flexibility Analysis (IRFA) for proposed rules where there would be a significant economic impact on a substantial number of small entities. (5 U.S.C. 601-612). Under the provisions of the law, each such analysis shall contain:

1. a description of the impact of the proposed rule on small entities;
2. a description of the reasons why action by the agency is being considered;
3. a succinct statement of the objectives of, and legal basis for, the proposed rule;
4. a description of and, where feasible, an estimate of the number of small entities to which the proposed rule will apply;
5. a description of the projected reporting, recordkeeping, and other compliance requirements of the proposed rule, including an estimate of the classes of small entities which will be subject to the requirements and the type of professional skills necessary for preparation of the report or record;
6. an identification, to the extent practicable, of all relevant Federal rules which may duplicate, overlap, or conflict with the proposed rule;
7. a description and discussion of any significant alternatives to the proposed rule which accomplish the stated objectives of applicable statutes and which minimize any significant economic impact of the proposed rule on small entities, such as:

a) the establishment of differing compliance or reporting requirements or timetables that take into account the resources available to small entities;

b) the clarification, consolidation, or simplification of compliance and reporting requirements under the rule for such small entities;

c) the use of performance rather than design standards; and

d) an exemption from coverage of the rule, or any part thereof, for such small entities.

5 U.S.C. 603, 607. The Regulatory Flexibility Act further states that the required elements of the IRFA may be performed in conjunction with, or as part of, any other agenda or analysis required by any other law if such other analysis satisfies the provisions of the IRFA. 5 U.S.C. 605.

While a full understanding of OSHA's analysis and conclusions with respect to costs and economic impacts on small entities requires a reading of the complete PEA and its supporting materials, this IRFA will summarize the key aspects of OSHA's analysis as they affect small entities.

1. A DESCRIPTION OF THE IMPACT OF THE PROPOSED RULE ON SMALL ENTITIES

Chapter VI of this PEA summarized the impacts of the proposed rule on small entities. Table VI-6 showed costs as a percentage of profits and revenues for small entities, classified as small by the Small Business Administration, and Tables VI-7 showed costs as a percentage of revenues and profits for business entities with fewer than 20 employees. (The costs in these tables were annualized using a discount rate of 3 percent.)

2. A DESCRIPTION OF THE REASONS WHY ACTION BY THE AGENCY IS BEING CONSIDERED

Chronic beryllium disease (CBD) is a hypersensitivity, or allergic reaction, to beryllium that leads to a chronic inflammatory disease of the lungs. It takes months to years after initial beryllium exposure before signs and symptoms of CBD occur. Removing an employee with CBD from the beryllium source does not always lead to recovery. In some cases CBD continues to progress following removal from beryllium exposure. CBD is not a chemical pneumonitis but an immune-mediated granulomatous lung disease. OSHA's preliminary risk assessment, presented in Section VI of the preamble, indicates that there is significant risk of beryllium sensitization and chronic beryllium disease from a 45-year (working life) exposure to beryllium at the current TWA PEL of 2 $\mu g/m^3$. The risk assessment further indicates that there is significant risk of lung cancer to workers exposed to beryllium at the current TWA PEL of 2 $\mu g/m^3$. The proposed standard, with a lower PEL of .2 $\mu g/m^3$, will help to address these health concerns.

For CBD to occur, an employee must first become sensitized (i.e., allergic) to beryllium. Once an employee is sensitized, inhaled beryllium that deposits and persists in the lung may trigger a cell-mediated immune response (i.e., hypersensitivity reaction) that results in the formation of a type of lung scarring known as a granuloma. The granuloma consists of a localized mass of immune and inflammatory cells that have formed around a beryllium particle lodged in the interstitium, which is tissue between the air sacs that can be affected by fibrosis or scarring. With time, the granulomas spread and can lead to chronic cough, shortness of breath (especially upon exertion), fatigue, abnormal pulmonary function, and lung fibrosis.

While CBD primarily affects the lungs, it can also involve other organs such as the liver, skin, spleen, and kidneys. As discussed in more detail in the preamble of the proposed rule, some studies demonstrate that sensitization and CBD cases have occurred in workplaces that use a wide range of beryllium compounds, including several beryllium salts, refined beryllium metal, beryllium oxide, and the beryllium alloys. While water-soluble and insoluble beryllium compounds have the potential to cause sensitization, it has been suggested that CBD is the result of occupational exposure to beryllium oxide and other water-insoluble berylliums rather than exposure to water-soluble beryllium or beryllium ores. However, there are inadequate data, at this time, on employees selectively exposed to specific beryllium compounds to eliminate a potential CBD concern for any particular form of this metal. Regardless of the type of beryllium compound, in order to cause respiratory disease the inhaled beryllium must contain particulates that are small enough to reach the bronchoalveolar region of the lung where the disease takes place (OSHA, 2007).

Some research suggests that skin exposure to small beryllium particles or beryllium-containing solutions may also lead to sensitization (Tinkle et al., 2003). These additional risk factors may explain why some individuals with seemingly brief, low level exposure to airborne beryllium become sensitized while others with long-term high exposures do not. Other studies indicate that even though employees sensitized to beryllium do not exhibit clinical symptoms, their immune function is altered such that inhalation to previously safe levels of beryllium can now trigger serious lung disease (Kreiss et al., 1996; Kreiss et al., 1997; Kelleher et al., 2001 and Rossman, 2001).

In the 1980s, the laboratory blood test known as the BeLPT was developed. The test substantially improved identification of beryllium-sensitized individuals and provides an opportunity to diagnose CBD at an early stage. The BeLPT measures the ability of immune cells (i.e., peripheral blood lymphocytes) to react with beryllium. It has been reported that the BeLPT can identify 70 to 90 percent of those sensitized with a high specificity (approximately one to three percent false positives) (Newman et al., 2001; Stange et al., 2004).

An employee with an abnormal BeLPT (i.e., the individual is sensitized) can undergo fiber-optic bronchoscopy to obtain a lung biopsy sample from which granulomatous lung inflammation can be pathologically observed prior to the onset of symptoms. The combination of a confirmed abnormal BeLPT (that is, a second abnormal result from the BeLPT) and microscopic evidence of granuloma formation is considered diagnostic for CBD. The BeLPT assists in differentiating CBD from other granulomatous lung diseases (e.g., sarcoidosis) with similar lung pathology. This pre-clinical diagnostic tool provides opportunities for early intervention that did not exist when diagnosis relied on clinical symptoms, chest x-rays, and abnormal pulmonary function (OSHA, 2007).

The BeLPT/lung biopsy diagnostic approach has been utilized in several occupational surveys and surveillance programs over the last fifteen years. The findings have expanded scientific awareness of sensitization and CBD prevalence among beryllium employees and provided a better understanding of its work-related risk factors.

Some of the more informative studies come from nuclear weapons facilities operated by the Department of Energy (Viet et al., 2000; Stange et al., 2001; DOE/HSS, 2006), a beryllium ceramics plant in Arizona (Kreiss et al., 1996; Henneberger et al., 2001; Cummings et al., 2007), a beryllium production plant in Ohio (Kreiss et al., 1997; Kent et al., 2001), a beryllium machining facility in Alabama (Kelleher et al., 2001; Madl et al., 2007), and a beryllium alloy plant (Schuler et al., 2005) and another beryllium processing plant (Rosenman et al., 2005), both in Pennsylvania. The prevalence of beryllium sensitization from these surveyed workforces generally ranged from 1 to 10 percent with a prevalence of CBD from 0.6 to 8 percent.

In most of the surveys discussed above, 36-100 percent of those workers who initially tested positive with the BeLPT were diagnosed with CBD upon pathological evaluation. Most of these workers diagnosed with CBD had worked four to ten years on the job, although some were diagnosed within several months of employment. Surveys that found a high proportion (e.g., larger than 50 percent) of CBD among the sensitized employees were from facilities with a large number of employees who had been exposed to respirable beryllium for many years. It has been estimated from ongoing surveillance of sensitized individuals, with an average follow-up time of 4.5 years, that 37 percent of beryllium-exposed employees were estimated to progress to CBD (Newman et al., 2005). Another study of nuclear weapons facility employees enrolled in an ongoing medical surveillance program found that only about 20 percent of sensitized individuals employed less than five years eventually were diagnosed with CBD while 40 percent of sensitized employees employed ten years or more developed CBD (Stange et al., 2001). This observation, along with the study findings that CBD prevalence increases with cumulative exposure (described below), suggests that sensitized employees who acquire a higher lung burden of beryllium may be at greater risk of developing CBD than sensitized employees who have lesser amounts of beryllium in their lungs.

The greatest prevalence of sensitization and CBD were reported for production processes that involve heating beryllium metal (e.g., furnace operations, hot wire pickling, and annealing) or generating and handling beryllium powder (e.g., machining, forming, firing). For example, nearly 15 percent of machinists at the Arizona beryllium ceramics plant were sensitized, compared to just 1 percent of workers who never worked in machining (Kreiss et al., 1996). A low prevalence of sensitization and CBD was reported among current employees at the Department of Energy (DOE) clean-up sites where beryllium was once used in the production of nuclear weapons (DOE/HSS, 2006). These sites have been subject to the DOE CBD-prevention programs since 1999. While the prevalence of sensitization and CBD in non-production jobs was less, cases of CBD were found among secretaries, office employees, and security guards. CBD cases have also been reported in downstream uses of beryllium such as dental laboratories and metal recycling (OSHA, 2007).

The potential importance of respirable and ultrafine beryllium particulates in the onset of CBD is illustrated in studies of employees at a large beryllium metal, alloy, and oxide production plant in Ohio. An initial cross-sectional survey reported that the highest prevalence of sensitization and CBD occurred among workers employed in beryllium metal production, even though the highest airborne total mass concentrations of beryllium were generally among employees operating the beryllium alloy furnaces in a different area of the plant (Kreiss et al., 1997). Preliminary follow-up investigations of particle size-specific sampling at five furnace sites within the plant determined that the highest respirable (e.g., particles less than10 μm in diameter) and alveolar-deposited (e.g., particles less than1 μm in diameter) beryllium mass and particle number concentrations, as collected by a general area impactor device, were measured at the beryllium metal production furnaces rather than the beryllium alloy furnaces (Kent et al., 2001; McCawley et al., 2001). A statistically significant linear trend was reported between the above alveolar-deposited particle mass concentration and prevalence of CBD and sensitization in the furnace production areas. On the other hand, a linear trend was not found for CBD and sensitization prevalence and total beryllium mass concentration. The authors concluded that these findings suggest that alveolar-deposited particles may be a more relevant exposure metric for predicting the incidence of CBD or sensitization than the total mass concentration of airborne beryllium (OSHA, 2007).

Several epidemiological cohort studies have reported excess lung cancer mortality among workers employed in U.S. beryllium production and processing plants during the 1930s to 1960s. The largest and most comprehensive study investigated the mortality experience of over 9,000 workers employed in seven different beryllium processing plants over a 30 year period (Ward et. al., 1992). The employees at the two oldest facilities (i.e., Lorain, OH and Reading, PA) were found to have significant excess lung cancer mortality relative to the U.S. population. These two plants were believed to have the highest exposure levels to beryllium. A different analysis of the lung cancer mortality in this cohort using various local reference populations and alternate adjustments for smoking generally found smaller, non-significant, excess mortality among the beryllium employees (Levy et al., 2002). All the cohort studies are limited by a lack of job history and air monitoring data that would allow investigation of mortality trends with beryllium exposure.

