

Sensitization and Chronic Beryllium Disease Among Workers in Copper–Beryllium Distribution Centers

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Objective: Little is known about the risk of sensitization and chronic beryllium disease (CBD) among workers performing limited processing of copper–beryllium alloys downstream of the primary beryllium industry. In this study, we performed a cross-sectional survey of employees at three copper–beryllium alloy distribution centers. **Methods:** One hundred workers were invited to be tested for beryllium sensitization using the beryllium blood lymphocyte proliferation test (BeLPT); a sensitized worker was further evaluated for CBD. Available beryllium mass concentration air sampling data were obtained for characterization of airborne exposure. **Results:** One participant, who had exposure to other forms of beryllium, was found to be sensitized and to have CBD, resulting in a prevalence of sensitization/CBD of 1% for all tested. **Conclusions:** The overall prevalence of beryllium sensitization and CBD for workers in these three copper–beryllium alloy distribution centers is lower than for workers in primary beryllium production facilities. (J Occup Environ Med. 2006;48:204–211)

Copper–beryllium alloys are the most widely used form of beryllium and range in beryllium content from 0.15% to 2%.¹ These alloys are used in a wide variety of industrial, commercial, and consumer products because of their unique properties of strength, flexibility, and thermal and electrical conductivity.² The leading global producer and supplier of beryllium operates three copper–beryllium alloy distribution centers in the United States, each of which either sells products as received from the primary production and finishing facilities or fits the materials to customer specification by performing limited final processing such as sawing, leveling, heat treating, welding, and slitting (Fig. 1). The centers also distribute small quantities of copper–beryllium and, to a lesser extent, aluminum– or nickel–beryllium alloy materials in the form of shot or small ingots, which are occasionally weighed and repackaged into smaller containers. Workers in these distribution centers have exposures similar to a sizable fraction of the estimated 134,000 current workers who are potentially exposed to beryllium in the United States.³

Workers exposed to beryllium may develop a cell-mediated immune response that can be detected in the peripheral blood with the beryllium blood lymphocyte proliferation test (BeLPT). Sensitized workers may have or subsequently may develop noncaseating granulomas and interstitial infiltrates in their lungs, characteristic of chronic beryllium

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The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

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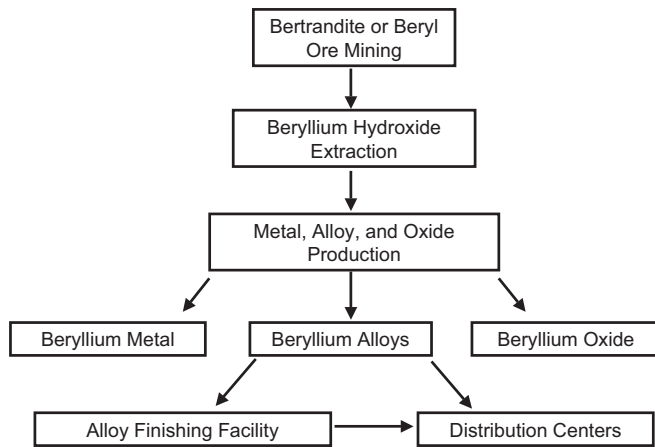


Fig. 1. Process flow of beryllium product from mining through distribution.

disease (CBD); it is not known what proportion of sensitized individuals will eventually develop CBD. Previous cross-sectional surveys in beryllium facilities revealed that between 0.9% and 10% of tested workers were sensitized to beryllium, and 0.1% to 4% were classified as having CBD.^{4–14}

One of three distribution centers, established in 1963, is located in the midwestern United States and stocks bulk product materials in the form of rod, tube, plate, and heavy-gauge strip. This facility serves as the central warehouse location for distribution of its bulk products worldwide. The first of two distribution centers that handle largely strip products was established in 1968 and is located in the eastern United States. This facility handles not only the strip product line, but also some rod and beryllium-containing alloy ingots; its primary customer base is the computer and telecommunications industry. The second distribution center located in the midwestern United States handles primarily strip products and was established in 1972; its primary customer base is the automotive and telecommunications industries. Before the surveillance reported here, no documented cases of clinical CBD were known to have occurred among the current or former employees of these distribution centers ($N = 178$).

