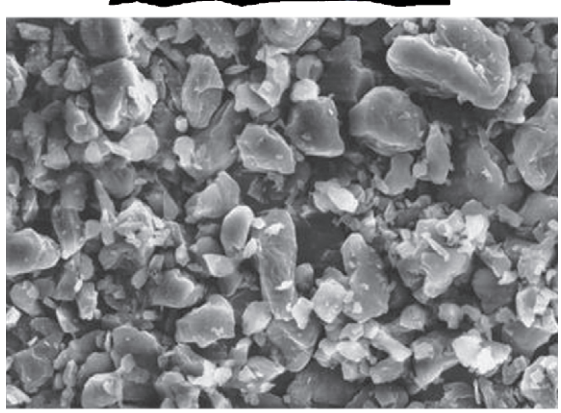
JULY/AUGUST 2008
Volume 15, Number 4

Journal of CHEMICAL Health & Safety

Evaluation, Airborne Release Fractions, and Control of Beryllium Hazards at Los Alamos National Laboratory



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PUBLISHED BY ELSEVIER INC. FOR THE ACS DIVISION OF CHEMICAL HEALTH AND SAFETY

FEATURE

Beryllium health effects, exposure limits and regulatory requirements

By Paul F. Wambach, J.C. Laul

Beryllium is the lightest chemically stable metallic element. Research and development in the 1930s led to its use in industrial applications beginning in the 1940s. Subsequently, reports of lung and skin disease surfaced leading to epidemiologic and toxicology studies of beryllium's health effects. These studies have identified a range of health effects with solubility of the chemical form of beryllium as a key determinant whether the effects are acute (short term) or chronic (long term).

The development of lymphocyte proliferation testing (BeLPT) for beryllium sensitization (BeS) in the 1980s and its use in medical screening has led to increasing awareness that occupational chronic beryllium disease (CBD) has not been controlled to the extent once thought. The enforceable long-standing occupational exposure limits intended to prevent CBD are now considered to be obsolete. However, proposed new limits have yet to be adopted. The basis for existing and proposed occupational and public exposure limits and regulatory requirements are discussed here. The current ACGIH and OSHA adopted occupational exposure limit for workers is 2.0 $\mu g/m^3$, based as an 8-hour time weighted average (TWA). An occupational exposure limit of 0.2 μ/m^3 (8-Hr TWA) has been adopted by California as a regulatory limit and is being used by others as well. To protect the public from CBD, there is a long-standing EPA beryllium ambient air limit set of 0.01 $\mu g/m^3$ as a 30-day TWA.

Unlike the acute health effects, CBD affects a few percent (0–4%) of those exposed to beryllium. The latency period between exposure and CBD can vary from months to decades. CBD is caused by the immune system's continuing reaction to the less soluble forms of beryllium retained in the body. An individual is considered to be sensitized to beryllium if BeLPT results show they are able to mount an immune response to beryllium. The morbidity and mortality associated with CBD are primarily due to lung damage caused by chronic inflammation. CBD is treatable but not curable.

The existing ERPGs for Be are intended to prevent the acute health effects, primarily chemical pneumonitis caused by the more soluble forms of Be. Patients who survive acute beryllium disease will typically recover in less than 1 year. The need for an emergency response to prevent chronic effects is less obvious, and short-term exposure to the less soluble forms of Be could contribute to risk for CBD. Based on medical surveillance data from various DOE sites for current workers tested (13,270) and former workers (43,628), the number of sensitization and CBD cases at each site is a few percent (0–4%). Sensitization and CBD are due to an immune-system response, and they have not been found to be sensitive to the length of employment of a worker in a beryllium facility.

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INTRODUCTION

Beryllium is a naturally occurring lightweight metallic element. Smith et al.[1] report that the concentration of beryllium in surface soils in the United States range from 0.09 to 3.4 parts per million (ppm) with a median of 1.2 ppm beryllium. Trace levels are present in food, water and the ambient air. Aquamarine and emerald are gemstone forms of beryl. Beryllium for industrial use is extracted from beryl and bertrandite ores. Beryllium hydroxide is the feedstock for production of beryllium oxide, beryllium metal, and beryllium alloys and composite materials.[2]

In 2005, the United States is estimated to have accounted for 80% of world production.[3] China and Kazakhstan are the other two countries known to process beryllium ore into beryllium-containing materials. Automotive electronics, telecommunications and computers are the major international markets for beryllium. Approximately 84 metric tons of beryllium were contained in products

1871-5532/$32.00
doi:10.1016/j.jchas.2008.01.012

consumed in the United States market in 2005. Electrical components, aerospace and defense applications accounted for an estimated 80% of that total.

