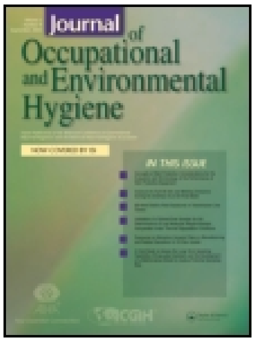

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Industries in the United States with Airborne Beryllium Exposure and Estimates of the Number of Current Workers Potentially Exposed

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Estimates of the number of workers in the United States occupationally exposed to beryllium were published in the 1970s and 1980s and ranged from 21,200 to 800,000. We obtained information from several sources to identify specific industries with beryllium exposure and to estimate the number of current workers potentially exposed to beryllium. We spoke with representatives from the primary beryllium industry and government agencies about the number of exposed workers in their facilities. To identify industries in the private sector but outside the primary industry, we used data from the Integrated Management Information System (IMIS), which is managed by the Occupational Safety and Health Administration, and the Health Hazard Evaluation program of the National Institute for Occupational Safety and Health. We used IMIS data from OSHA inspections with a previously developed algorithm to estimate the number of potentially exposed workers in nonprimary industries. Workers potentially exposed to beryllium included 1500 current employees in the primary beryllium industry and 26,500 individuals currently working for the Department of Energy or the Department of Defense. We identified 108 four-digit Standard Industrial Classification (SIC) categories in which at least one measurement of airborne beryllium was $\geq 0.1\ \mu g/m^3$. Based on the subset of 94 SIC categories with beryllium $\geq 0.1\ \mu g/m^3$, we estimated 26,400 to 106,000 workers may be exposed in the private sector (outside the primary industry). In total, there are as many as 134,000 current workers in government and private industry potentially exposed to beryllium in the United States. We recommend that the results of this study be used to target at-risk audiences for hazard communications intended to prevent beryllium sensitization and chronic beryllium disease.

Keywords beryllium, chronic beryllium disease, exposed workers, exposed workers, industry, sensitization

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Although beryllium was discovered more than 200 years ago, it was not until 1927 that the first beryllium-containing products were manufactured.[1] Beryllium was initially used in military equipment and then in products such as fluorescent lights and neon signs. Due to their strength, light weight, good thermal and electrical conductive properties, neutron-moderating properties, beryllium and beryllium alloys were used in experimental nuclear reactors and the production of nuclear weapons, radar, and other defense applications during World War II and the subsequent cold war.[1] The government demand for beryllium has declined since the end of the cold war because of the decrease in production of nuclear weapons.

Beryllium and beryllium alloys also have been used in consumer products since the middle of the 20th century. However, as certain technologies have evolved and expanded (e.g., the electronics industry), the extent to which beryllium alloys are used has increased. Today, many of the beneficial properties of beryllium alloys in areas such as flexible, noncorroding switch components or connections have made them popular in products like personal computers and mobile telephones. Beryllium is also used in products such as golf clubs and jewelry, where its beneficial properties are not essential or may not justify worker risk.[1,2]

Beryllium is mined as bertrandite or beryl ore, refined through a series of processes, and later sold as pure beryllium metal, alloys containing beryllium, or beryllium oxide ceramics. It is during both refining and subsequent applications that workers may become exposed to particles containing beryllium. Workers who are exposed may develop a sensitization to beryllium via a cell-mediated immune mechanism. A proportion of those who are sensitized also have evidence of chronic beryllium disease (CBD), which is a granulomatous lung disease that resembles sarcoidosis in its clinical features. It can be debilitating and is sometimes fatal. Recent evidence from cross-sectional surveys indicates that 5% to 10% of workers in the primary beryllium industry are sensitized to beryllium; a third to a half of those sensitized also have evidence of CBD.[3,4] The primary beryllium industry includes the mining, refining, and production of beryllium, beryllium alloys, and beryllium ceramics, and manufacture of a limited number of products containing beryllium.

The Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) for beryllium is 2.0 $\mu g/m^3$. Despite the existence of this limit, the exposure level that protects workers from sensitization and disease is unknown, and dermal as well as inhaled exposure may play a role in the development of sensitization.[5,6] Studies have suggested that workers who are exposed to low airborne concentrations can still become sensitized to beryllium and may develop CBD. For example, investigators described 12 cases of CBD, diagnosed in the 1940s and 1950s, among secretaries working in plants or laboratories where beryllium was used.[7] A study at a nuclear weapons facility documented sensitization among those with minimal exposure, including a secretary and a security guard.[8]

A survey conducted in 1992 documented CBD in an employee working only in a nonproduction job at a beryllium ceramics facility.[9] When a subsequent survey was conducted at the same facility in 1998, a job-exposure matrix (JEM) was developed using task- and area-specific measurements of beryllium from relatively short-term breathing zone and general area samples.[3] The JEM was combined with detailed work histories to derive summary measurements of exposure for each survey participant. There were two sensitized beryllium ceramics workers whose airborne exposures were low, with mean exposure < 0.1 $\mu g/m^3$, cumulative < 0.1 $\mu g\text{-yr}/m^3$, and peak < 0.4 $\mu g/m^3$.[3] In each of these examples, brief, high-exposure excursions could have occurred when the individuals were present; however, such occurrences seem unlikely for many of these affected workers.