Beryllium sensitization and cases of CBD have been documented as early as the 1950s among workers in facilities that process low-percentage beryllium-containing alloys.^{15–17} In 1999, two cases of CBD were documented in a plant that processed 2% copper–beryllium alloy, where both workers reported no history of working with any other forms of beryllium.¹⁸ In a cross-sectional survey of current workers at a copper–beryllium alloy strip and wire-finishing facility, 7% of the workers (10 of 153) were found to be sensitized and 4% (six of 153) to have CBD.¹⁴ These results were similar to the results of surveys performed in facilities associated with higher beryllium exposures.

Workers in distribution centers might be expected to experience lower beryllium exposures than workers in primary beryllium production facilities. Unlike work performed in primary production facilities, work at distribution centers does not require large-scale heat treatment or manipulation of material. Such activities are known to generate higher levels of beryllium-containing fumes and/or dusts. This is particularly true at the strip distribution centers, where the main production activity, slitting, generates low levels of airborne particles. Therefore, the workers from the three distribution centers in this

study were expected to be at lower risk for the adverse health effects of beryllium exposure. We sought to better understand the health implications related to limited processing of copper–beryllium alloy products by testing workers in these distribution centers for beryllium sensitization and CBD and by examining historical airborne beryllium-exposure records. The findings may be pertinent to workers in other facilities who perform similar limited operations with copper–beryllium alloys.

Materials and Methods

Study Population

We invited all 100 employees at three distribution centers to participate in testing for beryllium sensitization and CBD. The National Institute for Occupational Safety and Health (NIOSH) Human Subjects Review Board approved the study protocol. Written informed consent was obtained from all study participants. In addition, the individual described in the case report gave additional specific written consent.

Evaluation for Beryllium Sensitization and Chronic Beryllium Disease

Between November 2000 and March 2001, the company's medical staff collected blood samples for the BeLPT in heparinized Vacutainer tubes.¹⁹ For the two centers that handle primarily strip metal, initial samples were split and sent by overnight courier to two laboratories. Initial samples for the third center were sent to a single laboratory. Follow-up testing (for confirmation of abnormal results) or repeat testing (following indeterminate initial results) was completed by May 2001. Mononuclear cells were isolated from each blood sample, stimulated with three different concentrations of either beryllium sulfate or beryllium fluoride, and then cultured for 5 and either 6 or 7 days. The cell counts per minute for each of the six beryllium concentration/duration combinations were

expressed as a ratio of the counts per minute of unstimulated cultures.

A BeLPT was defined as abnormal if at least two of the six stimulation index ratios were ≥ 3.0 . An individual was considered to be "sensitized" if results from two BeLPTs were found to be abnormal either from separate laboratories or by repeated testing at the same laboratory. Sensitized individuals were referred for clinical evaluation for CBD, which included bronchoalveolar lavage (BAL) and fiberoptic bronchoscopy for collection of transbronchial biopsies. BAL cells were examined for lymphocytosis, and a lymphocyte proliferation test was performed on the BAL fluid (BALLPT) to evaluate lung response to beryllium stimulation. The clinical evaluation also included an additional BeLPT, pulmonary function testing, and chest radiography. Sensitized individuals were considered to have CBD if granulomas or other pathologic abnormalities consistent with that diagnosis were identified.

Work History Questionnaire Information

A company occupational health nurse administered questionnaire interviews from which information was obtained about beryllium-related work histories, including each job held and the related work processes, complete with start and end dates. Because there were three centers in this study, with relatively few workers in individual jobs or processes, we grouped processes and jobs into one of three categories: 1) ever worked production jobs, 2) ever worked production support jobs, and 3) ever worked in administration.