The weight of evidence indicates that beryllium compounds should be regarded as potential occupational lung carcinogens, and OSHA has regulated it since 1974. Other organizations, such as the International Agency for Research on Cancer (IARC), the National Toxicology Program (NTP), the U.S. Environmental Protection Agency (EPA), the National Institute for Occupational Safety and Health (NIOSH), and the American Conference of Governmental Industrial Hygienists (ACGIH) have reached similar conclusions with respect to the carcinogenicity of beryllium.

3. A STATEMENT OF THE OBJECTIVES OF, AND LEGAL BASIS FOR, THE PROPOSED RULE

The objective of the proposed beryllium standard is to reduce the number of fatalities and illnesses occurring among employees exposed to beryllium. This objective will be achieved by requiring employers to install engineering controls where appropriate and to provide employees with the equipment, respirators, training, medical surveillance, and other protective measures to perform their jobs safely. The legal basis for the rule is the responsibility given the U.S. Department of Labor through the Occupational Safety and Health Act of 1970 (OSH Act). The OSH Act provides that, in promulgating health standards dealing with toxic materials or harmful physical agents, the Secretary “shall set the standard which most adequately assures, to the extent feasible, on the basis of the best available evidence that no employee will suffer material impairment of health or functional capacity even if such employee has regular exposure to the hazard dealt with by such standard for the period of his working life." 29 U.S.C. Sec. 655(b)(5).

See Section II of the preamble for a more detailed discussion.

4. A DESCRIPTION OF, AND AN ESTIMATE OF, THE NUMBER OF SMALL ENTITIES TO WHICH THE PROPOSED RULE WILL APPLY

OSHA has completed a preliminary analysis of the impacts associated with this proposed rule, including an analysis of the type and number of small entities to which the proposed rule would apply, as previously described in this PEA. In order to determine the number of small entities potentially affected by this rulemaking, OSHA used the definitions of small entities developed by the Small Business Administration (SBA) for each industry.

The proposed standard would impact occupational exposures to beryllium in all forms, compounds, and mixtures in general industry. Based on the definitions of small entities developed by SBA for each industry, the proposal is estimated to potentially affect a total of 3,741 small entities as shown in Table IX-1.

The Agency also estimated costs and conducted a screening analysis for very small employers (those with fewer than 20 employees). OSHA estimates that approximately 2,875 very small entities would be affected by the proposed standard, as shown in Table III-13 in Chapter III of this PEA.

5. A DESCRIPTION OF THE PROJECTED REPORTING, RECORDKEEPING, AND OTHER COMPLIANCE REQUIREMENTS OF THE PROPOSED RULE

Tables IX-1 and IX-2 show the average costs of the proposed standard by NAICS code and by compliance requirement (PEL/STEL or ancillary provisions) for, respectively, small entities (classified as small by SBA) and very small entities (those with fewer than 20 employees). Total costs are reported as N/A for NAICS codes with no affected entities in the relevant size classification. The weighted average cost per small entity for the proposed rule would be about $8,108 annually, with PEL/STEL compliance accounting for about 24 percent of the costs and ancillary provisions accounting for about 76 percent of the costs.

The weighted average cost per very small entity for the proposed rule would be about $1,955 annually, with PEL/STEL compliance accounting for about 38 percent of the costs and ancillary provisions accounting for about 62 percent of the costs.

Table IX-1

Average Costs for Small Entities Affected by the Proposed Beryllium Standard (2010 dollars)

Application Group	NAICS	Industry	PEL Compliance (Includes Respirators)	Ancillary Provisons	Total
Beryllium Production					
	331419	Primary Smelting and Refining of Nonferrous Metals	N/A	N/A	N/A
Beryllium Oxide Ceramics and Composites					
	327113a	Porcelain electrical supply manufacturing (primary)	$85,376	$10,438	$95,814
	327113b	Porcelain electrical supply manufacturing (secondary)	$5,478	$7,502	$12,979
	334220	Cellular telephones manufacturing	$5,901	$13,417	$19,319
	334310	Compact disc players manufacturing	$5,331	$11,438	$16,769
	334411	Electron Tube Manufacturing BeO traveling wave tubes	$6,721	$14,878	$21,599
	334415	Electronic resistor manufacturing	$5,812	$9,241	$15,052
	334419	Other electronic component manufacturing	$5,357	$7,625	$12,982
	334510	Electromedical equipment manufacturing	$5,268	$3,545	$8,812
	336322b	Other motor vehicle electrical & electronic equipment	$5,735	$12,681	$18,416
Nonferrous Foundries					
	331521	Aluminum die-casting foundries	$24,256	$14,141	$38,397
	331522	Nonferrous (except aluminum) die-casting foundries	$23,001	$12,013	$35,015
	331524	Aluminum foundries (except die-casting)	$25,338	$15,180	$40,518
	331525a	Copper foundries (except die-casting) (non-sand casting foundries)	$25,540	$15,755	$41,295
	331525b	Copper foundries (except die-casting) (sand casting foundries)	$27,012	$18,120	$45,132
Secondary Smelting, Refining, and Alloying					
	331314	Secondary smelting & alloying of aluminum	$22,432	$11,325	$33,757
	331421b	Copper rolling, drawing, and extruding	$22,432	$11,775	$34,206
	331423	Secondary smelting, refining, & alloying of copper	$23,335	$11,767	$35,102
	331492	Secondary Smelting, Refining, and Alloying of Nonferrous Metal (Except Copper and Aluminum)	$11,155	$11,029	$22,183
Precision Machining					
	332721a	Precision turned product manufacturing (high beryllium content)	$8,643	$10,839	$19,482
	332721b	Precision turned product manufacturing (low beryllium content)	$2,904	$11,304	$14,208
Copper Rolling, Drawing and Extruding					
	331421a	Copper rolling, drawing, and extruding	$2,316	$116,815	$119,132
	331422	Copper wire (except mechanical) drawing	$2,867	$102,598	$105,465
Stamping, Spring, and Connector Manufacturing					
	332612	Light gauge spring manufacturing	$2,035	$5,242	$7,277
	332116	Metal stamping	$1,935	$6,460	$8,395
	334417	Electronic connector manufacturing	$1,905	$3,860	$5,765
	336322a	Other motor vehicle electrical & electronic equipment	$2,032	$8,017	$10,049
Arc and Gas Welding					
	331111	Iron and Steel Mills	$3,613	$6,764	$10,377
	331221	Rolled Steel Shape Manufacturing	$3,879	$8,663	$12,541
	331513	Steel Foundries (except Investment)	$2,472	$6,185	$8,657
	332117	Powder Metallurgy Part Manufacturing	$2,113	$6,166	$8,278
	332212	Hand and Edge Tool Manufacturing	$2,234	$4,803	$7,037

Table IX-1, continued					
Average Costs for Small Entities Affected by the Proposed Beryllium Standard (2010 dollars)					
Application Group	NAICS	Industry	PEL Compliance (Includes Respirators)	Ancillary Provisons	Total
	332312	Fabricated Structural Metal Manufacturing	$2,111	$3,964	$6,076
	332313	Plate Work Manufacturing	$2,597	$4,783	$7,379
	332322	Sheet Metal Work Manufacturing	$2,459	$4,552	$7,010
	332323	Ornamental and Architectural Metal Work Manufacturing	$2,289	$4,258	$6,548
	332439	Other Metal Container Manufacturing	$1,975	$3,883	$5,858
	332919	Other Metal Valve and Pipe Fitting Manufacturing	$1,927	$4,374	$6,301
	332999	All Other Miscellaneous Fabricated Metal Product Manufacturing	$2,376	$4,407	$6,782
	333111	Farm Machinery and Equipment Manufacturing	$1,304	$2,594	$3,899
	333414a	Heating Equipment (except Warm Air Furnaces) Manufacturing	$1,933	$3,836	$5,769
	333911	Pump and Pumping Equipment Manufacturing	$1,455	$3,002	$4,457
	333922	Conveyor and Conveying Equipment Manufacturing	$2,370	$4,439	$6,809
	333924	Industrial Truck, Tractor, Trailer, and Stacker Machinery Manufacturing	$3,116	$6,006	$9,122
	333999	All Other Miscellaneous General Purpose Machinery Manufacturing	$1,820	$3,463	$5,282
	336211	Motor Vehicle Body Manufacturing	$3,201	$5,854	$9,055
	336214	Travel Trailer and Camper Manufacturing	$1,490	$2,914	$4,404
	336399a	All Other Motor Vehicle Parts Manufacturing	$3,302	$6,143	$9,445
	336510	Railroad Rolling Stock	$4,298	$8,685	$12,983
	336999	All Other Transportation Equipment Manufacturing	$1,291	$3,048	$4,339
	337215	Showcase, Partition, Shelving, and Locker Manufacturing	$2,253	$4,713	$6,966
	811310	Commercial and Industrial Machinery and Equipment Repair	$1,880	$3,565	$5,445
Resistance Welding					
	333411	Air Purification Equipment Manufacturing	$0	$8,363	$8,363
	333412	Industrial and Commercial Fan and Blower Manufacturing	$0	$11,780	$11,780
	333414b	Heating Equipment (except Warm Air Furnaces) Manufacturing	$0	$10,186	$10,186
	333415	Air-Conditioning, Warm Air Heating, and Industrial Refrigeration Equipment Manufacturing	$0	$18,247	$18,247
	335211	Electric Housewares and Household Fan Manufacturing	$0	$15,789	$15,789
	335212	Household Vacuum Cleaner Manufacturing	$0	$17,638	$17,638
	335221	Household Cooking Appliance Manufacturing	$0	$15,870	$15,870
	335222	Household Refrigerator and Home Freezer Manufacturing	$0	$16,548	$16,548
	335224	Household Laundry Equipment Manufacturing	$0	$8,274	$8,274
	335228	Other Major Household Appliance Manufacturing	$0	$1,740	$1,740
	336311	Carburetor, Piston, Piston Ring, and Valve Manufacturing	$0	$5,227	$5,227
	336312	Gasoline Engine and Engine Parts Manufacturing	$0	$16,015	$16,015
	336321	Vehicular Lighting Equipment Manufacturing	$0	$6,084	$6,084
	336322c	Other Motor Vehicle Electrical and Electronic Equipment Manufacturing	$0	$16,355	$16,355
	336330	Motor Vehicle Steering and Suspension Components (except Spring) Manufacturing	$0	$17,707	$17,707

Table IX-1, continued

Average Costs for Small Entities Affected by the Proposed Beryllium Standard (2010 dollars)

Application Group	NAICS	Industry	PEL Compliance (Includes Respirators)	Ancillary Provisons	Total
	336340	Motor Vehicle Brake System Manufacturing	$0	$18,828	$18,828
	336350	Motor Vehicle Transmission and Power Train Parts Manufacturing	$0	$18,037	$18,037
	336360	Motor Vehicle Seating and Interior Trim Manufacturing	$0	$6,586	$6,586
	336370	Motor Vehicle Metal Stamping	$0	$8,894	$8,894
	336391	Motor Vehicle Air-Conditioning Manufacturing	$0	$16,715	$16,715
	336399b	All Other Motor Vehicle Parts Manufacturing	$0	$17,568	$17,568
Dental Laboratories					
	339116	Dental laboratories	$494	$900	$1,394
	621210	Offices of dentists	$577	$1,053	$1,630
		Weighted Averages	$1,940	$6,168	$8,108