Individuals with sensitization and CBD have been documented among workers who handle beryllium alloys. Some of these workers are employed in the primary beryllium industry. For example, four new cases of CBD were found in a copper-beryllium alloy strip and wire finishing facility.[4] Workers outside the primary beryllium industry who handle these alloys also may become sensitized to beryllium and develop CBD. In a 1982 Health Hazard Evaluation (HHE), the National Institute for Occupational Safety and Health (NIOSH) documented a case of CBD occurring in a person working at a secondary copper smelter facility where exposures were well below the OSHA PEL.[10] There have also been reports of two cases of CBD in workers at a facility with 2% beryllium copper alloys,[11] and five possible cases of CBD in a reclamation facility that received scrap from electronic, computer, photographic, chemical, and decorative industries that contained beryllium compounds and alloys.[12]

Several surveys have estimated the number of workers exposed to beryllium in the United States. A survey done in 1970 by the U.S. Public Health Service and the Bureau of Occupational Safety and Health estimated 30,000 persons potentially exposed to beryllium in the work force.[13] Between 1972 and 1974, NIOSH conducted the National Occupational Hazard Survey (NOHS) to quantify the number of persons working with different materials, including beryllium and beryllium compounds. This survey of 4645 facilities in 66 different two-digit Standard Industrial Classification (SIC) categories estimated 21,233 workers potentially exposed to beryllium. However, the survey included only urban workplaces, not government agencies or mining operations.[14–16] Using the NOHS as a basis, investigators later estimated that more than 800,000 persons are potentially exposed to beryllium in the workplace.[17] However, the methods used to calculate this estimate are unclear and have not been documented.

The National Occupational Health Survey of Mining enumerated the number of workers exposed to beryl or betrandite in the mining industry. As of 1996, there were only two mines in the United States with a total of 121 workers exposed to beryl.[18] Between 1981 and 1983, NIOSH conducted the National Occupational Exposure Survey (NOES), which was a follow-up survey to NOHS, sampling 4490 facilities in 39 different two-digit SIC categories.[19–21] An unpublished analysis of the NOES data by NIOSH staff yielded an estimate of approximately 14,000 workers potentially exposed to beryllium (personal communication, R. Young, NIOSH, August 2001).

Although the primary beryllium industry is relatively small, there are a number of other establishments outside the primary industry that use beryllium metals, beryllium oxide ceramics, or alloys containing beryllium. For example, the primary producer of beryllium in the United States reported that they had 7000 direct customers worldwide in the year 2001, of which approximately 3200 were located in the United States. Based mainly on a random survey of 5% of their direct customers in the United States, they estimated that 19,376 persons were working with beryllium-containing materials (personal communication, M Kolanz, Brush Wellman Inc., November 2001). However, the survey's list of customers did not include indirect customers such as distributors' customers, equipment manufacturers, and other establishments that work with beryllium. A recent report to members of Congress by the General Accounting Office (GAO) indicated that beryllium has been used or detected in government facilities or the private sector in 45 states and the District of Columbia.[22] Fifteen of these jurisdictions had 11 or more locations where beryllium was used or detected.

We used several approaches to identify industries in the United States with beryllium exposure and to estimate the number of current workers potentially exposed. This is an important step in alerting all workers that handle beryllium-containing materials about the potential risks of sensitization and CBD, and the precautions needed to prevent or reduce exposure.

METHODS

We obtained estimates of the number of workers exposed at the United States Department of Energy (DOE) and Department of Defense (DOD) facilities from government reports and government officials. We spoke with industry representatives to obtain the number of workers in the primary beryllium industry. The specific sources for the DOE, DOD, and primary industry estimates are provided in the Results section.

Outside the primary beryllium industry, the types of industries in the private sector with beryllium-exposed workers were determined by using the OSHA Integrated Management Information System (IMIS) and reports from the NIOSH HHE program. IMIS includes data from all inspections and from consultations that were requested by employers. We specifically used data from OSHA inspections that occurred during the 18-year period 1979–1996. From both the OSHA and NIOSH data, we identified industries with documented beryllium exposures at or above 0.1 μg/m^3. This level is considered to be a minimal value that could have been reasonably obtained during the study period by most qualified laboratories from personal 8-hour samples (personal communication, M. McCawley, McCawley Consulting, March 2003).

We were concerned that 0.1 μg/m^3 may have been a default level that was recorded when no beryllium was detected. As a result, we also identified the subset of industries that had beryllium measured above this level. Finally, we sought to draw attention to specific industries where beryllium exposure may be poorly controlled by identifying four-digit SIC categories[(23)] with at least two samples at or above the current NIOSH recommended exposure limit (REL) of 0.5 μg/m^3.

To estimate the number of potentially exposed workers in the private sector outside the primary beryllium industry, we applied an algorithm to IMIS data that is similar to what was used by Linch and colleagues[(24)] to estimate the number of workers with crystalline silica exposure. Additional details for this procedure may be found in that paper. The final goal of the algorithm was to generate estimates of the number of workers with exposures >0.1 μg/m^3 beryllium. We used three sets of information when applying the algorithm. The first set was the IMIS data from inspections with beryllium samples for the years 1979–1996. The second set of information was the complete IMIS inspection data for the same years, including all inspections with or without beryllium samples. This second set was needed to provide a proper scale for the final estimates. The third set of information was a recent market research database from MarketPlace, which we used to provide worker population estimates for four-digit SIC categories for the year 2001.[(25)]

The IMIS database contains over 9700 samples for beryllium from approximately 3200 OSHA inspections conducted during the years 1979–1996. Personal samples accounted for about 97% of the samples and were the only type of sample used in our calculations. When a work site had more than one inspection, we chose the most recent for the analysis because the resulting exposure information was to be applied to recent estimates of employees. In addition, we used data from all types of OSHA inspections. When we excluded the primary beryllium producers, there was a total of 108 four-digit SIC categories with beryllium $\geq$ 0.1 μg/m^3, of which 94 SIC categories had beryllium > 0.1 μg/m^3. During the editing of the inspection data, we deleted observations that had incomplete or inconsistent information. These observations included instances where the IMIS data indicated that: (1) the total number of workers exposed was less than the number of personal samples, or (2) the total number of workers exposed was greater than the recorded total number of workers at the establishment. These deletions reduced the 94 SIC categories to 77 in the nonprimary industries.