Pure beryllium metal is used in defense, aerospace, X-ray imaging and nuclear applications where its combination of strength, lightweight, low neutron absorption, transparency to X-rays, and dimensional stability over a wide temperature range justify the high cost. Beryllium salts (e.g., sulfate or fluoride) and beryllium hydroxide are intermediates in production processes and small quantities are used as laboratory reagents. The thermal conductivity and transparency to microwaves of beryllium oxide (BeO) ceramics has led to use in electronics, microwave and communication equipment. Most beryllium is used to strengthen copper. The high strength alloys retain copper's electrical conductivity, heat dissipation and corrosion resistance leading to many electronic and specialty tool applications. Copper–beryllium alloys are common substrates for gold plated electrical connectors.[3] As a result, beryllium may be encountered in both the precious metal recovery and metal recycling industries. Mining, processing ore and gemstone polishing can result in exposure to naturally occurring beryllium-containing silicates.

Henneberger et al.[4] estimated the number of workers in the United States currently exposed to beryllium as being between 54,000 and 134,000, with perhaps 3–5 times as many having been exposed at some time in the past. Recent studies find chronic beryllium disease (CBD) rates of a few percent among current and former beryllium workers with a wide range of exposure levels and duration. Acute health effects that were once a significant occupational health problem appear to have been controlled by the lower exposure levels of recent years. The DOE has ongoing medical surveillance program for current and former beryllium workers at various DOE sites. Findings of these results such as number of sensitization and CBD cases, effects of job categories and length of employment, coupled with the beryllium health effects as a result of short-term (acute) and long-term (chronic) exposure, regulatory requirements are discussed in this report.

BERYLLIUM HEALTH EFFECTS

Lung disease has been the major source of morbidity, mortality and disability associated with exposure to beryllium. In 1945, Van Ordstrand et al. reported 170 cases of beryllium poisoning (including both respiratory and dermatological symptoms) in three plants producing beryllium metal, oxide and alloys.[5] In the following year, Hardy and Tabershaw[6] reported 17 cases of CBD in a fluorescent light plant. These cases were related to exposure from beryllium-containing phosphors used in the manufacture of the lamps.

Acute beryllium disease is a chemical pneumonitis thought to be due to direct toxicity to cells in the lung from exposure to high levels of the more soluble forms of beryllium.[7] The onset of the disease can range from a few hours after a very high exposure to a within a few weeks of the beginning of continuing exposures. Recovery time for survivors can take as long as a year and acute beryllium disease is sometimes defined as beryllium associated lung disease lasting less than a year. Similar effects can be reproduced in laboratory animals. Laboratory animal toxicology studies provide the primary basis for exposure limits aimed at preventing this effect. While initially the major source of morbidity and mortality in the beryllium production industry during the 1940s, acute beryllium disease is very rare now with the last published case reports occurring in the 1970s.

CBD is a delayed hypersensitivity granulomatous lung disease due to even very low levels of exposure to the more insoluble forms of beryllium.[8] Granulomas are an abnormal tissue that forms due to a proliferation of immune-system cells (Figure 1).

In the lung, granulomas interfere with gas exchange. If they persist, scar tissue forms (fibrosis), which causes permanent lung damage. CBD is treatable with anti-inflammatory medications that reduce granulomas, improve lung function and minimize permanent damage from fibrosis. However, it is considered an incurable disease and some individuals will progress despite treatment. CBD is known to have a genetic susceptibility component so that only a few percent of exposed individuals will develop the disease.[9] The latency period, rate of progression and severity of the disease are highly variable, presumably due to host susceptibility factors.