Production work included sawing, shearing, heat treating, shot handling, and pickling at the bulk products center; tensioning/leveling, welding, and slitting at the two strip centers; and material handling at all three centers. At the bulk products center, sawing operations used chip-
ping plate and small band sawing; in

the former, plates from 0.75 to 3 inches (1.9 and 7.6 cm) in thickness were cut to customers' requested length and width, and in the latter, rods up to 8 inches (approximately 20 cm) in diameter were cut to specified length. Shearing of heavy-gauge (0.0625- to 0.125-inch; 0.16- to 0.32-cm) strip metal, up to 20 inches (approximately 51 cm) in width, was also performed. The hardness and temper of sheared strip, rod, and plate were adjusted by short-duration heat treating, which was followed by pickling in phosphoric acid to remove oxidation that may have formed. At the two strip centers, the straightness of lengths of strip metal was adjusted by tensioning and leveling, after which lengths were rewound on a traverse winder. Strip metal was slit to customer-specified width with either high-speed slitting, 600 to 1100 feet of strip per minute (3–6 meters per second), or low-speed slitting, 125 to 300 feet per minute (0.6–1.5 meters per second). After slitting, lengths of metal may be welded end to end to achieve customer-specified lengths using the use of close-capture local high-efficiency particulate air (HEPA)-filtered exhaust ventilation.

Production support jobs included shipping and receiving and janitorial work. Shipping and receiving workers were responsible for loading and unloading material sent from the company's main beryllium production facility and from its copper-beryllium alloy finishing plant from all delivery trucks. Products ready for shipping were placed on pallets, wrapped (shrink-wrapping, banding, or boxed), and loaded onto outgoing trucks. These workers occasionally accessed drums of beryllium-containing alloy shot or ingot, removed these materials, weighed and repackaged them for shipping. Janitorial work consisted of vacuuming and dusting in office areas as well as trash removal and mopping in production areas.

Administrative work was subdivided into two categories: office-area

and plant-area jobs. Office-area jobs involved little or no time spent in production areas (eg, sales and administrative positions such as secretary, receptionist, and business system analyst), whereas plant-area jobs involved a significant proportion of time spent in production areas (eg, distribution center manager, production leader, and material planner).

Airborne Beryllium Exposure

We examined company records of full-shift personal lapel samples for airborne beryllium from the period 1996 to 2004 ($N = 393$). We included samples collected after the medical survey had ended because no process changes were made subsequent to the survey. Personal lapel samplers were attached to workers' collars in the breathing zone area and were operated at a flow rate of approximately 2 L per minute (L/min) for a duration of approximately 8 hours. All samples were analyzed for total mass of beryllium by either of two methods, flame atomic absorption spectrophotometry or graphite furnace atomic absorption spectrophotometry, and results were presented in micrograms of beryllium per cubic meter ($\mu\text{g}/\text{m}^3$). When results were reported at or below the limit of detection (LOD), which ranged from 0.02 to 0.1 $\mu\text{g}/\text{m}^3$, we assigned a value equal to half of that LOD. The sample data were grouped by work category and also by process within each work category.

Statistical Analysis

We analyzed the data with SAS software²⁰ using χ^2 and Fisher exact tests for categorical variables and Student *t* test for continuous variables. We calculated measures of central tendency, variability, and characteristics of the upper tail of the distribution to describe the exposure data.

For full-shift personal samples, when the data followed or approximated a log normal distribution, we calculated the upper 95% confidence limit around the 95th percentile of the distribution (the upper tolerance limit)

and around exceedances of two occupational exposure limits (OELs),²¹ the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL)²² of $2 \mu\text{g}/\text{m}^3$ and the Department of Energy (DOE) action level of $0.2 \mu\text{g}/\text{m}^3$.²³ We used the upper 95% confidence limit to account for the uncertainty around each exceedance point estimate. An area is generally considered to be well controlled to a level when the exceedance fraction for that level is 5% or less.²⁴ *P* values equal to or less than 0.05 were considered to be statistically significant.

Results

Demographics of the Study Population

Of the 100 employees invited to participate, 88% (88 of 100) completed the questionnaire and gave a blood sample for the BeLPT. Most interviews were conducted within 2 days of the initial blood draw (91%, 80 of 88); the remaining interviews were conducted within a month of the blood draw date. A majority of survey participants were male (75%, 66 of 88), non-Hispanic whites (76%, 67 of 88), and were either current or former smokers (59%, 52 of 88). The mean age was 36.8 years (standard error [SE], 1.1), with a range of 19 to 66 years. We were able to obtain demographic information on 11 of the 12 nonparticipants; most were male (82%) and white (80%), similar to the participants, but were slightly older (mean age, 41.8 years; SE, 3.5; range, 21–62 years). The difference in age between the two groups was not statistically significant ($t = 1.49$).

