SECTION 5

ALUMINUM AND COPPER FOUNDRIES

5.1 PROFILE

Nonferrous foundries produce a variety of cast products using alloyed and unalloyed copper, aluminum and other metals. These foundries may produce castings of beryllium copper and, to a lesser extent, beryllium aluminum. Foundries who might use beryllium alloys are classified in the following industries as defined by 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])

Industry representatives suggest, however, that because of its metallurgical properties beryllium copper is not likely to be die-cast (Mallory, 2001). Table 5-1 shows Census data describing the copper and aluminum foundry industries. A limited amount of pure beryllium is cast for specialized aerospace applications; however, beryllium is usually alloyed with another metal. According to a U.S. Department of Energy publication, beryllium is alloyed with copper, aluminum, nickel, zinc, and zirconium (DOE, 2002). Beryllium-copper, beryllium-aluminum, and beryllium-nickel are cast in the United States. Typically, cast beryllium alloy contains 5 percent or less of beryllium. ERG found no information about casting of beryllium-zinc or beryllium-zirconium alloys in the United States. ERG found little information about the types of products produced by casting beryllium alloys. It is known, however, that beryllium-copper is cast to produce resistance welding electrodes and other parts of the welding electrode assembly such as holders and shanks; parts for the aerospace industry; and other specialized applications.

ERG found limited information about the number of foundries casting beryllium and beryllium alloys. Representatives of neither the American Foundry Society nor the Non-Ferrous Founders' Society could provide an estimate of the number of foundries casting these metals. However, both believe the number is small (Robinson, 2002; NFFS, 2002). Other industry sources contacted representing companies that use beryllium alloys, including a copper and 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 estimate the number (Barbetti, 2002; Capozzi, 2002; Erickson, 2002; Specialloy, 2002).

Table 5-1. Copper and Aluminum Foundries, 2002

NAICS	No. of Firms	No. of Facilities	Total Employees	Production Workers	Facilities with <20 Employees	Facilities with 20 - 99 Employees	Facilities with >99 Employees
NAICS 331525, Copper foundries (except die-casting)	280	281	7,062	5,831	175 (62%)	92 (33%)	14 (5%)
NAICS 331524, Aluminum foundries (except die-casting)	508	542	29,108	23,623	310 (57%)	156 (29%)	76 (14%)
NAICS 331521, Aluminum die-casting foundries	255	295	28,264	23,551	109 (37%)	102 (35%)	84 (28%)
NAICS 3311522, Nonferrous (except aluminum) die-casting foundries	218	238	14,839	11,875	110 (46%)	84 (35%)	44 (19%)

Source: U.S. Census Bureau, 2004.

Information from OSHA's Integrated Management Information System indicated that beryllium was detected in 20, or 18.7 percent, of the 107 copper foundries where samples were taken during the period 1979 through 2001 (OSHA, 2003). An extrapolation of this percentage to the population of copper foundries (281) suggests that about 52 such foundries work with beryllium-copper alloys. Industry contacts suggest that the number of foundries casting beryllium alloys has declined in recent years. Of seven foundries contacted that indicated they have used beryllium copper, two (28.6 percent) have stopped using the material in recent years

(Dollard, 2002; Enviro, 2001; Johnson, 2002; Specialloy, 2002; Taylor, 2001; Tricast, 2001; Worldcast, 2001).

Table 5-2 shows Census data describing the number of copper foundries with shipments in categories that would include beryllium-cooper, specifically high-copper alloys. The table shows that 25 firms produced copper and high-copper sand castings, and 25 firms also produced investment castings out of high-copper alloy alloys. 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. The number of foundries using high-copper alloys is, therefore, less than the aggregate shown on the table (89). Assuming the number of unique foundries represented in Table 5-2 is one-half the aggregate, 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 recent decline in beryllium-copper use in the foundry industry.

Table 5-2. Number of Firms Producing High-Copper Alloy Castings, 1997

All Copper Foundries	281
3312504 Tin bronze, copper and high-copper alloy sand castings	
331250416 Copper and high-copper sand castings (except bearings and bushings)	25
3312505 Other copper and copper-base alloy castings	
331250531 Permanent and semipermanent mold castings	12
331250536 Centrifugal casings	13
331250541 Investments castings	25
331250546 Other castings	10
33152506 Copper-base alloy bearings and bushings, nonmachined*	4

Source: U.S. Census Bureau, 2—4: Number of firms with $100,000 or more in shipments.
* Includes high-copper as well as other types of copper alloys

ERG found little information to estimate the number of foundries in the United States that cast beryllium-aluminum alloys. The use of these alloys is thought to be much less common than the use of beryllium copper. Further, the representative of an aluminum foundry that uses beryllium-aluminum master alloys indicated that he believes the trend is away from the use of beryllium alloys in aluminum foundries (Barbetti, 2002).

As presented in Table 5-3, an estimated 14 foundry companies cast beryllium-aluminum alloys. Of these foundries, at least 12 are estimated to use beryllium-aluminum 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 (DOD, 2002; Peregrine, 2002). For purposes of this analysis, ERG divided these establishments between the two aluminum foundry industries

Table 5-3 summarizes these estimates of the numbers of beryllium alloy foundries. Employee estimates are based on the average employments sizes for the respective industries. ERG, thus, estimates a total of 97 foundry establishments with 4,547 employees, of which 3,694 are employed in production occupations.

Table 5-3. Foundries Casting Beryllium and Beryllium Alloys

Industry	Establishments	Total Employees	Production Employees
NAICS 331521, Aluminum die-casting foundries	7	671	559
NAICS 3311522, Nonferrous (except aluminum) die-casting foundries	38	2,369	1,896
NAICS 331524, Aluminum foundries (except die-casting)	7	376	305
NAICS 331525, Copper foundries (except die-casting)	45	1,131	934
Total	97	4,547	3,694

Source: ERG estimates; see text.

ERG also used information from the 2002 Economic Census to estimate the numbers of beryllium-alloy foundries that perform sand casting. Based on Census data, ERG estimated that 25 copper foundries in NAICS 331525 might perform sand casting of copper-beryllium alloys (US Census Bureau, 2004). The remaining establishments in this industry are assumed to perform other types of casting operations (e.g., permanent mold, investment, or lost wax casting).

5.1.1 Affected Job Categories

The metal casting industry is extremely diverse, employing many different casting processes for a wide variety of applications. The following sections address, by job category, foundry processes typically associated with worker exposure to beryllium, worker exposure levels, baseline working conditions, additional controls available, and preliminary conclusions regarding the extent of exposure reduction possible.

The production of castings using beryllium alloys includes the following basic processes: 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, 1985). The primary job categories with potential for beryllium exposure in foundries are as follows:

- Molder (including sand mold-maker and permanent mold maintenance)[see note below]
- Material handler
- Furnace operator (also melt operator)
- Pouring operator
- Shakeout operator (only in foundries using sand molds or cores)
- Abrasive blasting (shotblast) operator
- Finishing/grinding operator
- Maintenance operator (including furnace and ladle maintenance)
- Housekeeping worker

Note: In this analysis, the term *sand* is used generically to refer to any granular media used in “green sand casting” or other sand-casting process. As an alternative to silica, sand may consist of zircon, olivine, granular ceramic media, or other materials.

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, furnace operator) whereas 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, 1978).

In addition to the categories listed above, other operations may occur in foundries, including the following: pattern making, core making, welding, arc-air gouging, X-ray inspection of castings, and buffing. Welding (and air-arc gouging) is the subject of a specific section of this analysis and is not further addressed here. ERG assumes that the other operations are not associated with significant direct beryllium exposure and therefore they are not discussed in detail in this report. Table 5-4 presents a summary of the major activities of foundry workers potentially exposed to beryllium foundries.

Table 5-4. 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)	In foundries with re-usable molds, maintains molds, removes metal deposits, cleans molds. In sand casting foundries, monitors sand systems and molding machine operation. May apply mold parting/coating/release compound.
Material Handler (forlklift operator, crane operator)	May operate 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).
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 depends on the degree of automation.

Table 5-4. Job Categories and Major Activities of Workers Potentially Exposed to Beryllium in Foundries

Job Category	Major Activities
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, Sanding Operator)	Uses portable or bench tools such as chippers, grinders, and polishers to remove defects and adhered molding material from castings.
Maintenance Operator	Repairs and maintains foundry and furnace equipment. May perform repair and maintenance of refractory lining on furnace, ladle, and tundish. Activities may include dry sweeping, vacuuming, shoveling. Chips metal splatter from floors and equipment.
Housekeeping Worker	Activities may include dry sweeping, vacuuming, shoveling, and wiping. Chips metal splatter from floors and equipment.

To derive estimates of the detailed distribution by occupation, ERG used the 2002 Occupational Employment Survey to estimate the percentages of foundry employees in each of these job classifications (BLS, 2003). The percentages were then 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 numbers of employees by job category in the affected establishments. These estimates are shown in Table 5-4.

5.2 PROCESS DESCRIPTIONS

Molder: 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, sweeping, scraping, minor grinding, and applying mold release agents). If the previous casting left beryllium residue (usually in the form of oxides) on the molds, molders may be exposed to beryllium as they remove this material. When molds will be reused immediately, workers perform these tasks in the pouring area (in foundries with a small workforce, molder tasks may be performed by the pouring operator). Molds can also be transported to other areas for maintenance.

Table 5-5. Distribution of Beryllium Alloy Foundry Employment by Affected Job Category

Job Category	Percentage of Employment	Number of Employees
Molder	13.8%	627
Material handler	2.1%	95
Furnace operator	2.6%	118
Pouring operator	4.2%	191
Shakeout operator	1.5%	68
Abrasive blasting operator	2.4%	109
Grinding/sawyer	7.2%	327
Maintenance operator	2.2%	100
Housekeeping workers	3.3%	150
Total – affected job categories	39.4%	1,787
Other, non-affected occupations	60.6%	2,760
Total	100.0%	4,547

Sources: BLS, 2003; US Census Bureau, 2004; ERG estimates. See text.

In facilities that use non-permanent molds (e.g., sand casting foundries), molders typically prepare molds by shaping granular media (sand or similar substances) media 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 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.

These sand molders usually work in an area of the foundry that is functionally separate from other foundry activities; however, air monitoring of lead and cadmium in copper and bronze sand casting foundries indicates that molders can experience secondary metal fume 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 system indicate that molders can also be exposed to beryllium (OSHA, 2003).

Note: ERG finds that the available information (with results exclusively from OSHA's IMIS) is inadequate to differentiate workers handling reusable molds and those working with expendable or sand molds. This is an area where additional process and exposure information would help determine whether workers performing these tasks should be divided into two separate job categories.

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 that can be disturbed by the transport equipment they operate (such as forklifts), dust released directly from loads being transported by the material handler (e.g., fuming ladles, open barrels of excess metal trimmed from casting), and beryllium fume and dust that cause cross contamination in areas frequented by material handlers. Forklift operators who charge furnaces and move dross/scrap receptacles can experience beryllium dust exposure from these sources. Forklift and crane operators who move new castings may encounter beryllium oxide dust from these items or be exposed to fume as they pass near active melting and pouring operations. As has been shown in other studies, forklift drivers' exposure often related to areas they enter where other workers' activities generate elevated airborne concentrations of contaminant (ERG, 2003a).

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., bubble gas through molten metal to promote mixing), skim dross (use a scoop/wand to remove oxides and other contaminants that form a scum at the surface of the molten metal). The tasks associated with managing dross are reportedly among the activities that generate the highest beryllium exposure levels in foundries (Corbett, 2004).

Furnace operators spend the majority of their time melting metal. The more automated this process, the less physically involved the operator will be with the furnace. 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 must be performed for each melt. Furnace charges (raw materials in the form of ingot or foundry returns) must be prepared (weighed) to create the desired mix, pre-heated, 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, pre heating 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 in the furnace the operator initiates the melting process, which 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. The 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 (a “scum” on top of the molten metal). 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. As was previously noted, beryllium has an affinity for oxygen and oxides that form on the surface of metal can have a higher beryllium content than the base metal. 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. Furnace operators experience beryllium exposure when they reach into 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. Additional exposure may occur when the operator handles 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 gas-generating substance on a wand or using an automated process, collecting samples for analysis (again reaching into the furnace), and cleaning the melt deck. Operators also visually check the melt frequently to determine whether other actions are required. Eventually the metal is properly formulated, melted, drossed, and sparged – at this point the furnace operator adjusts the furnace for tapping, that is 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 (gravity-feeds molds) or a 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, same individual will often perform a number of jobs, for example furnace operators can control both the furnace and the pouring operations (ERG, 2003b). These jobs are separate in larger foundries, therefore exposures and controls relating to pouring activities are addressed under the Pouring Operator job category. Additionally, some furnace operators also maintain furnace refractory linings, which can be 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 job category of Maintenance Workers (furnace maintenance).

Furnace operators frequently receive help from designated furnace operation assistants and employees who normally work in other job categories, but are appointed as helpers during the melt process (ERG, 2003b). During their time in working in the furnace area ERG has considered these assistants and helpers to be performing work associated with the furnace operator job category.

Pouring Operator: Pouring operators supervise the transfer of molten metal from furnace (and any intermediary ladles) into molds. Depending on the type of casting performed by the foundry, these workers oversee a wider range of common or molding equipment. Examples include sand molds, permanent molds such as dies, vacuum molding equipment (sucks molten metal into mold), centrifugal (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 (AFS, 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, 2003b).

Beryllium fumes can enter pouring operators' breathing zones as the fume rises off molten metal in open ladles, tundishs, and molds. 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 sate, they produce more metallic fume. Since the main reservoir for the molten metal is the ladle(s), the majority of emissions from these pouring operations emanates from that source than the mold itself. Once copper-based alloys have solidified, the emission of air contaminants drops to a very low level."

Fume escaping into the work area contribute to background exposure levels in the pouring area and any other areas where air currents transport the fume. 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 the Maintenance Operator job category). Adjacent operations can also influence employee exposure in the pouring area. For practical reasons, the pouring area is nearly always located adjacent to the furnace area, with minimal barriers between the two spaces. Beryllium fume and dust released from the furnace area can be a substantial source of exposure for pouring operators. As an example, in Case History Foundry A, CCMA (2000) describes a foundry in which make-up air was introduced behind the furnaces. "The induced air supply swept any fugitive fume emissions from the melting and ladle filling operations and moved them toward shakeout, pouring, and molding, in that order…. The pouring lines were also stagnant to a large extent, because the fans doing the general ventilation were high overhead with no potential for creating air movement near the factory floor."

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) feed 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). Shakeout operators may observe automated equipment or might perform manual operations, primarily loading and unloading the vibrating equipment. Additionally, depending on the size of the cast metal, a material handler (e.g., crane operator) may work in the shakeout area, hoisting the flask and then dumping it on a vibrating table. During this operation, a second operator may be responsible for rehooking the cast metal piece onto the crane for transfer to the finishing area

(NIOSH, 1978). Shakeouts vary from a method of manually turning over the mold to systems that are fully automated (AFS, 1985).

A 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 any of the five mold conveyor lines. Three workers operated the shakeout, two to dump the molds from the pouring conveyor and simultaneously to retrieve the bottom board, and the other worker to hook the casting off the conveyor (NIOSH, 1978). Workers may also use sledgehammers and compressed air to move excess sand from castings (NIOSH HETA 92-0090-2296, 1993). These high-energy processes release substantial dust. If the molding materials are contaminated with beryllium, beryllium dust might be released (Corbett, 2004).

Shakeout operator's duties frequently overlap with those of pouring operators and material handlers. For some casting methods (e.g., extruded casting processes), the shakeout operator job category may be completely eliminated.

Abrasive blasting operator: Abrasive blasting operators clean casting to remove residual molding material (sand, investment) and surface oxides, and to prepare the metal surface for additional treatment (e.g., painting). To blast the casting, theses workers use abrasive media, usually steel shot or steel grit. Abrasive blasting operators typically operate automated blasting machines (e.g., Wheelabrator) or related equipment such as tumbling media mills that perform a similar function in cleaning castings. Large castings are abrasively blasted in booths, although castings too large to fit in a booth are typically blasted in an open area. Both surface oxide and metal alloy dust can be released (chipped) from surface of casting during surface preparation, which is typically performed using steel grit or steel shot as the abrasive blasting media. Some abrasives can themselves be a source of additional beryllium exposure (due to beryllium content of abrasive media) (see Section 11 – Abrasive Blasting).

Grinding/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 can use saws to removes 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, 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 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 (ERG, 2003b).

Maintenance Operators: Maintenance operators repair equipment throughout the facility. From the perspective of beryllium exposure, important maintenance functions of this job category are the maintenance of refractory linings on furnaces, ladles, and tundishes, and changing ventilation system bags or filters.

Maintenance operators encounter beryllium when they chip and scrape refractory ceramic linings that have been in contact with beryllium alloys. 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). As noted previously, oxides of beryllium can contain an 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 original beryllium alloy held in that receptacle. Because refractory ceramic linings are fragile (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 use manual (hammer and chisel, or scraping tools) or power equipment (pneumatic chipping tools) to chip away damaged/cracked refractory lining prior to patching (Refractory Services Provider A, 2003b; ERG, 2003a). In some foundries, furnace operators and pouring operators also perform this task. At the ERG Site Visit 7 foundry, tundish maintenance was performed immediately after the metal was poured, while the metal on the tundish was still hot. Debris were removed from one or more square feet of surface area and placed in a ventilated receiving container. The furnace operator than patched and painted the tundish with a coating similar to mold-release agent. Throughout the entire process, the operator moved in and out of the area of influence of the pouring area exhaust ventilation (Corbett, 2005a; Corbett, 2005b).

Housekeeping workers: Sources of exposure during housekeeping include beryllium-containing dust disturbed during housekeeping (handling contaminated equipment, dry sweeping, dry wiping, moving dusty items, and chipping splattered metal).

5.3 EXPOSURE PROFILE

Sources of exposure information: For aluminum and copper foundries, ERG examined the affected job categories, including mold maker, material handler, furnace operator, pouring operator, shakeout operator, abrasive blasting operator, grinding/finishing operator, maintenance operator and housekeeping worker.

Limited information is available regarding worker exposure to beryllium in copper and aluminum foundries. The available sources of exposure information include:

- Reports containing individual exposure results
- Information from analogous industries (from various sources summarized in the relevant section of this analysis)
- OSHA's Integrated Management Information System (IMIS)

Individual exposure results: The three sources of individually reported exposure results include:

- A 2003 ERG site visit conducted in a copper-beryllium casting facility (ERG, 2003). This small foundry used direct chill casting methods to cast 2 percent beryllium alloy. A total of four PZB beryllium samples were obtained for three workers over two days. Because the workers were permitted to end the shift when they melted and poured one batch of ally, the sampling periods were all less than 5 hours. Investigators obtained hand and surface wipe samples at this facility. The ERG investigators also obtained three personal particle number samples.

- A site visit (Case History D) conducted in 1999 at a ferrous/non-ferrous centrifugal casting foundry by the California Cast Metals Associations (CCMA, 2000). The case history offers a brief description of the pouring area and several days worth of PBZ air sampling results (beryllium, arsenic, cadmium, chromium, lead, nickel and selenium) for various job categories. Most samples were at least 7 hours in duration. One beryllium result that exceeded OSHA's current PEL for beryllium, while all other results were well below the respective PELs for the metals evaluated (many of these results were also below the limits of detection.

- A much earlier NIOSH Health Hazard Evaluation, conducted in 1975, at a facility that handled beryllium alloys of aluminum and copper in several capacities, including foundry melting and casting operations (NIOSH, 1976). For this analysis, ERG extracted the results for foundry-related operations, which indicate that beryllium was present in variable concentrations in many areas of the facility. In addition to air monitoring, NIOSH conducted a review of randomly selected employee medical records, which indicated that one employee experienced beryllium dermatosis, one employee had acute beryllium pneumonitis, and nine employees had chronic beryllium disease.