Table IX-2					
Average Costs for Very Small Entities (<20 employees) Affected by the Proposed Beryllium Standard (2010 dollars)					
Application Group	**NAICS**	**Industry**	**PEL Compliance (Includes Respirators)**	**Ancillary Provisions**	**Total**
Beryllium Production					
	331419	Primary Smelting and Refining of Nonferrous Metals (Brush Wellman)	N/A	N/A	N/A
Beryllium Oxide Ceramics and Composites					
	327113a	Porcelain electrical supply manufacturing (primary)	N/A	N/A	N/A
	327113b	Porcelain electrical supply manufacturing (secondary)	$5,176	$1,670	$6,846
	334220	Cellular telephones manufacturing	$5,182	$1,091	$6,273
	334310	Compact disc players manufacturing	$5,202	$3,181	$8,383
	334411	Electron Tube Manufacturing BeO traveling wave tubes	$5,172	$1,258	$6,430
	334415	Electronic resistor manufacturing	$5,176	$1,673	$6,849
	334419	Other electronic component manufacturing	$5,179	$1,783	$6,962
	334510	Electromedical equipment manufacturing	$5,171	$1,099	$6,271
	336322b	Other motor vehicle electrical & electronic equipment	$5,198	$1,170	$6,368
Nonferrous Foundries					
	331521	Aluminum die-casting foundries	N/A	N/A	N/A
	331522	Nonferrous (except aluminum) die-casting foundries	N/A	N/A	N/A
	331524	Aluminum foundries (except die-casting)	N/A	N/A	N/A
	331525a	Copper foundries (except die-casting) (non-sand casting foundries)	N/A	N/A	N/A
	331525b	Copper foundries (except die-casting) (sand casting foundries)	N/A	N/A	N/A
Secondary Smelting, Refining, and Alloying					
	331314	Secondary smelting & alloying of aluminum	N/A	N/A	N/A
	331421b	Copper rolling, drawing, and extruding	N/A	N/A	N/A
	331423	Secondary smelting, refining, & alloying of copper	$19,724	$1,864	$21,589
	331492	Secondary Smelting, Refining, and Alloying of Nonferrous Metal (Except Copper and Aluminum)	$9,626	$1,430	$11,055
Precision Machining					
	332721a	Precision turned product manufacturing (high beryllium content)	$3,033	$3,849	$6,882
	332721b	Precision turned product manufacturing (low beryllium content)	$1,023	$4,022	$5,046
Copper Rolling, Drawing and Extruding					
	331421a	Copper rolling, drawing, and extruding	$1,133	$4,550	$5,684
	331422	Copper wire (except mechanical) drawing	$1,304	$6,379	$7,682
Stamping, Spring, and Connector Manufacturing					
	332612	Light gauge spring manufacturing	$1,839	$1,471	$3,310
	332116	Metal stamping	$1,846	$1,697	$3,543
	334417	Electronic connector manufacturing	$1,841	$1,173	$3,014
	336322a	Other motor vehicle electrical & electronic equipment	$1,851	$1,157	$3,007
Arc and Gas Welding					
	331111	Iron and Steel Mills	N/A	N/A	N/A
	331221	Rolled Steel Shape Manufacturing	N/A	N/A	N/A
	331513	Steel Foundries (except Investment)	N/A	N/A	N/A
	332117	Powder Metallurgy Part Manufacturing	N/A	N/A	N/A

Table IX-2, continued					
Average Costs for Very Small Entities (<20 employees) Affected by the Proposed Beryllium Standard (2010 dollars)					
Application Group	**NAICS**	**Industry**	**PEL Compliance (Includes Respirators)**	**Ancillary Provisions**	**Total**
	332212	Hand and Edge Tool Manufacturing	$782	$2,389	$3,171
	332312	Fabricated Structural Metal Manufacturing	$715	$1,584	$2,299
	332313	Plate Work Manufacturing	$935	$1,956	$2,891
	332322	Sheet Metal Work Manufacturing	$834	$1,786	$2,620
	332323	Ornamental and Architectural Metal Work Manufacturing	$1,032	$2,121	$3,153
	332439	Other Metal Container Manufacturing	$726	$1,745	$2,471
	332919	Other Metal Valve and Pipe Fitting Manufacturing	$834	$3,469	$4,302
	332999	All Other Miscellaneous Fabricated Metal Product Manufacturing	$812	$1,748	$2,560
	333111	Farm Machinery and Equipment Manufacturing	$715	$1,584	$2,299
	333414a	Heating Equipment (except Warm Air Furnaces) Manufacturing	$732	$1,805	$2,536
	333911	Pump and Pumping Equipment Manufacturing	$727	$1,750	$2,477
	333922	Conveyor and Conveying Equipment Manufacturing	$717	$1,619	$2,335
	333924	Industrial Truck, Tractor, Trailer, and Stacker Machinery Manufacturing	$750	$2,011	$2,761
	333999	All Other Miscellaneous General Purpose Machinery Manufacturing	$715	$1,583	$2,298
	336211	Motor Vehicle Body Manufacturing	$715	$1,583	$2,298
	336214	Travel Trailer and Camper Manufacturing	$715	$1,585	$2,300
	336399a	All Other Motor Vehicle Parts Manufacturing	$723	$1,702	$2,424
	336510	Railroad Rolling Stock	N/A	N/A	N/A
	336999	All Other Transportation Equipment Manufacturing	$764	$2,174	$2,938
	337215	Showcase, Partition, Shelving, and Locker Manufacturing	$771	$2,264	$3,035
	811310	Commercial and Industrial Machinery and Equipment Repair	$1,327	$2,623	$3,949
Resistance Welding					
	333411	Air Purification Equipment Manufacturing	$0	$2,506	$2,506
	333412	Industrial and Commercial Fan and Blower Manufacturing	$0	$2,401	$2,401
	333414b	Heating Equipment (except Warm Air Furnaces) Manufacturing	$0	$2,321	$2,321
	333415	Air-Conditioning, Warm Air Heating, and Industrial Refrigeration Equipment Manufacturing	$0	$1,094	$1,094
	335211	Electric Housewares and Household Fan Manufacturing	$0	$1,151	$1,151
	335212	Household Vacuum Cleaner Manufacturing	N/A	N/A	N/A
	335221	Household Cooking Appliance Manufacturing	$0	$1,056	$1,056
	335222	Household Refrigerator and Home Freezer Manufacturing	N/A	N/A	N/A
	335224	Household Laundry Equipment Manufacturing	N/A	N/A	N/A
	335228	Other Major Household Appliance Manufacturing	N/A	N/A	N/A
	336311	Carburetor, Piston, Piston Ring, and Valve Manufacturing	$0	$1,395	$1,395
	336312	Gasoline Engine and Engine Parts Manufacturing	$0	$1,331	$1,331
	336321	Vehicular Lighting Equipment Manufacturing	$0	$1,056	$1,056
	336322c	Other Motor Vehicle Electrical and Electronic Equipment Manufacturing	$0	$1,452	$1,452
	336330	Motor Vehicle Steering and Suspension Components (except Spring) Manufacturing	$0	$1,056	$1,056

Table IX-2, continued					
Average Costs for Very Small Entities (<20 employees) Affected by the Proposed Beryllium Standard (2010 dollars)					
Application Group	NAICS	Industry	PEL Compliance (Includes Respirators)	Ancillary Provisions	Total
	336340	Motor Vehicle Brake System Manufacturing	$0	$1,056	$1,056
	336350	Motor Vehicle Transmission and Power Train Parts Manufacturing	$0	$1,056	$1,056
	336360	Motor Vehicle Seating and Interior Trim Manufacturing	$0	$1,056	$1,056
	336370	Motor Vehicle Metal Stamping	$0	$1,329	$1,329
	336391	Motor Vehicle Air-Conditioning Manufacturing	$0	$1,056	$1,056
	336399b	All Other Motor Vehicle Parts Manufacturing	$0	$1,267	$1,267
Dental Laboratories					
	339116	Dental laboratories	$325	$598	$923
	621210	Offices of dentists	$518	$947	$1,465
		Weighted Averages	$736	$1,220	$1,955.00

6. Federal Rules which May Duplicate, Overlap or Conflict with the Proposed Rule

Section 4(b)(1) of the OSH Act exempts the working conditions for certain Federal and non-Federal employees from the provisions of the OSH Act to the extent that other Federal agencies exercise statutory authority to prescribe and enforce occupational safety and health standards. The Department of Energy (DOE) issued a regulation in 1999 entitled Chronic Beryllium Disease Prevention Program (CBDPP) (10 CFR Part 850, 64 FR 68854 – 68914). Additionally, DOE issued 10 CFR Part 851, Worker Safety and Health Program (71 FR 6931- 6948), which establishes requirements for worker safety and health for DOE contractors at DOE sites. The CBDPP establishes a beryllium program for DOE employees and DOE contractor employees. Therefore, under Section 4(b)(1) of the OSH Act, OSHA's beryllium standard would not apply to work subject to the CBDPP. DOE has included in its regulations a requirement for compliance with any more stringent PEL established by OSHA in rulemaking (10 CFR 850.22). OSHA requests comment on the potential overlap of DOE's rule with OSHA's proposed rule. (See I *Issues and Alternatives*)

7. ALTERNATIVES TO THE PROPOSED RULE WHICH ACCOMPLISH THE STATED OBJECTIVES OF APPLICABLE STATUTES AND WHICH MINIMIZE ANY SIGNIFICANT ECONOMIC IMPACT OF THE PROPOSED RULE ON SMALL ENTITIES

This section first discusses several provisions in the proposed standard that OSHA has adopted or modified based on comments from small entity representatives (SERs) during the SBREFA process or on recommendations made by the SBAR Panel as potentially alleviating impacts on small entities (see the SBAR panel report at (SBAR, 2008).). Then, the Agency presents various regulatory alternatives to the proposed OSHA beryllium standard.

<u>Elements of the Proposed Rule to Reduce Impacts on Small Entities</u>

During the SBAR Panel, SERs requested a clearer definition of the triggers for medical surveillance. This concern was rooted in the cost of BeLPTs and the trigger of potential skin contact. For the proposed rule, the Agency has removed skin contact as a trigger for medical surveillance along with providing four clearly defined trigger mechanisms. The newly defined medical surveillance provision reduces the number of employees requiring a BeLPT, particularly for small businesses with low exposures.

Some of the SERs in low-exposure industries wanted to be "shielded" from "expensive" compliance with a standard they perceive to be unnecessary and suggested a PEL-only standard that triggered provisions on the PEL. The alternative of a PEL-only standard and ancillary provisions triggered only by the PEL were discussed in the preceding Regulatory Alternatives chapter (and is repeated in the following section).

Some SERs were already applying many of the protective controls and practices that would be required by the ancillary provisions of the standard. However, many SERs objected to the requirements regarding hygiene facilities. For this proposed rule, OSHA has preliminarily concluded that all affected employers currently have hand washing facilities. OSHA has also preliminarily concluded that no affected employers will be required to install showers. The Agency has determined that the long-term rental of modular units was representative of costs for a range of reasonable approaches to comply with the change room part of the provision. Alternatively, employers could renovate and rearrange their work areas in order to meet the requirements of this provision.

Regulatory Alternatives

For the convenience of those persons interested only in OSHA's regulatory flexibility analysis, this section repeats the discussion presented in Chapter VIII of this PEA, but only for the regulatory alternatives to the proposed OSHA beryllium standard that lower costs. OSHA believes that this presentation of specific regulatory alternatives explores the possibility of less costly ways (than the proposed rule) to provide an adequate level of worker protection from exposure to beryllium.