The National Toxicology Program (NTP) lists beryllium and beryllium compounds as "known to be human carcinogens" in its most recent report on carcinogens.[10] The conclusion is based on consistent finding of lung cancer in several animal species exposed to metallic beryllium and beryllium-containing compounds. Beryllium has also been shown to cause bone cancer in rabbits. The conclusion is also supported by findings suggestive of excess lung cancer among beryllium production plant workers.

Different beryllium compounds cause a range of skin diseases.[11] The more soluble beryllium salts cause irritant and allergic contact dermatitis. Larger crystals accidentally implanted or contaminating wounds can cause a chemical ulcer or ulcerating granulomas. The less soluble forms of beryllium can cause delayed hypersensitivity dermal granulomas at the site of implantation or contaminated wounds. Reports of cases where granulomas spread away from the wound are thought to be due to movement of removable beryllium oxide on the surface of the particle or sliver. The fact that beryllium can cause immune-cell-mediated skin diseases has led to conclusions that skin exposure may have a role in the sensitization step of CBD.[12]

CURRENT EXPOSURE STANDARDS: WORKPLACE AND PUBLIC, AND RATIONALE FOR DERIVATIONS

Worker Protection

There are eight published occupational exposure limits for beryllium, including five that are obsolete, but still listed in published standards and guides. The Occupational Safety and Health Administration (OSHA) lists three permissible exposure limits (PELs)

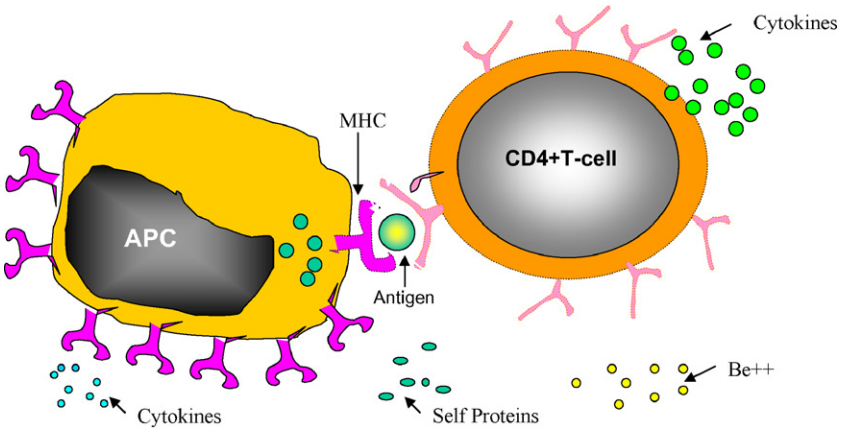

Figure 1. Immunopathogenesis of chronic beryllium disease. Beryllium plus 2 ions (Be^{2+}) combine with a self-protein or the major histocompatibility complex (MHC) protein on antigen presenting cells (APC) to present antigen to CD4+ T-cell lymphocytes. The lymphocytes emit signaling molecules called cytokines that cause a proliferation of immune-system cells and inflammation. The continuing presence of Be^{2+} from the slow dissolution of the less soluble forms of beryllium sustains the inflammation leading to the chronic, slowly progressive disease called chronic beryllium disease (CBD).

that it acknowledges are not protective for CBD.[13,14] However, these currently remain the enforceable PELs.

(1) The 2 microgram per cubic meter ($\mu g/m^3$) 8-hour time weighted average (8-Hr TWA) PEL is listed in the OSHA Z-1 Table, was an exiting standards adopted by OSHA in 1971. The 2 $\mu g/m^3$ limit was first promulgated in the 1940s by the Atomic Energy Commission (AEC) through analogy with other toxic metals and was a quarterly mean of "daily weighted averages".[15] Daily weighted averages were a method of estimating exposure used prior to the development of wearable personal samplers.

(2) In 1959, 2 $\mu g/m^3$ was adopted by the American Conference of Governmental Industrial Hygienists (ACGIH) as an 8-Hr TWA Threshold Limit Value (TLV®), exposure limit.

(3) The OSHA table Z-2 PELs were adopted from American National Standards Institute (ANSI) standards. An existing ANSI standard listed 25 $\mu g/m^3$ 30-minute TWA, which was also first promulgated in the 1940s by the AEC to prevent acute beryllium disease. It is based on laboratory animal studies and supported by limited epidemiology.