Beryllium Sensitization and Disease

Of the 88 participants, one individual was found to be sensitized and on further clinical evaluation to have CBD. Thus, the prevalence of sensitization/CBD among this group of distribution center employees was 1% (one of 88) for all tested.

Characterization of Work Histories

Average length of employment among all participants was 8.4 years, with a range from 0.3 to 29 years. Workers at all three centers were similar, with mean durations of 7.7 to 9.1 years and ranges of less than 1 year to more than 20 years. Among all workers tested, 35% (31 of 88) had worked only in office-area administration jobs. Among the remaining workers, 88% (50 of 57) had ever worked in production jobs and 26% (15 of 57) had ever worked in production support.

Airborne Sampling Data

The overall median beryllium concentration for the 393 full-shift personal lapel samples was $0.03 \mu\text{g}/\text{m}^3$ with an arithmetic mean of $0.05 \mu\text{g}/\text{m}^3$. The 95th percentile upper tolerance limit (UTL) values ranged from $0.07 \mu\text{g}/\text{m}^3$ to $1.18 \mu\text{g}/\text{m}^3$ for this dataset. Fifty-four percent of all samples were at or below the LOD. All measurements were below the current OSHA PEL ($2 \mu\text{g}/\text{m}^3$) and 97% were below $0.2 \mu\text{g}/\text{m}^3$. Eight of the 10 sample results at or above $0.2 \mu\text{g}/\text{m}^3$ were from the bulk products distribution center. The two remaining measurements were from samples collected in the tensioning process at the midwestern strip distribution center.

By work category or process/job, median values ranged from 0.01 to $0.07 \mu\text{g}/\text{m}^3$, geometric means (GMs) ranged from 0.02 to $0.07 \mu\text{g}/\text{m}^3$, and geometric standard deviations (GSDs) ranged from 1.8 to 3.6 (Table 1). The two single highest measurements were in heat-treating (bulk products) and tensioning (strip products), 1.6 and $1.4 \mu\text{g}/\text{m}^3$, respectively. The 95th percentile UTL was highest in bulk products production ($0.26 \mu\text{g}/\text{m}^3$), compared with strip production ($0.13 \mu\text{g}/\text{m}^3$), production support ($0.07 \mu\text{g}/\text{m}^3$), and administration jobs ($0.12 \mu\text{g}/\text{m}^3$).

The upper 95% upper confidence limit (UCL) for the fraction of the

data that exceeded $2 \mu\text{g}/\text{m}^3$ (ie, the OEL exceedance UCL) was less than 1% in all four work categories. The analogous exceedance UCL for $0.2 \mu\text{g}/\text{m}^3$ was 9% in bulk products production and 2% or less in the other categories. Among specific processes or jobs in bulk products, the higher exceedance fractions for $0.2 \mu\text{g}/\text{m}^3$ were in shearing (24%), heat treating/pickling (15%), and plate sawing (13%). Only one of the processes in the strip metal facilities had a similarly high exceedance fraction: tensioning (27%). Please note, however, that the exceedance values for shearing and tensioning were each based on 12 samples; exceedance values calculated on less than 15 samples may be less reliable. The OEL exceedance UCL of $0.2 \mu\text{g}/\text{m}^3$ for administration-plant personal samples was 6%. All other processes/jobs were less than 5%.

Chronic Beryllium Disease Case Report

The worker was diagnosed with CBD based on positive BeLPT tests and the presence of granulomas on biopsy. This worker was in the 90th percentile of the participants in both age and years of beryllium-related work. He was employed in a strip distribution center from 1978 to 2000 only in the production support role of shipper/receiver. His daily activities included loading and unloading materials with forklifts and pallet jacks onto and off delivery trucks. A contract trucking company delivered materials from the company's beryllium metal, alloy, and oxide production facility and its copper-beryllium alloy facility to this distribution center, whereas common carrier trailer vans were used to transport materials from this center to customers. He typically entered and exited both common carrier and contracted vans throughout the day.