Table 5A-1 in Appendix 5A includes the individual results (full- and partial-shift) obtained from these sources for the job categories of interest. The full-shift results are summarized here in Tables 5-6 and 5-7.

Table 5-6. Summary of Individual Full-Shift PBZ Beryllium Exposure Levels By Job Category for Workers in Copper and Aluminum Foundries (SIC 3364, 3365, and 3366)

	Job Categories	Number of Positive Results	Range (µg/m^3)	Mean (µg/m^3)	Median (µg/m^3)
	Molder	--	--	--	--
	Material handler (crane/forklift operator)	1	0.93	0.93	0.93
	Furnace operator (melt/heating operator	5	0.2 to 19.76	4.3	0.69

Table 5-6. Summary of Individual Full-Shift PBZ Beryllium Exposure Levels By Job Category for Workers in Copper and Aluminum Foundries (SIC 3364, 3365, and 3366)

	Job Categories	**Number of Positive Results**	**Range ($\mu g/m^3$)**	**Mean ($\mu g/m^3$)**	**Median ($\mu g/m^3$)**
	and assistants)				
	Pouring operator	3	0.2 to 2.2	0.87	0.2
	Shakeout operator	--	--	--	--
	Abrasive blasting operator	--	--	--	--
	Grinder/sawyer/sander/finisher	4	0.2 to 0.69	0.3	0.2
	Maintenance operator	--	--	--	--
	Housekeeping workers	--	--	--	---

Only quantified results are considered. Results below the limit of detection are conservatively set at the limit of detection, when that value is available.
Source: NIOSH, 1976; CCMA 2000; Appendix 5-A; and associated notes. See the industry profile and process description for additional information.

Table 5-7. Distribution of Individual PBZ Total Beryllium Exposure Readings for Aluminum and Copper Foundries (SIC 3364, 3365, and 3366)

Job Categories	**Number of Results in Range ($\mu g/m^3$)**						**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	**--**	**--**	**--**	**--**	**--**	**--**	**--**
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 (40%)**	**0 (0%)**	**2 (40%)**	**0 (0%)**	**1 (20%)**	**5 (100%)**
Pouring operator	**0 (0%)**	**2 (66%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**1 (33%)**	**3 (100%)**
Shakeout operator	**--**	**--**	**--**	**--**	**--**	**--**	**--**
Abrasive blasting operator	**--**	**--**	**--**	**--**	**--**	**--**	**--**
Grinder/sawyer/sander/finisher	**3 (75%)**	**0 (0%)**	**0 (0%)**	**1 (25%)**	**0 (0%)**	**0 (0%)**	**4 (100%)**
Maintenance operator	**--**	**--**	**--**	--	**--**	**--**	--
Housekeeping worker	**--**	**--**	**--**	--	**--**	**--**	--
All Foundries	**3 (23%)**	**4 (31%)**	**0 (0%)**	**4 (31%)**	**0 (0%)**	**2 (15%)**	**13 (100%)**

Sources: NIOSH, 1976; CCMA, 2000. Data not available for all job categories.
Percentages may not add up to 100 due to rounding.

Analogous industries: Further information is available for a related industry, secondary smelting, which includes similar melting and casting operations (see Section 6 – Secondary Smelting, Refining and Alloying). Additionally, a beryllium producer operates foundry facilities and information is available for this company's alloy furnace operations (See Section 3 – Beryllium Production). Results for applicable job categories are summarized here in Tables 5-8 and 5-9.

Table 5-8. Summary of Individual Full-Shift PBZ Beryllium Exposure Levels By Job Category for Workers Performing Analogous Activities in Other Industries

Industry	Job Description	Number of Positive Results	Range ($\mu g/m^3$)	Mean ($\mu g/m^3$)	Median ($\mu g/m^3$)
Smelting (code)	Material Handling Worker	25	0.005 to 0.21	0.063	0.005
Beryllium Production	Furnace Operations – Alloy, Induction furnaces	97	0.06 to 48.07	1.46	0.50
Beryllium Production	Furnace Operations – Alloy, Arc furnaces	38	0.15 to 9.37	1.95	0.95
Smelting (code)	Furnace Operator (melting)	41	0.004 to 1.7	0.39	0.25
Smelting (code)	Furnace Helper (melting)	48	0.004 to 1.5	0.29	0.21
Smelting (code)	Casting Operator	14	0.23 to 0.6	0.52	0.52
Smelting (code)	Casting Helper	8	0.5 to 0.59	0.53	0.52
Smelting (code)	Maintenance worker (furnaces)	12	0.006 to 0.3	0.11	0.10
Smelting (code)	Housekeeping workers	13	0.19 to 1.1	0.40	0.3

Sources: Section 3 – Beryllium Production; Section 6 – Smelting, Refining, and Alloying

Table 5-9. Distribution of Individual PBZ Total Beryllium Exposure Readings in Analogous Industries

Industry/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	
Smelting/ Material Handling Worker	18 (72%)	0 (0%)	7 (28%)	0 (0%)	0 (0%)	0 (0%)	**25** **(100%)**
Beryllium production/ – Alloy, Induction furnaces (used for 0.1% to 2 % beryllium alloys)	5 (5%)	12 (12%)	32 (33%)	26 (27%)	13 (14%)	9 (9%)	**97** **(100%)**
Beryllium production/ – Alloy, Arc furnaces (used for beryllium “master” alloys containing 4% beryllium)	0 (0%)	1 (3%)	6 (16%)	14 (37%)	7 (18%)	10 (26%)	**38** **(100%)**
Smelting/ Furnace Operator (melting)	9 (22%)	3 (7%)	15 (37%)	12 (29%)	2 (5%)	0 (0%)	**41** **(100%)**
Smelting/ Furnace Helper (melting)	15 (31%)	0 (0%)	20 (42%)	11 (23%)	2 (4%)	0 (0%)	**48** **(100%)**
Smelting/ Casting Operator	0 (0%)	0 (0%)	4 (29%)	10 (71%)	0 (0%)	0 (0%)	**14** **(100%)**
Smelting/ Casting Helper	0 (0%)	0 (0%)	3 (38%)	5 (62%)	0 (0%)	0 (0%)	**8** **(100%)**
Smelting/ Maintenance operator (furnace maintenance)	6 (50%)	2 (17%)	4 (33%)	0 (0%)	0 (0%)	0 (0%)	**12** **(100%)**
Smelting/ Housekeeping worker	0 (0%)	5 (38%)	5 (38%)	2 (15%)	1 (8%)	0 (0%)	**13** **(100%)**

Sources: Section 3 – Beryllium Production; Section 6 – Smelting, Refining, and Alloying
Percentages may not add up to 100 due to rounding.

IMIS: OSHA’s Integrated Management Information System (IMIS) entries for the years 1979 to 2003 also contain beryllium personal air sampling results associated with aluminum and copper foundries (SIC 3363, 3364, 3365, and 3366). These results are summarized by SIC in Tables 5-10 and 5-11. The subsequent Tables 5-12 and 5-13 contain the means, medians and distribution of positive-value results (beryllium detected in the sample) associated with relevant job categories in SIC 3364, 3365, and 3366. Information was inadequate to classify the three positive results from SIC 3363 into applicable job categories.

As is typical of results in IMIS, information is not available regarding worker activities, the engineering controls in place, personal protective equipment worn during sampling, non-detectable sample concentrations, and sample duration. This source of results was not designed to capture that level of detail.

Table 5-10. Summary of Results in IMIS for Foundry Workers Associated With Aluminum And Copper Foundries (SICs 3363, 3364, 3365, and 3366)

SIC Code	Total Number of Establishments	SIC Description	Total Samples/ Number Samples with Positive Results[a]	Job Descriptions	Range[b] (µg/m^3)	Mean[b] (µg/m^3)	Median[b] (µg/m^3)
3363	Not determined	Aluminum Die-Casting Foundries	3/18 (2%)	Laborer	0.17 to 0.2	0.19	0.2
3364	Not determined	Non-Ferrous Die Casting Foundries (except aluminum)	17/63 (10%)	Furnace operator, Grinder operator, "spinner operator"	0.01 to 13	1.54	0.05
3365	Not determined	Aluminum Foundries	68/179 (40%)	Furnace operator, Pouring operator Grinder/sanding machine operator, Welder, Mold maker	0.03 to 8.8	1.22	0.5
3366	Not determined	Copper Foundries	81/821 (48%)	Furnace operator, Pouring operator, Shakeout operator, Grinder/sanding machine operator, Abrasive blasting operator, Welder, Mold maker	0.016 to 6.1	0.63	0.1
Total		All Aluminum and Copper Foundries	**169/821**		**0.016 to 13**	**N/A**	**N/A**

Source: OSHA IMIS Database 1979 to July 2003**.** Information regarding worker activities, the engineering controls in place, personal protective equipment worn during sampling, non-detectable sample concentrations, and sample duration is not available.

[a] Includes all PBZ samples by SIC code and all positive results regardless of the job description (except job description listed as "N/A")

[b] The range, mean and median results are based on positive sample results only. All positive results are included regardless of the total sample time.

PBZ: means personal breathing zone.

IMIS contained no personal air sampling results for beryllium in SIC 3843 – Dental Equipment and Supplies.

Table 5-11. Distribution of Personal Total Beryllium Exposure Readings in IMIS for Aluminum and Copper Foundries (SICs 3363, 3364, 3365, and 3366)

SIC Description	Number of Positive 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	
3363 Aluminum Die-Casting Foundries	0 (0%)	3 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	**3 (100%)**
3364 Non-Ferrous Die Casting Foundries (except aluminum)	13 (76%)	0 (0%)	0 (0%)	0 (0%)	2 (12%)	2 (12%)	**17 (100%)**
3365 Aluminum Foundries	14 (21%)	11 (16%)	9 (13%)	11 (16%)	10 (15%)	13 (19%)	**68 (100%)**
3366 Copper Foundries	40 (49%)	13 (16%)	10 (12%)	7 (9%)	2 (2%)	9 (11%)	**81 (100%)**
Combined Aluminum and Copper Foundries	**67 (40%)**	**27 (16%)**	**19 (11%)**	**18 (11%)**	**14 (8%)**	**24 (14%)**	**169 (100%)**

Source: OSHA IMIS Database 1979 to July 2003.
Percentages may not add up to 100 due to rounding.

Table 5-12. Personal Total Beryllium Exposure Readings in IMIS For Workers In Specific Job Categories In Aluminum And Copper Foundries (SICs 3364, 3365, and 3366)

	Job Categories	Number of positive results	Range (μg/m³)	Mean (μg/m³)	Median (μg/m³)
	Molder	10	0.018 to 1.7	0.75	0.85
	Material handler (crane/forklift operator)	0	N/A	N/A	N/A
	Furnace operator (melt/heating operator and assistants)	27	0.01 to 13.0	2.01	0.17
	Pouring operator	32	0.016 to 5.0	0.623	0.1
	Shakeout operator	6	0.05 to 0.5	0.22	0.11
	Abrasive blasting operator	3	0.02 to 0.101	0.074	0.101
	Grinder/sawyer/sander /finisher	29	0.02 to 1.1	0.3	0.1
	Maintenance operator	0	N/A	N/A	N/A
	Housekeeping worker	0	N/A	N/A	N/A
Total		**107**	**0.01 to 13**	**N/A**	**N/A**

Source: OSHA IMIS Database 1979 to July 2003.
N/A means "not applicable"

Table 5-13. Distribution of Positive-Value PBZ Total Beryllium Exposure Readings in IMIS for Workers in Specific job Categories in Aluminum and Copper Foundries (SIC Groups 3364, 3365, and 3366)

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	1 (10%)	1 (10%)	1 (10%)	5 (50%)	2 (20%)	0 (0%)	**10 (100%)**
Material handler (crane/forklift operator)	--	--	--	--	--	--	**--**
Furnace operator (melt/heating operator and assistants)	11 (41%)	4 (15%)	0 (0%)	1 (4%)	1 (4%)	10 (37%)	**27 (100%)**
Pouring operator	18 (56%)	4 (13%)	2 (6%)	3 (9%)	1 (3%)	4 (13%)	**32 (100%)**
Shakeout operator	3 (50%)	1 (17%)	2 (33%)	0 (0%)	0 (0%)	0 (0%)	**6 (100%)**
Abrasive blasting operator	1 (33%)	2 (67%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	**3 (100%)**
Grinder/sawyer/sander/finisher	15 (52%)	1 (3%)	9 (31%)	1 (3%)	3 (10%)	0 (0%)	**29 (100%)**
Maintenance operator	**--**	**--**	**--**	--	**--**	**--**	--
Housekeeping worker	**--**	**--**	**--**	**--**	**--**	**--**	**--**
All Job Categories	**49 (46%)**	**13 (12%)**	**14 (13%)**	**10 (9%)**	**7 (7%)**	**14 (13%)**	**107 (100%)**

Source: OSHA IMIS Database 1979 to July 2003. See the industry profile and process description for additional information.
Only positive results are considered.
Percentages may not add up to 100 due to rounding.

Dental alloys: ERG was not able to identify exposure information for workers engaged in producing non-precious metal dental alloys (e.g., nickel-beryllium dental alloys). No beryllium exposure results for SIC 3843 (Dental Equipment and Supplies) were entered into the IMIS database between the years 1979 and 2003. However, an OSHA inspection report offers insight into a dental equipment manufacturer's dental alloy production facility (a captive foundry), which at the time of OSHA's visit operated as a typical non-ferrous sand casting foundry (OSHA Inspection Report 122252281). Furthermore, as with most facilities that melt beryllium alloys, foundries that cast nickel-based alloys generally do so as a portion of their business, which usually includes a variety of other metal alloys (e.g., copper, aluminum, bronze). Thus, ERG considers the information available for aluminum and copper foundries to be generally relevant to the dental alloy production industry, taking into account the possible difference in foundry facility size. Captive foundries associated with establishments dedicated to producing materials for the dental industry might be smaller than the average industrial foundry. The process of casting dental alloys to form dental appliances (e.g., bridges and crowns) is covered under Section 10 - Dental Laboratories.

Influence of beryllium oxide formation: Due to beryllium affinity for oxygen, oxide on molten metal can contain substantially higher percentage of beryllium – by several fold - than the alloy it forms on, based on industry experience with bulk air sampling and ventilation filter dust percentages that are higher in beryllium content than the alloys handled in the area (Corbett, 2004).

5.3.1 Air Samples

This exposure profile for copper and aluminum foundries describes worker exposure levels in each of the affected job categories. For each job category, ERG reviewed the available exposure information and selected the set of results that appears to best represent foundry industry workers. In some cases ERG combined individually reported results with IMIS results for the same job category to produce a more robust profile of the category. In other cases, only IMIS results are available and ERG has relied on that data set. For two job categories, maintenance operators and housekeeping workers, ERG was not able to identify exposure information specific to the foundry industry. For these two groups, ERG has relied on results from the analogous smelting industry, which uses some of the same processes as are encountered in foundries. Tables 5-14 and 5-15 summarize the exposure profile for each job category and for the industry as a whole.

Table 5-14. Exposure Profile By Job Category For Workers In Aluminum And Copper Foundries

Source	Job Categories	Number of Samples	Range ($\mu g/m^3$)	Mean ($\mu g/m^3$)	Median ($\mu g/m^3$)
IMIS	Molder	10	0.018 to 1.7	0.75	0.85
Individual results	Material handler (crane/forklift operator)	2	0.93 to 2.38	1.66	1.66
IMIS+Individual results	Furnace operator (melt/heating operator and assistants)	38	0.01 to 25.06	3.28	0.73
IMIS+Individual results	Pouring operator	35	0.016 to 5.0	0.64	0.1
IMIS	Shakeout operator	6	0.05 to 0.5	0.22	0.11
IMIS+Individual results	Abrasive blasting operator	4	0.02 to 0.7	0.231	0.101
IMIS+Individual results	Grinder/sawyer/sander/finisher	34	0.02 to 15.56	0.75	0.2
Analogous industry	Maintenance (furnace maintenance)	12	0.006 to 0.3	0.11	0.10
Analogous industry	Housekeeping workers	13	0.19 to 1.1	0.40	0.3
	All Job Categories	**154**	**0.006 to 25.06**	**N/A**	**N/A**

Source: See Tables 5-6 through 5-13.

Table 5-15. Exposure Profile. Distribution by Job Category for Workers in Aluminum and Copper Foundries

Job Categories	Number of Results in Range ($\mu g/m^3$)						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	1 (10%)	1 (10%)	1 (10%)	5 (50%)	2 (20%)	0 (0%)	**10 (100%)**
Material handler (crane/forklift operator)	0 (0%)	0 (0%)	0 (0%)	1 (50%)	0 (0%)	1 (50%)	**2 (100%)**
Furnace operator (melt/heating operator and assistants)	11 (29%)	7 (18%)	0 (0%)	3 (8%)	2 (5%)	15 (39%)	**38 (100%)**
Pouring operator	18 (51%)	6 (17%)	2 (6%)	3 (9%)	1 (3%)	5 (14%)	**35 (100%)**
Shakeout operator	3 (50%)	1 (17%)	2 (33%)	0 (0%)	0 (0%)	0 (0%)	**6 (100%)**

Table 5-15. Exposure Profile. Distribution by Job Category for Workers in Aluminum and Copper Foundries

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	
Abrasive blasting operator	1 (25%)	2 (50%)	0 (0%)	1 (25%)	0 (0%)	0 (0%)	**4 (100%)**
Grinder/sawyer/sander/finisher	15 (44%)	4 (12%)	9 (26%)	2 (6%)	3 (9%)	1 (3%)	**34 (100%)**
Maintenance operator (furnace maintenance)	6 (50%)	2 (17%)	4 (33%)	0 (0%)	0 (0%)	0 (0%)	**12 (100%)**
Housekeeping worker	0 (0%)	5 (38%)	5 (38%)	2 (15%)	1 (8%)	0 (0%)	**13 (100%)**
All Job Categories	**55 (36%)**	**28 (18%)**	**23 (15%)**	**17 (11%)**	**9 (6%)**	**22 (14%)**	**154 (100%)**

Source: See Tables 5-6 to 5-14 and the industry profile and process description for additional information.

5.3.2 Exposure profile

Molder: The OSHA IMIS database contains 10 PZB beryllium results for molders in aluminum and copper foundries. Because these are the only quantified results available, ERG has used this group for the exposure profile despite the limited documentation available for individual results contained in IMIS. These results, summarized in Tables 5-14 and 5-15, range from 0.018 µg/m^3 to 1.7 µg/m^3. The median value for these results is 0.8 µg/m^3 (mean 0.7 µg/m^3). Fifty percent, or half (5) of the 10 results fall between 0.5 µg/m^3 and 1.0 µg/m^3. Two results (20 percent) lie between 1.0 and 2.0 µg/m^3. The remaining three results are 0.5 µg/m^3 or less and include one value less than 0.1 µg/m^3 and one value between 0.1 and 0.2 µg/m^3. As with all data obtained from IMIS, no additional information is available regarding the sampling or working conditions associated with these results. Additionally, because these values may include some less-than-full-shift results, they may overestimate the workers' true average daily exposure level.

An additional molder result (below the limit of detection) was obtained when NIOSH visited a beryllium ally (copper and aluminum) casting facility in 1975. The limit of detection, however, was not stated in the source documentation and this result could not be included in the exposure profile. Local exhaust ventilation was reportedly available at all operations where dust and fume were generated. At the same facility, NIOSH obtained several full-shift results between 0.5 μg/m^3 and 1.0 μg/m^3 for workers in other job categories (furnace operators, crane operator, and a finish grinder) and short-term results as high as 25.06 μg/m^3, indicating that beryllium was present in the facility and exposure was wide-spread (NIOSH, 1976).

