

6. POTENTIAL FOR HUMAN EXPOSURE

6.1 OVERVIEW

Beryllium has been identified in at least 535 of the 1,613 hazardous waste sites that have been proposed for inclusion on the EPA NPL (HazDat 2002). However, the number of sites evaluated for beryllium is not known. The frequency of these sites can be seen in Figure 6-1. Of these sites, 524 are located within the United States, 2 are located in the Territory of Guam, 2 are located in the U.S. Virgin Islands, and 7 are located in the Commonwealth of Puerto Rico (not shown).

Beryllium is naturally emitted to the atmosphere by windblown dusts and volcanic particles (EPA 1987). The major anthropogenic emission source to the environment is the combustion of coal and fuel oil, which releases particulates and fly ash that contain beryllium into the atmosphere (DOE 1996). Other anthropogenic processes, such as ore processing, metal fabrication, beryllium oxide production and use, and municipal waste combustion, release only a fraction of the amounts emitted from coal and oil combustion (Cleverly et al. 1989; EPA 1987; Fishbein 1981). Beryllium naturally enters waterways through the weathering of rocks and soils (EPA 1980). The sources of anthropogenic release of beryllium to surface waters include treated waste water effluents from beryllium or related industries and the runoff from beryllium-containing waste sites (EPA 1980, 1981). Deposition of atmospheric beryllium aerosols from both natural and anthropogenic sources is also a source of beryllium in surface waters. Some beryllium compounds are naturally present in soil, but the concentration of beryllium in localized soils can be increased because of the disposal of coal ash, municipal combustor ash, industrial wastes that contain beryllium, and deposition of atmospheric aerosols.

Beryllium released to the atmosphere from combustion processes and ore processing will probably be present as beryllium oxide. Atmospheric beryllium particulates will eventually settle to the earth's surface by dry deposition or may be removed from the atmosphere by wet deposition (i.e., precipitation). Upon reaching water and soil, beryllium will probably be retained in an insoluble form in sediment and soil and will be generally immobile. Although chemical reactions may transform one beryllium compound into another, beryllium cannot be degraded by environmental reactions. However, the data regarding transformation reactions of beryllium in water and soil are limited. Bioconcentration of beryllium in plants and animals is low. In plants, uptake of beryllium appears to be restricted to the root

Figure 6-1. Frequency of NPL Sites with Beryllium Contamination



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system; no significant translocation of beryllium to the above ground parts of the plant has been observed. Beryllium is not expected to bioconcentrate in aquatic animals (EPA 1980).

The average concentration of beryllium in air in the United States is 0.03 ng/m³, but the median concentration in cities is 0.2 ng/m³ (Bowen 1979; EPA 1987). Dissolved beryllium was detected in groundwater at 352 of 504 sites in the United States (6.4% of sites) with an average concentration of 13.6 µg/L. In surface water, dissolved beryllium was detected at 85 of 504 sites in the United States (16.1%) with an average concentration of 23.8 µg/L (EPA 2000a). The mean concentration of beryllium in U.S. soils is 0.6 mg/kg (Eckel and Langley 1988). The beryllium concentrations in both raw carrots and field corn grown in the United States were <25 µg/kg (fresh weight) (Wolnik et al. 1984).

The general population is exposed to beryllium through inhalation of air and consumption of food and drinking water. The total beryllium intake by the general U.S. population cannot be estimated due to the lack of data regarding beryllium content in food. People who work in beryllium manufacturing, fabricating, and reclaiming industries are exposed to higher levels of beryllium than the general population. Smokers may also be exposed to higher levels of beryllium than nonsmokers because cigarette smoke contains beryllium (Reeves 1986).

6.2 RELEASES TO THE ENVIRONMENT

Releases of beryllium and beryllium compounds are required to be reported under Superfund Amendments and Reauthorization Act Section 313; consequently, data are available for this compound in the Toxics Release Inventory (TRI) (EPA 1995). According to the TRI, a total of 74,178 pounds (33,647 kg) of beryllium and 910,491 pounds (412,990 kg) beryllium compounds were released to the environment in 1999 (TRI99 2002). The TRI data should be used with caution because only certain types of facilities are required to report. This is not an exhaustive list.

Beryllium has been identified in a variety of environmental media (air, surface water, leachate, groundwater, soil, and sediment) collected at 535 of 1,613 current or former NPL hazardous waste sites (HazDat 2002).

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6.2.1 Air

Anthropogenic and natural emissions of beryllium to the atmosphere from various sources are reported in Table 6-1. In addition to ore processing, beryllium is also released into the atmosphere during the production and use of beryllium alloys and chemicals. Beryllium is released into the atmosphere from anthropogenic sources including the combustion of coal and fuel oil, the incineration of municipal solid waste (MSW), the production, use, and recycling of beryllium alloys and chemicals, and, to a minor extent, the burning of solid rocket fuel. According to the TRI data (TRI99 2002) shown in Tables 6-2 and 6-3, 769 and 7,816 pounds of beryllium and beryllium compounds, respectively, were released in the atmosphere from alloys, chemicals, and user industries in 1999.