He recalled that when he first began working, trucks bringing materials to the center were also trans-

TABLE 1

Airborne Beryllium in Three Distribution Centers—Personal Sample Total Mass Exposure Concentration by Work Category, and by Process or Job Within Each Category—1996 to 2004

Work Category Process or Job*	n	Range ($\mu\text{g}/\text{m}^3$)	Median ($\mu\text{g}/\text{m}^3$)	GM ($\mu\text{g}/\text{m}^3$)	GSD	95th Percentile UTL† ($\mu\text{g}/\text{m}^3$)	OEL Exceedance UCL (%)‡	
							2.0 $\mu\text{g}/\text{m}^3$	0.2 $\mu\text{g}/\text{m}^3$
Production: bulk products	130	<i>(<0.02–1.62)</i>	<i>0.04</i>	<i>0.04</i>	<i>2.87</i>	<i>0.26</i>	<1	9
Shearing	12	<i>(0.03–0.20)</i>	<i>0.07</i>	<i>0.07</i>	<i>1.99</i>	<i>0.48</i>	<1	24
Heat treating/pickling	40	<i>(<0.02–1.62)</i>	<i>0.04</i>	<i>0.04</i>	<i>3.11</i>	<i>0.42</i>	<1	15
Plate sawing	52	<i>(<0.02–0.81)</i>	<i>0.04</i>	<i>0.04</i>	<i>3.00</i>	<i>0.36</i>	<1	13
Small band sawing	26	<i>(<0.02–0.07)</i>	<i>0.02</i>	<i>0.02</i>	<i>2.06</i>	<i>0.11</i>	<1	2
Production: Strip metal	162	<i>(<0.01–1.40)</i>	<i>0.03</i>	<i>0.03</i>	<i>2.25</i>	<i>0.13</i>	<1	2
Tensioning	12	<i>(<0.02–1.40)</i>	<i>0.03</i>	<i>0.04</i>	<i>3.60</i>	<i>1.18</i>	3	27
Welding	44	<i>(<0.01–0.17)</i>	<i>0.01</i>	<i>0.02</i>	<i>2.11</i>	<i>0.07</i>	<1	<1
Low-speed slitting	88	<i>(<0.01–0.18)</i>	<i>0.05</i>	<i>0.04</i>	<i>1.81</i>	<i>0.12</i>	<1	1
High-speed slitting	18	<i>(<0.02–0.08)</i>	<i>0.02</i>	<i>0.02</i>	<i>2.03</i>	<i>0.13</i>	<1	3
Production support	35	<i>(<0.02–0.13)</i>	<i>0.01</i>	<i>0.02</i>	<i>2.05</i>	<i>0.07</i>	<1	<1
Shipping and receiving	35	<i>(<0.02–0.13)</i>	<i>0.01</i>	<i>0.02</i>	<i>2.05</i>	<i>0.07</i>	<1	<1
Administration	66	<i>(<0.02–0.32)</i>	<i>0.01</i>	<i>0.02</i>	<i>2.48</i>	<i>0.12</i>	<1	2
Administration-plant	35	<i>(<0.02–0.32)</i>	<i>0.02</i>	<i>0.02</i>	<i>2.75</i>	<i>0.20</i>	<1	6
Administration-office	31	<i>(<0.02–0.15)</i>	<i>0.01</i>	<i>0.02</i>	<i>2.10</i>	<i>0.08</i>	<1	<1

*Summary data for each work category are presented in italics, followed by individual processes or jobs within that category.

†95th percentile upper tolerance limit (UTL)—upper 95% confidence limit around the 95th percentile of the distribution.

‡Occupational exposure limit (OEL) exceedance fraction upper confidence limit (UCL)—upper 95% confidence limit for fraction of samples that exceed a given occupational exposure limit.