Material Handler: Results for material handlers in beryllium alloy casting foundries are very limited. NIOSH reported a single full-shift PZB result of 0.93 μg/m^3 for a crane operator at the previously described beryllium alloy (copper and aluminum) casting facility (NIOSH, 1976). A more recent less-than-full-shift (252-minute) result of 2.38 μg/m^3 was obtained by ERG for a forklift operator at a facility casting copper-beryllium (ERG, 2003). The short duration of the sample was 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 TWA of 1.25 μg/m^3. However, a worker performing equivalent activities for a full 8-hour shift would likely have experienced a full-shift exposure similar to the short-term 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 tundish (pour lines) into position in the pouring area, and removed large castings from direct chill casting molds. The same worker also 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 ranged from 1.92 to 14.04 μg/m^3.

In the absence of other results, ERG has relied upon these two values for the material handler exposure profile (see tables 5-14 and 5-15). ERG notes that this is an area where additional information would increase the reliability of the profile.

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 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). 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).

Furnace Operator: 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/maintenance of ventilation systems.

This exposure profile for furnace operators is based on 38 combined results obtained from OSHA IMIS and several sources that report individual beryllium results for foundry workers (OSHA, 2003; ERG, 2003b; NIOSH 1976; CCMA, 2000). This combination incorporates information from the widest possible group of foundries and foundry types. It is important to note that, because sample durations are not available for IMIS PBZ results and these values might be associated with a wide range of sample durations, ERG has also included in the exposure profile all available individually reported results for furnace operators, regardless of sample duration, including six less-than-full shift results (265 minutes to 350 minutes). As IMIS results may not have been adjusted as 8-hour TWAs, nor have the individually reported results been adjusted. Instead, ERG asserts that the exposure level reported for the duration sampled represents the exposure that would have been reported had the sampling period continued for a full 8 hours. For the interested reader, ERG calculated the 8-hour TWAs for these six results (see Table 5A-1 in Appendix 5A) and determined that their use in the exposure profile (in place of the value for the period sample) would not have a notable impact on the profile. While the upper range and median would be somewhat lower (yet still above the current PEL), the median and distribution of the results would be unchanged. Each calculated 8-hour TWA result remained in the same exposure range as its original value.

As indicated in Tables 5-14 and 5-15 the 38 results range from 0.01 μg/m^3 to 25.06 μg/m^3, with a median of 0.73 μg/m^3 (mean 3.28 μg/m^3). More than one-third of the 38 results (15 values, or 39 percent) are above the current PEL of 2.0 μg/m^3 and over half the results (52 percent) exceed 0.5 μg/m^3. Nearly another one-third (29 percent, or 11 of 38 readings) are 0.1 μg/m^3 or less, while 47 percent are 0.2 μg/m^3 or less. The apparent bimodal distribution, with more than 85 percent of the results either below 0.2 and greater than 2.0 suggest dramatic differences in either the work practices, the engineering controls, or both. Among the few results for which work condition information is available, ERG notes a trend toward higher exposure levels in cases where ventilation systems were deemed inadequate or poorly designed for worker protection. The following discussion describes these results in greater detail.

Tables 5-16, 5-17, and 5A-1 summarize and present the five full-shift PBZ beryllium results that ERG identified for furnace operators. These results range from 0.2 μg/m^3 to 19.76 μg/m^3, with a median of 0.69 μg/m^3 (mean 4.3 μg/m^3). These represent the highest range and mean exposure value among the job categories in this industry. The median is the third highest (behind molders and material handlers). The distribution of these five results includes two exposure levels (40 percent) less than 0.2 μg/m^3 (in this case also the limit of detection), two results (40 percent) that fall between 0.5 μg/m^3 and 1.0 μg/m^3, and the highest result, a single value (20 percent) that lies well above 2.0 μg/m^3. These results were obtained in the centrifugal casting foundry and the beryllium alloy foundry evaluated by NIOSH, both of which have been mentioned previously (CCMA, 2000; NIOSH, 1976).

The two lowest of the individually reported full-shift furnace operator results, both less than the limit of detection of 0.2 μg/m^3, were obtained at the ferrous/non-ferrous centrifugal casting foundry. (A third less-than-full-shift result at the same level was also reported.) This facility manufactured cylindrical castings of various diameters, which ranged in length from 6 inches to 120 inches (10 feet). The presence of beryllium in this facility (Case History Foundry D) was confirmed by a result of 2.2 μg/m^3 for a worker in the pouring operator job category. These furnace operators (“melters”) tended induction furnaces fitted with close-fitting furnace-mounted exhaust hoods. Additional local exhaust ventilation was present in the adjacent pouring area, where fumes were collected by mobile ladle hoods and “suction at the pour spout of the centrifugal caster” (CCMA, 200).

The three highest individually reported full-shift results available for this job category (0.69 µg/m^3, 0.79 µg/m^3, and 19.76 µg/m^3) were obtained in 1975 at a beryllium alloy tool and parts manufacturing facility that cast copper and aluminum in the foundry portion of their operations. At the time, the facility employed 447 personnel, 350 of whom were production workers. Other industrial operations, including alloy recovery from dross, occurred elsewhere in the facility. NIOSH noted “Local exhaust ventilation is supplied at all operations where dust and fumes re generated.” However, “where engineering controls existed, they were inadequate, considering the toxicity of the contaminant”(NIOSH, 1976).

Several additional results were reported for this job category. Specifically, five less-than-full-shift results between 0.2 µg/m^3 (the limit of detection) and 25.06 µg/m^3 are available for furnace operators (and their helpers) casting copper and aluminum alloys of beryllium. These values represent the actual exposure level for the period sampled (all between 250 to 350 minutes). A sixth result of 14.08 µg/m^3 was obtained using the same sample filter over two abbreviated shifts (about 265 minutes each) for a total sample time of 532 minutes (investigators used this strategy to ensure an adequate sample volume to achieve a quantifiable result – a step that proved to be unnecessary). This result represents the composite TWA for the two shifts.

Three of these less-than-full-shift results, 1.92 µg/m^3, 4.18 µg/m^3, and the 14.08 µg/m^3 value, are known to have encompassed the workers’ total exposure for the day(s) (ERG, 2003b). ERG calculated 8-hour TWA readings of 1.07 µg/m^3, 2.31 µg/m^3, and 7.80 µg/m^3 for these values.[1] These results are particularly interesting because they demonstrate that foundry workers continue to experience the level of exposure reported by NIOSH in the 1970’s.

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[1] For the result obtained over two shifts, ERG calculated the 8-hour TWA by assuming that the exposure contribution and sample times were the same on each day (one half of 532 minutes, or about 266 minutes each day). Based on results for other furnace workers those days, the sample time assumption is probably accurate to within a few minutes; however, the actual exposure levels might have been different on the two days. Although further analysis is not possible with the available information, the results suggest that the actual exposure of the furnace operator likely exceeded the current PEL of 2.0 µg/m^3 each day.

These three less-than-full-shift results, even when reported as 8-hour TWAs, all exceed the median for furnace operators and two of the results exceed the current PEL for beryllium (2.0 μg/m^3). The results for a furnace operator (one sample over 2 days) and an assistant (two samples over two days) were obtained in 2003 at a copper-beryllium casting foundry. These exposure levels are associated with an overhead canopy hood located over the furnace, under which the furnace operator stood while checking the furnace and skimming the dross "so that the furnace operator is standing in the exhaust stream of contaminants from the furnace" (ERG, 2003b). Neither the hood nor the associated ductwork was designed to maximize employee protection. The furnace operator positioned the dross receptacle (a bucket) under a second smaller hood (Corbett, 2005b).

At the facility visited by ERG, the foundry area and adjacent offices were separated by doors, which were usually open. Foundry employees spent some of the shift sitting in the office while waiting for the melt, taking no special precautions when entering the office from the plant area. A dark film of graphite mold release covered many surfaces, influencing the appearance of the facility and indicating the possibility of widespread cross contamination. There was, however, a central vacuum system available for cleaning the furnace area. ERG believes that this descriptive information is illustrative, although the individual results from this study are not necessarily representative of exposure levels in all foundries due to the abbreviated work shift. These workers conducted one melt and pour over a period of about 4 hours, then were allowed to consider the shift complete and leave the facility for the day (ERG, 2003b, Corbett, 2005a).

Other summary results for furnace operators suggest similar exposure trends. OSHA's IMIS database contains 27 PBZ results for furnace operators in aluminum and copper foundries. The applicable results in OSHA's IMIS database (summarized in Tables 5-10 and 5-11) range from 0.01 μg/m^3 to 13.0 μg/m^3 and are described by a median of 0.17 μg/m^3 and a mean of 2.01 μg/m^3 (OSHA, 2003). The range, mean and median for IMIS results are all somewhat lower than group of individual results, but present a similar trend of exposure values spread across a wide range and frequently exceeding the current PEL. For example, eleven of the 27 IMIS results (41 percent) are 0.1 μg/m^3 or less and 56 percent are 0.2 μg/m^3 or less, while 10 of the 27 results (37 percent) exceeds 2.0 μg/m^3.

The full-shift PBZ results from furnace operations obtained at a beryllium production facility (summarized in Section 3 – Beryllium Production) and reproduced here in Table 5-16 also support the trend described by the exposure profile for 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 0.5 µg/m^3, mean 1.46 µg/m^3). At the same company, alloy melting using another type of furnace follow the same general trend; the 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) (see Section 3 – Beryllium Production).

Tables 5-16 and 5-17 compare the summarized results and distribution of the furnace operator exposure profile with results from the supporting data sets and other sources (e.g., beryllium production industry and smelting industry). The tables show a clear pattern of wide exposure ranges characterized by results that are frequently well above the current PEL of 2.0 µg/m^3 and medians that often fall between 0.5 µg/m^3 and 1.0 µg/m^3.

Table 5-16. Comparison of Furnace Operator PBZ Beryllium Results from Various Sources

Source	**Job Category or Title**	**Number of Samples**	**Range[c] (µg/m^3)**	**Mean[c] (µg/m^3)**	**Median[c] (µg/m^3)**
Exposure profile	Furnace operator	38	0.01 to 25.06	3.28	0.73
Individual full-shift results	Furnace operator	5	0.2 to 19.76	4.3	0.69
IMIS	Furnace operator	27	0.01 to 13.0	2.01	0.17
Section 3 Beryllium production	Furnace Operations – Alloy, Induction furnaces (0.1% to 2 % beryllium alloys)	97	0.06 to 48.07	1.46	0.50
Section 3 Beryllium production	Furnace Operations – Alloy, Arc furnaces (4% beryllium alloy)	38	0.15 to 9.37	1.95	0.95
Section 6 Smelting	Furnace Operator (melting)	41	0.004 to 1.7	0.39	0.25
Section 6 Smelting	Furnace Helper (melting)	48	0.004 to 1.5	0.29	0.21

Source: See Tables 5-6 to 5-15

Table 5-17. Comparison of Distribution of Furnace Operator PBZ Beryllium Results from Various Sources

Source	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	
Exposure profile	11 (29%)	7 (18%)	0 (0%)	3 (8%)	2 (5%)	15 (39%)	**38** **(100%)**
Individual full-shift results	0 (0%)	2 (40%)	0 (0%)	2 (40%)	0 (0%)	1 (20%)	**5** **(100%)**
IMIS	11 (41%)	4 (15%)	0 (0%)	1 (4%)	1 (4%)	10 (37%)	**27** **(100%)**
Brush Wellman – Alloy, Induction furnaces (used for 0.1% to 2 % beryllium alloys)	5 (5%)	12 (12%)	32 (33%)	26 (27%)	13 (14%)	9 (9%)	**97** **(100%)**
Brush Wellman – Alloy, Arc furnaces (used for beryllium “master” alloys containing 4% beryllium)	0 (0%)	1 (3%)	6 (16%)	14 (37%)	7 (18%)	10 (26%)	**38** **(100%)**
Smelting/ Furnace Operator (melting)	9 (22%)	3 (7%)	15 (37%)	12 (29%)	2 (5%)	0 (0%)	**41** **(100%)**
Smelting/ Furnace Helper (melting)	15 (31%)	0 (0%)	20 (42%)	11 (23%)	2 (4%)	0 (0%)	**48** **(100%)**

Source: See Tables 5-6 to 5-15 and the industry profile and process description for additional information.
Only positive results are considered.
Percentages may not add up to 100 due to rounding.

Pouring operator: The exposure profile for pouring operators is based on combined results obtained from OSHA’s IMIS and a California Cast Metals Association case study that reports individual beryllium results for foundry workers in the pouring area (OSHA, 2003; CCMA, 2000).

As indicated in Tables 5-14 and 5-15 the 35 pouring operator results range from 0.016 μg/m^3 to 5.0 μg/m^3, with a median of 0.1 μg/m^3 (mean 0.64 μg/m^3). Most beryllium results for pouring operators (68 percent, or 24 of 35 values) are less than or equal to 0.2 μg/m^3. In fact, 18 values, or more than half (51 percent) of the 35 results are less than 0.1 μg/m^3. Of the 11 results exceeding 0.2 μg/m^3, five (14 percent) also exceed the current PEL of 2.0 μg/m^3.

ERG identified three individual full-shift PBZ beryllium exposure results for pouring operators. These are summarized in Tables 5-6 and 5-7. The results, which include two values less than the limit of detection (0.2 μg/m^3) and a single value of 2.2 μg/m^3, were all obtained on the same date at the centrifugal casting foundry mentioned previously as Case History Foundry D (CCMA, 2000). These results are associated with pouring/casting-area workers performing various tasks, including pouring metal. The worker designation of the pouring "casting" operator with the highest exposure (2.2 μg/m^3) suggests this worker was primarily involved in the actual casting process; however, no further details are available. The pouring area was fitted with engineering controls 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. Elevated crystalline silica results associated with a worker brushing silica mold release agent out the centrifugal castings subsequently prompted the foundry to improve ventilation at the mold access point (CCMA, 2000). Although the pouring operator result of 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).

The OSHA IMIS database also includes beryllium results for pouring operators working in aluminum and copper foundries.[2] The 32 results range from 0.016 μg/m^3 to 5.0 μg/m^3, with a median of 0.1 μg/m^3 and a mean of 0.623 μg/m^3. As the median indicates, the majority of pouring operator results in IMIS (56 percent, or 18 of 32 results) are less than 0.1 μg/m^3. Tables 5-18 and 5-19 summarize these results and show that the remainder of the values are distributed widely across the ranges of interest, with four results (13 percent) exceeded the current PEL of 2.0 μg/m^3, and 8 results (25 percent) exceeding 0.5 μg/m^3. Although the values for pouring operators included in IMIS range more widely than do the limited number of available individually reported results, the mean and median values for IMIS results are both somewhat lower than for the individually reported results.

Tables 5-18 and 5-19 also show that workers performing similar activities (casting and casting helper) in the smelting industry are associated with a tighter range of exposure levels. Readings for fourteen castors and eight castor's helpers working in the smelting industry were

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[2] ERG searched for results associated with aluminum and copper foundries and the term "pour" in the job description.

well within the range experienced by foundry pouring operators and the means are remarkably similar, although the medians are higher in the smelting industry.

Table 5-18. Comparison of Pouring Operator PBZ Beryllium Results from Various Sources

Source	Job Category or Title	Number of Samples	Range[c] ($\mu g/m^3$)	Mean[c] ($\mu g/m^3$)	Median[c] ($\mu g/m^3$)
Exposure profile	Pouring operator	35	0.016 to 5.0	0.64	0.1
Individual full-shift results	Pouring operator	3	0.2 to 2.2	0.87	0.2
IMIS	Pouring operator	32	0.016 to 5.0	0.623	0.1
Smelting Section 6	Casting operator	14	0.23 to 0.6	0.52	0.52
Smelting Section 6	Casting helper	8	0.5 to 0.59	0.53	0.52

Source: See Tables 5-6 to 5-15.

Table 5-19. Comparison of Distribution of Pouring Operator PBZ Beryllium Results from Various Sources

Source/Job Category	Number of Results in Range ($\mu g/m^3$)						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	
Exposure profile	18 (51%)	6 (17%)	2 (6%)	3 (9%)	1 (3%)	5 (14%)	**35 (100%)**
Individual full-shift results	0 (0%)	2 (66%)	0 (0%)	2 (40%)	0 (0%)	1 (33%)	**3 (100%)**
IMIS/Pouring operator	18 (56%)	4 (13%)	2 (6%)	3 (9%)	1 (3%)	4 (13%)	**32 (100%)**
Smelting/ Casting Operator	0 (0%)	0 (0%)	4 (29%)	10 (71%)	0 (0%)	0 (0%)	**14 (100%)**
Smelting/ Casting Helper	0 (0%)	0 (0%)	3 (38%)	5 (62%)	0 (0%)	0 (0%)	**8 (100%)**

Source: See Tables 5-6 to 5-15 and the industry profile and process description for additional information.
Only positive results are considered.
Percentages may not add up to 100 due to rounding.

No results specifically for pouring tasks area available from the beryllium-copper foundry visited by ERG (2003b). There, the pouring activities were performed during the last hour of the shift and investigators judged that 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, 2005b).

Shakeout Operator: ERG based the exposure profile for shakeout operators on six results contained in OSHA's IMIS system. Because ERG was unable to identify other results for this job category, ERG has used the IMIS group for the exposure profile despite the limited documentation available for individual results contained in IMIS. As presented in Tables 5-14 and 5-15, the results used for the exposure profile range from 0.05 μg/m^3 to 0.5 μg/m^3 and are represented by a median of 0.11 μg/m^3 (mean 0.22 μg/m^3). Three of the results (50 percent) are 0.1 μg/m^3 or less, one reading (17 percent) falls between 0.1 μg/m^3 and 0.2 μg/m^3, while the remaining two results (33 percent) are 0.5 μg/m^3 or less. No further details are available regarding the activities and conditions associated with these samples. ERG suggests that additional information on exposure levels and working conditions for this job category would increase the reliability of this exposure profile.

Abrasive Blasting Operator: ERG based the exposure profile for abrasive blasting operators on three results contained in OSHA's IMIS system, plus a single value from CCMA's Case History D (OSHA, 2003; CCMA, 2000). The value from CCMA is from a short-duration PBZ sample (112 minutes); however, to be consistent with results from IMIS, and for the reasons described under furnace operators, ERG has used the result in the exposure profile without converting it to an 8-hour TWA. The source documentation does not indicate whether or not the sampling period encompassed the abrasive blasting operator's total beryllium exposure for the shift. Because abrasive blasting operators in foundries typically spend the majority of their shift at this task, ERG believes that the result of less than the limit of detection (0.7 μg/m^3) could also reasonably represent an exposure level that a full-time abrasive blasting operator might experience. To check the impact this decision had on the analysis, ERG calculated the 8-hour TWA (0.16 μg/m^3) and found that use of this lower value would reduce the upper range and median for the abrasive blasting operator job category, but would not impact the median (0.16

μg/m^3 would remain the highest of the results that ERG identified for this job category). By using the result reported for the period sampled, ERG estimates that the exposure profile is more likely to overestimate than underestimate the extent to which abrasive blasting operators are exposed to beryllium levels exceeding 0.5 μg/m^3. A larger group of full-shift samples would confirm or disprove this hypothesis. The other values, from IMIS, include the minimum value of 0.02 μg/m^3 and two results of 0.101 μg/m^3. IMIS reports neither the sample durations associated with these results, nor whether they represent 8-hour TWA values.

The single short-term result, from the centrifugal casting facility previously described in this analysis, is the only value for which additional information is available. The worker used a "blast booth" in a foundry where exposure levels for several metals were all well below the respective PELs and usually below the limits of detection.