(4) The ANSI standard continued the use of 2 $\mu g/m^3$ as a quarterly mean of "daily weighted averages" but supplemented this with a 5 $\mu g/m^3$ an 8-hour TWA limit for any work shift within the quarter and is listed in the OSHA Z-2 Table as a "ceiling" value.

(5) There is a NIOSH recommended exposure limit (REL) of 0.5 $\mu g/m^3$ 8-Hr TWA,[16] which was first published in the 1980s under policies of the era that required control of carcinogenic materials to levels as low as reasonably achievable.

(6) In 2006, the California Occupational Safety and Health Standards Board adopted a PEL for beryllium of 0.2 $\mu g/m^3$ as an 8-Hr TWA, which is the enforceable exposure limit in that state.[17]

(7) In 1999, the Department of Energy (DOE) adopted an action level of 0.2 $\mu g/m^3$ as an 8-Hr TWA,[18] at which respiratory protection, exposure reduction plans, and additional controls are required.

(8) In 2006, the ACGIH published a notice of intent to change its existing TLVs® for beryllium to 0.05 $\mu g/m^3$ as an 8-Hr TWA and 0.2 $\mu g/m^3$ as a 15-minute Short-Term Exposure Limit (STEL®). These limits were derived by applying safety factors to observed adverse effects levels reported in recent epidemiology studies. This proposal was republished in 2007 and remains under consideration.[19]

Public Protection

There are four published Be exposure limits aimed at protecting the public from air emissions.

(1) The 0.01 $\mu g/m^3$ Environmental Protection Agency (EPA) National Emission Standard for Hazardous Pollutants (NESHP), per 40 CFR 61.32, is a mean ambient air level not to be exceeded in any 30-day period.[20] This is a long-standing ambient air limit based on the estimated 'no observed adverse effects' level from a study of neighborhood cases.[21,22]

(2) The 75 $\mu g/m^3$ of air within the limits of 10–60 min, accumulated during any 2 consecutive weeks EPA NESHP for Beryllium Rocket Motor Firing.[23] This standard is based on studies of laboratory animals exposed to these emissions, which contain a mixture of beryllium oxide, chloride, and fluoride.[24]

(3) The 0.02 $\mu g/m^3$ EPA Integrated Risk Information System (IRIS) Reference Concentration, which is a mean ambient air level not to be exceeded in any 24-hour day.[7] This was arrived at by applying safety factors to the 'observed adverse effects level' established in an occupational study[25] and supported by the neighborhood study.

ERPGs/TEELs for Beryllium and its Compounds and their Criteria

The Emergency Response Planning Guidelines (ERPGs) and Temporary Emergency Exposure Limits (TEELs) listed in Table 1 are commonly used to assess the severity of exposure from beryllium and compound to a receptor. The ERPGs/TEELs with increasing severity are defined as follows.[26]

ERPG/TEEL-1: The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing other than mild, transient adverse health effects or without perceiving a clearly defined objectionable odor.

ERPG/TEEL-2: The maximum airborne concentration, below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective actions.

ERPG/TEEL-3 is the "maximum airborne concentration, below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing life threatening health effects".

DISCUSSION

Hazardous Beryllium Aerosols

Recognition in the late 1980s that CBD remained a significant occupational health problem has led to a body of new publications on this disease. These include reports on epidemiologic studies of exposed workers, studies of the cellular and molecular biology of CBD and of the aerosols associated with CBD.[27–32] The aerosols in these studies were produced by machining metal, precision grinding beryllium oxide ceramics, fume from casting and metal recovery of copper beryllium alloys and the heat from rolling and extruding copper beryllium alloys that result in a removable oxide layer. The aerosols were found to contain a high percentage of particles less than 10 micrometers aerodynamic diameter (AED).[33,34] Studies of the solubility of these materials in simulated macrophage inter-cellular fluid show that they share similar characteristics of being more soluble in the acidic environment inside macrophages than out. Toxicity to macrophages may account for relatively insoluble particles long retention in the lung and the ability to contribute ions thought to combine with self-proteins that form antigens.[35] It is the continuing presence of these antigens that is thought to sustain inflammations that damage the lung.