Each regulatory alternative presented here is described and analyzed relative to the proposed rule. Where appropriate, the Agency notes whether the regulatory alternative, to be a legitimate candidate for OSHA consideration, requires evidence contrary to the Agency's preliminary findings of significant risk and feasibility. For this chapter on the Initial Regulatory Flexibility Analysis, the Agency is only presenting regulatory alternatives that reduce costs for small entities. (See Chapter VIII for the full list of all alternatives analysed.) There are eight alternatives that reduce costs for small entities (and for all businesses in total). Using the numbering scheme from Chapter VIII, these are Regulatory Alternatives #5, #6, #7, #8. #12, #16, #18, and #22. To facilitate comment, OSHA has organized these eight cost-reducing alternatives (and a general discussion of possible phase-ins of the rule) into four categories: (1) exposure limits; (2) methods of compliance; (3) ancillary provisions; and (4) timing.

(1) Exposure Limit (TWA PEL, STEL, and ACTION LEVEL) Alternatives

Regulatory Alternative #5, which would set a TWA PEL at 0.5 $\mu g/m^3$ and an action level at 0.25 $\mu g/m^3$, both higher than in the proposal, responds to an issue raised during the Small Business Advocacy Review (SBAR) process conducted in 2007 to consider a draft OSHA beryllium proposed rule that culminated in an SBAR Panel report (SBAR, 2008). That report included a recommendation that OSHA consider both the economic impact of a low TWA PEL and regulatory alternatives that would ease cost burden for small entities. OSHA has provided a full analysis of the economic impact of its proposed PELs (see Chapter VI of this PEA), and Regulatory Alternative #5 addresses the second half of that recommendation. However, the higher 0.5 $\mu g/m^3$ TWA PEL does not appear to be consistent with the Agency's mandate under the OSH Act to promulgate a lower PEL if it is feasible and could prevent additional fatalities and non-fatal illnesses. The data presented in Table IX-3 below indicate that the lower TWA PEL would prevent additional fatalities and non-fatal illnesses, but nevertheless the Agency solicits comments on this alternative and OSHA's analysis of the costs and benefits associated with it.

Table IX-3 below presents, for informational purposes, the estimated costs, benefits, and net benefits of the proposed rule under the proposed TWA PEL of 0.2 $\mu g/m^3$ for the regulatory alternative of a TWA PEL of 0.5 $\mu g/m^3$ (Regulatory Alternative #5), using alternative discount rates of 3 percent and 7 percent. Table IX-3 also breaks out costs by provision and benefits by type of disease and by morbidity/mortality.

As Table IX-3 shows, going from a TWA PEL of 0.5 $\mu g/m^3$ to a TWA PEL of 0.2 $\mu g/m^3$ would prevent, annually, an additional 28 beryllium-related fatalities and an additional 15 non-fatal illnesses. This is consistent with OSHA's preliminary risk assessment, which indicates significant risk to workers exposed at a TWA PEL of 0.5 μg/m^3; furthermore, OSHA's preliminary feasibility analysis indicates that a lower TWA PEL than 0.5 μg/m^3 is feasible. Net benefits of this regulatory alternative versus the proposed TWA PEL of 0.2 μg/m^3 would decrease from $538.2 million to $370.0 million using a 3 percent discount rate and from $216.2 million to $144.4 million using 7 percent discount rate.

Table IX-3: Annualized Costs, Benefits and Incremental Benefits of OSHA's Proposed Beryllium Standard of 0.5 μg/m3 PEL Alternative
Millions ($2010)

	Proposed PEL (PEL = 0.2 μg/m^3, AL = 0.10 μg/m^3)			Alternative 5 Incremental Costs/Benefits			Alternative 5 (PEL = 0.5 μg/m^3, AL = 0.25 μg/m^3)		
Discount Rate		**3%**	**7%**		**3%**	**7%**		**3%**	**7%**
Annualized Costs									
Control Costs		$9.5	$10.3		-$3.6	-$3.9		$6.0	$6.5
Respirators		$0.2	$0.3		-$0.1	-$0.1		$0.1	$0.1
Exposure Assessment		$2.2	$2.4		-$0.3	-$0.3		$1.9	$2.1
Regulated areas and Beryllium Work Areas		$0.6	$0.7		-$0.3	-$0.3		$0.3	$0.4
Medical Surveillance		$2.9	$3.0		-$0.1	-$0.1		$2.8	$2.9
Medical Removal		$0.1	$0.2		-$0.1	-$0.1		$0.1	$0.1
Exposure Control Plan		$1.8	$1.8		$0.0	$0.0		$1.8	$1.8
Protective Clothing and Equipment		$1.4	$1.4		$0.0	$0.0		$1.4	$1.4
Hygiene Areas and Practices		$0.4	$0.4		$0.0	$0.0		$0.4	$0.4
Housekeeping		$12.6	$12.9		$0.0	$0.0		$12.6	$12.9
Training		$5.8	$5.8		$0.0	$0.0		$5.8	$5.8
Total Annualized Costs (point estimate)		**$37.6**	**$39.1**		**-$4.4**	**-$4.8**		**$33.2**	**$34.4**
Annual Benefits: Number of Cases Prevented	Cases			Cases			Cases		
Fatal Lung Cancers (midpoint estimate)	4			0			4		
Fatal Chronic Beryllium Disease	92			-29			63		
Beryllium-Related Mortality	96	$573.0	$253.7	-28	-$171.8	-$76.1	67	$401.2	$177.7
Beryllium Morbidity	50	$2.8	$1.6	-15	-$0.9	-$0.5	34	$2.0	$1.1
Monetized Annual Benefits (midpoint estimate)		**$575.8**	**$255.3**		**-$172.7**	**-$76.6**		**$403.1**	**$178.8**
Net Benefits		**$538.2**	**$216.2**		**-$168.2**	**-$71.9**		**$370.0**	**$144.4**

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis

* Benefits are assessed over a 60-year time horizon, during which it is assumed that economic conditions remain constant. Costs are annualized over ten years, with the exception of equipment expenditures, which are annualized over the life of the equipment. Annualized costs are assumed to continue at the same level for sixty years, which is consistent with assuming that economic conditions remain constant for the sixty year time horizon.

Regulatory Alternative Featuring Unchanged PEL but Full Ancillary Provisions

An Informational Analysis: This proposed regulation has the somewhat unusual feature for an OSHA substance-specific health standard that most of the quantified benefits would come from the ancillary provisions rather than from meeting the PEL with engineering controls. OSHA decided to analyze for informational purposes the effect of retaining the existing PEL but applying all of the ancillary provisions, including respiratory protection. Under this approach, the TWA PEL would remain at 2.0 micrograms per cubic meter, but all of the other proposed provisions (including respiratory protection, which OSHA does not consider an ancillary provision) would be required with their triggers remaining the same as in the proposed rule—either the presence of airborne beryllium at any level (e.g., initial monitoring, written exposure control plan), at certain kinds of dermal exposure (PPE), at the action level of 0.1 $\mu g/m^3$ (e.g., periodic monitoring, medical removal), or at 0.2 $\mu g/m^3$ (e.g., regulated areas, respiratory protection, medical surveillance).

Given the record regarding beryllium exposures, this approach is not one OSHA could legally adopt because the absence of a more protective requirement for engineering controls would not be consistent with section 6(b)(5) of the OSH Act, which requires OSHA to "set the standard which most adequately assures, to the extent feasible, on the basis of the best available evidence, that no employee will suffer material impairment of health or functional capacity even if such employee has regular exposure to the hazard dealt with by such standard for the period of his working life." For that reason, this additional analysis is provided strictly for informational purposes. EO 12866 and EO 13563 direct agencies to identify approaches that maximize net benefits, and this analysis is purely for the purpose of exploring whether this approach would hold any real promise to maximize net benefits if it was permissible under the OSH Act. It does not appear to hold such promise because an ancillary-provisions-only approach would not be as protective and thus offers fewer benefits than one that includes a lower PEL and engineering controls, and we estimate the costs would be about the same (or slightly lower, depending on certain assumptions) under that approach as under the traditional proposed approach.

When examined on an industry by industry basis, OSHA found that some industries would have lower costs if they could adopt the ancillary provision only approach. Some employers would use engineering controls where they are cheaper, even if they are not mandatory. OSHA does not have sufficient information to do an analysis of the employer-by-employer situations in which there exist some employers for whom the ancillary-provisions-only approach might be cheaper. In the majority of affected industries, the Agency estimates there are no costs saving to the ancillary-provisions-only approach. However, OSHA estimates a total of $2,675,828 per year in costs saving for entire industries where the ancillary-provisions-only approach would be less expensive.

The above discussion does not account for the possibility that the lack of engineering controls would result in higher beryllium exposures for workers in adjacent (non-production) work areas due to the increased level of beryllium in the air. Because of a lack of data, and because the issue did not arise in the other regulatory alternatives

OSHA considered (all of which have a PEL of less than 2.0 μg/m^3), OSHA did not carefully examine exposure levels in non-production areas for either cost or benefit purposes. To the extent such exposure levels would be above the action level, there would be additional costs for respiratory protection.

The ancillary provisions only approach adds uncertainty to the benefits analysis such that the benefits of the rule as proposed may exceed, and perhaps greatly exceed, the benefits of this ancillary-provisions-only approach:

1) Most exposed individuals would be in respirators, which OSHA considers less effective than engineering controls in preventing employee exposure to beryllium. OSHA last did an extensive review of the evidence on effectiveness of respirators for its APFs rulemaking in 2006 (71 FR 50128-45 Aug 24, 2006). OSHA has not in the past tried to quantify the size of this effect, but it could partially negate the estimated benefits of 92 CBD deaths prevented per year and 4 lung cancer cases prevented per year by the proposed standard.

2) As noted above, in the proposal OSHA did not consider benefits caused by reductions in exposure in non-production areas. Unless employers act to reduce exposures in the production areas, the absence of a requirement for such controls would largely negate such benefits from reductions in exposure in the non-productions areas.

3) OSHA believes that there is a strong possibility that the benefits of the ancillary provisions (a midpoint estimate of eliminating 45 percent of all remaining cases of CBD) would be partially or wholly negated in the absence of engineering controls that would reduce both airborne and surface dust levels. The measured reduction in benefits

from ancillary provision was in a facility with average exposure levels of less than 0.2 μg/m^3.

Based on these considerations, OSHA believes that the ancillary-provisions-only approach is not one that is likely to maximize net benefits. The costs saving, if any, are estimated to be small, and the difficult-to-measure declines in benefits could be substantial.

(2) A Method-of-Compliance Alternative

Paragraph (f)(2) of the proposed rule contains requirements for the implementation of engineering and work practice controls to minimize beryllium exposures in beryllium work areas. For each operation in a beryllium work area, employers must ensure that one or more of the following engineering and work practice controls are in place to minimize employee exposure: material and/or process substitution; ventilated enclosures; local exhaust ventilation; or process controls, such as wet methods and automation. Employers are exempt from using engineering and work practice controls only when they can show that such controls are not feasible or where exposures are below the action level based on two exposure samples taken seven days apart.

These requirements, which are based on the stakeholders' recommended beryllium standard that beryllium industry and union stakeholders submitted to OSHA in 2012 (Materion and United Steelworkers, 2012), address a concern associated with the proposed TWA PEL. OSHA expects that day-to-day changes in workplace conditions, such as workers' positioning or patterns of airflow, may cause frequent exposures above the TWA PEL in workplaces where periodic sampling indicates exposures are between the action level and the TWA PEL. As a result, the default under the standard is that the controls are required until the employer can demonstrate that exposures have not exceeded the action level from at least two separate measurements taken seven days apart.