Grinding/Finishing Operator: As presented in Tables 5-14 and 5-15, the 34 PBZ exposure results for grinding/finishing operators range from 0.2 to 0.69 μg/m^3, with a median of 0.2 μg/m^3 (mean 0.3 μg/m^3). The results range from 0.02 μg/m^3 to 15.56 μg/m^3, with a median of 0.2 μg/m^3 and mean of 0.75 μg/m^3. Nearly half of the total (15 of the 34 results, or 44 percent) are 0.1 μg/m^3 or less. An additional 4 results (12 percent) fall between 0.1 μg/m^3 and 0.2 μg/m^3, and another 9 (26 percent) exceed 0.2 μg/m^3 but are less than 0.5 μg/m^3. Overall, 28 results (82 percent) are 0.5 μg/m^3 or less. Just one result exceeds the current PEL of 2.0 μg/m^3.

Twenty-nine of these 34 results are contained in OSHA's IMIS, while the remaining exposure values were reported individually by CCMA and NIOSH (OSHA, 2003; CCMA, 2000; NIOSH 1976). These individually reported values include the results of four full-shift samples and one less-than-full-shift (321-minute) sample. As with previous foundry job categories, in the absence of additional information, ERG considers the partial-shift result to represent the exposure level that a worker full-time grinding operator could experience during a complete shift. ERG calculated the 8-hour TWA for this result (10.41 μg/m^3) and determined that it's use would only impact the upper range (still 5 times greater than the current PEL) and, to a lesser extent the mean. The median and exposure profile would not be impacted.

Although this job category encompasses workers performing a variety of finishing tasks, all involve abrasive action on castings. Among the available data, ERG observes no trends indicating that any task contributes to exposure more than others and this grouping is justified. For example, investigators implicate cut-off saws and abrasive cutters as a primary source of non-fume metal dust in foundries (CCMA, 2000). However, among the results available to ERG, the exposure levels of workers using abrasive cut-off saws appear at the bottom, (0.03 μg/m^3), middle (0.18 μg/m^3), and top (15.56 μg/m^3) of the range for this job category. Workers sanding castings may be found near the bottom (0.1 μg/m^3) and near the top (1.1 μg/m^3) of the range. Finishing operators using grinding equipment appear throughout the range.

Three of the individually reported results, all less than the limit of detection (0.2 μg/m^3 in this case) were obtained by CCMA in 1999 at a centrifugal casting foundry (Case History D) that handled both ferrous and non-ferrous metals. The three workers included two machinists and a grinder/"snagger." Although these results were below the limit of detection, on the same date a measurable level of beryllium was found in the breathing zone of a worker in another job category, indicating beryllium was present in the foundry (CCMA, 2000).

Two other results (0.69 μg/m^3 and the less-than-full-shift value of 15.56 μg/m^3) were obtained by NIOSH for workers using a finish grinder and a cut-off/swing grinder (respectively) to finish beryllium alloy castings (NIOSH, 1976). These were among the highest exposure levels reported at the facility (the result from one furnace operator was higher). A third full-shift result below the limit of detection (not provided) was reported at this site for a grinding/finishing operator using a "saw cutter" (because the result can not be quantified, it is not included in the exposure profile). Although NIOSH noted that exhaust ventilation was used wherever dust and fume were generated, the investigators deemed the ventilation systems inadequate.

Maintenance Operators: ERG was not able to identify any beryllium exposure results for maintenance operators in aluminum or copper foundries. PZB beryllium results for maintenance operators are available, however, for maintenance workers involved with furnace maintenance activities in the smelting industry. Smelting facilities perform some of the same operations found in foundries, such as melting and casting of beryllium-containing alloys using equipment similar to that used in foundries. Section 6 of this analysis, dealing with Smelting, Refining, and Alloying describes the job category of "furnace maintenance worker," which is related to the foundry maintenance operator job category. In the absence of maintenance operator results obtained in foundries, ERG has selected the results for smelting industry furnace maintenance operators as a reasonable alternative. While these results might underestimate the actual exposure of foundry maintenance operators (in general, most beryllium air sampling results reported for smelting facilities are somewhat lower than the results measured in foundries), ERG believes that the smelting furnace maintenance operator job category provides a useful surrogate for foundry maintenance operators. Briefly, as presented in Tables 5-14 and 5-15, the 12 results for furnace maintenance operators in the smelting and metal recycling industry ranged from 0.006 μg/m^3 to 0.3 μg/m^3, with a median value of 0.10 μg/m^3 (mean 0.11 μg/m^3). Half (6) of the results are less the 0.1 μg/m^3, while 17 percent (2) results are greater than 0.1 μg/m^3 but less than 0.2 μg/m^3, and the remaining 33 percent (4) of the results exceed 0.2 μg/m^3 but are less than or equal to 0.5 μg/m^3.

See Section 6 for a more complete discussion of the exposure profile for this job category.

Housekeeping workers: ERG was not able to identify beryllium exposure results for housekeeping workers in aluminum or copper foundries. PZB beryllium results for housekeeping workers are available, however, for workers involved in housekeeping activities in the smelting industry. As was noted previously, smelting facilities perform some of the same beryllium alloy operations found in foundries. Section 6 of this analysis, dealing with Smelting, Refining, and Alloying describes the job category of "housekeeping worker," which is related to the foundry housekeeping worker job category. In the absence of maintenance operator results obtained in foundries, ERG has selected the results for smelting industry housekeeping workers as a reasonable alternative. As with other job categories, the smelter results might underestimate the actual exposure of foundry housekeeping workers. Nevertheless, ERG believes that the smelting housekeeping worker job category provides a useful surrogate for foundry housekeeping workers. A brief review of the housekeeping worker results from Section 6, also presented in Table 5-8, indicates that 13 results for this job category from the smelting and metal recycling industry ranged from 0.19 μg/m^3 to 1.1 μg/m^3, with a median value of 0.3 μg/m^3 (mean 0.40

$\mu g/m^3$). All 13 of the results exceed 0.1 $\mu g/m^3$, although 38 percent (5) of these results are 0.2 $\mu g/m^3$ or lower and 77 percent (10) of the results are 0.5 $\mu g/m^3$ or less. Fifteen percent of the results (2) are fall between 0.5 $\mu g/m^3$ and 1.0 $\mu g/m^3$, while a single final value (8 percent) exceeds 1.0 but is less than 0.2 $\mu g/m^3$.

Please see Section 6 for a more complete discussion of the exposure profile for this job category.

In a draft study of silica exposures, ERG determined that the exposures for housekeeping workers are closely related to the general exposure levels in the foundry, and to the specific area where they spend the most time. Where exposures are elevated, the cases presented in the exposure profile suggest that adjacent operations are the primary source of exposure for housekeeping workers, although their own work will likely contribute to their exposure when dry sand is involved (ERG, 2003a).

5.3.2 Wipe Samples

5.3.2.1 Hand Samples

Hand wipes were obtained by asking study participants to wipe their hands before the end of their shift or during the shift, at least two hours after their last hand washing. Participants were instructed to lift a fresh wet-wipe from its opened container and to thoroughly wipe both hands (including the front and back, up to the wrists, and each finger), removing as much dirt as possible. The wipe was then placed in a labeled screw-top glass vial for analysis. The hand wiping exercise was supervised and timed for 30 seconds by the investigators to ensure consistency from subject to subject. A tracing of both hands of each participant was taken to estimate the total surface area of the participants' hands. The concentration of beryllium on the workers' hands is reported in micrograms of beryllium per 100 square centimeters ($\mu g/100\ cm^2$) (ERG, 2003b).

Table 5-20 presents results of hand wipe samples obtained by ERG in a beryllium copper casting facility (Site Visit 7). The results range from 0.47 to 25.2 µg/100 cm^2, with five of the 6 readings (83 percent) exceeding 2.0 µg/100 cm^2. These results are markedly higher than those obtained in other types of facilities visited by ERG. For example, hand wipe samples at a smelting and recycling facility ranged from <0.006 to 1.21 µg/100 cm^2. At that facility, just one out of the 28 results exceeded 0.55 µg/100 cm^2 (ERG, 2004b-Site visit 2).

Table 5-20. Wipe Samples Obtained from Hands (combined results from both hands)

Activity	**Be Concentration**	**skin condition**	**surface area(cm^2)**	**date**	**job**
(hour previous to wipe)	**(µg/100 cm^2)**				
preparing mold for pour	2.98	good	649	9/16/2003	furnace helper
casting charging	2.52	good	649	9/17/2003	furnace helper
rubbing, skimming, sparge set-u	5.37	fair	625	9/16/2003	furnace operator
casting, charging	25.20	fair	625	9/17/2003	furnace operator
setting up sparging	0.47	fair	648	9/16/2003	forklift op
Casting	1.96	good	648	9/17/2003	forklift op

Source: ERG (2003b)

5.3.2.2 Surface Wipe Samples

Surface contamination sampling was done using a plastic template containing a 100 cm^2 square opening (10 cm on a side) and wet-wipes. Investigators donned a clean pair of disposable gloves, placed the template on the surface to be sampled, and marked the corners with a moistened wipe. The template was removed and the perimeter outlined with the same moistened wipe. The inside of the square was then wiped according to NIOSH Method 9100 and the wipe placed in a screw-top glass vial for analysis. The template was cleaned in preparation for the next wipe sample and the gloves were discarded (ERG, 2003b).

Surface wipe samples can be used to locate areas of contamination and to evaluate the effectiveness of cleaning practices and procedures. Table 5-21 presents beryllium surface contamination data collected during ERG site visit to a beryllium-copper foundry (ERG, 2003b). Note that these data represent readings obtained during production shifts and do not necessarily represent the levels that can be achieved after cleaning. These data do indicate that surfaces in both the foundry and office areas are contaminated with beryllium and that surface contamination within the workplace can be highly variable. Surfaces in foundry areas might become contaminated with beryllium through direct contact with beryllium-contaminated castings or materials (e.g., substances such as dust from granular casting media or graphite mold release used in contact with molten alloy) or through workers via hand, clothing, and shoe contamination. Once a worker contaminates his or her hands (or gloves), shoes, or clothing with beryllium, everything that worker touches or comes into contact with might in turn become contaminated with some level of beryllium (i.e., cross-contamination).

Not surprisingly, some of the highest contamination occurred on surfaces in the production area near major sources of beryllium dust (the top of the carbon drum and the top of the furnace control box in the furnace area). These surfaces are unless included in a rigorous housekeeping program, these surfaces are unlikely to be cleaned regularly. Other areas of notable contamination include porous or difficult-to-clean surfaces where workers from the foundry area frequently place their hands (the chair arm rest and the office telephone keypad, which was notably contaminated compared to the office desk top). The highest concentration of beryllium was found on a conduit on the office wall, another surface that would be difficult to clean. These results point to an incomplete housekeeping program that allows substantial levels of contaminant to spread and accumulate throughout the production areas, hygienic areas, and office.

As with hand wipe samples, the surface wipe results from the beryllium-copper casting facility are notably higher than the surface contamination levels reported for other types of facilities visited by ERG. The median surface contamination result was 1.1 μg/100 cm^2 at the smelting facility that ERG visited. Although results reported in the smelter "melt shop" were substantially higher (up to 680 μg/100 cm^2), only 1 (8 percent) of the 13 foundry production area surface results was less than the median level of 14 µg/100 cm^2 reported for the melting areas in the smelting facility (ERG, 2004b-Site visit 2).

Table 5-21. Results of Surface Samples

SAMPLE	AREA	TOTAL Be (µg)	SURFACE AREA (cm^2)	Be CONC (µg/100 cm^2)
1	secretary's desk	2.00	100	2.00
2	secretary's chair mat	13.45	100	13.45
3	secretary's filing cabinet	3.58	100	3.58
4	top of radio	69.22	100	69.22
5	forklift steering wheel	3.78	100	3.78
6	top of carbon drum	265.00	100	265.00
7	chair arm rest	270.00	100	270.00
8	#1 furnace hood canopy	110.00	100	110.00
9	top of drum lid	530.00	100	530.00
10	#1 furnace top of tilt control	565.00	100	565.00
11	top of clothes washer	12.70	100	12.70
12	restroom door handle	20.54	100	20.54
13	dresser top in rest room	10.93	100	10.93
14	counter top in rest room	4.35	100	4.35
15	forklift seat	1.93	100	1.93
16	forklift rear top	212.10	100	212.10
17	floor in front of casting pit	56.68	100	56.68
18	dross ventilation hood furnace #3	176.50	100	176.50
19	top of hack saw arm	355.00	100	355.00
21	office desk telephone keypad	35.38	100	35.38
22	conduit on wall in office	850	100	850
23	top of compressed gas cylinder on loading dock	18.96	100	18.96
24	top of vise	259.5	100	259.5
25	storage rack rail	201	100	201
26	restroom floor	30.74	100	30.74

Source: ERG (2003b)
*ND – less than 0.04 µg

5.4 TECHNOLOGICAL FEASIBILITY

5.4.1 Baseline and Additional Controls by Job Category

Foundry workers have historically encountered numerous contaminants in their workplaces. Metals, such as beryllium, present a serious challenge because dust from fume, dross, and other sources are difficult to control using traditional methods. Other hazards, such as crystalline silica ("silica") are also prevalent in foundries, particularly those that use sand casting methods. For crystalline silica, OSHA has conducted an analysis of exposure levels and control methods similar to this analysis for beryllium. There are many similarities, including the elevated exposure levels reported for in foundries for both contaminants relative to the levels in other industries. Most of the affected job categories can experience exposure to both beryllium and silica. Some of the same controls methods available for one of these contaminants will also help control the other. However, because the sources of beryllium and silica exposure are different, several job categories require different controls to limit the beryllium or silica exposures of foundry workers. For example, furnace operators exposure to silica tends to be modest unless they handle silica-contaminated charge metal (e.g., foundry return scrap) or repair furnace linings. In a facility that casts beryllium alloy, however, these same furnace operators can have notable exposure to beryllium. In addition to being present as a contaminant on charge metal, substantial amounts of beryllium fumes or dust can be released during every process involving the molten metal. For these reasons, the control methods appropriate for beryllium exposure reduction overlap with, but are not identical to the controls used for silica. Because OSHA's levels of interest for beryllium (0.1 $\mu g/m^3$ to 2 $\mu g/m^3$) are approximately 10 to 1,000 times lower than the silica levels OSHA considered (25 $\mu g/m^3$ to 100 $\mu g/m^3$), more substantial control measures are required to manage the beryllium exposure levels of workers in some job categories.

Molder —Baseline conditions/controls: Baseline conditions for molders in sand-casting foundries typically include use of reclaimed sand (NIOSH, 1985). Molders perform dry brushing and sweeping of molds and work surfaces and occasionally use pneumatic grinders or compressed air for cleaning. Ventilation is usually available for sand reclamation and sand handling equipment, although the systems may be poorly designed or ineffectively maintained (ERG, 2003a). General ventilation is typically available in the mold-preparation and pouring areas. Even in foundries that have installed substantial local exhaust ventilation, the plant-wide ventilation is not sufficiently balanced to prevent contaminants from migrating between areas of the foundry (CCMA, 2000).

Molders who handle and maintain reusable molds usually perform basic cleaning and conditioning (dry sweeping, applying surface preparations) in the pouring area where the mold is used (CCMA, 2000; Corbett, 2005b). These workers sometimes transport the molds to a special work area for additional care such as grinding and refurbishing (associated with median exposure levels of 0.05 μg/m^3) (see Section 3-Beryllium Production). However, based on the exposure levels reported for this job category (median 0.85 μg/m^3), ERG judges that molders do not typically use a dedicated, ventilated work area and more frequently work on molds where ever is most convenient (probably the pouring line), using ventilation available at that location. This ventilation would typically not be specifically intended for the purpose of mold maintenance.

All the results for molders identified by ERG are from OSHA's IMIS system, which includes no process or control information. Therefore, ERG is unable to determine the exposure level associated with baseline conditions. Nor is ERG able to confirm that molders in sand casting foundries and facilities using permanent molds are similarly exposed. Additional information regarding the process, work conditions/controls, and exposure levels of both types of molders would allow ERG to define this group more precisely, or divide it into two job categories if more appropriate. In the interim, and in the absence of other information, ERG suggests that the median exposure level for molders (0.85 μg/m^3) serves as an adequate surrogate for the baseline exposure level. If more specific or efficient controls were commonly in use, ERG estimates that exposure levels for this job category would be closer to the median exposure for pouring operators (0.1 μg/m^3) or grinding/finishing operators (0.2 μg/m^3) – who either work nearby or frequently perform generally similar tasks.

Molder —Additional Controls: The estimated baseline exposure level for this job category is 0.85 μg/m^3. Additional controls will be required to reduce the exposure of most molders to levels of 0.5 μg/m^3 or less.

Casting processes with reusable molds (e.g., die casting) can be relatively clean, with a minimum amount of oxide produced (Corbett, 2004). Oxide formation is particularly low with direct chill (DC) casting methods currently in use by some foundries, which use a (water) cooling jacket surrounding the mold to reduce the casting surface temperature rapidly (within seconds), before oxide can form (Corbett, 2004; ERG, 2003). Even so, oxide deposits can develop on molds and molders require local exhaust ventilation to minimize exposures during cleaning.

Anecdotal evidence describes a beryllium exposure result well in excess of the current PEL (2.0 μg/m^3) obtained for a foundry worker who used a pneumatic grinder to remove a beryllium oxide deposit from a mold without local exhaust ventilation (Corbett, 2004). In contrast, a beryllium producer reports that the majority (71 percent) of results were 0.1 μg/m^3 or less (median 0.05 μg/m^3) for workers who reconditioned molds and dies using the following controls (see Section 3 – Beryllium Production) (Corbett, 2005b)[3]:

- HEPA vacuuming molds before handling;
- wet wiping molds before handling;
- transporting molds to special work zone away from the pouring area; and
- using dedicate workbenches with operator-positioned exhaust trunk for grinding on molds with hand-held grinder/polisher.

The specific benefit of HEPA vacuuming and wet wiping molds before handling them is not known. However, a report of lead abatement methods suggests that using wet scraping methods and a HEPA vacuum can reduce airborne exposure levels during lead abatement activities by 75% compared to dry scraping and sweeping (reducing lead exposure levels to 25 μg/m^3 from 100 μg/m^3) (Sussell, 1999). Although the processes are not precisely equivalent, ERG hypothesizes the use of HEPA vacuum and wet-cleaning methods accounts for a similar percentage of molders beryllium exposure levels. Thus, workers who do not HEPA vacuum and wet wipe the molds might have exposure level that are 4-times higher (the inverse of a 75 percent reduction) than workers who do pre-clean molds in this manner. This suggests that the majority of molders who do use special workbenches and exhaust trunks, but *do not* use HEPA

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[3] The percentage of beryllium in the beryllium producer's castings can be substantially higher (5 percent or more) than is typical of aluminum and copper foundries (2 percent or less, and often below 0.5 percent)

vacuum and wet-cleaning methods could experience median exposure levels in the range of 0.4 μg/m^3, which is 4-times higher than the 0.1 μg/m^3 level experience by most beryllium production workers who also employ exhaust trunks at special workbenches and *do* use such methods to pre-clean molds.

This scenario just presented demonstrates that most molders exposures could potentially be reduced from the estimated current baseline (0.85 μg/m^3), to a level of 0.5 μg/m^3 or less, through the use of dedicated workbenches and operator-positioned exhaust trunks for mold maintenance work. Furthermore, by also pre-cleaning the molds using HEPA vacuums and wet-cleaning methods, the exposure levels of most molders could be reduced to a level of 0.1 μg/m^3 or less, as has been reported for 71 percent of the mold maintenance workers who use this method.