Beryllium emissions from coal and fuel oil combustion account for a majority of the U.S. beryllium emissions from natural and anthropogenic sources (EPA 1987). The average beryllium concentration in coal is between 1.8 and 2.2 $\mu\text{g/g}$ (EPA 1987). A study by the Department of Energy (DOE) and the University of North Dakota examined the emissions of toxic trace elements from coal-fired power plants (DOE 1996). The data in this study show that stack concentrations are 2–3 orders of magnitude greater than the range of ambient air concentrations for beryllium (DOE 1996). The median stack concentration for beryllium was 0.8 $\mu\text{g Be/m}^3$, and the average emission from the nine coal-fired power plants was 22.6 pounds/year (range 0.49–55.8 pounds/year). The estimated total emissions of beryllium in 1990 from the 3,266 fuel oil-fired power plants in the United States was 0.45 tons (0.41 metric tons) (DOE 1999a). TRI release data for electric utilities of 6,988 pounds of beryllium compounds were reported for 1999 (EPA 1987; TRI99 2002). The largest atmospheric releases of beryllium compounds were reported by Roxboro Steam Electric Plant in Person, North Carolina; Mt. Storm Power Station in Grant, West Virginia; and FirstEnergy Power Plant in Beaver, Pennsylvania with 487, 680, and 1,250 pounds (0.22, 0.31, and 0.57 metric tons), respectively, for the year 1999. The TRI99 data should be used with caution since only certain types of facilities are required to report. This is not an exhaustive list (TRI99 2002).

In 1986, there were 494 of 7,835 incinerated municipal waste streams containing beryllium in the United States (Behmanesh et al. 1992). There are 58 municipal Waste-to-Energy (WTE) facilities in the United States (DOE 1999a). At a municipal WTE facility in Commerce, California, stack emissions for

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Table 6-1. Anthropogenic and Natural Emissions of Beryllium and Beryllium Compounds to the Atmosphere^a

Emission source	Emission (tons/year) ^b
Natural	
Windblown dust	5
Volcanic particles	0.2
Anthropogenic ^{c,d}	
Industry	0.6
Metal Mining	0.2
Electric utilities	3.5
Waste and Solvent Recovery (RCRA)	0.007
Total	9.507

^aAdapted from Drury et al. 1978; EPA 1987; TRI99 2002

^bUnits are metric tons.

^cData in TRI are maximum amounts released by each industry.

^dThe sum of fugitive and stack releases are included in releases to air by a given industry.

RCRA = Resource Conservation and Recovery Act; TRI = Toxic Release Inventory

Table 6-2. Releases to the Environment from Facilities that Produce, Process, or Use Beryllium

State ^b	Number of facilities	Reported amounts released in pounds per year ^a						Total on and off-site release
		Air ^c	Water	Underground injection	Land	Total on-site release ^d	Total off-site release ^e	
CA	3	0	No data	No data	No data	0	No data	0
IN	3	0	No data	No data	2,650	2,650	2,415	5,065
LA	1	2	No data	No data	No data	2	No data	2
MO	1	0	No data	No data	10	10	0	10
NC	1	38	No data	No data	No data	38	No data	38
OH	6	721	27	No data	50,532	51,280	9,870	61,150
OK	2	No data	23	No data	5	28	6,830	6,858
PA	1	1	7	No data	No data	8	966	974
SC	1	7	No data	No data	74	81	No data	81
TN	1	No data	No data	No data	No data	No data	No data	No data
UT	1	0	No data	No data	0	0	No data	0
WI	1	No data	No data	No data	No data	No data	No data	No data
Total	22	769	57	0	53,271	54,097	20,081	74,178

Source: TRI99 2002

^aData in TRI are maximum amounts released by each facility.

^bPost office state abbreviations are used.

^cThe sum of fugitive and stack releases are included in releases to air by a given facility.

^dThe sum of all releases of the chemical to air, land, water, and underground injection wells.

^eTotal amount of chemical transferred off-site, including to publicly owned treatment works (POTW).

Table 6-3. Releases to the Environment from Facilities that Produce, Process, or Use Beryllium Compounds

State ^b	Number of facilities	Reported amounts released in pounds per year ^a						
		Air ^c	Water	Underground injection	Land	Total on-site release ^d	Total off-site release ^e	Total on and off-site release
AL	6	419	250	No data	62,691	63,360	326	63,686
AR	2	197	48	No data	9,130	9,375	1	9,376
AZ	4	50	No data	No data	16,421	16,471	1,630	18,101
FL	3	390	250	No data	5,745	6,385	5	6,390
GA	5	764	0	No data	76,925	77,689	No data	77,689
IL	1	79	850	No data	8,500	9,429	No data	9,429
IN	4	340	63	No data	40,019	40,422	3,808	44,230
KY	5	351	1,221	No data	27,730	29,302	No data	29,302
MD	1	No data	No data	No data	No data	No data	No data	No data
MI	2	313	17	No data	15,000	15,330	250	15,580
MO	3	10	No data	No data	No data	10	555	565
MS	1	2	20	4,100	19	4,141	0	4,141
MT	1	250	No data	No data	6,900	7,150	750	7,900
NC	4	817	403	No data	51,010	52,230	260	52,490
NM	4	112	77	No data	47,724	47,913	39,000	86,913
NY	1	20	0	No data	400	420	No data	420
OH	4	450	30	No data	25,846	26,326	11,422	37,748
PA	4	1,580	16	No data	8,700	10,296	6,411	16,707
TN	2	256	250	No data	14,100	14,606	640	15,246
TX	1	19	0	No data	31,400	31,419	No data	31,419
UT	4	366	No data	No data	299,952	300,318	5	300,323
WI	1	10	5	No data	No data	15	255	270