We arrived at two different estimates for the > 0.1 μg/m^3 exposure cutoff point. The upper estimate was based on the less restrictive assumption that all workers in an establishment where beryllium was measured were at risk for exposure. The lower of the two estimates was based on the more restrictive assumption that, for each establishment with measured beryllium, we would count only the number of workers that the OSHA compliance officer indicated were similarly exposed. This variable in the IMIS database enumerates not only the worker who was personally sampled but also workers in the immediate vicinity and workers on the same shift or on other shifts who had similar exposures. OSHA compliance officers ensure that each exposed worker is counted only once regardless of how many workers are sampled in the same work area. To obtain the total number of workers at a single site who were exposed, we summed this variable over all the samples above the 0.1 μg/m^3 limit. This process was repeated for each of the sites.

The preceding first part of the algorithm resulted in an estimate of the number of workers exposed for the 124 inspections in the 77 nonprimary industries that entered into the following modeling. These numbers, and especially the upper estimate, would clearly be expected to be a function of the size of the work force. Before the next step, we obtained population information from the MarketPlace data in order to calculate the mean work force for the 94 SIC categories. The resulting mean value of 12.5 workers per site was inserted into a regression model that was derived using the 124 inspections in the 77 SIC categories. This model considered the total number of workers at each site as a fixed variable (although there is probably some unknown measurement error). It fit the outcome, the natural logarithm of the number of workers exposed above 0.1 μg/m^3, against two predictors: (1) the natural logarithm of the total workers at the site, and (2) the year of the inspection.

To account for residual curvature, quadratic terms were also included in the final model:

$$\ln(n_{ij}) = \beta_0 + \beta_1 \ln(\text{size}_i) + \beta_2 \ln^2(\text{size}_i) + \beta_3 \text{year}_j + \beta_4 \text{year}_j^2 + \varepsilon_{ij}$$

where n_{ij} was the number exposed for a site, $size_i$ was the size of the work force at the site, year_j was the year of the inspection, and where we assumed that the errors $_{ij}$ were independent and normally distributed. We then used the fitted model to predict the number of workers exposed at a site with a work force of approximately 12.5 workers in the year 1996, the most recent year for the range of our data.