These same molders could achieve additional reductions in beryllium exposure by improving exhaust ventilation at the dedicated workbenches. For example, use of downdraft tables in addition to exhaust trunks would increase the consistency of the dust control over the benefit provided by operator-positioned trunks alone. Studies have demonstrated that exposures can be reduced by improving local exhaust ventilation and reducing dependence on workers to correctly position exhaust systems. Additionally, Haung et al. (2004) demonstrated that a flanged exhaust duct over a work table provided simulated vapor capture levels by 28 percent, while an improved "wake-controlled" hood design reduced exposure levels by 52 percent. This hood design is open-sided to accommodate large workpieces and is intended to minimize the effects of cross drafts.

Local exhaust ventilation can also be installed at the mold position to help control beryllium released during mold cleaning. Specifically, local exhaust ventilation is used by some foundries to control other hazards associated with mold release agents. CCMA reported on a centrifugal casting foundry (Case History Foundry D) that was implementing improved local exhaust ventilation the at the centrifugal mold cleaning position when it was discovered that the crystalline silica mold release agent contributed to workers' silica exposures (CCMA, 2000).

If a sand-casting facility finds that reclaimed granular media previously used to cast beryllium alloy is an ongoing source of beryllium dust, the facility has several options for eliminating this exposure of molding operator exposure. First, the foundry can avoid reclaiming granular media used to cast beryllium alloy. Disposing of media rather than reusing it will virtually eliminate the media as a source of possible exposure. [Note: In some regions low levels of naturally occurring beryllium contamination may occur in certain granular media – however, the percent beryllium content are fractional. ERG estimates that molder exposure from this source would be substantially lower than occurs during abrasive blasting with the equivalent media. This has been shown to be the case for other air contaminants, such as crystalline silica, which generates exposure levels during silica sand blasting that are routinely thousands of times greater than the maximum values reported for molders using silica sand.]

As a second option, some foundries where granular media is a source of beryllium exposure for molders might be able to switch to other non-sand casting methods that both eliminate the granular media and reduce surface oxide formation. While this control method would be suitable for some types of castings (e.g., simple shapes), non-sand casting methods will not be appropriate for some alloys and more complex casting shapes.

The beryllium exposure levels of molders who spend time in the pouring area will be decreased to the extent that pouring operator exposures are reduced. Until such a time as exposures during the pouring operation can be completely controlled, molders should avoid working in the pouring area when fumes or beryllium dust could be present –during pouring, initial phases of casting cooling, and tundish refurbishing (see the job category for furnace maintenance workers).

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 fume) may be spread through a facility 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 elements (CCMA, 2000).

Results for molders obtained between 1994 and 1999 in two copper alloy and bronze foundries (Case Histories A and B) indicated personal breathing zone (PBZ) lead ranging from 20 to 90 percent of the permissible exposure limit (PEL) for lead of 50 $\mu g/m^3$ (CCMA, 2000).

Industry consultants conducted a detailed ventilation assessment in one of these foundries (Case History A), revealing that :

> *The ventilation in this foundry was predominantly exhaust-driven. Because of the negative pressure created by the local hoods and several roof ventilators, air was induced into the casting department through openings behind the furnaces. The induced supply air swept any fugitive fume emissions from the melting and ladle filling operations and moved them toward shakeout, pouring, and molding, in that order. This cross-contamination pattern probably explains why the shakeout operators and molders were exposed as they were. The molders were downstream of both the furnace and the pouring operations in a very stagnant part of the facility* (CCMA, 2000).

At this foundry (Case History A), where the majority of castings contained 81 percent copper and approximately 8 percent lead, the lead exposure of furnace tenders and pouring operators were 2 to 10 times higher than the levels associated with molders (or 1 to 5 times the OSHA PEL for lead). The cadmium exposure levels for pouring operators and furnace tenders rarely approached the cadmium PEL of 5 $\mu g/m^3$, but were approximately 10 (or more) times the cadmium results associated with molders (two results of 0.22 $\mu g/m^3$ and 0.37 $\mu g/m^3$) (CCMA, 2000). This example demonstrates the effect that improper balance in foundry ventilation can have on the metal exposure levels of molders. However, due to differences in an alloy's metal content, melting points, and oxide generation rate, it is not possible to infer that airborne beryllium levels would be at the same concentration as are measured for cadmium (or any other metal).

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 fume at the points where it is generated and balances all (local and general) air exhaust and supply systems in each work area to minimize cross contamination. Initial and routine system testing and air monitoring point to areas where improvements or maintenance are needed. One of the system's authors goes on to note that "Cross-contamination can be virtually eliminated by establishing zones of balanced ventilation" (Scholz and Liellom, 2000). Elimination of cross-contamination will also virtually eliminate (to levels less than µg/m^3) airborne contamination from other foundry areas as a source of beryllium exposure for workers in the molding area.

Molder—Conclusion*:* Over 80 percent of all molders currently achieve beryllium exposure levels less than 1.0 µg/m^3. The vast majority of these, who work in mold making areas remote from the furnace and pouring departments, are likely to achieve levels of 0.1 µg/m^3 when other job categories are controlled to a similar level and by avoiding reclamation (reuse) of beryllium-contaminated granular casting media. Alternatively, in addition to avoiding reclamation of granular casting media, sand-casting foundries can balance facility ventilation systems to eliminate cross-contamination of the molding area from other foundry spaces.

Furthermore, ERG estimates that the exposure level of most molders who clean and maintain permanent molds (assumed to include the 20 percent of molders currently exposed to levels between 1 and 2.2 µg/m^3) might be reduced to levels of 0.1 µg/m^3 or less by consistently using HEPA vacuums, wet-cleaning methods, and local exhaust ventilation (flexible trunks) at dedicated workbenches when maintaining with the molds. Seventy one percent of mold maintenance workers using this method achieved exposure levels of 0.1 µg/m^3 or less. The addition of downdraft or other booth-based ventilation would likely increase the percentage of molders who achieve this level.

Material handler—Baseline conditions/controls: Material handlers typically operate open cab cranes and forklifts (ERG, 2003; OSHA H054A). 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, 2003; OSHA H054A).

Material handlers also assist with manual work in foundry departments where process ventilation exists to some extent, but is not 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, 2003b). This work would be conducted in the vicinity of the furnace hood (or even a charge bucket heating hood), but with no ventilation specifically applied to the charge transfer operation (see furnace operator job category).

A material handler who operated a crane from an open cab in a beryllium alloy casting facility experienced a full shift exposure of 0.93 $\mu g/m^3$. While ERG does not have additional information that would confirm the validity of this value as the baseline level for the job category, ERG judges this result to better represent the exposure of material handlers in relation to work with their own equipment than does the other available value (for a forklift operator who spent considerable time assisting with other tasks and used a cutting saw during the shift).

Material handler—Additional Controls: The beryllium exposure levels of material handlers will decrease substantially 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. Until such measures are introduced, material handlers should minimize entry at peak periods of exposure in areas where exposure is difficult to control, such as the furnace area during dross skimming.

Housekeeping: Plant-wide diligent housekeeping and migration control efforts will also 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 can be disturbed by passing vehicles, including forklifts, trucks, and in-plant tractors and rail transport equipment. In a separate analysis of a different contaminant, ERG identified numerous instances in several industries where poor housekeeping contributed to the crystalline silica exposure of material handlers driving on dusty surfaces (2003a). Because both substances are components of dust in contaminated areas, ERG judges that the effect of poor housekeeping has a similar effect on the beryllium exposure of material handlers. A combination of controlling other job categories to a similar level and increasing housekeeping to eliminate settled dust should reduce material handler exposures to levels well below the ranges of interest.

Process enclosures: 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 process 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 the 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: Operator cabs on equipment such as forklifts and cranes can help reduce the beryllium exposure level of material handlers. A 1996 NIOSH report of a lead smelting facility demonstrated an 80 percent reduction in lead concentrations inside the cab compared to outside the cab on a front-end loader (NIOSH, 1996). During raw material storage operations the protective value of the cab was even greater, providing 95 percent reduction. NIOSH obtained these values at a time when visible dust was noted in the cab and another data collection effort indicated that the dust in the cabs contained lead. Exposure reduction levels would likely have been lower if cabs had been cleaned and NIOSH recommended cabs receive a thorough cleaning (using wet methods) after each shift.

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). 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 protective factors of 43 and 16 for the two cabs, indicating that exposure reductions in the range of 94 percent to 97 percent are possible for these fine particles. Greater protection factors were reported for larger particles (greater 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."

In another recent report on cab enclosures, Cecala et al (2005) measured an average cab efficiency of 93 percent for respirable dust (measured inside and outside the cab) during active operating conditions at an earth-drilling site. The operator opened and closed the door several times, which contributed to the dust inside the cab.

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. In this example, 230 cubic feet per minute (CFM) of makeup air was provided to an 80 cubic foot (ft^3) cab (NIOSH, 2000 - Case 07). Although the cab operator experienced crystalline silica exposure (for reasons that are not clear), this NIOSH report offers just one of several example of how cabs can be modified. Cecala et al (2005) also made modifications to an earth drill that included adding a pressurization system that provided 70 CFM filtered make-up air (outside air) to the 45-ft3 cab. The system raised the cab pressurization from 0.005 inches of water to 0.1 inches of water and also provided "about 1½ filtered air changes to the enclosed cab every minute" through a near-respiratory quality electrostatic filter with a rating of 97 percent efficiency for test particles of 0.3 μm. An electrostatic filter was selected because it provided less resistance (restriction per unit area of filter) than a traditional mechanical filter. Cecala further improved the cab by disconnecting the original floor-level heater and installing a ceiling-level combination A/C and heater unit after the investigators found that the floor-level heater greatly increased dust concentrations inside the cab, perhaps by disturbing dust on the floor and the operator's boots. It was this cab that achieved the previously mentioned 93 percent average reduction in respirable dust (when operated without the original floor-level heater) (Cecala et al., 2005). In this case, the modifications cost approximately $3,200 plus an additional 40 man-hours to change equipment and seal/inspect the cab.

To calculate the benefit such a cab would offer foundry material handlers, ERG calculated that a 90 percent reduction (rounding down from the exposure reductions reported by most authors) in the 0.93 μg/m^3 value offered as the baseline exposure level for this job category would result in an exposure level of 0.093 μg/m^3 (or less than 0.1 μg/m^3).

Automation: Many manual processes with which material handlers assist other foundry departments can be automated. For example, the material handler at ERG Site 7 assists other workers in loading the furnace charge manually (ERG, 2003b). This process is performed automatically using a fully-enclosed conveyer at (Case History) Foundry E (CCMA, 2000). Such a system would all but eliminate the involvement of the material handler in the process.

Work practices: Modified work practices can have an impact on material handler exposure. For example, raw material/charge deliveries might be timed so that material handlers or overhead crane operators approached 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 deliver large castings to shakeout areas should move out of the area before vibratory equipment is activated. Material handlers should not linger in areas where exposure is incompletely controlled.

Material handler—Conclusion: The extremely limited available information suggests that the current baseline full-shift beryllium exposure levels for material handlers could be 0.93 μg/m^3. ERG estimates that most material handlers will achieve exposure levels of 0.1 μg/m^3 or less when exposure levels of other job categories are reduced to an equivalent level and at the same time by improving housekeeping to minimize the presence of settled dust in the facility and in the cab of any material handling equipment.

Where exposure levels continue to exceed this level (including in facilities where other job categories continue to exceed 0.1 μg/m^3), ERG estimates that material handlers can still achieve this level through consistent use of fully enclosed, sealed, pressurized, and air conditioned operator cabs for most. Such cabs routinely provide the operator with better than 90 percent reduction in dust exposure levels (Cecala et al., 2005; Hall et al, 2002; Haney, 2000). A 90 percent reduction to the baseline exposure result of 0.93 μg/m^3 would bring the beryllium exposure level of material handlers down to 0.093 μg/m^3.

Furnace operator—Baseline conditions/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 under environmental initiatives. These systems are not necessarily in optimal working condition or of a suitable design to minimize worker exposure, but may have been improved from the original intend of capturing heat. Where furnace ventilation systems were described for non-ferrous foundries by NIOSH, ERG, and CCMA, few of the systems were fully effective (designs did not incorporate adequate features for worker protection) (NIOSH, 1976; ERG, 2003b; CCMA 2000). Most foundries make a minimal effort, if any, to control exposure from collected dross and/or charge preparation activities (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 with adequate frequency or efficiency to eliminate accumulations of beryllium-containing dust (ERG, 2003b). Therefore, ERG considers baseline controls to include some form of local exhaust ventilation (such as a slotted plenum), which provides somewhat improved worker protection over traditional canopy hoods. Other baseline controls include an industrial vacuum system, which is used inconsistently as part of a modest housekeeping program. Furnace operators also typically use some form of dross collection receptacle, but without dedicated exhaust ventilation. Nor is exhaust ventilation typically available for furnace charge preparation or charge bucket heating activities.

The modest number of individually reported exposure results available to ERG include several that might represent baseline conditions (ERG, 2003b; NIOSH, 1976). Most of these, however, are several times higher than the median level, suggesting that the situation was atypical of foundries in general (for example operators could have performed additional activities such as furnace relining, addressed here in the maintenance operator job category, or these results might be associated with an increased reliance on poorly performing canopy hoods, as at ERG Site 7).

In the absence of additional well-documented exposure results, ERG judges that the lowest of the results obtained by NIOSH best represents the baseline exposure level for furnace operators. Thus, the preliminary baseline exposure level is 0.69 $\mu g/m^3$. This judgment is based on the assertion by NIOSH that all dust and fume producing activities were ventilated at this facility, but that “where engineering controls existed, they were inadequate, considering the toxicity of the contaminant” (NIOSH, 1976). Other, higher results were also obtained at this facility, but again, they exceed the levels experienced by most furnace operators to the extent that they cannot be considered to represent the baseline.

ERG acknowledges that many years have passed since NIOSH obtained the designated baseline air sample. ERG notes that this baseline level is preliminary until such time as additional, more recent information becomes available.

ERG also acknowledges that few results for furnace operators are in the range of the estimated baseline level. However, the little information associated with the lower results (0.2 $\mu g/m^3$ or less) suggests this level can be achieved through use of furnace mounted hoods and use of efficient controls for metal fume and dust throughout the facility, as was the case in Case History D (CCMA, 2000). Yet other information from other foundries described in the same reference, and from ERG’s Site 7, suggest this type of control is not widely used and cannot be considered as a baseline condition (CCMA, 2000; ERG, 2003b). Furthermore, the numerous results above the baseline level appear to represent a range of conditions and include large variations in exposure level even within the same facility, including in the foundry where the provisory baseline level was obtained. ERG argues that this baseline result is better associated with the upper half of the bimodal distribution of furnace operator results. ERG selected the lowest level in that range to acknowledge that half the available furnace operator results fall below this interim baseline level.

Furnace operator—Additional Controls: The preliminary baseline beryllium exposure level for furnace operators is 0.69 μg/m^3. Furnace operators will require additional controls to achieve beryllium results of 0.5 μg/m^3 or the lower levels of interest. Additionally, it is important to note that a substantial number of furnace operators (39 percent) experience exposure levels well in excess of the current beryllium PEL of 2.0 μg/m^3. Although the available information is inadequate to confirm the reasons for these elevated exposure levels, ERG finds that some of the highest results are associated with furnace operators who performed extensive dross skimming and other furnace tending activities under a canopy exhaust that pulled fume and dust from dross skimming through the workers' breathing zone. Additionally, the operator with highest exposures also conducted pouring tasks – which can contribute elevated peak exposures.

Particular challenges associated with reducing the exposure levels of furnace operators include the high temperatures in and around furnaces (which render impractical many traditional materials and designs for engineering controls or automation), the frequent need for furnace operators to work at the furnace edge, and handling dross and dross receptacles (Corbett, 2005a).

To reduce most furnace operator exposures to levels of 0.5 μg/m^3 or less, furnace operators will need to implement several control measures:

- Installing local exhaust ventilation on the dross receptacle;
- Improving local exhaust ventilation on furnaces;
- Installing operator's booths pressurized with filtered air; and
- HEPA vacuuming or otherwise cleaning clothing when exiting the furnace area.

Dross receptacles must be fitted with exhaust ventilation. A beryllium producer designed and installed a *ventilated dross collection* tray that holds several scoops of dross removed from the furnace. When the tray is full, the operator activates a control that withdraws the dross tray into a ventilated enclosure and dumps the tray contents into a barrel (also under exhaust ventilation). The tray is then extended from the upper enclosure, ready to be refilled (Corbett, 2005a).

Foundries will also need to improve local exhaust ventilation on furnaces to improve fume and dust capture and to reduce the influence of cross drafts (CCMA, 2000). A foundry casting copper-based alloy, 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 skimmed dross and the associated scoop constantly would be held under exhaust ventilation as they passed between the furnace mouth, the dross receptacle, and the scoop storage area. Although no metal air sampling results are available for this system, studies of other equipment have demonstrated the effectiveness of circular or semicircular slots at the mouths of process containers such as bag dumping receptacles (bins and totes), ball mills, and mixing vats. Iwasaki and Ojima (1997) provide details for designing a circular hood which, when compared to the uncontrolled situation, reduced chromic oxide dust by 96 percent in the vicinity of mixing vessel mouths. The measurements were made while the chromic oxide was being introduced into the vessel, when the falling dust caused turbulence in the vessel and displaced air through the vessel opening. ACGIH (2001) offers several designs for circular slot ventilation systems. The beryllium production industry also uses slotted ventilation hoods around induction furnace openings

Furthermore, furnace operators must be provided with *control booths equipped* with air conditioning and high efficiency particulate air (HEPA) filters (99.97 percent effective against particles of 0.3 micrometers size). The same principles described for operator cabs (in the material handler job category) will be effective for furnace operator booths. As a final control method necessary 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 vacuum or a HEPA-filtered air shower). This step reduces the extent to which clothing continue to contribute to worker exposure as they move to other, possibly cleaner areas. Additionally, the step will reduce the spread of beryllium to other facility areas.

The effectiveness of this combination of controls (improved ventilation at the furnace, ventilated dross collection receptacles, operator's control booth, and cleaning clothing after spending time in the furnace area) are demonstrated by results achieved by a beryllium production facility for induction furnace alloy casting operations (working with 0.1 percent to 2 percent beryllium in alloy). Using these controls, the median exposure level of furnace operators involved in beryllium production is 0.5 μg/m^3.

Other controls will be required to help furnace operators achieve the lower exposure levels of interest.

Furnace-mounted exhaust hoods: Ventilation exhaust hoods located at any distance above the furnace are subject to air disturbances and cross currents that render them less effective. These furnaces hoods also make it possible for workers to lean over the furnace, placing their breathing zone between the source of fume and the exhaust hood.

Several alternative hood designs are readily available, although some require modifications to, or even replacement of the furnace. A centrifugal casting foundry (Case History Foundry D), which casts both ferrous and non-ferrous alloys, uses furnace-mounted exhaust hoods. This type of hood eliminates 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 limit of detection (in this case 0.2 μg/m^3). ACGIH (2001) offers a design for an enclosing induction furnace melting hood (VS-55-07). Foundries that do not perform extensive dross removal might also achieve this level, but ERG anticipates that this type of hood would present a challenge to facilities casting high-purity beryllium alloys.

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, ERG 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 fume and dust while providing access to the furnace. At the same time, to better capture fume 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. ERG 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 local exhaust ventilation (CCMA, 2000; Corbett, 2005a). 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, 2002–EPHB 233-133c; Huang et al., 2004; Heinonen et al., 1996).

Preventive maintenance on the furnace and ventilation system is a critical component of worker protection. A continuous maintenance program, including frequent inspections, is necessary. NIOSH visited a foundry (Case History 11) that found it was important to check the furnace cover seal seat after each charging to ensure 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, 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, might further reduce furnace operator exposure levels. For example, current exposure levels at with beryllium production furnace operations are associated with problems such as overfilling the specially designed dross tray (adding more scoops than the tray will hold), thus preventing the tray from retracting properly (Corbett, 2005a).