The ERPGs are intended to prevent acute beryllium disease, a health effect associated with exposures 2–3 orders of magnitude higher than those associated with CBD and due to exposure to soluble beryllium compounds. Accident scenarios leading to the release of significant quantities of beryllium involve structural fires or other energetic reactions that volatilize an inventory of solid articles to the gas phase that would then precipitate to a particulate aerosol, presumably made-up of relatively insoluble beryllium oxide. Commercial beryllium oxide is produced by calcining beryllium hydroxide solutions. There are studies showing that "low calcined" beryllium oxide causes acute beryllium disease rather than chronic.[36] This is largely of historical interest as studies showing that beryllium oxide calcined at less than 500 °C caused acute disease led to its replacement with beryllium calcined at greater than 1000 °C. The low calcined material is made of agglomerates of smaller primary particles that have a very high surface area to mass ratio that makes them more soluble. The melting point of beryllium metal is 1287 °C and over 2500 °C for beryllium oxide[37] so accidents capable of volatilizing these materials occur at temperatures higher than calcining temperatures. However, it is uncertain that conditions leading to formation of soluble agglomerates can be completely ruled-out.

On the other hand, long or short-term inhalation exposure of beryllium at low levels can cause CBD among the few percent of the population that is susceptible. It is generally accepted that sensitization occurs anywhere in the respiratory tract and is precursor to CBD. The less soluble forms of beryllium responsible for CBD are retained in the lungs for a long period of time.[38]

The airborne pathway for humans is largely through inhalation exposure, although absorption through nose or skin can also contribute risk. Tinkle et al.[12] have suggested that skin should be considered as a possible route to sensitization. However, for risk management, it should not matter whether beryllium aerosols cause CBD through inhalation or skin exposure. It is generally accepted that the sensitization and CBD are caused by the immune-system response of individual workers and that genetic susceptibility is an important risk factor. Thus, not every one who is exposed, even to high levels of beryllium, gets sensitized. The numbers of sensitization and CBD cases are a few percent of the population exposed.

There is considerable variation in the lag time for sensitization, weeks

Table 1. ERPGs/TEELs Values for Beryllium and its Compounds[a,b]

Compound	ERPG/TEEL-1 (mg/m^3)	ERPG/TEEL-2 (mg/m^3)	ERPG/TEEL-3 (mg/m^3)
Beryllium metal, Be	0.005	0.025	0.1
Beryllium hydroxide, $Be(OH)_2$	0.025	0.25	20
Beryllium oxide, BeO	0.0125	1.25	10[a,b]
Ratio of BeO/Be	2.5	50	100

[a] $1\ mg/m^3 = 2.72$ ppm.

[b] On oxidation, Be is converted to BeO, which has 100 times more threshold value than Be metal ($10\ mg/m^3$ vs. $0.1\ mg/m^3$). Based on this assumption, BeO is lot less hazard than Be to a receptor on a short-term exposure. For long term (chronic) exposure, both Be metal and BeO can lead to CBD, however, their relative degree of hazards is not known.

to years after exposure. However, there is a consensus that sensitization is precursor to the CBD. The lung damage caused by CBD is due to the immune-system response localized in the part of the deep lung where oxygen exchange occurs and where only particles <10 μm AED deposit.

Research and development of beryllium-containing solid rocket propellant in the late 1950s and early 1960s included toxicology studies of the propellant exhaust. The exhaust was found to contain a mixture of chloride and fluoride soluble salts that were capable of causing acute beryllium disease.[24] This led to the use of aluminum instead of beryllium in solid rocket propellant. However, from this it would appear that soluble beryllium compounds can be formed if acid gases are being produced in the same fire or other accident scenario responsible for volatilizing and releasing beryllium.