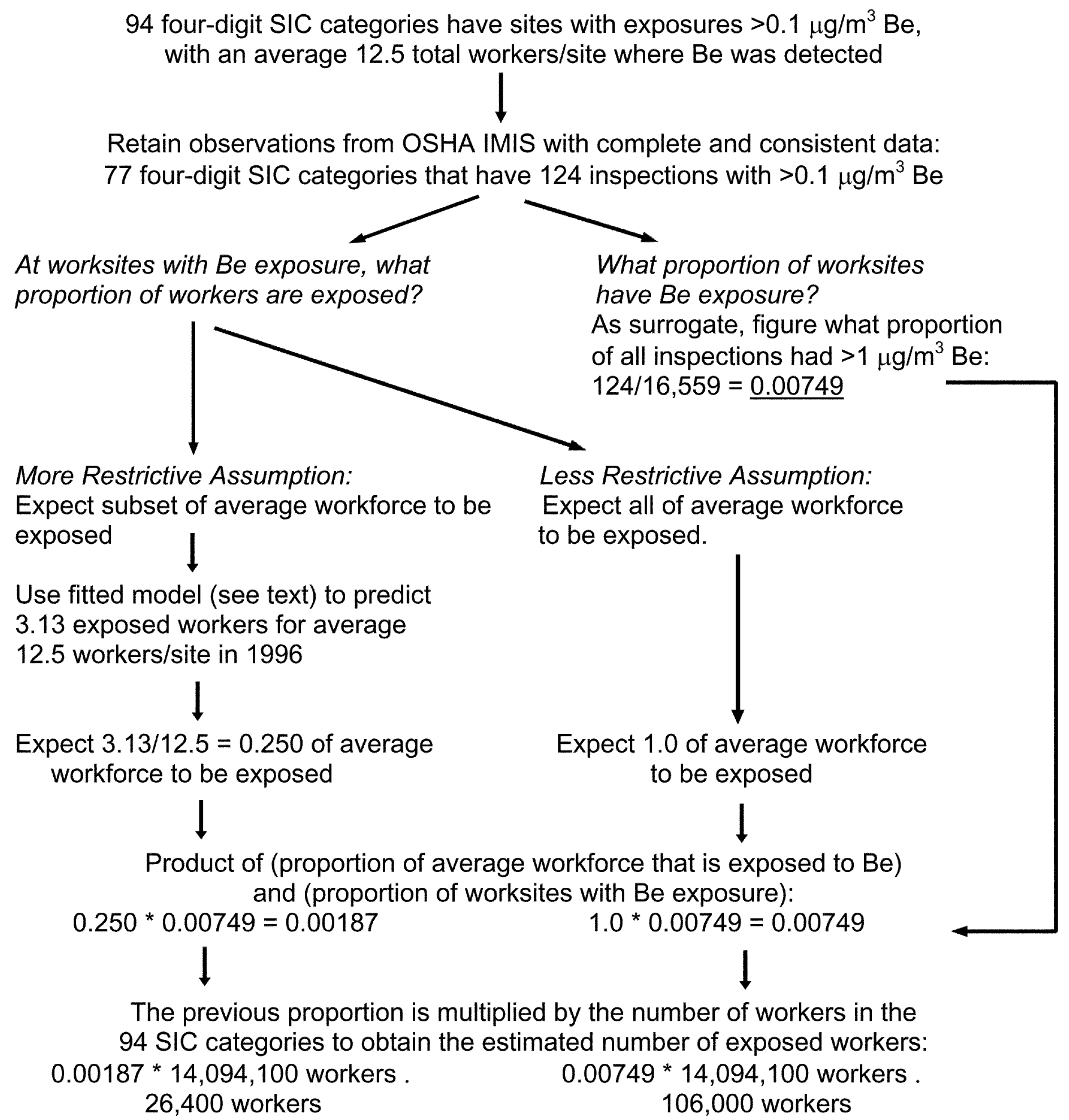

FIGURE 1. Outline for part of the algorithm to estimate the number of current workers potentially exposed to beryllium in private industry (does not include workers in the primary beryllium industry or government)

After back-transformation, we divided our result of 3.13 by 12.5 to get the predicted proportion of workers exposed for our average work force (approximately 0.250). This and subsequent steps in the algorithm are presented in Figure 1. However, this estimate is applicable to only a small portion of the worker population because only a percentage of all inspections during the years 1979–1996 had beryllium samples, and only a subset of these inspections had exposures above 0.1 μg/m^3. Therefore, we scaled the average proportion by multiplying it by the proportion of all inspections within the 77 SIC categories that had exposures above 0.1 μg/m^3 (i.e., $124/16{,}559 = 0.00749$). The resulting product ($0.250 \cdot 0.00749 = 0.00187$) represented an estimate of the proportion of all workers exposed in the 94 SIC categories.

In the final step the scaled proportion was multiplied by 14,094,100, the population estimate of all current U.S. workers in our 94 four-digit SIC categories according to the MarketPlace data. This resulted in an estimate of the number of workers potentially exposed to beryllium based on the more restrictive assumption about who is exposed. Some additional details concerning the treatment of missing values and the construction of confidence intervals can be found in the article by Linch et al.[24]

To estimate the number of workers potentially exposed to beryllium based on the less restrictive assumption, we assumed that 100% of workers were exposed to beryllium at each site that had at least one beryllium sample above the 0.1 μg/m^3 limit. Consequently, this estimate was found by multiplying

0.00749, the estimated proportion of all IMIS inspections with beryllium samples above the 0.1 μg/m^3 limit, by 14,094,100, the population estimate for the 94 four-digit SIC categories.

Following the same procedures as already described, we estimated the number of workers potentially exposed to beryllium at 0.1 μg/m^3 and above. Of the 108 SIC codes from the OSHA data listed in Table I that fulfilled this exposure limit, 21 were deleted due to incomplete or inconsistent information, which included the 17 deleted for the estimate described above. With the remaining 87 codes, a total of 145 inspections entered into the modeling. Based on the 2001 MarketPlace data, there were 15.4 million current U.S. workers in these 108 categories.

RESULTS

Number of Workers Exposed to Beryllium in Federal Agencies

As part of recent rulemaking, the DOE identified 1634 persons routinely working with beryllium as of 1999.[26] There have been approximately 23,000 former employees and 5000 current employees (including the 1634 currently working with beryllium) who have enrolled in the DOE's CBD medical surveillance program. This means there are approximately 26,370 formerly exposed workers enrolled (i.e., 23,000 + 5,000 − 1634). Almost all participants have reported potential exposure to beryllium at some point in the past. Recruitment into the program is ongoing, and government officials believe that the CBD medical surveillance program may reach 40,000 participants in the next few years (personal communication, P. Wambach, DOE, March 2002).

The GAO reports there have been 17 DOE facilities that have actual or potential beryllium exposure, with a total of about 8100 current workers, including contractors and subcontractors, who are associated with beryllium activities.[27] However, the number of contractors and subcontractors ever exposed to beryllium while working for the DOE is much greater. At the DOE Hanford site alone, University of Washington researchers estimate that approximately 15,000 persons may have been exposed to beryllium, counting construction contractors and subcontractors.[28]

Those working for the DOD may have been exposed to beryllium during welding, sandblasting, soldering, grinding, and other operations. The GAO has identified 73 locations where beryllium was detected during air sampling conducted by the DOD between 1982 and 2000. This included 17 Army, 5 Air Force, and 51 Navy locations.[22] Recent information provided by the Army indicates 15 Army installations currently report beryllium as a potential hazard, with an estimated 62 exposed workers, all of whom are exposed below the OSHA PEL (personal communication, S. Monk, U.S. Army, September 2001). However, this estimate is probably incomplete because some installations do not maintain robust local databases.

The Navy estimates there are approximately 16,560 civilian and military personnel who are potentially exposed to beryllium (personal communication, J. Bishop, Navy Environmental Health Center, November 2001). Many of these persons are employed as aviation mechanics, dental technicians, welders, and machinists.

The Air Force estimates fewer than 1740 potentially exposed personnel. The vast majority of the current (1998–present) exposures are well below the threshold limit value of 0.2 μg/m^3 beryllium, which was specified in the American Conference of Governmental Industrial Hygienists Notice of Intended Changes for 2003 and used by the Air Force as their occupational exposure limit (personal communication, W. Weisman, U.S. Air Force, April 2003).