An additional work practice challenge involves overfilling the dross collection barrel (in the ventilated enclosure) before changing the barrel. Employees of the beryllium production industry reportedly find it difficult to predict when the barrel is full. These problems could be eliminated by enforcing strict policies on work practices such as dross tray filling and barrel filling. A level indicator (mechanical or optical) to help workers determine barrel fullness could be installed to aid the process. As indicated in Section 3 - Beryllium Production, work practice enhancements might achieve an average exposure reduction of 32 percent. A 32 percent reduction in the 0.5 μg/m^3 exposure level would result in a median exposure level for furnace operators of 0.34 μg/m^3, but this control alone would not necessarily reduce exposures to the next level of interest (0.2 μg/m^3 or less).

To meet this next lowest level of interest, it might be necessary to eliminate manual dross skimming and dross barrel changing by automating these processes. Dross barrel changing could 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 the barrel exterior before removing the dross barrel from the ventilated enclosure.

Automating the dross skimming process presents a greater challenge and the feasibility of this technology needs to be investigated. However, two induction furnace manufacturers contacted by ERG 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 furnace dross skimming is a “sensitive” task, requiring the correct amount of hand pressure during the rubbing and scraping. If not performed correctly, molten metal could become superheated and/or the refractory lining could be damaged (resulting in furnace explosion). Given the potential safety issues, furnace manufacturers suggest that employers might be reluctant to automate the dross removal process (Pillar Induction Company, 2004). 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 USA, 2004). By completely eliminating both manual dross barrel changing and manual dross skimming as a source of furnace operator exposure, ERG estimates that furnace operators could achieve exposure levels of 0.2 or less µg/m^3. ERG was not able to obtain exposure information for this combination of processes because these methods are not currently in use.

Another option for reducing (but not eliminating) manual dross skimming involves prevention of dross formation. Dross is formed by impurities in the metal with which the furnace is charged and by oxygen (in air) contacting the hot metal surface. Increasing the cleanliness of the molten metal helps minimize dross formation. Another means of reducing dross/oxide formation is using 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. Manufacturers who heat treat beryllium alloys as part of the annealing process often do so in an inert atmosphere to minimize oxide production on the surface of the alloy (Corbett, 2004). Inert atmospheres include an evacuated chamber (oxygen sucked out, creating a vacuum), or alternatively, a chamber or blanket of an inert gas, such as argon or nitrogen, which displaces air at the molten metal surface. The oxygen level can be reduced from the usual 21 percent in air to 1 percent in the inert gas) (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 (Corbett, 2005a; Beryllium Casting Facility A, 2005; Air Products, 2005).

The NGK Company (Japan) reports success with this method (Corbett, 2004). That company, however, did not respond to an inquiry. Other attempts at inert gas layering have had mixed success and not 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, facilities that use this method may need to spend time modifying the ventilation system and balancing exhaust rate/exhaust point to maximize heat removal 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 assist foundries in achieving the optimal equipment configuration for excluding oxygen while conserving inert gas supplies (Air Products, 2005). At this time, however, these services do not evaluate employee exposure as one criteria for a satisfactory design.

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 will need to conduct both processes under local exhaust ventilation. Although not widely used, such systems have been in use for many years. In 1978 NIOSH described a gray iron foundry (Case History 9) that used a 10,000 CFM exhaust system to provide local exhaust ventilation first at the point where the charge bucket was filled, then at the charge pre-heater hood. Dampers were used to divert the entire air flow to the first hood used in this sequential process, then to the second hood (NIOSH, 1978). Much of the process was automated at this foundry, however the principles of ventilating the bucket loading and heating steps hold for all methods. In ERG's professional judgment a downdraft table or back-draft 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, are pictured in a review of Case History Foundry G - iron and aluminum casting foundry (CCMA, 2000). As mentioned previously in the discussion of material handlers, CCMA also describes a gray iron foundry (Case History Foundry E) that used an enclosed charge feed conveyer to transfer the charge to the furnace. In figure VS-50-21, ACGIH (2001) 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).

Furnace operator—Conclusion: ERG estimates that most furnace operators can achieve exposure levels of 0.5 $\mu g/m^3$ or less by installing local exhaust ventilation on the dross receptacle; improving local exhaust ventilation on furnaces; installing operator's booths pressurized with filtered air; and HEPA vacuuming or otherwise cleaning clothing when exiting the furnace area. Nearly half of the furnace operator results presented in the exposure profile are already below this value. Additionally, alloy induction furnace operators employed by a beryllium producer achieved used this combination of controls to achieve a median of 0.5 µg/m^3 (see Section 3 – Beryllium Production).

In foundries where alloy purity is less critical, furnace operators can further reduce their exposure level, to levels of 0.2 µg/m^3 or less by using fully enclosing furnace hoods and all but eliminating manual dross skimming. Many furnace operators have already achieve this level, possibly by this method, as did two furnace operators at Case History Foundry D (CCMA, 2000). To the extent that nearly all furnace operators are able to eliminate dross skimming and dross barrel handling, ERG estimates that the exposure level of nearly all furnace operators would be reduced to 0.2 µg/m^3 or less. Until that time, many furnace operators (possibly the 39 percent with exposure levels exceeding the current PEL) would require respiratory protection to reach this level.

Although a number of additional controls are available to furnace operators, and each could reduce one source of beryllium exposure by some percent, ERG judges that even when all methods are combined, it may not be possible for most furnace operators to achieve levels of 0.1 or less µg/m^3, unless, as above, dross skimming and barrel changing are eliminated as part of the control method.

Pouring operator—Baseline Conditions/Controls*:* The median exposure level for pouring operators is 0.1 µg/m^3. This median level suggests that baseline controls for pouring operators include mobile ladle hoods and some form of ventilation on pouring lines. However, the systems might not be maintained in optimal condition.

There is some evidence to support this assertion. Due to the greater toxicity of the alloy components in these foundries, pouring area ventilation in non-ferrous casting facilities is typically designed to provide better exposure control than the pouring area ventilation systems in other foundries. For example, four of the non-ferrous casting foundries (Case History Foundries A through D) for which CCMA described pouring facilities and the ERG site visit foundry all contained some form of local exhaust ventilation in the pouring area (CCMA, 2000; ERG 2003; Corbett, 2005b). Although two of these systems were described as “state of the art,” none functioned optimally due to problems with work practices, inadequate exhaust rates, cross-currents and lack of makeup air, or system design.

There is inadequate information to definitively state the baseline exposure level for pouring operators. Control information is available for just three results, all from one facility. The baseline controls were in place at this facility (Case History Foundry D) (CMA, 2000). However, all three of the results exceed the median value of 0.1 μg/m^3 presented in the exposure profile (although two of the results are below the limit of detection of 0.2 μg/m^3, it is not possible to say they are less than 0.1 μg/m^3). This situation suggests that either the exposure profile does not represent an accurate profile of this job category, or the three results do not accurately represent the typical conditions. Additional, well-documented exposure information for pouring operators would allow ERG to better judge which is the case. Until such information is available, ERG estimates that the baseline exposure level is equal to the median level, 0.1 μg/m^3. Furthermore, ERG judges this to be a reasonable preliminary estimate. More results are at this level (or near it 0.1 μg/m^3 to 0.11 μg/m^3) than any other single exposure level in the exposure profile. Additionally, it is entirely possible that the two values from Case History Foundry D that are below the limit of detection (0.2 μg/m^3) are also in fact in the range of 0.1 μg/m^3.

Pouring operator—Additional Controls: As presented in Tables 5-14 and 5-15, the estimated baseline beryllium exposure level for pouring operators is 0.1 μg/m^3. The baseline controls include a fairly advanced group of control methods, however, there is always room for improvement.

Foundry experts agree that local exhaust ventilation is the primary control measure for pouring operations involving toxic metals, such as beryllium (and lead). “Properly engineered source exhaust, whereby air contaminants are drawn away from the breathing zone, is the only really effective means of air contaminant control. General ventilation, in the form of powered roof ventilation, is used by foundries, which pour and cool molds in open floor areas. This type of ventilation is, at best, effective only in minimizing the excursion of fume, smoke, and gases to other workplace areas. For those employees involved in the actual pouring, general ventilation methods offer little breathing zone protection" (AFS, 1985). "Experience of nonferrous foundries alloying with lead indicates that control to a 50 lead µg/m^3 exposure level warrants that the casting process be ventilated the entire time that the metal is in the molten state. The molten metal cycle includes melting, furnace drossing, tapping into ladles, ladle drossing, hot metal transport, mold pouring, and pigging. Ladle preheaters should be added to the list of casting processes to be ventilated, because of the fume produced by the flames contacting the residual metal in the ladle" (CCMA, 2000).

A number of ventilation system designs for pouring operator tasks are available in the AFS *Foundry Ventilation Manual*, the American Conference of Governmental Industrial Hygienists (ACGIH) Industrial Ventilation – A Manual of Recommended Practice, and a report by CCMA (AFS, 1985, ACGIH, 2001; CCMA, 2000). These documents describe special mobile ventilation hoods that pouring operators can attach to ladles. The hoods connect to flexible ducts extending from overhead trunks (ACGIH, 2001). When the ladle is transported by crane, the duct moves with the crane. Other similar designs are available for ladles pushed on wheeled carts or on tracks. When appropriately designed, ventilated, and fitted to the ladle, these hoods continuously exhaust the ladle as it carries metal from the furnace to the molds. With their enclosing design, these hoods have the potential to collect virtually all fume (and other contaminants) rising from molten metal in the ladle.

The act of filling the ladle during furnace tapping can disrupt ladle-mounted ventilation if a portion of the hood must be displaced to allow workers to pour metal into the ladle. To maximize fume control during furnace tapping, CCMA (2000) advocates the use of close-capture hoods on both the furnace and on the ladle. "During tapping into the ladles, both hoods draw at the fume, from either side of the ladle. Ladle hoods are usually built with a hinged section over the front of the ladle that can be swung away during tapping without disconnecting the ventilation suction" (CCMA, 2000). Most ladle hood designs specify that a source of make-up air should be provided near the furnace tapping position. Not only will make-up air cool and provide fresh air to the worker, but the air will also help balance the direction of air currents, maximizing the ventilation effectiveness while the ladle hood is open.

Ladle hoods in some foundries require access ports that allow the pouring operator to treat the molten metal using methods similar to those used by furnace operators (e.g., skimming dross and inoculating the metal with additives). As a related work practice, pouring operators can perform these tasks while the ladle is still under the influence of both the ladle and the furnace ventilation systems.

Several examples offer insight into metal fume exposure levels when circumstances prevent these controls from working as intended. For example, CCMA (2000) describes Case History Foundry A, a brass (8 to 9 percent lead) sand-casting foundry with "state-of-the-art" local exhaust controls in the pouring area. The system consisted of:

- a canopy hood over the ladle preheating station (a photograph shows a hood approximately twice the diameter of the ladle, positioned about one ladle diameter above the ladle)
- ventilation at the furnace tapping station
- a mobile ladle hood (a photo shows a gap of a few inches between the hood and the ladle)
- a slotted duct above the molds to exhaust fumes after pouring (photograph shows that the slotted duct runs down the centerline of a row of molds, with slots on the side of the duct at about the same spacing as the molds are spaced on their conveyer)

Nevertheless, the lead exposure levels for pouring operators were, on average, the highest in the facility. The CCMA report notes that fumes at this facility appeared to be well controlled throughout the pouring process, except while workers manually moved and positioned the hoist-supported ladle. One noted problem was the speed at which the ladle moved. "Fume could be seen trailing behind the ladle during fast movement, exposing the operator who was behind the moving ladle." The CCMA investigator suggested that the airflow rates be evaluated to be sure that individual hoods in the ventilation system were drawing air at the intended rate (CCMA, 2000). Additionally, the investigator noted that poor ventilation balance in the foundry and the strength and location of other exhaust hoods in the pouring area also may have contributed to pouring operator exposures. Supply air from behind the furnace was drawn past the furnace and into the pouring area, sweeping with it any fugitive emissions from the furnace. Under these conditions, eight full-shift PBZ lead exposure levels for pouring operators, obtained on 8 different occasions between 1994 and 1999, were routinely two to four times the PEL for lead (50 µg/m^3). On three of these occasions, cadmium was also evaluated. The three full-shift PBZ cadmium results for pouring operators were also among the highest of the 16 cadmium results reported for all job categories at that foundry. The cadmium readings ranged from 2.7 µg/m^3 to 4.4 µg/m^3, which approaches the PEL for cadmium of 5 µg/m^3. Together the lead and cadmium results indicate that the combined problems were adequate to overcome this “state-of-the-art” exhaust system and resulted in significant metal exposures for pouring operators.

Lead results for pouring operators were also elevated at a second foundry casting copper-based alloy (5 percent lead). The second foundry (Case History Foundry B) was also described as having a “state-of-the-art” ventilation system in the fume producing areas, including hoods on the furnace, pouring ladles, and ladle pre-heater. In this case, the investigator believed that “draw on the hoods was weak” and that an “inadequate exhaust rate may have been responsible for these high readings” (CCMA, 2000). ERG believes that the findings at these two foundries suggest that, had beryllium been present, beryllium exposures might also have been significant.

In the absence of more definitive results, ERG also believes that those pouring operator beryllium results that exceed the baseline exposure level (0.1 µg/m^3) are likely to be associated with either a ventilation system that is not state-of-the-art, or one that could be so designated – but is not operated in an efficient manner. The decreased in efficiency might either be due to inadequate exhaust rates as seen in the previous two examples from CCMA (2000), and/or due to work practices that contribute to exposure, as was also evident in the first example).[4]

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[4] It is interesting to note that Case History Foundry D, where the three best-documented exposure profile results were obtained, was not described as having a state-of-the-art ventilation system in the pouring area (although several elements of a good system were in place and reported employee exposures to other metals were generally below the limits of detection) (CCMA, 2000). The metals cast at this foundry are described only as “ferrous and non-ferrous.” Results for arsenic, beryllium, cadmium, chromium, lead, nickel, and selenium are reported.

Thus ERG proposes that foundries where pouring operators frequently experience exposure levels exceeding 0.1 μg/m^3 can reduce exposures to that level by the baseline 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.

Pouring operators currently working with the baseline controls can reduce their exposure levels by augmenting the controls with ventilated ladle heaters, as recommended by CCMA (2000). Increased attention to work practices, such as avoiding the path of any fumes that do escape, and to ventilation system maintenance, will also help reduce the exposure level of this group. As noted elsewhere in this analysis, improvements in either work practices or engineering controls can reduce exposure levels by 20 to 50 percent *each*. Using a ladle heater (instead of a torch that applies heat inconsistently and can overheat residual alloy, causing it to fume) will further decrease exposure levels by an undetermined amount. By improving both work practices (fume avoidance) and engineering controls (routine maintenance and testing of ventilation systems), ERG estimates that a larger group of pouring operators (well over the current 51 percent) will achieve exposure levels of 0.1 μg/m^3 or less. Applying the cumulative exposure reduction of at least 50 percent to the results of those of pouring operators (17 percent) with current exposure levels of 0.2 μg/m^3 or less, ERG estimates that nearly 70 percent of pouring operators (51 percent plus 17 percent) would be able to achieve results of 0.1 μg/m^3 or less.

Pouring operator—Conclusion: Based on the exposure profile, more than half (51 percent) of pouring operators already achieve exposure results of 0.1 μg/m^3 or less. ERG's preliminary estimate suggests that most (nearly 71 percent) of pouring operators would be able to reach this level by improving work practices and engineering controls.

Access to additional information regarding the beryllium exposure levels, work practices, and controls associated with beryllium alloy casting foundries would allow ERG to confirm or revise this preliminary estimate.

Shakeout operator—Baseline conditions/controls: Little information is available to describe the working conditions of shakeout operators in foundries that cast beryllium alloys. The foundry that ERG visited (Site Visit 7) did not use a shakeout process. Rather, the casting extruded from the direct-chill mold passed directly to the finishing area on a conveyer fitted with exhaust ventilation.

Some beryllium alloy casting facilities, however, do use sand-casting methods or sand cores that require a shakeout process (Corbette, 2004). According to the *AFS Foundry Ventilation Manual* (AFS, 1985), the shakeout operation is typically one of the dirtiest operations in foundries. The source of exposure is dust released as hot, dry sand molds are agitated, broken, and separated from castings. Shakeout conditions vary dramatically; however, an analysis of crystalline silica exposure in other types of foundries (e.g., ferrous sand-casting foundries SIC 3321, NAICS 331511), the majority of facilities have installed LEV in the shakeout area (ERG, 2003a). Thus, ERG concludes that the baseline condition involves shakeout work performed by an operator positioning castings on enclosed or ventilated equipment that is used to separate sand from castings. However, the report also suggests that enclosure and ventilation are not uniformly effective as used.

The available exposure information for this job category (from IMIS) does not allow ERG to link any beryllium results with specific controls. Of the six exposure results available, three are equal to 0.05 $\mu g/m^3$. In the absence of other information, ERG judges these results to offer the best representation of the baseline exposure level available at this time.

Shakeout operator—Additional Controls: The industry profile suggests that the beryllium exposure level of half the operators is 0.05 $\mu g/m^3$, while the remaining shakeout operators experience exposure levels that are all 0.5 $\mu g/m^3$ or less (median 0.11 $\mu g/m^3$).

In some foundries the beryllium exposure level of shakeout operators could be nearly eliminated by switching to 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) (AFS, 2000). Use of foam or other expendable material for cores (rather than sand) is increasingly popular. When sand is used, it should be collected under ventilated conditions for disposal. Foundries should avoid re-using contaminated sand.

A draft 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, 2003a). 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; ACGIH, 2001). Additionally, to minimize exposure of shakeout operators to beryllium released from other processes, foundries should ensure that local exhaust ventilation systems are coordinated with general ventilation to prevent flow of contaminated air from/between the furnace, pouring and shakeout areas. For the lowest PEL options, consider automating and fully enclose the shakeout (except for very large castings).

The following discussion notes the methods available for reducing shakeout operator exposures to dust containing crystalline silica. ERG believes that dusts containing beryllium will be controlled to an equivalent extent by these methods.

Shakeout enclosures are available as standard equipment or may be constructed by the foundry. The ACGIH ventilation manual (ACGIH (2001)) provides four ventilation designs for open and enclosed styles of shakeout equipment. As an option on all their machines, a shakeout equipment manufacturer offers standard covers specifically to help control dust. This company sells shakeout equipment to handle molds from 0 to 40 tons; however the benefits of enclosure have not been quantified for any size mold (Kinergy, 2000). Although data is 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 μg/m^3 (an average of 33 percent) in 1999 (OSHA SEP Inspection Report 300530029). When contaminated sand is the source of beryllium exposure, a corresponding reduction in beryllium levels might also be assumed for this control method.

NIOSH also supports the use of ventilated enclosures. 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 92-0044-2265,1992).

Rotary sand/casting separators or rotary media drums are an alternative to vibrating shakeout equipment for many small to medium size casting applications (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 metal shapes or “media” (for example, 1- to 2-inch stars) 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, according to one manufacturer, castings are cleaner and require less shot blasting time and less labor during subsequent phases of casting production (Didion, 2003).

“Four-in-one” shotblast 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 the benefits of this enclosed, ventilated design (O’Brien, 2000). Multiple automated processes in one continuous enclosure may reduce the chance of worker exposure during manual handling or from dust escaping at transfer points.

Enclosing the process is preferable to enclosing the operator because dust emissions from shakeout operations have been implicated in cross-contamination dust exposure of other foundry workers (ERG, 2003a). However, enclosing the operator has proven effective in specific circumstances. For example, NIOSH evaluated a foundry that had enclosed an entire shakeout and finishing line in an isolation room (NIOSH ECTB-233-107c, 2000).