GM indicates geometric mean; GSD, geometric standard deviation.

ferring containers of beryllium oxide (BeO) powder; however, he did not remember any visible breaks or leaks of materials from those barrels. The incoming trucks also hauled barrels containing copper–beryllium scrap, and he remembered occasionally seeing loose scrap materials on the floor of the truck. Overall, he stated that the trucks delivering products were generally clean. Typical duties for his job also included receiving and putting products away, processing orders for rod materials, and packaging orders for shipment. When filling rod orders, he would usually open large boxes of rods, remove the amount requested by a customer, and cut the rods to customer-specified lengths with either bolt cutters or a hacksaw, operations not expected to create detectable air levels because few airborne particles are produced. Smaller rod orders were then repackaged for shipment to the customer. He also recalled working in the late 1990s with 5-pound aluminum–beryllium ingots. These in-

gots were received in large fiber drums, and he weighed smaller amounts of the ingots and transferred them into smaller fiber drums to fill customer orders. He described the ingots as being dusty. After implementation of improved trailer cleanliness and ingot-handling procedure changes, his three lapel samples collected in 2000 were below $0.02 \mu\text{g}/\text{m}^3$.

During clinical evaluation for CBD, this exsmoker was noted to have significant pulmonary function impairment. His forced expiratory volume in 1 second was 33% of predicted, and his forced vital capacity was 64% of predicted. The chest x-ray showed hyperinflation. BAL revealed 37% lymphocytes and the BALLPT results were indeterminate.

Discussion

Prevalences of sensitization and CBD found in these copper–beryllium alloy distribution centers were lower than observed in several other studies of beryllium-exposed workers (Table 2), which found prevalences

for beryllium sensitization ranging from 0.9% to 10% and for CBD ranging from 0.1% to 4%.

In this study, we did not find sensitization or CBD in the bulk distribution center facility with the highest measured exposures or in the workgroup with the highest measured exposures (ie, production). Rather, the single case of sensitization/CBD was found in an employee who spent his entire 22-year career in a production support job as a shipper/receiver at one of the strip centers. A case of both beryllium sensitization and CBD has been identified in shipping/receiving personnel at another beryllium processing facility.²⁵ The available exposure data in this study offer no specific information to support the role of higher beryllium mass concentration exposures in the development of his disease, because he worked at a strip metal facility, which had lower measured exposures than the other distribution centers and in a work category/job with among the lowest

TABLE 2
Prevalence of Sensitization and Chronic Beryllium Disease (CBD) From Previous Studies

Facility	Prevalence		
	Sensitization (including CBD)	CBD Only	
Kreiss et al, 1993*	Nuclear weapons plant	2% (18/890)	2% (15/890)
Kreiss et al, 1993	Beryllium ceramics	2% (9/505)	2% (9/505)
Stange et al, 1996†	Nuclear weapons plant	2% (97/4397)	0.6% (28/4397)
Kreiss et al, 1996	Beryllium ceramics	6% (8/136)‖	4% (6/136)
Kreiss et al, 1997	Metal, alloy, oxide production	7% (43/627)‖	4% (24/627)
Newman et al, 2001‡	Beryllium precision machining	6% (15/235)¶	3% (8/235)
Henneberger et al, 2001§	Beryllium ceramics	10% (15/151)¶	3% (5/151)
Deubner et al, 2001	Beryllium mining and extraction	4% (3/75)	1% (1/75)
Sackett et al, 2004	Nuclear decontamination and decommission	0.9% (19/2221)	0.1% (2/2221)
Welch et al, 2004	Nuclear construction	1.4% (53/3842)	0.1% (5/3842)
Schuler et al, 2005	Copper–beryllium alloy processing	7% (10/153)‖	4% (6/153)
Current study	Copper–beryllium alloy distribution centers	1% (1/88)	1% (1/88)

*Population was a stratified random sample.

†Data from initial round of participation in Beryllium Health Surveillance Program.

‡Results from round 1 of the original test year.

§Six-yr follow up at the same facility as Kreiss et al 1996; does not include any workers with sensitization or CBD from the 1992 survey.

‖ $0.05 < P \leq 0.10$, compared with the study results from the current study.