OSHA believes that substitution or engineering controls such as those outlined in paragraph (f)(2)(i) provide the most reliable means to control variability in exposure levels. However, OSHA also recognizes that the requirements of paragraph (f)(2)(i) are not typical of OSHA standards, which usually require engineering controls only where exposures exceed the TWA PEL or STEL. The Agency is therefore considering **Regulatory Alternative #6**, which would drop the provisions of (f)(2)(i) from the proposed standard and make conforming edits to paragraphs (f)(2)(ii) and (iii). This regulatory alternative does not eliminate the need for engineering controls to comply with the proposed TWA PEL and STEL, but does eliminate the requirement to use one or more of the specified engineering or work practice controls where exposures equal or exceed the action level. As shown in Table IX-4, Regulatory Alternative #6 would decrease the annualized cost of the proposed rule by about $457,000 using a discount rate of 3 percent and by about $480,000 using a discount rate of 7 percent. OSHA has not been able to estimate the change in benefits resulting from Regulatory Alternative #6 at this time and invites public comment on this issue.

Table IX-4: Cost of Regulatory Alternatives, Alternative 6
(Proposed PEL=0.2, STEL=2.0, AL=0.1)

3% Discount Rate	Total Cost	Incremental Cost Relative to Proposal
Proposed Rule	$37,597,325	——
Alternative 6: Eliminate (f)(2) controls	$37,140,020	-$457,304

7% Discount Rate	Total Cost	Incremental Cost Relative to Proposal
Proposed Rule	$39,147,434	——
Alternative 6: Eliminate (f)(2) controls	$38,667,896	-$479,538

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis

(3) Regulatory Alternatives That Affect Ancillary Provisions

The proposed standard contains several ancillary provisions (provisions other than the exposure limits), including requirements for exposure assessment, medical surveillance, medical removal, training, and regulated areas or access control. As reported in Chapter V of this PEA, these ancillary provisions account for $27.8 million (about 74 percent) of the total annualized costs of the rule ($37.6 million) using a 3 percent discount rate, or $28.6 million (about 73 percent) of the total annualized costs of the rule ($39.1 million) using a 7 percent discount rate. The most expensive of the ancillary provisions are the requirements for housekeeping and training, with annualized costs of $12.6 million and $5.8 million, respectively, at a 3 percent discount rate ($12.9 million and $5.8 million, respectively, at a 7 percent discount rate).

OSHA's reasons for including each of the proposed ancillary provisions are explained in Section XVIII of the preamble, Summary and Explanation of the Standards. In particular, OSHA is proposing the requirements for exposure assessment to provide a basis for ensuring that appropriate measures are in place to limit worker exposures. Medical surveillance is especially important because workers exposed above the proposed TWA PEL, as well as many workers exposed below the proposed TWA PEL, are at significant risk of death and illness. Medical surveillance would allow for identification of beryllium-related adverse health effects at an early stage so that appropriate intervention measures can be taken. OSHA is proposing regulated areas and access control because they serve to limit exposure to beryllium to as few employees as possible. OSHA is proposing worker training to ensure that employers inform employees of the hazards to which they are exposed, along with associated protective measures, so that employees understand how they can minimize their exposure to beryllium. Worker training on beryllium-related work practices is particularly important in controlling beryllium exposures because engineering controls frequently require action on the part of workers to function effectively.

OSHA has examined a variety of regulatory alternatives involving changes to one or more of the proposed ancillary provisions. The incremental cost of each of these regulatory alternatives and its impact on the total costs of the proposed rule is summarized in Table IX-5 at the end of this section. OSHA has preliminarily determined that several of these ancillary provisions will increase the benefits of the proposed rule, for example, by helping to ensure the TWA PEL is not exceeded or by lowering the risks to workers given the significant risk remaining at the proposed TWA PEL. However, except for Regulatory Alternative #7 (involving the elimination of all ancillary provisions), OSHA did not estimate changes in monetized benefits for the regulatory alternatives that affect ancillary provisions. Two regulatory alternatives that involve all ancillary provisions are presented below (#7 and #8), followed by regulatory alternatives for regulated areas (#12), for medical surveillance (#16 and #18), and for medical removal (#22).

(a) All Ancillary Provisions

The SBAR Panel recommended that OSHA analyze a PEL-only standard as a regulatory alternative. The Panel also recommended that OSHA consider not applying ancillary provisions of the standard where exposure levels are low so as to minimize costs for small businesses (SBAR, 2008). In response to these recommendations, OSHA analyzed Regulatory Alternative #7, a PEL-only standard, and Regulatory Alternative #8, which would apply ancillary provisions of the beryllium standard only where exposures exceed the proposed TWA PEL of 0.2 $\mu g/m^3$ or the proposed STEL of 2 $\mu g/m^3$.

Regulatory Alternative #7 would solely update 1910.1000 Tables Z-1 and Z-2, so that the proposed TWA PEL and STEL would apply to all workers in general industry. This alternative would eliminate all of the ancillary provisions of the proposed rule, including exposure assessment, medical surveillance, medical removal, PPE, housekeeping, training, and regulated areas or access control. Under this regulatory alternative, OSHA estimates that the costs for the proposed ancillary provisions of the rule (estimated at $27.8 million annually at a 3 percent discount rate) would be eliminated. In order to meet the PELs, employers would still commonly need to do monitoring, train workers on the use of controls, and set up some kind of regulated areas to indicate where respirator use would be required. It is also likely that, under this alternative, many employers would follow the recommendations of Materion and the United Steelworkers to provide medical surveillance, PPE, and other protective measures for their workers (Materion and United Steelworkers, 2012). OSHA has not attempted to estimate the extent to which these ancillary-provision costs would be incurred if they were not formally required or whether any of these costs under Regulatory Alternative #7 would reasonably be attributable to the proposed rule. OSHA welcomes comment on the issue.

OSHA has also estimated the effect of this regulatory alternative on the benefits of the rule. As a result of eliminating all of the ancillary provisions, annualized benefits are estimated to decrease 56 percent, relative to the proposed rule, from $575.8 million to $249.1 million, using a 3 percent discount rate, and from $255.3 million to $110.4 million using a 7 percent discount rate. This estimate follows from OSHA's analysis of benefits in Chapter VII of this PEA, which found that about 58 percent of the benefits of the proposed rule, evaluated at their mid-point value, were attributable to the combination of the ancillary provisions. As these estimates show, OSHA expects that the benefits estimated under the proposed rule will not be fully achieved if employers do not implement the ancillary provisions of the proposed rule.

Both industry and worker groups have recognized that a comprehensive standard is needed to protect workers exposed to beryllium. The stakeholders' recommended standard that representatives of the primary beryllium manufacturing industry and the United Steelworkers union provided to OSHA confirms the importance of ancillary provisions in protecting workers from the harmful effects of beryllium exposure (Materion and United Steelworkers, 2012). Ancillary provisions such as personal protective clothing and equipment, regulated areas, medical surveillance, hygiene areas, housekeeping requirements, and hazard communication all serve to reduce the risks to beryllium-exposed workers beyond that which the proposed TWA PEL alone could achieve.

Moreover, where there is continuing significant risk at the TWA PEL, the decision in the Asbestos case (Bldg. and Constr. Trades Dep't, AFL-CIO v. Brock, 838 F.2d 1258, 1274 (D.C. Cir. 1988)) indicated that OSHA should use its legal authority to impose additional requirements on employers to further reduce risk when those requirements will result in a greater than de minimis incremental benefit to workers' health. Nevertheless, OSHA requests comment on this alternative.

Under **Regulatory Alternative #8**, several ancillary provisions that the current proposal would require under a variety of exposure conditions (e.g., dermal contact, any airborne exposure, exposure at or above the action level) would instead only apply where exposure levels exceed the TWA PEL or STEL. Regulatory Alternative #8 affects the following provisions of the proposed standard:

- Exposure monitoring: Whereas the proposed standard requires annual monitoring when exposure levels are at or above the action level and at or below the TWA PEL, Regulatory Alternative #8 would require annual exposure monitoring only where exposure levels exceed the TWA PEL or STEL;

- Written exposure control plan: Whereas the proposed standard requires written exposure control plans to be maintained in any facility covered by the standard, Regulatory Alternative #8 would require only facilities with exposures above the TWA PEL or STEL to maintain a plan;
- Housekeeping: Whereas the proposed standard's housekeeping requirements apply across a wide variety of beryllium exposure conditions, Alternative #8 would limit housekeeping requirements to areas and employees with exposures above the TWA PEL or STEL;
- PPE: Whereas the proposed standard requires PPE for employees under a variety of conditions, such as exposure to soluble beryllium or visible contamination with beryllium, Alternative #8 would require PPE only for employees exposed above the TWA PEL or STEL;
- Medical Surveillance: Whereas the proposed standard's medical surveillance provisions require employers to offer medical surveillance to employees with signs or symptoms of beryllium-related health effects regardless of their exposure level, Alternative #8 would require surveillance only for those employees exposed above the TWA PEL or STEL.

To estimate the cost savings for this alternative, OSHA re-estimated the group of workers that would fall under the above provisions and the changes to their scope. Combining these various adjustments along with associated unit costs, OSHA estimates that, under this regulatory alternative, the costs for the proposed rule would decline from $37.6 million to $18.9 million using a 3 percent discount rate and from $39.1 million to $20.0 million using a 7 percent discount rate.

The Agency has not quantified the impact of this alternative on the benefits of the rule. However, ancillary provisions that offer protective measures to workers exposed below the proposed TWA PEL, such as personal protective clothing and equipment, beryllium work areas, hygiene areas, housekeeping requirements, and hazard communication, all serve to reduce the risks to beryllium-exposed workers beyond that which the proposed TWA PEL and STEL could achieve. OSHA's preliminary conclusion is that the requirements triggered by the action level and other exposures below the proposed PELs will result in very real and necessary, but difficult to quantify, further reduction in risk beyond that provided by the PELs alone.

The remainder of this chapter discusses additional regulatory alternatives that apply to individual ancillary provisions. At this time, OSHA is not able to quantify the effects of these regulatory alternatives on benefits. The Agency solicits comment on the effects of these regulatory alternatives on the benefits of the proposed rule.

(b) Regulated Areas

Proposed paragraph (e) requires employers to establish and maintain beryllium work areas wherever employees are exposed to airborne beryllium, regardless of the level of exposure, and regulated areas wherever airborne concentrations of beryllium exceed the TWA PEL or STEL. Employers are required to demarcate beryllium work areas and regulated areas and limit access to regulated areas to authorized persons.

The SBAR Panel report recommended that OSHA consider dropping or limiting the provision for regulated areas (SBAR, 2008). In response to this recommendation, OSHA examined **Regulatory Alternative #12**, which would eliminate the requirement that employers establish regulated areas. This alternative is meant only to eliminate the requirement to set up and demarcate specific physical areas: all ancillary provisions would be triggered by the same conditions as under the standard's definition of a "regulated area." For example, under the current proposal, employees who work in regulated areas for at least 30 days annually are eligible for medical surveillance. If OSHA were to remove the requirement to establish regulated areas, the medical surveillance provisions would be altered so that employees who work more than 30 days annually in jobs or areas with exposures that exceed the TWA PEL or STEL are eligible for medical surveillance. This alternative would not eliminate the proposed requirement to establish beryllium work areas. As shown in Table IX-5, Regulatory Alternative #12 would decrease the annualized cost of the proposed rule by about $522,000 using a 3 percent discount rate, and by about $523,000 using a 7 percent discount rate.