Number of Workers Exposed to Beryllium in the Private Sector

There are currently about 1500 employees in the primary beryllium industry in the United States, including about 1350 with the major producer (personal communication, M. Kolanz, Brush Wellman Inc., August 2001) and 150 in another company (personal communication, L. Woodside, NGK Metals Corp., February 2002). It is difficult to arrive at an accurate estimate of the number of exposed former workers from these companies who are still alive. An estimated 4400 persons have ever worked for the major producer of beryllium since the 1940s (personal communication, M. Kolanz, Brush Wellman Inc., August 2001). Also, the other company in the primary beryllium industry previously had more workers than they do now, with about 450 workers in 1987 vs. 150 in 2001 (personal communication, L. Woodside, NGK Metals Corp., February 2002) A mortality study of workers from the three companies in the primary beryllium industry identified 9225 male workers employed at seven processing facilities for at least 2 days during the 30 years of 1940 through 1969.[29]

Table I itemizes the 108 specific four-digit SIC categories in the private sector but outside the primary beryllium industry that had one or more samples at or above 0.1 μg/m^{3}as determined by inspection data from the IMIS and HHE reports. Ninety-five of the SIC categories were identified exclusively by IMIS, and 13 were identified by both IMIS and HHE reports.

The industries identified were in the general categories of mining, construction, manufacturing of nondurable and durable goods, transportation and public utilities, wholesale trade, and services. Based on data from 2001, there were approximately 1,190,000 businesses and 15,400,000 persons employed in these industries.[25] According to the IMIS data, 38 of the 108 industries had two or more samples at or above the NIOSH REL of 0.5 μg/m^3 and are indicated in Table I by bold text. Of these, 58% (22/38) had two or more samples at or above the OSHA PEL (2.0 μg/m^3). There were 14 SIC categories that had exposures no greater than 0.1 μg/m^3 (see italic text in Table I).

There was a total of 818 positive beryllium samples (i.e., samples with beryllium $\geq$ 0.1 μg/m^3) among the 108 SIC categories based on the IMIS data, but these samples were not distributed equally. In particular, five of the SIC categories (i.e., 1721, 1799, 3341, 3365, and 3366) accounted for 44% of

TABLE I. Industries by Standard Industrial Classification (SIC) Codes with Beryllium Exposure $\geq$ 0.1 μg/m^3

SIC Code	Industry	Examples of Jobs
	MINING	
1081	**Metal mining services**	**Driller**
	Construction	
	Building Construction-General Contractors and Operative Builders	
1522	**Residential construction, not elsewhere classified**	**Laborer**
1541	**General building contractors, industrial buildings and warehouses**	**Welder**
1542	General building contractors, nonresidential buildings (not industrial buildings or warehouses)	Carpenter
	Heavy Construction Other Than Building Construction-Contractors	
1611	**Highway and street construction, except elevated buildings**	**Blaster, slater, laborer**
1622	Bridge, tunnel, and elevated highway construction	Blaster, sandblaster
1629	**Heavy construction, not elsewhere classified**	
	Construction-Special Trade Contractors	
1711	**Plumbing, heating, and air conditioning**	**Welder**
1721 (76)[A]	**Painting and paper hanging**	**Abrasive blaster, sandblaster, painter blaster, laborer**
1731	**Electrical work**	**Electrician**
1791	Structural steel erection	Welder
1794	*Excavation work*	*Laborer*
1795	**Wrecking and demolition work**	**Cutter, burner, operator, lead man**
1799 (49)[A]	**Special trade contractors, not elsewhere classified**	**Insulator, deleading operator, abatement tech, laborer**
	MANUFACTURING, NONDURABLE GOODS	
	Paper and Allied Products	
2621	Paper mills	Ash handler
2631	**Paperboard mills**	**Filter worker**
	Chemicals and Allied Products	
2819[B]	**Industrial inorganic chemicals, not elsewhere classified**	**Chemical operator, general manager**
2834	Pharmaceutical preparations	Mold maker
2843	**Surface active agents, finishing agents, sulfonated oils, and assistants**	**Finisher**
2851	*Paints, varnishes, lacquers, enamels, and allied products*	*Operator*
2869[B]	**Industrial organic chemicals, not elsewhere classified**	**Painter/Sandblaster, assistant operator**
	Rubber and Miscellaneous Plastics Products	
3087	Custom compounding of purchased plastics resins	Blender
3089	Plastic products, not elsewhere classified	Artist
	MANUFACTURING, DURABLE GOODS	
	Lumber and Wood Products, Except Furniture	
2491	Wood preserving	Maintenance
	Furniture and Fixtures	
2542	Office and store fixtures, partitions, shelving, and lockers, except wood	Power coater
	Stone, Clay, Glass, and Concrete Products	
3229	*Pressed and blown glass and glassware, not elsewhere classified*	*Stick welder, MIG/TIG welder*
3231	Glass products, made of purchased glass	Operator
3261	**Vitreous china plumbing fixtures**	**Ground coat sprayer**
3272	Concrete products, except block and brick	Welder
3297	**Nonclay refractories**	**Ceramics grinder, machine operator**

(Continued on next page)

TABLE I. Industries by Standard Industrial Classification (SIC) Codes with Beryllium Exposure ≥ 0.1 μg/m^3 *(Continued)*