Small jobbing foundries or foundries producing very large castings may employ floor shakeout operators who perform manual operations as they upset molds or retrieve castings. According to the AFS foundry ventilation manual (AFS, 1985), this type of floor shakeout operation is most difficult to control. The manual notes that PBZ protection may be required in such cases, but adds, "Exposure is usually short and can be further reduced by transporting the castings and sand to a ventilated station." However, the principles of enclosure and ventilation apply even to large objects and some exposure reduction is possible. ERG proposes that it is also feasible to use portable enclosures and ventilation systems, as well as ventilated tools and, under some circumstances, operator cabs during separation of molds and sand from large castings.

Certain ventilation system designs will be more practical for large castings than others; however, effectiveness of any system will be reduced if used improperly. NIOSH evaluated several scenarios for reducing exposure during shakeout activities involving large castings. In 1998 NIOSH visited a gray iron foundry producing large castings (bathtubs) and reported full-shift or near-full shift (342 to 465 minutes) silica sampling results obtained on two dates under differing conditions (NIOSH EPHB 233-133c, 2002). At this facility, the shakeout stations were fitted with side panels (that provided fresh air to the worker) and exhaust hoods that formed a partial canopy above; the area directly above the process was left open to allow overhead cranes to move the large castings in and out of the area. This ventilation system had been renovated and overhauled in two previous (but unsuccessful) attempts to reduce worker silica exposure levels. In an attempt to control worker exposures, the foundry was considering a third major modification to the system.

NIOSH noted several possible problems with both the existing and proposed systems. First, the hoods were located too far from the contaminant source (the casting) to be classified as receiving hoods for the shakeout process. Additionally, the workers typically did not activate the hood exhaust fans and used man-cooling fans only. On the first sampling day, the silica results for shakeout operators were 140 μg/m³, 290 μg/m³, 320 μg/m³, and 400 μg/m³ under typical working conditions, which included the cooling fans blowing on the workers and exhaust fans turned off. Shakeout operator exposure levels were reduced 30 to 50 percent on the following day, when the cooling fans were turned off and the exhaust fans turned on (as designed). Under these improved conditions NIOSH obtained generally lower results of 80 μg/m³, 200 μg/m³, 210 μg/m³, and 260 μg/m³ during the periods sampled (NIOSH EPHB 233-133c, 2002).[26] Although still well above the current PEL for crystalline silica, these result show that workers can achieve some reduction in exposure levels by modifying work practices to use existing ventilation systems as intended, even when the system is not fully effective. Until poorly performing systems can be improved or replaced, shakeout operators should continue to use the ventilation system that are in place. Fans used for worker comfort can disturb airflow patterns associated with exhaust ventilation systems intended to remove contaminated air.

Next, as part of the same study, NIOSH used computer modeling to test 18 different combinations of ventilation system modifications that might be used to improve dust control at the shakeout stations. The model predicted how well each design would reduce the concentration of airborne respirable dust and also considered energy usage factors. The simulation design results suggested the following points regarding the situation at this foundry:

- 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 be effective for capturing dust.
- The existing overhead exhaust ducts acted as a ceiling that helped provide direction to and improve the effectiveness of the [fresh air] supply jet.
- The overhead exhaust at this foundry did not offer a clear benefit to worker exposure.

Furthermore, the results suggested several ventilation system designs, based on the points noted above, that might reduce respirable particulates (including silica) by a substantial amount.

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[26] These sample results are not included in the exposure profile.

The computer model predicted the five best designs might reduce exposure by 98 percent or more compared to no ventilation. The model also predicted that these designs would offer a reduction of 86 percent compared to the existing ineffective ventilation system if that system were operated at twice the actual air exhaust rate (NIOSH EPHB 233-133c, 2002).[27] 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, ERG concludes that large reductions are possible with appropriately designed ventilation systems, but that more realistic values might include a reduction of 90 percent compared to no ventilation (or 75 percent reduction compared to the existing ineffective overhead ventilation system). Finally, 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.

Wet methods, such as wetting sand as it is removed from the casting might also be beneficial for controlling shakeout operator exposures to silica. A gray iron foundry visited by NIOSH used a water spray for dust control where a vibratory conveyer exited an enclosed shakeout area (NIOSH ECTB 233-107c). At this facility, NIOSH noted that the water spray was sputtering, not noticeably misty, and offered marginal coverage of the dust source, indicating that the spray was not performing optimally. Together, the inefficient water spray and slot ventilation (presumably working as intended), was associated with results of 22 $\mu g/m^3$ to 104 $\mu g/m^3$ for workers in various job categories (shakeout operator, knockout operator, finishing operator) who performed tasks in the area. A well-maintained water spray would likely have improved the dust control in this area. Directional water mist sprays offer effective silica dust control during operations in other industries. For example, NIOSH found that a fine water mist spray reduced the respirable dust exposures of impact drill (jackhammer) operators by 70 to 90 percent during construction work, compared to 50 to 60 percent reduction when jackhammers

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[27] NIOSH notes that this type of modeling (computational fluid dynamics) is best used to help experienced engineers "identify quantitative factors that point the way to an optimal design, and that historical ventilation design experience [should] be used to bring the design to its final form." The model is not intended to predict actual exposure levels.

were fitted with LEV (Echt et al. 2003; NIOSH EPHB 282-11a, 2003). Although one is mobile and one is a stationary activity, impact drilling on concrete and foundry shakeout operations are both high-energy activities that generate substantial quantities of respirable silica dust.

Several cases demonstrate the value of enclosed and ventilated shakeout equipment, particularly when combined with other dust control measures. An enclosed dust collection system (not further described) was associated with full-shift PBZ readings for shakeout operators of less than or equal to 13 (2 readings), 30, and 41 μg/m³. These readings were obtained at a foundry that had made a systematic effort to identify and abate all sources of dust emission with the establishment of a "Sand Leak Team" consisting of an engineer, maintenance and production supervisors, and employees (ERG# MI-1483). Another foundry enclosed the shakeout conveyer and exhausted the enclosure at a rate of 8,000 cfm (for a 10-foot segment) as part of a comprehensive effort to reduce exposure throughout the facility. With the enclosure in place results of 13 and μg/m³ and 37 μg/m³ were obtained for workers in the shakeout area (OSHA SEP Inspection Report 303207518).

A combination of controls substantially reduced shakeout operator exposure levels at a foundry evaluated by OSHA and described earlier in the section on molders. 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 exposure level that was 380 percent of the current PEL (measured as respirable dust containing crystalline silica). 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. Once these changes were in place and the facility had been vacuumed and power washed, shakeout operator exposure levels decreased to 20 percent of the current PEL (Irwin, 2003). ERG estimates shakeout operator crystalline silica exposure levels were reduced from approximately 300 μg/m³ to less than 40 μg/m³ when the facility implemented these controls.[28]

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[28] This estimate is based on the initial (2.93 mg/m³) and post abatement (0.55 mg/m³) respirable dust results (Irwin, 2003). The respective OSHA-calculated PELs (0.7 mg/m³ and 2.04 mg/m³) and the equation PEL = 10/(2 + % silica in the sample), from 29 CFR 1910.1000 Table Z3, were used to determine the percentage of silica in the

Shakeout operator—Conclusion: Based on the limited exposure profile, half (50 percent) of shakeout operators already achieve exposure levels of 0.1µg/m³ or less. ERG judges that another 25 percent of shakeout operators, those currently exposed to levels of 0.2 µg/m³, could reach the lower value by improving the function and maintenance of existing shakeout ventilation systems. A foundry visited by NIOSH found that by simply reducing crosscurrents cause by man-cooling fans and using a foundry ventilation system as designed allowed shakeout operators to reduce exposure levels 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 (NIOSH EPHB 233-133c, 2002). A 50 percent or greater reduction in exposure levels of 0.2 µg/m³ would reduce operator exposures to 0.1µg/m³.

Abrasive blasting operator—Baseline conditions/controls: Abrasive blasting operators in foundries typically use enclosed and ventilated blasting units that are partially or fully automated. As noted earlier, large castings are blasted in a booth or in the open. 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, 2003a). This assertion is also supported by an 8-hour TWA chromium VI result of 1.5 µg/m³ (based on a 387-minute sample) for the operator of a tumbling mill at an iron and steel foundry where the equipment jammed and worker climbed into the mill to correct the problem. (Tumbling mills serve a similar metal cleaning function as abrasive blasting machines). This exposure level was elevated above the normal level (estimated by the investigator to be approximately1.0 µg/m³ of chromium (OSHA HO54A).[5]

The four beryllium exposure results available for abrasive blasting operators in aluminum and copper foundries include two results of 0.101, plus a result that is higher and another that is lower. Thus, among the very limited available results, the exposure level of 0.101 is the most prevalent. No supporting information is available regarding the work conditions associated with

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respirable dust samples. For each results, ERG multiplied the fraction of silica by the respirable dust result to obtain the corresponding respirable silica result.

[5] Note that this example is offered only as an indication of the extent to which the relative exposure levels can be affected when equipment is poorly maintained. Chromium air sampling results cannot be directly equated to the results that might have been obtained for beryllium had this scenario occurred at a beryllium alloy foundry.

any of these exposure results. Until additional information becomes available, for the purposes of this analysis ERG judges that 0.101 μg/m^3 is the most likely baseline exposure value and is associated with the baseline controls.

Abrasive blasting operator—Additional Controls: The preliminary baseline beryllium exposure levels for abrasive blasting operators in aluminum and copper foundries is 0.101 μg/m^3. As was previously described under the discussion on molders, cross contamination between foundry areas can contribute to workers' exposure levels. ERG notes that when the exposures of workers in other job categories are reduced to a similar level, abrasive blasting operator exposure levels are likely to decrease by the very small increment (one-one hundredth of a μg/m^3) needed for most abrasive blasting operators (75 percent) to achieve exposure results of 0.1 or less.

Although they do not appear to be necessary in most foundries, a number of additional control methods are available for abrasive blasting operators.

Improve existing blasting machines: A primary control for abrasive blasting operators involves repairing or improving the blasting machines to seal leaks, augmenting ventilation systems to achieve 500 fpm air flow through all openings as recommended for blasting cabinets by ACGIH or as recommended by the machine manufacturer (ACGIH, 2001; Pangborn, 2003). Blasting machine manufacturers offer programs to rebuild and retrofit these machines and also provide long-term service contracts (Pangborn, 2003). New abrasive blasting machines are readily available from a variety of commercial sources. Even a minor improvement in blasting machine function, such as servicing the fan motor and adjusting belt tension, would be likely add enough benefit to reduce the exposure level of abrasive blasting operators currently at the baseline level (0.101 μg/m^3) to a level of 0.1 μg/m^3 or less.

Sealed blasting machines: To minimize beryllium exposure to levels, foundries might wish to select airtight, batch-style blasting 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, while a well-functioning, completely sealed blasting machine could be expected to reduce exposures to minimum levels. An important feature of a fully enclosed blasting machine (or blast cabinet) is an interlock that prevents the blasting machine door from being opened until the ventilation system has had a chance to exhaust the unit. To achieve these lowest exposure levels, ERG judges that it will also be necessary to control dust release during transport of castings to and away from blasting machines. To this end, conveyers, containers and other equipment used to transport castings to the blasting machines should be enclosed and any openings exhausted with local exhaust ventilation. After blasting with abrasive, castings and the interior of blasting unit should be wiped to remove dust from surfaces (similar techniques are used to minimize dust from machining operations; see Sections 3 – Beryllium Production and Section 7 – Precision Turned Products). Additionally, ERG believes that unless blast media can be thoroughly cleaned, the media should be completely replaced periodically to minimize increasing levels of beryllium contamination of the media. Although ERG has not been able to quantify the benefit of this control for abrasive blasting operators working on beryllium alloys, higher concentrations of a contaminant in bulk samples typically result in higher exposure concentrations if dust from the bulk sample become airborne.

Isolating booths: A control option for manual abrasive blasting of small and large castings involves booths that separate the worker from the casting. For small castings, a well enclosed, ventilated glove-box-style blasting cabinet would serve the purpose. For large castings, available options include linking glove boxes (suitable for long castings). For example, one manufacturer produces ventilated cabinets with internal working compartment dimensions 60 inches wide by 48 inches deep by 36 inches high, which has reportedly been used for abrasive blasting of granite tombstones (Pauli, 2001a; Pauli, 2001b). This size box is interlocked, to prevent operation unless the unit is sealed, and ventilated at 840 cfm. In addition, the boxes are fitted with a dust collector (filter efficiency 99.9 percent for 0.3 micron particles available on some models) and a completely enclosed, ventilated media reclamation system. A larger ventilation system is required when two or more of these cabinets are linked together to provide a larger internal workspace (Pauli, 2001b).

Castings that are larger in more than one dimension would require the roomier, but less effective alternative. Abrasive blast booths that include an incompletely sealed partition to separate the operator from the blasting activity (for example 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 was used by two granite working facilities in which NIOSH conducted control technology assessments (Ruemelin, 2000; NIOSH, 1999-Case 06; NIOSH, 2000-Case 31). NIOSH, however, reported mixed results in these booths' ability to control crystalline silica exposures. Air pressure and turbulence introduced during blasting may limit the reliability of this control option.

Wet abrasive blasting: Wet abrasive blasting or water-jetting methods (adding water to the blasting solution or blasting with high pressure water) offers an additional control option 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 workers had a 33 percent to 44 percent risk of exceeding the PELs for lead (50 $\mu g/m^3$) or cadmium (5 $\mu g/m^3$) when using dry blasting methods (open abrasive blasting and blasting inside 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.[6]

Although wet methods can reduce dust levels substantially, contaminant-bearing mist or water can generated during the processes can contribute to worker exposure levels if these sources are not subsequently controlled. Exposures to heavy metals can occur if dust-laden water from the blasting process is allowed to dry and the dust becomes re-suspended in air. Combining exhaust ventilation appears to be particularly important for controlling air contaminants at the beryllium levels under consideration. The same report just described includes an example that demonstrates the importance of controlling mist and dust during wet blasting methods. In this

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[6] 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). Neither individual results nor information on the metals content of the material (coatings) being removed are available.

case, a consultant conducted air sampling for the Army National Guard while a worker used hydroblasting (abrasive media in water) to remove lead paint from a vehicle trailer. A short-term (115 minutes) PBZ air sample resulted in a lead exposure level of 120 µg/m^3, nearly 2.5 times the PEL for lead. Study results indicate "paint removal was performed inside a building that had no ventilation system to evacuate the air mist" (Industrial Hygiene West, 2000).

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. Because any oxide on the casting will be removed during blasting, and because beryllium oxide often has a greater beryllium content than the base metal, reducing oxide formation might have a notable effect on blasting operator exposure. Casting methods that minimize oxide formation include methods that minimize the contact of air (oxygen) with the hot metal surface, such as permanent mold or die-casting. Particularly effective are methods that cool the casting rapidly to reduce surface temperatures to a level at which oxide does not form as quickly (e.g., direct chill casting). One casting facility visited by NIOSH (a secondary smelter that also cast copper anodes for an electrolysis process) sprayed and submerged red-hot castings in water to cool them as quickly as possible (NIOSH, 1984). 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 contaminant-bearing coatings is a common exposure control method in other industries. For example, workers use chemical strippers to remove lead or cadmium paints from metal that will subsequently be worked (welded, or sanded/blasted to improve the anchor pattern for future paint). In the case of beryllium alloy castings, the base metal would continue to be a source of exposure for blasting operators.

Abrasive blasting operator—Conclusions: As discussed previously, the preliminary baseline exposure level for abrasive blasting operators is 0.101 µg/m^3. Based on the potential for background levels of beryllium to decrease slightly when the exposure levels of other job categories are controlled, ERG estimates that this change will be adequate to reduce the exposure of most abrasive blasting operators (75 percent) by the one-one hundredth of a µg/m^3 needed for this group to achieve exposure levels of 0.1 µg/m^{3}or less.

Grinding/finishing operator—Baseline conditions/controls: Grinding, sanding, cutting and polishing of aluminum and copper castings is most frequently performed as a wet process. Wet methods were used with the saw at ERG Site 7, a copper beryllium casting facility (ERG, 2003b). Housekeeping in and around the grinding/finish workstation, however, is not always thorough or performed consistently.

As with other job categories, little information is available to describe controls associated with the exposure results ERG (2003b) was able to obtain for this job category. The saw at ERG Site 7, for which the best documentation is available, was used briefly by a material handler who worked in all areas of the foundry over the abbreviated shift. No grinding/finishing operator results are available from this site (no worker was dedicated to this task at that small foundry). Supporting information is available for several job categories at Case History Foundry D; however, the narrative does not describe the working conditions of the grinding/finishing operators (two machinists and a grinder/snagger) (CCMA, 2000). Nevertheless, these three results represent ERG's best estimate of the baseline conditions for grinding/finishing operators.

The case history reports the presence of well-considered exposure controls in other foundry areas. This suggests that controls such as wet methods are likely used for the facility's non-ferrous finishing activities. The three full-shift beryllium results for grinding/finishing operators at Case History Foundry D are all less than the limit of detection (0.2 $\mu g/m^3$). As noted in the exposure profile, this value also happens to represent the median result (0.2 $\mu g/m^3$) for grinding/finishing operators. Until additional information becomes available on the exposure level associated with baseline conditions, ERG has adopted 0.2 $\mu g/m^3$ as the baseline exposure level for grinding/finishing operators.

Grinding/finishing operator—Additional Controls: The baseline exposure level for grinding/finishing operators is 0.2 $\mu g/m^3$. These operators will require additional controls to achieve the lower level of interest. Some of the available methods for reducing the beryllium exposure of grinding/finishing operators are specific to foundries (e.g., decreasing casting defects). Other methods are work practice and engineering controls related to the equipment and processes, which are generally similar to the equipment and processes described for machinists (including those operating cutting equipment and hand-held grinding tools) in Section 7 – Precision Turned Products. The following discussion covers the control methods unique to foundries. For a detailed discussion of equipment- and process-based controls, please refer to Section 7.

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 and also reduce the quantity of casting defects that require grinding and/or finishing.

Reduce 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, (e.g., direct chill casting) reportedly offer an added benefit. These rapid cooling methods reduce the molten metal surface to a temperature less than the level where oxides form readily (Corbett, 2004). Direct chill casting, involving a chilled water jacket circulating around the mold, is the method used by ERG Site 7, a beryllium-copper casting facility (ERG, 2003b). The castings at this site were described as "very clean" (Corbett, 2005a). 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 opportunity for oxides to form. A smelting facility visited by NIOSH used this technique to cool cast anodes (NIOSH, 1984).

Reduce 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 appearing in Modern Casting magazine, nine different process-related problems can leave sand tightly adhered to the casting surface (burn-in) and eleven process problems may result in sand embedded as projections into the casting (sand inclusions) (Spada, 2000). Causes range from low (or high) mold moisture or the wrong sand mixture to equipment problems. Once identified, each cause may be eliminated by modifying and improving process quality control (Spada, 2000). Use of refractory mold and core coatings may also minimize burn-in (Coelho and Bharati, 1999). Another option is substitution of one granular media for another that reduces the incident of burn-in. For example, five gray and ductile iron foundries testing a ceramic alternative to silica sand for casting and each reported reduction of burn-in/burn-on during green sand, core, shell, and lost foam casting applications (Carbo, 2000). Of these, one foundry (Number 6) reported an estimated 90 percent reduction in burn-in when it switched to the alternate ceramic media for cores.

Pre-cleaning castings: Most castings may 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, 2000b). 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.

Other control methods for grinding/finishing operators are based on the tools or work practices. See Section 7 – Precision-turned Products for a discussion of these methods.

Grinding/finishing operator—Conclusion: [To be added]

Maintenance operators—Baseline conditions/controls: Based on information from the ERG, NIOSH, and CCMA reports, ERG believes that maintenance operators most typically work with general ventilation only, unless work is performed on equipment that is exhausted. 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.