(c) Medical Surveillance

The proposed requirements for medical surveillance include: (1) medical examinations, including a test for beryllium sensitization, for employees who are exposed to beryllium in a regulated area (i.e., above the proposed TWA PEL or STEL) for 30 days or more per year, who are exposed to beryllium in an emergency, or who show signs or symptoms of CBD; and (2) CT scans for employees who were exposed above the proposed TWA PEL or STEL for more than 30 days in a 12-month period for 5 years or more. The proposed standard would require annual medical exams to be provided for employees exposed in a regulated area for 30 days or more per year and for employees showing signs or symptoms of CBD, while tests for beryllium sensitization and CT scans would be provided to eligible employees biennially.

OSHA estimated in Chapter V of this PEA that the medical surveillance requirements would apply to 4,528 workers in general industry, of whom 387 already receive that surveillance.[471] In Chapter V, OSHA estimated the costs of medical surveillance for the remaining 4,141 workers who would now have such protection due to the proposed standard. The Agency's preliminary analysis indicates that 4 workers with beryllium sensitization and 6 workers with CBD will be referred to pulmonary specialists annually as a result of this medical surveillance. Medical surveillance is particularly important for this rule because beryllium-exposed workers, including many workers exposed below the proposed PELs, are at significant risk of illness. OSHA did not estimate, and the benefits analysis does not include, monetized benefits resulting from early discovery of illness.

Medical surveillance was a subject of special concern to SERs during the SBAR Panel process, and the SBAR Panel offered many comments and recommendations related to medical surveillance for OSHA's consideration. Some of the Panel's concerns have been partially addressed in this proposal, which was modified since the SBAR Panel was convened (see the preamble at Section XVIII, Summary and Explanation of the Proposed Standard, for more detailed discussion). The regulatory alternatives presented in this sub-section (#16, #18, and #20) also respond to recommendations by the SBAR Panel to reduce burdens on small businesses by dropping or reducing the frequency of medical surveillance requirements. OSHA has preliminarily determined that a significant

[471] See current compliance rates for medical surveillance in Chapter V of this PEA, Table V-15.

risk of beryllium sensitization, CBD, and lung cancer exists at exposure levels below the proposed TWA PEL and that there is evidence that beryllium sensitization can occur even from short-term exposures (see the preamble at Section V, Health Effects, and Section VIII, Significance of Risk). The Agency therefore anticipates that more employees would develop adverse health effects without receiving the benefits of early intervention in the disease process because they are not eligible for medical surveillance (see the preamble at Section V, Health Effects).

In response to concerns raised during the SBAR Panel process about testing requirements, OSHA is considering two regulatory alternatives that would provide greater flexibility in the program of tests provided as part of an employer's medical surveillance program. Under **Regulatory Alternative #16**, employers would not be required to offer employees testing for beryllium sensitization. As shown in Table IX-5, this alternative would decrease the annualized cost of the proposed rule by about $710,000 using a discount rate of 3 percent, and by about $724,000 using a discount rate of 7 percent.

Regulatory Alternative #18 would eliminate the CT scan requirement from the proposed rule. This alternative would decrease the annualized cost of the proposed rule by about $472,000 using a discount rate of 3 percent, and by about $481,000 using a discount rate of 7 percent.

OSHA is considering several alternatives to the proposed frequency of sensitization testing, CT scans, and general medical examinations. The frequency of periodic medical surveillance is an important factor in the efficacy of the surveillance in protecting worker health. Regular, appropriately frequent medical surveillance promotes awareness of beryllium-related health effects and early intervention in disease processes among workers. In addition, the longer the time interval between when a worker becomes sensitized and when the worker's case is identified in the surveillance program, the more difficult it will be to identify and address the exposure conditions that led to sensitization. Therefore, reducing the frequency of sensitization testing would reduce the usefulness of the surveillance information in identifying problem areas and reducing risks to other workers. These concerns must be weighed against the costs and other burdens of surveillance.

Finally, under **Regulatory Alternative #20**, employers would only have to provide all periodic components of the medical surveillance exams biennially to eligible employees. This alternative would decrease the annualized cost of the proposed rule by about $446,000 using a discount rate of 3 percent and by about $433,000 using a discount rate of 7 percent.

(d) Medical Removal

Under paragraph (l) of the proposed standard, Medical Removal, employees in jobs with exposure at or above the action level become eligible for medical removal when they are diagnosed with CBD or confirmed positive for beryllium sensitization. When an employee chooses removal, the employer is required to remove the employee to comparable work in an environment where beryllium exposure is below the action level if such work is available and the employee is either already qualified or can be trained within one month. If comparable work is not available, paragraph (l) would require the employer to place the employee on paid leave for six months or until comparable work becomes available (whichever comes first). Or, rather than choosing removal, an eligible employee could choose to remain in a job with exposure at or above the action level and wear a respirator. The proposed medical removal protection (MRP) requirements are based on the stakeholders' recommended stakeholders' recommended beryllium standard that representatives of the beryllium production industry and the United Steelworkers union submitted to OSHA in 2012 (Materion and United Steelworkers, 2012).

The scientific information on effects of exposure cessation is limited at this time, but the available evidence suggests that removal from exposure can be beneficial for individuals who are sensitized or have early-stage CBD (see the preamble at Section VIII, Significance of Risk). As CBD progresses, symptoms become serious and debilitating. Steroid treatment is less effective at later stages, once fibrosis has developed (see the preamble at Section VIII, Significance of Risk). Given the progressive nature of the disease, OSHA believes it is reasonable to conclude that removal from exposure to beryllium will benefit sensitized employees and those with CBD. Physicians at National Jewish Health, one of the main CBD research and treatment sites in the US, "consider it important and prudent for individuals with beryllium sensitization and CBD to minimize their exposure to airborne beryllium," and "recommend individuals diagnosed with beryllium sensitization and CBD who continue to work in a beryllium industry to have exposure of no more than 0.01 micrograms per cubic meter of beryllium as an 8-hour time-weighted average" (National Jewish Health, 2013). However, OSHA is aware that MRP may prove costly and burdensome for some employers and that the scientific literature on the effects of exposure cessation on the development of CBD among sensitized individuals and the progression from early-stage to late-stage CBD is limited.

The SBAR Panel report included a recommendation that OSHA give careful consideration to the impacts that an MRP requirement could have on small businesses (SBAR, 2008). In response to this recommendation, OSHA analyzed **Regulatory Alternative #22**, which would remove the proposed requirement that employers offer MRP. As shown in Table IX-5, this alternative would decrease the annualized cost of the proposed rule by about $149,000 using a discount rate of 3 percent, and by about $166,000 using a discount rate of 7 percent.

Table IX-5: Cost of Regulatory Alternatives Affecting Ancillary Provisions
(Proposed PEL=0.2, STEL=2.0, AL=0.1)

3% Discount Rate	Total Cost	Incremental Cost Relative to Proposal	Benefits	Incremental Benefits Relative to the Proposal
Proposed Rule	$37,597,325	——	$575,826,633	——
Alternative 7: Update Z table 1910.1000 only, (No ancillary provisions)	$9,789,873	-$27,807,451	$249,099,326	-$326,727,308
Alternative 8: Ancillary provisions apply only when exposure above PEL/STEL	$18,917,028	-$18,680,297		
Alternative 12: No regulated areas, ancillary provisions triggered by PEL or STEL	$37,075,072	-$522,252		
Alternative 16: No BeLPTs in medical surveillance	$36,887,307	-$710,018		
Alternative 18: No CT Scans	$37,124,958	-$472,367		
Alternative 20: All periodic components of medical surveillance are biannual	$37,150,975	-$446,349		
Alternative 22: No medical removal protection	$37,448,499	-$148,826		

Table IX-5: Cost of Regulatory Alternatives Affecting Ancillary Provisions , Continued
(Proposed PEL=0.2, STEL=2.0, AL=0.1)

7% Discount Rate	Total Cost	Incremental Cost Relative to Proposal	Benefits	Incremental Benefits Relative to the Proposal
Proposed Rule	$39,147,434	——	$255,334,295	——
Alternative 7: Update Z table 1910.1000 only, (No ancillary provisions)	$10,586,317	-$28,561,116	$110,383,499	-$144,950,796
Alternative 8: Ancillary provisions apply only when exposure above PEL/STEL	$19,986,867	-$19,160,567		
Alternative 12: No regulated areas, ancillary provisions triggered by PEL or STEL	$38,624,295	-$523,139		
Alternative 16: No BeLPTs in medical surveillance	$38,423,316	-$724,117		
Alternative 18: No CT Scans	$38,666,205	-$481,229		
Alternative 20: All periodic components of medical surveillance are biannual	$38,714,200	-$433,233		
Alternative 22: No medical removal protection	$38,981,379	-$166,054		

Source: OSHA, Directorate of Standards and Guidance, Office of Regulatory Analysis

(4) Timing

As proposed, the new standard would become effective 60 days following publication in the Federal Register. The majority of employer duties in the standard would become enforceable 90 days following the effective date. Change rooms, however, would not be required until one year after the effective date, and the deadline for engineering controls would be no later than two years after the effective date.

OSHA invites suggestions for alternative phase-in schedules for engineering controls, medical surveillance, and other provisions of the standard. Although OSHA did not explicitly develop or quantitatively analyze any other regulatory alternatives involving longer-term or more complex phase-ins of the standard (possibly involving more delayed implementation dates for small businesses), some general outcomes are likely. For example, a longer phase-in time would have several advantages, such as reducing initial costs of the standard or allowing employers to coordinate their environmental and occupational safety and health control strategies to minimize potential costs. However, a longer phase-in would also postpone and reduce the benefits of the standard. Suggestions for alternatives may apply to specific industries (e.g., industries where first-year or annualized cost impacts are highest), specific size-classes of employers (e.g., employers with fewer than 20 employees), combinations of these factors, or all firms covered by the rule.

OSHA requests comments on all these regulatory alternatives, including the Agency's regulatory alternatives presented above, the Agency's analysis of these alternatives, and whether there are other regulatory alternatives the Agency should consider.

SBAR Panel

Table IX-8 lists all of the SBAR Panel recommendations and OSHA's response to those recommendations.

Table IX-8: SBAR Panel Recommendations and OSHA Responses

Panel Recommendation	**OSHA Response**
The Panel recommends that OSHA evaluate carefully the costs and technological feasibility of engineering controls at all PEL options, especially those at the lowest levels.	OSHA has reviewed its cost estimates and the technological feasibility of engineering controls at various PEL levels. These issues are discussed in the Regulatory Alternatives Chapter.

Panel Recommendation	OSHA Response
The Panel recommends that OSHA consider alternatives that would alleviate the need for monitoring in operations with exposures far below the PEL. The Panel also recommends that OSHA consider explaining more clearly how employers may use “objective data” to estimate exposures. Although the draft proposal contains a provision allowing employers to initially estimate exposures using “objective data” (e.g., data showing that the action level is unlikely to be exceeded for the kinds of process or operations an employer has), the SERs did not appear to have fully understood how this alternative may be used.	OSHA has removed the initial exposure monitoring requirement for workers likely to be exposed to beryllium by skin or eye contact through routine handling of beryllium powders or dusts or contact with contaminated surfaces. The periodic monitoring requirement presented in the SBAR Panel report required monitoring every 6 months for airborne levels at or above the action level but below the PEL, and every 3 months for exposures at or above the PEL. The proposed standard requires annual exposure monitoring for levels at or above the action level and at or below the PEL. By reducing the frequency of periodic monitoring from every 6 months (version submitted to the SBAR panel) to annually where exposure levels are at or below the PEL (the proposed standard), the Agency has lessened the need for monitoring in small business operations with exposures at or below the PEL. In the preamble to the proposed standard, OSHA has clarified the circumstances under which an employer may use historical and objective data in lieu of initial monitoring.