SIC Code	Industry	Examples of Jobs
	Primary Metal Industries	
3312	*Steel works, blast furnaces (incl. coke ovens), and rolling mills*	*Welder, billet handler, machinist*
3317	**Steel pipe and tubes**	**Tube cutter, turf cutter**
3325	Steel foundries, not elsewhere classified	Welder, casting, furnace helper, rotoblast worker
3339	*Primary smelting and refining of nonferrous metals, except copper and aluminum*	*Shredder feeder helper, shredder operator*
3341[B] (122)[A]	**Secondary smelting and refining of nonferrous metals**	**Lathe operator, furnace operator, incinerator operator, ball mill operator**
3351	**Rolling, drawing, and extruding of copper**	**Melter, caster helper**
3353	Aluminum sheet, plate, and foil	Furnace attendant
3356[B]	**Aluminum rolling and drawing, nec**	**Lead man atomization, lathe operator, metal conditioner**
3363	Aluminum die-castings	Laborer
3364	**Nonferrous die-castings, except aluminum**	**Furnace operator, grind operator**
3365 (63)[A]	**Aluminum foundries**	**Foundry tender, mold assembler**
3366 (49)[A]	**Copper foundries**	**Melter, caster/pourer**
3369[B]	**Nonferrous foundries, except aluminum and copper**	**Mold maker, furnace operator, saw operator, pebbles operator**
	Fabricated Metal Products, Except Machinery and Transportation Equipment	
3411	Metal cans	Lathe operator
3429	*Hardware, not elsewhere classified*	*Machine operator*
3431	Enameled iron and metal sanitary ware	Crane operator
3433[B]	**Heating equipment, except electric and warm air furnaces**	**Welder**
3441	Fabricated structural metal	Welder, blaster
3442	Metal doors, sash, frames, molding, and trim	Welder, foreman
3443	**Fabricated plate work (boiler shops)**	**Welder, plasma cutter, plating**
3444	Sheet metal work	Welder
3446	*Architectural and ornamental metal work*	*Panel welder*
3452	Bolts, nuts, screws, rivets, and washers	Slotter operator
3465	Automotive stampings	Maintenance welder
3469	Metal stampings, not elsewhere classified	Painter
3471[B]	Electroplating, plating, polishing, anodizing, and coloring	Polisher, grinder, plater
3479	Coating, engraving, and allied services, nec	Painter
3483	*Ammunition, except for small arms*	*Solder assembly work*
3497	Metal foil and leaf	Technician
3498	Fabricated pipe and pipe fittings	Welder
3499	**Fabricated metal products, not elsewhere classified**	**Welder, operator-alloy**
	Industrial and Commercial Machinery and Computer Equipment	
3511	*Steam, gas, and hydraulic turbines, and turbine generator set units*	*Welder*
3519	Internal combustion engines, not elsewhere classified	Engine tester
3523	*Farm machinery and equipment*	*Welder*
3524	Lawn and garden tractors, home lawn and garden equipment	
3531	Construction machinery and equipment	Conveyor
3532	Mining machinery and equipment, except oil and gas field machinery and equipment	Painter
3535	Conveyors and conveying equipment	Welder

(Continued on next page)

TABLE I. Industries by Standard Industrial Classification (SIC) Codes with Beryllium Exposure ≥ 0.1 μg/m^3 *(Continued)*

SIC Code	Industry	Examples of Jobs
3536	Overhead traveling cranes, hoists, and monorail systems	Fitter, welder, machinist
3541	Machine tools, metal cutting types	Brazer, grinder
3544	**Special dies and tools, die sets, jigs, and fixtures, and industrial molds**	**Machinist, miller, plasma arc, welder, bencher**
3545[B]	*Cutting tools, machine tool accessories, and machinists' precision measuring devices*	*Tool and die maker*
3559	**Special industry machinery, not elsewhere classified**	**Machinist, sandblaster primer**
3561	*Pumpsand and pumping equipment*	*Foundry worker*
3565	*Packaging machinery*	*Cutter*
3569	**General industrial machinery and equipment, not elsewhere classified**	**Welder**
3599	**Industrial and commercial machinery amd equipment, not elsewhere classified**	**Lathe operator, machinist, foundry worker**
	Electronic and Other Electrical Equipment and Components, Except Computer Equipment	
3625	Relays and industrial controls	Auto line operator
3674	**Semiconductors and related devices**	**Hot press operator, production operator**
3679[B]	Electronic components, not elsewhere classified	Solder
	Transportation Equipment	
3711	*Motor vehicles and passenger car bodies*	*Prep shop*
3713	Truck and bus bodies	Welder
3714[B]	**Motor vehicle parts and accessories**	**Welder, MIG welder, maintenance**
3715	**Truck trailers**	**Painter, booth blaster**
3716	Motor homes	Welder
3721	Aircraft	Holder
3728	Aircraft parts and auxiliary equipment, not elsewhere classified	Grinder
3731	**Ship building and repair**	**Abrasive blaster, sandblaster, welder**
3743	Railroad equipment	Welder, painter/grinder
3769	**Guided missile and space vehicle parts and auxiliary equipment, not elsewhere classified**	**Machinists, deburr workers, lappers**
3799	Transportation equipment, not elsewhere classified	Ring welder, painter
	Measuring, Analyzing, and Controlling Instruments	
3843	**Dental equipment and supplies**	**Cutter/grinder, caster, induction melter**
3911	**Jewelry, precious metal**	**Caster, polisher, modeling**
	Miscellaneous Manufacturing Industries	
3942	Dolls and stuffed toys	Welder
	TRANSPORTATION AND PUBLIC UTILITIES	
	Railroad Transportation	
4011	Railroads, line-haul operating	Painter
	Local and Suburban Transit and Interurban Highway Passenger Transportation	
4151	School buses	Mechanic
	Motor Freight Transportation and Warehousing	
4231	Terminal and joint terminal maintenance facilities for motor freight transportation	Blaster
	Transportation By Air	
4581	Airports, flying fields, and airport terminal services	Grinder
	Electric, Gas, and Sanitary Services	
4911[B]	Electric services	Electrician
4953[B]	Refuse systems	

(Continued on next page)

TABLE I. Industries by Standard Industrial Classification (SIC) Codes with Beryllium Exposure ≥ 0.1 μg/m³ *(Continued)*