CBD does not create casualties that would require an emergency response. It is a highly variable disease that can range from mild cases that do not require treatment to severe case with significant disability and reduction in life expectancy. The latency period between exposure and disease also varies from less than a year to decades. The reason for a latency period is not understood but thought to be similar to autoimmune diseases, such as multiple sclerosis, where the antigen has been present for the individual's lifetime and the immune response is triggered by some other insult to the immune system. Because the insoluble forms of beryllium are retained in the lung, acute exposure can cause the disease and no subsequent or continuing exposure is required.[38]

Medical Surveillance Findings

There are several published reports showing the results of medical surveillance programs for CBD. Programs at Department of Energy (DOE) sites are among the largest. These show differences from site-to-site and groups at the same site that indicated exposure level is a significant risk factor for CBD. Table 2 lists the medical surveillance data for selected DOE sites for current workers.[39]

The data shown in Table 2 is from a report summarizing medical surveillance results through December 2005, which lists the DOE site or organization, number of individuals tested, number of sensitized cases, number of CBD cases, and combined percent rate of sensitized and CBD cases. Since sensitization is precursor to CBD, number of sensitization cases is also a useful indication of working conditions capable of causing CBD.

It is to note that the people representing the sensitization cases are different from those representing the CBD cases. For example, at Pantex Plant, number of sensitization cases is 17 and number of CBD cases is 15 with a total of 32 cases, out of 1,617 individuals tested with a combined sensitized and CBD rate of 2.0%. The range varies mostly from 0.3% to 5.2%. Among a total number of workers tested 13,270 the number of sensitized cases are 157 (1.2%) and CBD cases are 90 (0.68%) with a total sensitized and CBD of 247, which is 1.9% of those tested.

Table 3 lists similar medical surveillance data for former workers (no longer employed).[40] Again there are differences between the sites that are presumably due to differences in exposure.

Former workers at Rocky Flats (Table 3) included individuals who fabricated beryllium metal components have a much higher rate of sensitization and CBD then current workers who have primarily been performing facility decontamination and environmental restoration tasks. Among the Rock Flats former workers there are also differences between groups that are typical of the differences reported by other studies.[41]

Table 4 shows that the Rocky Flats workers with the greatest opportunity for exposure have the highest rates of sensitization and disease. However workers who did not work directly with beryllium and who probably only had only intermittent exposure, are also at risk for CBD. For example, machinists have a higher rate of sensitization and CBD cases (11.9%) than craftsmen, administrators, and engineers (4.2–4.8%).

Duration of employment (Table 5) is often used as an indicator of total lifetime exposure although it has not been an important risk factor in studies of sensitization and CBD rates. There is no apparent trend in this data for former DOE beryllium workers.[40] Sensitization and CBD have not been found to be sensitive to the length of employment of a worker in a beryllium facility.

Table 2. Medical Surveillance Data for DOE Sites with More than 1000 Current Worker Participants

Site	Number Tested	Number Sensitized	Number CBD	Rate Sensitized and CBD (%)
Y-12 National Security Complex	1,642	44	42	5.20
Kansas City Plant	1,011	21	11	3.20
Pantex Plant	1,617	17	15	2.00
Hanford Reservation	3,359	42	19	1.80
Rocky Flats Environmental Technology Site	3,980	31	0	0.80
Los Alamos National Laboratory	1,661	2	3	0.30
Total	13,270	157 (1.2%)	90 (0.68%)	1.86

Table 3. Medical Surveillance Data for DOE Sites with More than 1000 Former Worker Participants

Site	Number Tested	Number Sensitized	Number CBD	Rate Sensitized and CBD (%)
Rocky Flats Environmental Technology Site	8,695	224	131	4.10
Lawrence Livermore National Lab	1,804	47	7	3.00
Pantex Plant	1,228	22	5	2.20
Kansas City Plant	3,272	64	4	2.10
Oak Ridge Site (Y-12, ORNL, ETTP)	9,129	121	39	1.70
Hanford Construction	3,982	47	12	1.50
Savannah River Site	3,331	42	1	1.30
Nevada Test Site	1,836	21	2	1.30
Los Alamos National Laboratory	2,114	22	2	1.10
Idaho National Laboratory	2,734	16	0	0.60
Paducah Gaseous Diffusion Plants	2,483	13	0	0.50
Portsmouth Gaseous Diffusion Plant	3,020	7	0	0.20
Total	43,628	646 (1.5%)	203 (0.45%)	1.95

Table 4. Medical Surveillance Data by Job Category[a]