Panel Recommendation	OSHA Response
	OSHA is also considering whether to create a guidance product on the use of objective data. These issues are discussed in the preamble at Section XVIII, Summary and Explanation of the Proposed Standard, (d): Exposure Monitoring.

Panel Recommendation	OSHA Response
The Panel recommends that OSHA consider providing some type of guidance to describe how to use objective data to estimate exposures in lieu of conducting personal sampling. Using objective data could provide significant regulatory relief to several industries where airborne exposures are currently reported by SERs to be well below even the lowest PEL option. In particular, since several ancillary provisions, which may have significant costs for small entities may be triggered by the PEL or an action level, OSHA should consider encouraging and simplifying the development of objective data from a variety of sources.	In the preamble to the proposed standard, OSHA has clarified the circumstances under which an employer may use historical and objective data in lieu of initial monitoring. OSHA is also considering whether to create a guidance product on the use of objective data to satisfy the requirements of the proposed rule. These issues are discussed in the preamble at Section XVIII, Summary and Explanation of the Proposed Standard, (d): Exposure Monitoring.

Panel Recommendation	OSHA Response
The Panel recommends that OSHA revisit its analysis of the costs of regulated areas if a very low PEL is proposed. Drop or limit the provision for regulated areas: SERs with very low exposure levels or only occasional work with beryllium questioned the need for separating areas of work by exposure level. Segregating machines or operations, SERs said, would affect productivity and flexibility. Until the health risks of beryllium are known in their industries, SERs challenged the need for regulated areas.	SERs with very low exposure levels or only occasional work with beryllium will not be required to have regulated areas unless exposures are above the proposed PEL of 0.2 $\mu g/m^3$. The proposed standard requires the employer to establish and maintain a regulated area wherever employees are, or can be expected to be exposed to airborne beryllium at levels above a PEL of 0.2 $\mu g/m^3$.

Panel Recommendation	OSHA Response

The Panel recommends that OSHA revisit its cost model for hygiene areas to reflect SERs' comments that estimated costs are too low and more carefully consider the opportunity costs of using space for hygiene areas where SERs report they have no unused space in their physical plant for them. The Panel also recommends that OSHA consider more clearly defining the triggers (skin exposure and contaminated surfaces) for the hygiene areas provisions. In addition, the Panel recommends that OSHA consider alternative requirements for hygiene areas dependent on airborne exposure levels or types of processes. Such alternatives might include, for example, hand washing facilities in lieu of showers in particular cases or different hygiene area triggers where exposure levels are very low.	The Agency has removed skin exposure as a trigger for the hygiene provision. The requirement for washing facilities applies to each employee working in a beryllium work area. A beryllium work area means any work area where employees are, or can reasonably be expected to be, exposed to airborne beryllium. OSHA has preliminarily concluded that all affected employers currently have hand-washing facilities. OSHA has also preliminarily concluded that no affected employers will be required to install showers. Change rooms have only been costed for regulated areas or where employees are, or can reasonably be expected to be, exposed to airborne beryllium at levels above the PEL. The Agency has determined that the long-term rental of modular units was representative of costs for a range of reasonable approaches to comply with the change room part of the provision. Alternatively, employers could renovate and rearrange their work areas in order to meet the requirements of this provision. OSHA requests comment on the cost estimates for these facilities.

Panel Recommendation	OSHA Response
The Panel recommends that OSHA consider clearly explaining the purpose of the housekeeping provision and describing what affected employers must do to achieve it. For example, OSHA should consider explaining more specifically what surfaces need to be cleaned and how frequently they need to be cleaned. The Panel recommends that the Agency consider providing guidance in some form so that employers understand what they must do. The Panel also recommends that once the requirements are clarified that the Agency re-analyze its cost estimates. The Panel also recommends that OSHA reconsider whether the risk and cost of all parts of the medical surveillance provisions are appropriate where exposure levels are very low. In that context, the Panel recommends that OSHA should also consider the special problems and costs to small	In the preamble to the proposed rule, OSHA has clarified the purpose of the housekeeping provision. However, due to the variety of work settings in which beryllium is used, OSHA has preliminarily concluded that a highly specific directive on what surfaces need to be cleaned, and how frequently, would not provide effective guidance to businesses. Instead, at the suggestion of industry and union stakeholders (Materion and USW, 2012), OSHA's proposed standard includes a more flexible requirement for employers to develop a written exposure control plan specific to their facilities. The written exposure control plan must include documentation of operations and jobs with beryllium exposure and housekeeping procedures, including surface cleaning and beryllium migration control. OSHA requests suggestions for examples of specific guidance that could be helpful to employers preparing written exposure control plans. These issues are discussed in the preamble at Section XVIII, Summary and Explanation of the Proposed Standard, (f) Methods of Compliance and (j) Housekeeping.

Panel Recommendation	OSHA Response
businesses that up until now may not have had to provide or manage the various parts of an occupational health standard or program.	Regulatory Alternative #20 would reduce the frequency of physical examinations from annual to biennial, matching the frequency of BeLPT testing in the proposed rule. These alternatives for medical surveillance are discussed in the Regulatory Alternatives Chapter and in the preamble at section XVIII, Summary and Explanation of the Proposed Standard, (k) Medical Surveillance.

Panel Recommendation	OSHA Response
The Panel recommends that OSHA consider that small entities may lack the flexibility and resources to provide alternative jobs to employees who test positive for the BeLPT, and whether MRP achieves its intended purpose given the course of beryllium disease. The Panel also recommends that if MRP is implemented, that its effects on the viability of very small firms with a sensitized employee be considered carefully.	Under the proposed standard, employees are only eligible for medical removal if they are sensitized or have been diagnosed with CBD; skin exposure is not a trigger for medical removal (unlike the version submitted by the SBAR Panel). After becoming eligible for medical removal an employee may choose to remain in a job with exposure at or above the action level, provided that the employee wears a respirator in accordance with the Respiratory Protection standard (29 CFR 1910.134). If the employee chooses removal, the employer is only required to place the employee in comparable work with exposure below the action level if such work is available; if such work is not available, the employer may place the employee on paid leave for six months or until such work becomes available. OSHA discusses the basis of the provision and requests comments on it in the preamble at Section XVIII, Summary and Explanation of the Proposed Standard, (l) Medical Removal Protection. OSHA provides an analysis of costs and economic impacts of the provision in this PEA in Chapter 5 and Chapter 6, respectively.

Panel Recommendation	OSHA Response
The Panel recommends that OSHA consider more clearly defining the trigger mechanisms for medical surveillance and also consider additional or alternative triggers--such as limiting the BeLPT to a narrower range of exposure scenarios and reducing the frequency of BeLPT tests and physical exams. The Panel also recommends that OSHA reconsider whether the risk and cost of all parts of the medical surveillance provisions are appropriate where exposure levels are very low. In that context, the Panel recommends that OSHA should also consider the special problems and costs to small businesses that up until now may not have had to provide or manage the various parts of an occupational health standard or program.	As stated above, the triggers for medical surveillance in the proposed standard have changed from those presented to the SBAR Panel. Whereas the draft standard presented at the SBAR Panel required medical surveillance for employees with skin contact--potentially applying to employees with any level of airborne exposure -- the proposed standard ties medical surveillance to exposures above the proposed PEL of 0.2 $\mu g/m^3$ (or signs or symptoms of beryllium-related health effects, or emergency exposure). Thus, small businesses with exposures below the proposed PEL would not need to provide or manage medical surveillance for their employees unless employees develop signs or symptoms of beryllium-related health effects or are exposed in emergencies. These issues are discussed in the preamble at section XVIII, Summary and Explanation of the Proposed Standard, (k) Medical Surveillance.

Panel Recommendation	OSHA Response
The Panel recommends that the Agency, in evaluating the economic feasibility of a potential regulation, consider not only the impacts of estimated costs on affected establishments, but also the effects of the possible outcomes cited by SERs: loss of market demand, the loss of market to foreign competitors, and of U.S. production being moved abroad by U.S. firms. The Panel also recommends that OSHA consider the potential burdens on small businesses of dealing with employees who have a positive test from the BeLPT. OSHA may wish to address this issue by examining the experience of small businesses that currently provide the BeLPT test.	OSHA has reviewed the possible effects of the proposed regulation on market demand and/or foreign production, in addition to the Agency's usual measures of economic impact (costs as a fraction of revenues and profits). This discussion can be found in Chapter VI of the PEA (entitled Economic Feasibility Analysis and Regulatory Flexibility Determination).

Panel Recommendation	OSHA Response
The Panel recommends that OSHA consider seeking ways of minimizing costs for small businesses where the exposure levels may be very low. Clarifying the use of objective data, in particular, may allow industries and establishments with very low exposures to reduce their costs and involvement with many provisions of a standard. The Panel also recommends that the Agency consider tiering the application of ancillary provisions of the standard according to exposure levels and consider a more limited or narrowed scope of industries.	The provisions in the standard presented in the SBAR panel report applied to all employees, whereas the proposed standard's ancillary provisions are only applied to employees in work areas who are, or can reasonably be expected to be, exposed to airborne beryllium. In addition, the scope of the proposed standard includes several limitations. Whereas the standard presented in the SBAR panel report covered beryllium in all forms and compounds in general industry, construction, and maritime, the scope of the proposed standard (1) applies only to general industry; (2) does not apply to beryllium-containing articles that the employer does not process; and (3) does not apply to materials that contain less than 0.1% beryllium by weight. In the preamble to the proposed standard, OSHA has clarified the circumstances under which an employer may use historical and objective data in lieu of initial monitoring

Panel Recommendation	OSHA Response
	(Section XVIII, Summary and Explanation of the Proposed Standard, (d) Exposure Monitoring). OSHA is also considering whether to create a guidance product on the use of objective data to comply with the requirements of the proposed standard. OSHA is considering two Regulatory Alternatives that would reduce the impact of ancillary alternatives on employers, including small businesses. Regulatory Alternative #7, a PEL-only standard, would drop all ancillary provisions from the standard. Regulatory Alternative #8 would limit the application of several ancillary provisions, including Exposure Monitoring, the written exposure control plan section of Method of Compliance, PPE, Housekeeping, and Medical Surveillance, to operations or employees with exposure levels exceeding the TWA PEL or STEL. These alternatives are discussed in the Regulatory Alternatives Chapter and in the preamble to the proposed standard at Section I, Issues and Alternatives.

Panel Recommendation	**OSHA Response**
The Panel recommends that OSHA provide an explanation and analysis for all health outcomes (and their scientific basis) upon which it is regulating employee exposure to beryllium. The Panel also recommends that OSHA consider to what extent a very low PEL (and lower action level) may result in increased costs of ancillary provisions to small entities (without affecting airborne employee exposures). Since in the draft proposal the PEL and action level are critical triggers, the Panel recommends that OSHA consider alternate action levels, including an action level set at the PEL, if a very low PEL is proposed.	The explanation and analysis for all health outcomes (and their scientific basis) are discussed in the preamble to the proposed standard at Section V, Health Effects, and Section VI, Preliminary Risk Assessment. They are also reviewed in the preamble to the proposed standard at Section VIII, Significance of Risk, and the Benefits Chapter of this PEA. OSHA requests comment on these health outcomes. As discussed above, OSHA is considering Regulatory Alternatives #7 and #8, which would eliminate or reduce the impact of ancillary provisions on employers, respectively. These alternatives are discussed in the Regulatory Alternatives Chapter of this PEA and in the preamble to the proposed standard at Section I, Issues and Alternatives. OSHA seeks comment on other ways to avoid costs of ancillary provisions when they are not necessary to protect employees from exposure to beryllium.