SIC Code	Industry	Examples of Jobs
	WHOLESALE TRADE	
	Wholesale Trade–Durable Goods	
5063	Electrical apparatus and equipment, wiring supplies, and construction materials	Finish grinder
5093[B]	Scrap and waste materials	Conveyor operator
	SERVICES	
	Automotive Repair, Services, and Parking	
7532	Top, body, and upholstery repair shops and paint shops	Spray painter
7538	General automotive repair shops	Abrasive blaster
	Miscellaneous Repair Services	
7692	Welding repair	Welder
7699	Repair shops and related services, not elsewhere classified	Welder, sandblaster
	Health Services	
8072	Dental laboratories	Dental technician
	Engineering, Accounting, Research, Management, and Related Services	
8731	Commercial physical and biological research	Electron gun operator

Notes: **Bold** text indicates industries that had two or more samples at or above the NIOSH REL of 0.5 μg/m^3. *Italic* text indicates industries that had no samples greater than 0.1 μg/m^3. Normal text indicates industries with at least one sample > 0.1 μg/m^3 but less than two samples at or above the NIOSH REL of 0.5 μg/m^3. A company that manufactures optical instruments and lenses (SIC 3827) was identified by an HHE. Although no samples were positive for beryllium, the request for the HHE mentioned a "beryllium room" where all work on beryllium was conducted.[30] Although this industry did not fit the exposure criterion of ≥ 0.1 μg/m^3 to qualify for inclusion in this table, this industry may have beryllium exposure.

[A] SIC codes with the most samples: Based on IMIS, these five SIC codes account for 44% of the beryllium samples that were ≥0.1 μg/m^3 among the 108 codes in the table. The number of samples per SIC is in parentheses.

[B] Identified by both the IMIS and Health Hazard Evaluation reports. All others are identified by IMIS only.

the total number of positive beryllium samples. The number of samples is indicated in parentheses for each of these five categories in Table I.

We also identified one additional industry from an HHE report on an establishment that manufactures optical instruments and lenses (SIC 3827) that is not mentioned in Table I. Although no samples were positive for beryllium, the request for this HHE mentioned a "beryllium room" where all work on beryllium was conducted.[30] Therefore, although this industry did not fit the criterion of beryllium measured at or above 0.1 μg/m^3, this industry may have beryllium exposure.

As described in Methods, we derived estimates of the number of workers in the private sector outside the primary industry with potential beryllium exposure using the 94 industry categories with at least one beryllium measurement > 0.1 μg/m^3. There were approximately 1,130,000 businesses and 14,094,100 employees in these industry groups based on the 2001 MarketPlace data. With the assumption that the only exposed workers were those indicated by the OSHA compliance officer, we estimated that approximately 26,400 workers (90% CI [confidence interval]: 15,900–36,800) had potential beryllium exposure > 0.1 μg/m^3, and this estimate represents about 0.19% of the total number of workers in the 94 four-digit SIC categories. The final steps in the algorithm that led to this estimate are presented in Figure 1. When we considered all workers in an establishment to be at risk for beryllium exposure, we estimated that approximately 106,000 current workers (90% CI: 90,000–121,000) were potentially exposed to beryllium at > 0.1 μg/m^3. This represented about 0.75% of all workers in the 94 four-digit SIC categories.

A summary of the estimated number of government and private sector workers potentially exposed to beryllium is provided in Table II.

We also estimated the number of workers potentially exposed to beryllium using a cutoff of ≥ 0.1 μg/m^3 beryllium, which meant we included all 108 four-digit SIC categories listed in Table I. Under the more restrictive and less restrictive assumptions about who was exposed, the estimates were 29,000 workers (90% CI: 18,000–39,900) and 124,000 workers (90% CI: 107,000–141,000), respectively.

DISCUSSION

Strengths and Limitations of the Data and Methods Used to Estimate the Number of Current Workers Potentially Exposed to Beryllium in the Private Sector

Our identification of industries with beryllium exposures and estimates of the number of exposed workers are based entirely on air measurements and do not account for dermal exposures. Recent publications have suggested that the dermal route of exposure might contribute to beryllium sensitization,[5,6]

TABLE II. Summary of the Estimated Number of Workers Potentially Exposed to Beryllium in the United States

Sector	Agency/Industry	Workers Potentially Exposed to Beryllium: Currently Exposed	Workers Potentially Exposed to Beryllium: Formerly Exposed	Data Source
Federal government	Department of Energy	(a) 8100	(b) 26,370[A]	(a) Government Accounting Office (b) Personal communication from DOE
	Department of Defense	18,400	Unknown	Personal communications
Private industry	Primary beryllium industry	1500	Unknown	Personal communications
	Other private industry	26,400–106,000[B]	Unknown	OSHA IMIS inspection data 1979–1996 and calculations in current article
Total		54,400–134,000	Unknown	

[A]Based on DOE beryllium disease medical surveillance program for which recruitment has not been completed.
[B]The estimates for "Other private industry" are based on industries where beryllium measured greater than 0.1 μg/m^3. When industries with beryllium measured equal to but not greater than 0.1 μg/m^3 are included, the lower and higher estimates for the number of current workers potentially exposed to beryllium are 29,000 and 124,000.

although this possibility is still under active investigation. At some work sites, the OSHA inspector may not have collected samples for beryllium because the inspection was focused on some other suspected risk. At the same time, it is likely that many samples were taken with a suspicion about some metal other than beryllium, but then a broad screen for a variety of metals was conducted by the laboratory. Therefore, some of the findings were serendipitous and not based on prior suspicion about beryllium exposure.