Job Categories	Number Tested	Number Sensitized	Number CBD	Rate Sensitized and CBD (%)
Beryllium machinist	201	7	17	11.9
Construction trades	191	14	5	10.0
Radiation technician	346	15	8	6.7
Repair	167	7	3	6.0
General machinist	1,077	33	28	5.7
Custodial	709	19	21	5.6
Laborer	483	14	13	5.6
Chemical technician	859	21	20	4.8
Crafts and trades	632	17	13	4.8
Facilities support	570	16	10	4.6
Administrative	2,254	69	29	4.4
Engineer	988	27	14	4.2
Technician/inspection	1,444	36	22	4.0
Scientist	329	10	1	3.3
Environmental	255	4	3	2.8
Security	288	4	0	1.4
All subjects	10,793	322 (2.98%)	169 (1.57%)	4.6

[a] Data from former Rocky Flats Environment Technology Site.[41]

Table 5. Medical Surveillance Data by Duration of Employment

Years Worked	Number Tested	Number Sensitized	Number CBD	Rate Sensitized and CBD (%)
Less Than 5	8,851	145	47	2.17
5 to <10	6,032	88	25	1.87
10 to <15	5,196	69	30	1.91
15 to <20	3,484	62	15	2.21
20 to <25	3,236	50	18	2.10
25 to <30	3,321	64	23	2.62
30 or >	5,897	124	40	2.78
Not reported	3,615	30	12	1.16
Totals	39,632	632 (1.59%)	210 (0.53%)	2.12

SUMMARY AND CONCLUSIONS

1 Beryllium aerosol exposures cause two major health effects: (a) acute beryllium disease from ERPG-3, ERPG-2 levels of the more soluble forms; and (b) chronic beryllium disease (CBD) from much lower levels of the less soluble forms.
2 Given the slow dissolution and long retention of the less soluble forms of beryllium, the possibility that acute exposures over minutes or hours create potential risk for chronic disease cannot be ruled-out.
3 Not all those exposed to beryllium get sensitized. There is a lag time of weeks–months–years between the exposure and sensitization and CBD. There are fewer CBD cases than sensitization cases. CBD symptoms may not appear for periods longer than 10 years. CBD is treatable but not curable.
4 Based on medical surveillance data from DOE sites for current workers (13,270) and former workers (43,628), the number of sensitization and CBD cases at each site is a few percent (0–4%). While individual susceptibility is an important risk factor, the differences in rates between sites and among different exposure groups at the same site indicate exposure level is an important risk factor as well. For example, machinists have a higher rate of sensitization and CBD cases than craftsmen, administrators, and engineers.
5 Sensitization and CBD are due to an immune-system response that has not been found to be associated with length of employment of a worker in a beryllium facility.
6 The current ACGIH and OSHA adopted beryllium exposure TLV for workers is 2.0 $\mu g/m^3$ (8-Hr TWA). However, California regulations and DOE Rule 10 CFR "850 CBD Prevention Program" require a protection at 0.2 μ/m^3 (8-Hr TWA), to further mitigate or prevent any health effects or CBD. To protect the public from CBD, the EPA ambient air limit is 0.01 $\mu g/m^3$ on a 30-day TWA.
7 Release of aerosols containing the less soluble forms of beryllium creates some potential risk for CBD to a susceptible few percent of an exposed population. This risk would justify taking primary preventive actions to minimize exposures during the release and perhaps secondary preventive measures aimed at early identification of cases to assure appropriate medical care.
8 More recent EPA reference concentration and proposed ACGIH TLV® result in approximately equivalent daily intake levels. These levels were derived by applying safety factors to levels that were shown to cause CBD in recent studies. An ERPG-1 that would limit daily intake to a similar level would seem reasonable.
9 It is uncertain if beryllium aerosols from accidental releases would contain soluble forms of beryllium capable of causing acute beryllium disease. Given this uncertainty, use of the current ERPG-3 and ERPG-2 seems relevant.

ACKNOWLEDGEMENTS

The authors appreciate Jim Tingey and Rich Norman of SB-Division, and Gary Whitney of HIS-IP of LANL for their useful comments. The authors acknowledge the U.S DOE for support of this work.

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