Maintenance operators—Additional Controls: The baseline beryllium exposure level for maintenance operators is inferred to be 0.10 μg/m^3 – (same as FURNACE MAINTENANCE, SMELTING).

Please see the discussion of furnace maintenance operators in Section 6- Smelting, Refining, and Alloying.

Work practices: Careful pre-cleaning of equipment before maintenance activities can reduce maintenance operator exposure levels. The following example describes procedures in a pharmaceutical firm, another industry that handles highly toxic dusts. A health and safety representative from this pharmaceutical manufacturer described pre-cleaning requirements and noted that the company requires equipment operators to be familiar with specific equipment cleaning and decontamination procedures before the operator is certified to use that piece of equipment. When maintenance or repair is required, the equipment is cleaned (typically by the equipment operator or a housekeeping assistant) to the required specifications before the maintenance operator or service person is permitted to approach the equipment (Pharmaceutical Manufacturer A, 2004).

The pharmaceutical manufacturer's cleaning procedure typically begins by shutting down the equipment (to prevent the release of additional particulate matter). The worker then uses a HEPA vacuum on all surfaces to remove any loose dust. This is followed by a wet wiping step, to remove lightly adhered particles. During and after this cleaning, the local work area ventilation system is operated to capture any particles disturbed during the cleaning. This company sometimes requires surface wipe tests to confirm the level of cleanliness before the equipment can be moved. While product protection is the original basis for this level of cleaning, company health and safety staff indicate that these steps effectively control the exposure levels of workers who subsequently perform maintenance or otherwise handle the equipment. Specifically, these methods reduce exposures to a level for which respiratory protection is not required for workers maintaining equipment that produces pharmaceutical substances with allowable occupational exposure limits in the "micron range" (this facility reportedly does not manufacture substances with occupational exposure limits lower than the approximate range of OSHA's current PEL for beryllium of 2 μg/m^3) (Pharmaceutical Manufacturer A, 2004).

To make the vigorous cleaning process easier, and to encourage meaningful visual cleanliness inspections, the pharmaceutical manufacturer places a priority on acquiring equipment made of stainless steel using "clean in place" designs. That is, equipment designed to be cleaned in it's operating location by the qualified worker, rather than using a design that would have to be transported to an equipment shower room, or shipped to the manufacturer for cleaning (Pharmaceutical Manufacturer A, 2004).

Maintenance operators can also reduce their exposure levels by using administrative controls such as scheduling routine maintenance to avoid times when 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."

Local exhaust ventilation: For most maintenance operators, the primary control might include portable local exhaust ventilation 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. As work progresses around the tundish, however, eventually 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.

A company that provides refractory overhaul services developed a method for installing temporary LEV in a gas-fired furnace. This method is used for complete lining removals, but is also applicable to smaller (patching jobs). The method involves company-built exhaust fans fitted with air filters (three filters of increasing efficiency in series) (Refractory Services Provider A, 2003a). The fans create an air flow pattern in the furnace that pulls fresh air from outside the furnace past the worker's face and removed dusty air from near the chipping point. Workers stretch plastic sheeting as necessary to ensure 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, 2003b). The position of sheeting and boxes might need to be moved as the work progresses to other sections of the furnace. 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 produce (approximately 30 dollars per box, plus the cost of the fan) (Refractory Services Provider A, 2003b).

Providing exhaust ventilation throughout a process, from start to finish, will help maximize control of metal dust and fume (CCMA, 2000). ERG believes this principle holds true regardless of whether the dust and fume are cadmium, lead, or beryllium. Maintenance operators who repair refractory linings benefit from enclosed, exhausted 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 local exhaust ventilation from the furnace or tundish to the receptacle.

V*entilated chipping tools*: The benefits of tool mounted systems for controlling beryllium has been demonstrated for the control of hazardous dusts (such as crystalline silica) in other industries, including the construction and the ready-mix concrete industries. 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 to 60 percent (NIOSH, 2003-EPHB 282-11a). In a separate evaluation, NIOSH showed that this type of LEV system controls dust equally well for larger and smaller chipping equipment. NIOSH collected short-term PBZ samples while workers used 25 or 30 pound jack hammers to chip concrete from inside concrete mixer truck drums. During 90 to 120 minute periods of active chipping, mean respirable silica levels decreased 69 percent (from 970 to 300 $\mu g/m^3$) when the workers used a tool-mounted LEV shroud in these enclosed spaces (NIOSH, 2001-EPHB 247-19). In this study, a combination of LEV and general exhaust ventilation provided additional dust control, resulting in a 78 percent decrease in respirable silica readings. Respirable dust levels decreased by a slightly smaller amount (54 percent) due to a lower percentage of silica in samples associated with shroud use.

Wet methods: Recent studies have also shown that wet dust control methods are effective for controlling respirable dust released during chipping. NIOSH (2003-EPHB 282-11a) investigated a water spray dust control used by construction workers breaking concrete with 60 and 90-pound jack hammers. A spray nozzle was fitted to the body of the chipping tool and a fine mist directed at the breaking point. Using both a direct reading instrument and a high-flow cyclone and filter media, NIOSH collected 10-minute readings with and without the spray activated. Compared to uncontrolled pavement breaking, PBZ respirable dust concentrations were between 72 and 90 percent lower when the water spray was used. The flow rate of 350 milliliters (12 ounces) per minute reportedly dried quickly, without adding a substantial amount of water to the work site (NIOSH, 2003-EPHB 282-11a). Sam and Williams (2000) also reported that a water spray nozzle mounted on a hand-held pneumatic chipper decreased respirable dust approximately 70 percent in the worker's breathing zone. Tool-mounted water spray devices can be manufactured using materials obtained from a hardware store and include a garden spray nozzle, tubing, clamps, and a control valve (Sam and Williams, 2000).

Water spray is also useful for controlling dust associated with cleanup. After chipping, Refractory Services Provider A (2003b) uses a garden mister to moisten refractory debris in the bottom of the furnace. This step helps control dust as the waste is removed from the furnace. Wetting the furnace lining requires an extra step to dry the refractory material before the furnace is brought to working temperature. However, despite this complication, wet methods remain the best option for controlling respirable dusts from high-energy activities such a pneumatic chipping and should be considered when toxic materials are involved.

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: [To be added – same as for smelters]

Housekeeping worker – Baseline conditions/controls: In a draft analysis of crystalline silica in foundries, ERG concludes that housekeeping workers most frequently perform manual cleaning tasks. Additionally, the exposure level of housekeeping workers appears closely related to the general exposure levels in the foundry, and to the specific area where they spend the most time. Where exposures are elevated, the cases presented in the exposure profile suggest that adjacent operations are the primary source of exposure for housekeeping workers, although their own work will likely contribute to their exposure when dry sand is involved. Limited information suggests that central vacuum systems may be available, particularly in the furnace area (ERG 2003b).

[Add housekeeping worker from smelters]

Housekeeping worker—Additional controls: In the absence of specific information on foundry housekeeping workers, and as shown in Table 5-8, the median exposure level for housekeeping workers in an analogous industry (smelting) is 0.3 μg/m^3. Table 5-9 indicates that 100 percent of the exposure levels for these workers are greater than the lowest proposed PEL option of 0.1 μg/m^3. Approximately 62 percent of the exposure levels are greater than 0.2 μg/m^3, and eight percent of the exposure levels exceed 1 μg/m^3. Additional controls will be required to reduce operator exposures. With one exception, the same controls outlined for the housekeeping worker job category in Section 6 – Smelters, Refining, and Alloying – will also apply to foundry housekeeping workers. The exception involves eliminating the use of beryllium-containing scrap or limiting its use to scrap containing a low percentage of beryllium. ERG believes that foundries casting beryllium alloys will not be able to reduce the beryllium content of their raw materials unless the foundry is able to implement a method for reducing dross/oxide formation, which decreases the amount of beryllium available for the finished alloy. Successful implementation of a dross-reduction method, such as inert gas layering, could reduce the background and furnace area beryllium exposure levels of housekeeping workers.

Housekeeping Worker—Conclusion: [To be added – same as smelters]

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Appendix 5A

Individual PBZ Beryllium Exposure Levels By Job Category for Workers in Copper and Aluminum Foundries

Table 5A-1. Individual PBZ Beryllium Exposure Levels By Job Category for Workers in Copper and Aluminum Foundries (SIC 3364, 3365, and 3366)

				Full-shift Results		Less-than Full-shift Results		
				Sample Duration (Minutes)	Concentration ($\mu g/m^3$)	Sample Duration (Minutes)	Concentration ($\mu g/m^3$)	
Source	Sample Year	**Job Category** Job title	Task Description/Comments				Sample period	8-hour TWA
		Molder						
NIOSH, 1976	1975	Molder	Beryllium alloy casting. Local exhaust ventilation reportedly available for all operations where dust and fume generated	382	ND	--	--	--
		Material handler (crane/forklift operator)						
ERG, 2003	2003	Forklift operator	Copper-beryllium direct-chill casting facility. Open-cab forklift, moved raw materials and castings in the furnace and pouring areas, removes large castings from molds, also performed some cutting with a saw.	--	--	252	2.38	1.25
NIOSH, 1976	1975	Crane operator	Beryllium alloy casting. Local exhaust ventilation reportedly available for all operations where dust and fume generated	424	0.93	--	--	--
		Furnace operator (melt/heating operator and assistants)						
ERG, 2003	2003	Furnace helper (day 1)	Copper-beryllium direct-chill casting facility. Assists furnace operator except during pouring.	--	--	265	4.18	2.31
ERG, 2003	2003	Furnace helper (day 2)	Copper-beryllium direct-chill casting facility. Assists furnace operator except during pouring.	--	--	267	1.92	1.07
ERG, 2003	2003	Furnace operator (days 1 and 2)	Copper-beryllium direct-chill casting facility. Oversees melt and pour. Works in office, leaving occasionally to check on melt or take samples, skims dross by hand, sparges melt, controls pour to mold or tundish from a platform.	--	--	532*	14.08*	7.80*
CCMA, 2000	1999	Melter	Ferrous and non-ferrous centrifugal casting. Airborne metals relatively well controlled throughout this facility. Furnace-mounted and mobile ladle exhaust hoods.	452	< 0.2**	--	--	
CCMA,	1999	Melter	Ferrous and non-ferrous centrifugal	415	< 0.2	--	--	--

Table 5A-1. Individual PBZ Beryllium Exposure Levels By Job Category for Workers in Copper and Aluminum Foundries (SIC 3364, 3365, and 3366)								
				Full-shift Results		Less-than Full-shift Results		
				Sample Duration (Minutes)	Concentration (µg/m^3)	Sample Duration (Minutes)	Concentration (µg/m^3)	
Source	Sample Year	Job Category Job title	Task Description/Comments				Sample period	8-hour TWA
2000			casting. Airborne metals relatively well controlled throughout this facility. Furnace-mounted and mobile ladle exhaust hoods.					
CCMA, 2000	1998	Melter	Ferrous and non-ferrous centrifugal casting. Airborne metals relatively well controlled throughout this facility. Furnace-mounted and mobile ladle exhaust hoods.	--	--	350	< 0.2	<0.14
NIOSH, 1976	1975	Furnace operator	Beryllium alloy casting. Local exhaust ventilation reportedly available for all operations where dust and fume generated, wore respirator for portion of shift	391	19.76	--	--	--
NIOSH, 1976	1975	Furnace operator	Beryllium alloy casting. Local exhaust ventilation reportedly available for all operations where dust and fume generated	425	0.69	--	--	--
NIOSH, 1976	1975	Heater-weigher (Remelt/melt and cast area)	Beryllium alloy casting. Local exhaust ventilation reportedly available for all operations where dust and fume generated	427	ND	--	--	--
NIOSH, 1976	1975	Furnace helper	Beryllium alloy casting. Local exhaust ventilation reportedly available for all operations where dust and fume generated	417	0.79	--	--	--
NIOSH, 1976	1975	Foundry operator	Beryllium-aluminum heating and button casting. Local exhaust ventilation reportedly available for all operations where dust and fume generated	--	--	306	25.06	15.98
NIOSH, 1976	1975	Foundry operator Helper	Beryllium-aluminum heating and button casting. Local exhaust ventilation reportedly available for all operations where dust and fume generated	--	--	309	3.33	2.14
		Pouring operator						
CCMA, 2000	1999	Mold sprayer/pourer	Ferrous and non-ferrous centrifugal casting. Airborne metals relatively well controlled throughout this facility. Exhaust hoods mounted on furnace, mobile ladle, and centrifugal caster pour spout.	415	< 0.2	--	--	--

Table 5A-1. Individual PBZ Beryllium Exposure Levels By Job Category for Workers in Copper and Aluminum Foundries (SIC 3364, 3365, and 3366)

				Full-shift Results		Less-than Full-shift Results		
				Sample Duration (Minutes)	Concentration (µg/m^3)	Sample Duration (Minutes)	Concentration (µg/m^3)	
Source	**Sample Year**	**Job Category** Job title	**Task Description/Comments**				**Sample period**	**8-hour TWA**
CCMA, 2000	1999	Plate spryer (casting area)	Ferrous and non-ferrous centrifugal casting. Airborne metals relatively well controlled throughout this facility. Exhaust hoods mounted on furnace, mobile ladle, and centrifugal caster pour spout.	402	< 0.2	--	--	--
CCMA, 2000	1998	Casting	Ferrous and non-ferrous centrifugal casting. Airborne metals relatively well controlled throughout this facility. Exhaust hoods mounted on furnace, mobile ladle, and centrifugal caster pour spout.	440	2.2	--	--	--
		Shakeout operator	<No results available>					
		Abrasive blasting operator						
CCMA, 2000	1999	Blast booth	Ferrous and non-ferrous centrifugal casting. Airborne metals relatively well controlled throughout this facility.	--	--	112	< 0.7	<0.16
		Grinder/sawyer/ sander/finisher						
CCMA, 2000	1999	Machinist	Ferrous and non-ferrous centrifugal casting. Airborne metals relatively well controlled throughout this facility.	410	< 0.2	--	--	--
CCMA, 2000	1999	Machinist	Ferrous and non-ferrous centrifugal casting. Airborne metals relatively well controlled throughout this facility.	415	< 0.2	--	--	--
CCMA, 2000	1999	Grinder/snagger	Ferrous and non-ferrous centrifugal casting. Airborne metals relatively well controlled throughout this facility.	398	< 0.2	--	--	--
NIOSH, 1976	1975	Finish grinder	Local exhaust ventilation reportedly available for all operations where dust and fume generated, wore respirator	384	0.69	--	--	--
NIOSH, 1976	1975	Saw cutter	Local exhaust ventilation reportedly available for all operations where dust and fume generated	422	ND	--	--	--
NIOSH, 1976	1975	Cut-off, swing grinder	Local exhaust ventilation reportedly available for all operations where	--	--	321	15.56	10.41

Table 5A-1. Individual PBZ Beryllium Exposure Levels By Job Category for Workers in Copper and Aluminum Foundries (SIC 3364, 3365, and 3366)

Source	**Sample Year**	**Job Category** Job title	**Task Description/Comments**	**Full-shift Results**		**Less-than Full-shift Results**		
				Sample Duration (Minutes)	**Concentration ($\mu g/m^3$)**	**Sample Duration (Minutes)**	**Concentration ($\mu g/m^3$)**	
							Sample period	**8-hour TWA**
			dust and fume generated, wore respirator					
		Maintenance/Housekeeping workers						
NIOSH, 1976	1975	Furnace repairman	Local exhaust ventilation reportedly available for all operations where dust and fume generated, wore respirator.	426	ND	--	--	--

PZB means Personal Breathing Zone.
ND means beryllium not detected in the sample (limit of detection not reported in NIOSH source document).

* TWA concentration obtained using the same filter to sample two evening work shifts (each less than 6 hours) on consecutive dates. The 8-hr TWA is estimated based on an assumption that the 532-minute 2-shift sample represents two equal 266-minute sampling periods each day: $(14.08\ \mu g/m^3)(532\text{ min.}) / 2(480\text{min.}) = 7.80 \mu g/m^3$. Other PBZ samples collected for coworkers suggest this assumption is valid, but that actual exposure during the two equal periods might have differed from the reported average. Nevertheless, this worker's exposure level would likely have exceeded the current PEL of 2 $\mu g/m^3$ on each sampling day.

** < means the result was less than the presented value, which is the limit of detection.

Appendix 5B

Beryllium Deposited Submicrometer Particle Concentration Results and Discussion for ERG Site 7

Beryllium Deposited Submicrometer Particle Concentration Results and Discussion for ERG Site 7

Particle size, surface area, number of particles, solubility, and the chemical form of beryllium involved may all be relevant to the development of disease. It has also been suggested that beryllium can enter through either intact skin or breaks in the skin to initiate sensitization. Recent studies have shown that particles less than 1 micrometer (µm) in diameter can penetrate intact skin that has been flexed. Therefore, ERG investigators evaluated the presence of these small particles, the deposited submicrometer particle concentration (DSP). The Be DSP represents the airborne concentration of beryllium particles that are of a size that would deposit in the lung and is reported as particles per cubic centimeter of air (p/cc).

Table 5B-1 contains the three personal breathing zone (PBZ) total beryllium and beryllium deposited submicrometer particle (Be DSP) number concentrations for the furnace operator and helper at ERG Site 7 – a beryllium alloy casting facility (ERB, 2003b). These readings represent the workers' entire exposure for the shift, although in this case the shifts were abbreviated - less than 5 hours.

The highest Be DSP (furnace operator) was associated with the highest total beryllium exposure result, the highest average DPS number (all DPS particles), and the highest percent beryllium. It is possible that the additional fume exposure experienced by the furnace operator during pouring could be responsible for these elevated levels. Beryllium (a strong reducing agent) is known to form fume and surface oxides more aggressively than most other metals commonly found in these alloys (Beryllium Casting Facility A, 2005). The furnace operator's increased contact with beryllium fume (a fine particle) might have increased both the average number of fine particles and the beryllium content in this worker's breathing zone. The dust exposure of the furnace helper likely represents some fume from the furnace and the general dust (including carbon particles) described throughout the foundry.

The furnace assistant experienced the lowest Be DSP number reported at this site (1.1 p/cc) on the second sampling day, when the percent beryllium in this worker's breathing zone was the lowest (0.06 percent on day 1, compared to 0.36 percent beryllium on day 2). The DPS fine particle count for the furnace assistant was actually somewhat higher on that second day than on the first day (indicating that the worker was exposed to more fine particles on day 2); however, the lower percent beryllium on day 2 is responsible for the decrease in Be DPS.

Table B-1. PBZ Total Beryllium and Beryllium Deposited Submicrometer Particle Number (Be DSP) Readings of a Furnace Operator and Assistant in a Beryllium Alloy Casting Facility

Facility	Description	Total Beryllium Concentration ($\mu g/m^3$)	Average Be DSP Concentration (p/cc)
ERG Site 7	*Furnace Helper:* Assisted and worked along side the furnace operator except during the pouring process (furnace helper did not participate in the pour). Day 1, 265-minute sample. (0.39% beryllium)	4.18	4.7
ERG Site 7	*Furnace Helper:* Assisted and worked along side the furnace operator except during the pouring process (furnace helper did not participate in the pour). Day 2, 267-minute sample. (0.06% beryllium)	1.92	1.1
ERG Site 7	*Furnace Operator:* Controlled melting and furnace operations from platform at furnace, worked in office. Also collected samples, sparged, and skimmed dross from molten metal. Furnace was fitted with canopy hood. LEV also present on dross receptacle and pouring conveyer. 532-minute sample obtained using the same sampling filters and equipment during abbreviated shifts (of approximately 266 minutes each) on two consecutive days. (1.57% beryllium)	14.08	65.1

[*] Be DSP number reading not determined due to sampling equipment malfunction.
PBZ: personal breathing zone.

LEV: local exhaust ventilation.

Sources: ERG, 2003b