We used all types of OSHA inspections from the IMIS database in our estimation of the number of private sector workers potentially exposed to beryllium, including follow-up visits and inspections that resulted from complaints. Ideally, one might want to use only the subset of programmed inspections that most closely fits the requirements of a random-sampling scheme. However, we found that point estimates of the number of workers exposed to beryllium that resulted from using all types of inspections were similar to those using only the programmed inspections, while the precision of the estimates was improved considerably by including all types of inspections.

It is possible that our estimates of the number of exposed workers in the private sector reflect past rather than current conditions, which could have led us to either underestimate or overestimate the number of currently exposed workers. In particular, we used information from the IMIS database spanning the 18-year period 1979–1996 to determine what percentage of workers were exposed, and then applied that percentage to work force numbers from 2001. We do not know what has happened since OSHA last sampled in a particular work site or industry. It is possible that control technologies may have improved, or the use of beryllium may have been discontinued in certain industries and some workers may no longer be exposed. At the same time, it is possible that the use of beryllium may have been initiated in some industries, and workers previously unexposed may now be exposed.

The IMIS database is probably closer to a representative sample of private work sites in the United States than any other source of occupational exposure data. However, it is a record of enforcement activity and was not designed for surveillance purposes. The exposure data are not the result of a systematic survey of all private work sites, and there was not a focused program within OSHA to detect beryllium. Therefore, it is likely that some work sites were missed where beryllium would have been detected if OSHA had sampled for it.

Our lower estimate of 26,400 potentially exposed workers in the private sector outside the primary beryllium industry is similar to earlier estimates that were also based on national exposure surveys. These earlier figures were from the U.S. Public Health Service (n = 30,000),[(13)] the NOHS (n = 21,233),[(14–16)] and the NOES (n = 14,000) (personal communication, R. Young, NIOSH, August 2001). Our lower estimate is based on the assumption that the only people with beryllium exposure were the workers for whom samples were taken and co-workers who worked at the same job or in the immediate area. This assumption is probably unreasonable given what has been observed about the occurrence of beryllium sensitization and CBD. Specifically, sensitization and CBD can occur in jobs with minimal exposure, such as secretaries or security guards.[(7–9)] In the interest of enforcing OSHA standards, an inspector would probably not consider such jobs as a priority for sampling. In plants where beryllium is used but strict controls are not enforced, beryllium will migrate within the plant and even leave the plant,[(31)] thus putting many co-workers considered to be "unexposed" at risk for exposure. The unrealistic assumption that beryllium exposure is localized within a company, plus the knowledge that we did not include some industries with beryllium exposure, leads to the conclusion that the lower figure of 26,400 workers potentially exposed to beryllium was probably underestimated.

Our upper estimate of 106,000 is based on the assumption that every person in an establishment with a positive beryllium sample is at risk for exposure. This assumption could possibly lead to an overestimate of the number of workers potentially exposed to beryllium, since some establishments sampled by OSHA may have several different buildings, of which only a portion may have workers exposed to beryllium. However, in the absence of strict controls, beryllium could migrate both within and between buildings at a single site.(31) Therefore, the assumption that all workers within an establishment are at risk for exposure may be appropriate in many facilities.

Former Workers

There are some estimates available from the DOE about the number of workers who were formerly exposed to beryllium and are still alive. However, the DOE continues to recruit employees for CBD medical surveillance, and the figure of 26,370 formerly exposed workers who have enrolled might increase to nearly 40,000 (personal communication, P. Wambach, DOE, March 2002). Based on these figures and the GAO estimate that 8100 current workers at DOE sites are potentially exposed,(27) the ratio of formerly exposed to currently exposed beryllium workers is at least 3:1, and may be as much as 5:1. In our study we did not estimate the number of private sector workers previously exposed to beryllium. There are several difficulties inherent in this; however, the number could possibly be derived with additional information, such as when specific industries started to use beryllium, the historical number of exposed workers, and industry-specific rates of turnover for exposed workers. CBD can be diagnosed decades after the cessation of beryllium exposure, so medical monitoring is important for formerly exposed workers. The identification of former workers makes it possible to inform them about findings from recent research, benefits of medical monitoring, and options for workers' compensation.

RECOMMENDATIONS

The results of this study can be used generally to target at-risk audiences for hazard communications intended to prevent beryllium sensitization and CBD. However, additional efforts are needed to provide a fuller account of which industries, workplaces, and occupations have workers potentially exposed to beryllium. One approach would be to contact the primary beryllium industry and obtain information about distributors, secondary manufacturers, and other users of beryllium. Web-based search engines, unions, and trade organizations also may provide useful information on additional establishments with beryllium exposure. These methods deserve exploration and could lead to the development of new surveillance techniques for occupational hazards.

In the meantime, all companies in the industries identified in Table I should determine whether beryllium is in the materials they use. Although the OSHA Hazard Communication Standard has required companies to make such a determination since 1985, it is unclear the extent to which it has been implemented. Also, this standard does not cover all articles that include beryllium, and users and recyclers of these articles might not be aware of what they are handling. Material safety data sheets, metal assays, and product information are some of the resources that are available to determine the presence of beryllium. If beryllium is present, controls should be implemented consistent with the likelihood and level of exposure. Environmental and medical surveillance should also be considered to monitor beryllium exposure in the workplace and the presence of sensitization and CBD among workers.

CONCLUSION

We estimate that as many as 134,000 current workers in the government and private industry are potentially exposed to beryllium in the United States. We recommend that all companies in industries identified to have beryllium exposure at or above 0.1 $\mu g/m^3$ should determine whether their employees are working with beryllium and take appropriate action. Additional efforts are needed to refine our understanding of the extent of the problem and to plan and implement preventive interventions.

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