¶ $P \leq 0.05$.

exposures measured at the time of the survey. However, because data for his job category were limited in number (35) and no samples were taken on this job in the 18-year period before 1996, we cannot draw firm conclusions about exposure conditions he may have experienced over the entire period he was employed. Exposures in the past were likely unique to shipping and receiving as the source of risk, notably weighing and repackaging of copper–beryllium alloy ingot, or unloading trailer vans possibly contaminated with other beryllium materials such as BeO. Risk patterns have been demonstrated to persist for many years despite transfer to other work, reduction in exposure, or removal from beryllium work.^{4,5,10,26}

The medical surveillance data from these distribution centers documented that low median exposures (in the range of 0.01–0.07 $\mu\text{g}/\text{m}^3$), and 95th percentile UTLs from 0.07 $\mu\text{g}/\text{m}^3$ to 1.18 $\mu\text{g}/\text{m}^3$ were associated with a relatively low rate of beryllium sensitization and CBD. Risk was demonstrated by the one long-term employee who developed CBD, who in addition to handling copper–beryllium materials, also

handled beryllium-containing alloy ingots and was potentially exposed to BeO, beryllium hydroxide, and beryllium scrap while moving materials in and out of trailer vans. This study reinforces previous studies, which have indicated that workers without documented airborne concentrations in excess of the OSHA PEL (2 $\mu\text{g}/\text{m}^3$) can develop beryllium disease.^{4,5,7} Such cases include those reporting minimal exposure potential such as a secretary and security guard in a nuclear weapons facility.⁴ CBD has been diagnosed in a worker at a former ceramics plant who had no recognized prior beryllium exposure and who began working 8 years after the production of beryllium ceramics at that facility had ended.⁵ One case of CBD was also found in an employee working only in an administrative position but who was likely to have spent time in production areas.⁷ In these instances, exposures were not characterized. In this study, recent exposure data demonstrated very low levels of airborne mass beryllium concentrations across all three distribution centers. However, even in an environment with seemingly low exposures in production areas, an individual may

still experience exposures in unanticipated ways sufficient to result in sensitization or CBD. These findings reinforce the need to further minimize beryllium particle migration by assuring container integrity and product cleanliness for materials in transit.

The company, before this survey, had identified several problems with shipping practices. Specifically, the employee diagnosed with CBD loaded and unloaded copper–beryllium alloy materials from trailers that also sometimes carried containers of BeO powder. During the period of his employment, trailers were known to be contaminated on several occasions when shipping and receiving personnel at other locations punctured containers of BeO with forklifts. In the mid-1990s, problems with contamination of plastic drums used for shipment of beryllium hydroxide were also recognized. Improved practices for washing empty beryllium hydroxide drums before transportation back to the ore-extraction facility were subsequently implemented. Although when interviewed, this employee did not recall seeing any powder residue in company-contracted trailers, one possi-

ble explanation for the employee's development of CBD was that unrecognized exposures may have occurred while loading and unloading beryllium-contaminated trailer vans. A second possible contributing cause was the handling of dusty ingots that had surface oxidation remaining from casting operations. Until the early 1990s, copper-, nickel-, and aluminum-beryllium alloy ingots were visibly dusty when sent to the distribution centers. At this time, the company introduced an additional step to the ingot-handling process that used a Wheelabrator to remove all visible surface dust from the ingots before shipping.

Limitations

There were a relatively small number of employees in these three distribution centers combined and, with only one sensitized/CBD worker, no statistical testing was appropriate. As such, results from this study could not be used to draw firm conclusions about job-related risk, creating uncertainty on how to best use the results to improve worker safety. Additionally, airborne beryllium sampling data available from these centers were limited and did not characterize exposures that occurred before 1996. Because historical risk patterns persist, inability to characterize exposures in the past limited our interpretation of results.

Recommendations

The relatively low prevalence of sensitization and CBD observed in this study is encouraging for "downstream" workers who may handle copper-beryllium alloy products in a similar manner. However, our results indicate that employees are still at risk for beryllium sensitization and CBD, despite very low airborne beryllium exposures, when all avenues of potential exposure are not well understood or managed. A better understanding of risk in low-exposure environments requires that studies be organized using well-characterized

exposure data with broad industry support so that the numbers of workers are adequate to ascertain process-associated risks downstream of the primary production industry. To further the understanding of exposure-response, studies should focus on relatively recently hired workers for whom there is representative exposure characterization.

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