Panel Recommendation	OSHA Response
The Panel recommends that OSHA consider more clearly and thoroughly defining the triggers for ancillary provisions, particularly the skin exposure trigger. In addition, the Panel recommends that OSHA clearly explain the basis and need for small entities to comply with ancillary provisions. The Panel also recommends that OSHA consider narrowing the trigger related to skin and contamination to capture only those situations where surfaces and surface dust may contain beryllium in a concentration that is significant enough to pose any risk—or limiting the application of the trigger for some ancillary provisions.	OSHA has removed skin exposure as a trigger for several ancillary provisions in the proposed standard, including Exposure Monitoring, Hygiene Areas and Practices, and Medical Surveillance. In addition, the language of the proposed standard regarding skin exposure has changed: for some ancillary provisions, including PPE and Housekeeping, the requirements are triggered by visible contamination with beryllium or dermal contact with soluble beryllium compounds. These requirements are discussed in the preamble at Section XVIII, Summary and Explanation of the Proposed Standard. The Agency has also explained the basis and need for compliance with ancillary provisions in the preamble at Section XVIII, Summary and Explanation of the Proposed Standard.

Panel Recommendation	OSHA Response
Several SERs said that OSHA should first assume the burden of describing the exposure level in each industry rather than employers doing so. Others said that the Agency should accept exposure determinations made on an industry-wide basis, especially where exposures were far below the PEL options under consideration. As noted above, the Panel recommends that OSHA consider alternatives that would alleviate the need for monitoring in operations or processes with exposures far below the PEL. The use of objective data is a principal method for industries with low exposures to satisfy compliance with a proposed standard. The Panel recommends that OSHA consider providing some guidance to small entities in the use of objective data.	In the Technological Feasibility Analysis presented in this PEA, OSHA has described the exposure level in each industry or application group. In the preamble to the proposed standard, OSHA has clarified the circumstances under which an employer may use historical and objective data in lieu of initial monitoring (section XVIII, Summary and Explanation of the Proposed Standard, (d) Exposure Monitoring). Industry-wide data may be used as objective data to support an employer's case that exposures at its facilities are far below the PEL. OSHA is also considering whether to create a guidance product on the use of objective data to comply with requirements in the proposed standard.

Panel Recommendation	OSHA Response
The Panel recommends that OSHA consider more fully evaluating whether the BeLPT is suitable as a test for beryllium sensitization in an OSHA standard and respond to the points raised by the SERs about its efficacy. In addition, the Agency should consider the availability of other tests under development for detecting beryllium sensitization and not limit either employers' choices or new science and technology in this area. Finally, the Panel recommends that OSHA re-consider the trigger for medical surveillance where exposures are low and consider if there are appropriate alternatives.	OSHA has provided discussion of the BeLPT in Appendix A to the regulatory text; in the preamble to the proposed rule at section V, Health Effects; and in the preamble at section XVIII, Summary and Explanation of the Proposed Standard, (k) Medical Surveillance. In the regulatory text, OSHA has clarified that a test for beryllium sensitization other than the BeLPT may be used in lieu of the BeLPT if a more reliable and accurate diagnostic test is developed. In the preamble at Section I, Issues and Alternatives, the Agency requests comments on the BeLPT and on the reliability and accuracy of alternate tests. As stated above, the triggers for medical surveillance in the proposed standard have changed from those presented to the SBAR Panel. Whereas the draft standard presented during the SBREFA process required medical surveillance for employees with skin contact--potentially applying to employees with any level of airborne exposure--

Panel Recommendation	OSHA Response
	the proposed standard ties medical surveillance to exposures above the proposed PEL of 0.2 μg/m^3 (or signs or symptoms of beryllium-related health effects, or emergency exposure). The triggers for medical surveillance are discussed in the preamble at section XVIII, Summary and Explanation of the Proposed Standard, (k) Medical Surveillance. OSHA is considering Regulatory Alternative #16, which would eliminate BeLPT testing requirements from the proposed standard. This alternative is discussed in the Regulatory Alternatives Chapter and in in the preamble at Section XVIII, Summary and Explanation of the Proposed Standard, (k) Medical Surveillance.

Panel Recommendation	**OSHA Response**
Seeking ways of minimizing costs to low risk processes and operations: OSHA should consider alternatives for minimizing costs to industries, operations, or processes that have low exposures. Such alternatives may include, but not be limited to: encouraging the use of objective data by such mechanisms as providing guidance for objective data; assuring that triggers for skin exposure and surface contamination are clear and do not pull in low risk operations; providing guidance on least-cost ways for low risk facilities to determine what provisions of the standard they need to comply with; and considering ways to limit the scope of the standard if it can be ascertained that certain processes do not represent a significant risk.	The standard presented in the SBAR panel report had skin exposure as a trigger. The only skin exposure trigger in the proposed standard is the requirement for PPE when employees' skin is potentially exposed to soluble beryllium compounds. OSHA uses an exposure profile to determine which workers will be affected by the standard. As a result, the proposed standard establishes regulated work areas and exposure monitoring only with respect to employees who are, or can reasonably be expected to be, exposed to airborne beryllium. In addition, the scope of the proposed standard includes several limitations. Whereas the standard presented in the SBAR panel report covered beryllium in all forms and compounds in general industry, construction, and maritime, the scope of the proposed standard (1) applies only to general industry; (2) does not apply to beryllium-containing articles that the employer does not process; and (3) does not apply to materials that contain less than 0.1% beryllium by weight. In the preamble to the proposed standard,

Panel Recommendation	OSHA Response
	OSHA has clarified the circumstances under which an employer may use historical and objective data in lieu of initial monitoring (Section XVIII, Summary and Explanation of the Proposed Standard, (d) Exposure Monitoring). OSHA is also considering whether to create a guidance product on the use of objective data.

Panel Recommendation	OSHA Response
PEL-only standard: One SER recommended a PEL-only standard. This would protect employees from airborne exposure risks while relieving the beryllium industry of the cost of the ancillary provisions. The Panel recommends that OSHA, consistent with its statutory obligations, analyze this alternative.	OSHA is considering Regulatory Alternative #7, a PEL-only standard. This alternative is discussed in the Regulatory Alternatives Chapter and in the preamble to the proposed standard at Section I, Issues and Alternatives.

Panel Recommendation	OSHA Response
Alternative triggers for ancillary provisions: The Panel recommends that OSHA clarify and consider eliminating or narrowing the triggers for ancillary provisions associated with skin exposure or contamination. In addition, the Panel recommends that OSHA should consider trying ancillary provisions dependent on exposure rather than have these provisions all take effect with the same trigger. If OSHA does rely on a trigger related to skin exposure, OSHA should thoroughly explain and justify this approach based on an analysis of the scientific or research literature that shows a risk of sensitization via exposure to skin. If OSHA adopts a relatively low PEL, OSHA should consider the effects of alternative airborne action levels in pulling in many low risk facilities that may be unlikely to exceed the PEL--and consider using only the PEL as a trigger at very low levels.	OSHA has removed skin exposure as a trigger for several ancillary provisions in the proposed standard, including Exposure Monitoring, Hygiene Areas and Practices, and Medical Surveillance. In addition, the language of the proposed standard regarding skin exposure has changed: for some ancillary provisions, including PPE and Housekeeping, the requirements are triggered by visible contamination with beryllium or skin contact with soluble beryllium compounds. These requirements are discussed in the preamble at Section XVIII, Summary and Explanation of the Proposed Standard. OSHA has explained the scientific basis for minimizing skin exposure to beryllium in the preamble to the proposed rule at Section V, Health Effects, and explains the basis for specific ancillary provisions related to skin exposure in the preamble at Section XVIII, Summary and Explanation of the Proposed Standard.

Panel Recommendation	OSHA Response
	In the proposed standard, the application of ancillary provisions is dependent on exposure, and not all provisions take effect with the same trigger. A number of requirements are triggered by exposures (or a reasonable expectation of exposures) above the PEL or action level (AL). As discussed above, OSHA is considering Regulatory Alternatives #7 and #8, which would eliminate or reduce the impact of ancillary provisions on employers, respectively. These alternatives are discussed in the Regulatory Alternatives Chapter of this PEA and in the preamble to the proposed standard at Section I, Issues and Alternatives.

Panel Recommendation	OSHA Response
Revise the medical surveillance provisions, including eliminating the BeLPT: The BeLPT was the most common complaint from SERs. The Panel recommends that OSHA carefully examine the value of the BeLPT and consider whether it should be a requirement of a medical surveillance program. The Panel recommends that OSHA present the scientific evidence that supports the use of the BeLPT as several SERs were doubtful of its reliability. The Panel recommends that OSHA also consider reducing the frequency of physicals and the BeLPT, if these provisions are included in a proposal. The Panel recommends that OSHA also consider a performance-based medical surveillance program, permitting employers in consultation with physicians and health experts to develop appropriate tests and their frequency.	Responding to comments from SERs, OSHA has revised the medical surveillance provision and removed the skin exposure trigger for medical surveillance. As a result, OSHA estimates that the number of small-business employees requiring a BELPT will be substantially reduced. OSHA has provided discussion of the BeLPT in Appendix A to the regulatory text; in the preamble to the proposed rule at section V, Health Effects; and in the preamble at section XVIII, Summary and Explanation of the Proposed Standard, (k) Medical Surveillance. In the regulatory text, OSHA has clarified that a test for beryllium sensitization other than the BeLPT may be used in lieu of the BeLPT if a more reliable and accurate diagnostic test is developed. In the preamble at Section I, Issues and Alternatives, the Agency requests comments on the BeLPT and on the reliability and accuracy of alternate tests.

Panel Recommendation	OSHA Response
	The frequency of periodic BeLPT testing in the proposed standard is biennial, whereas annual testing was included in the draft standard presented to the SBAR Panel. Regulatory Alternative #20 would reduce the frequency of physical examinations from annual to biennial, matching the frequency of BeLPT testing in the proposed rule. In response to the suggestion to allow performance-based medical surveillance, OSHA is considering two regulatory alternatives that would provide greater flexibility in the program of tests provided as part of an employer's medical surveillance program. Regulatory Alternative #16 would eliminate BeLPT testing requirements from the proposed standard. Regulatory Alternative #18 would eliminate the CT scan requirement from the proposed standard. These alternatives are discussed in the Regulatory Alternatives Chapter and in the preamble at Section XVIII, Summary and Explanation of the Proposed Standard, (k) Medical Surveillance.

Panel Recommendation	OSHA Response
No medical removal protection (MRP): OSHA's draft proposed standard did not include any provision for medical removal protection, but OSHA did ask the SERs to comment on MRP as a possibility. Based on the SER comments, the Panel recommends that if OSHA includes an MRP provision, the agency provide a thorough analysis of why such a provision is needed, what it might accomplish, and what its full costs and economic impacts on those small businesses that need to use it might be.	The proposed standard includes an MRP provision. OSHA discusses the basis of the provision and requests comments on it in the preamble at Section XVIII, Summary and Explanation of the Proposed Standard, (l) Medical Removal Protection. OSHA provides an analysis of costs and economic impacts of the provision in this PEA in Chapter V and Chapter VI, respectively. The Agency is considering Alternative #22, which would eliminate the MRP requirement from the standard. This alternative is discussed in the Regulatory Alternatives Chapter and in in the preamble at section XVIII, Summary and Explanation of the Proposed Standard, (l) Medical Removal Protection.

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