**Table 6-3. Releases to the Environment from Facilities that Produce, Process, or Use Beryllium Compounds
(continued)**

State ^b	Number of facilities	Reported amounts released in pounds per year ^a						Total on and off-site release
		Air ^c	Water	Underground injection	Land	Total on-site release ^d	Total off-site release ^e	
WV	9	861	10	No data	70,765	71,636	6,800	78,436
WY	1	160	No data	No data	3,970	4,130	No data	4,130
Total	73	7,816	3,510	4,100	822,947	838,373	72,118	910,491

Source: TRI99 2002

^aData in TRI are maximum amounts released by each facility.

^bPost office state abbreviations are used.

^cThe sum of fugitive and stack releases are included in releases to air by a given facility.

^dThe sum of all releases of the chemical to air, land, water, and underground injection wells.

^eTotal amount of chemical transferred off-site, including to publicly owned treatment works (POTW).

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beryllium were measured at $0.2 \mu\text{g}/\text{m}^3$ (Hasselriis and Licata 1996). The stack emissions from individual municipal WTE facilities are about the same order of magnitude as stack emissions from individual coal fired power plants; however, the number of municipal WTE facilities in the United States is a factor of 20 less than the number of coal fired power plants.

Natural emission sources of beryllium include windblown dusts and volcanic particles. The beryllium amounts released to the atmosphere from these sources are comparable with anthropogenic sources (see Table 6-1).

Beryllium has been identified in 9 air samples collected from 535 current or former NPL hazardous waste sites where it was detected in some environmental media (HazDat 2002).

6.2.2 Water

Anthropogenic sources of beryllium release to water include industrial waste water effluents. A compilation of data for the beryllium levels in raw and treated waste water from various industrial sources is available (EPA 1981). The concentrations of beryllium compounds are the highest in waste waters from electric utility industries (TRI99 2002). The total reported amounts of beryllium and beryllium compounds released to surface water for 1999 were 57 pounds (26 kg) and 3,510 pounds (1,592 kg), respectively, as shown in Tables 6-2 and 6-3 (TRI99 2002).

Deposition of atmospheric beryllium is also a source in surface waters; however, the relative significance of the contribution from this source, compared to industrial discharge to surface water, cannot be assessed. Beryllium also enters the waterways from the weathering of rocks and soils (EPA 1980). Since coal contains beryllium, it is also likely that beryllium will enter surface water via leaching of coal piles.

The industrial releases of beryllium and beryllium compounds into surface water are shown in Tables 6-2 and 6-3, respectively. The largest releases to water were reported by electric utility facilities such as St. Johns River Power Park (Duval, Florida), U.S. TVA Widows Creek Fossil Plant (Jackson, Alabama), Baldwin Power Station (Randolph, Illinois), and U.S. TVA Cumberland Fossil Plant (Stewart, Tennessee), which reported releases of 250, 250, 850, and 1,000 pounds (0.11, 0.11, 0.39, and 0.45 metric tons), respectively (TRI99 2002).

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Beryllium has been identified in 92 surface water and 376 groundwater samples collected from 535 NPL hazardous waste sites, where it was detected in some environmental media (HazDat 2002).

6.2.3 Soil

Beryllium is naturally present in soils and sediments. Releases of beryllium and beryllium compounds to U.S. soils in 1999 as reported to the TRI are shown in Tables 6-2 and 6-3, respectively. According to the TRI, 53,271 pounds (52 metric tons) of beryllium and 822,947 pounds (179 metric tons) of beryllium compounds were released on-site to land by facilities that manufacture or process beryllium and beryllium compounds (TRI99 2002). An additional 20,081 pounds (9 metric tons) of beryllium and 72,118 pounds (33 metric tons) of beryllium compounds were released off-site to locations within the United States in 1999 (TRI99 2002).

Coal fly ash and municipal solid waste incinerator ash are disposed of in landfills and used in building materials (Kalyoncu 1998). Coal fly ash contains beryllium at levels of 46 mg beryllium/kg ash (Stadnichenko et al. 1961). About 100 million tons of coal fly ash containing various levels of beryllium are generated each year (Kalyoncu 1998). This translates to about 420 metric tons of beryllium disbursed as coal fly ash.

Land application of sewage sludge containing higher than background concentrations of beryllium can be source of beryllium contamination of soil. Deposition of atmospheric aerosols on terrestrial surfaces is another source of beryllium in soil. Valberg et al. (1996) estimated the amount of time that it would take to double the ambient soil concentration of beryllium by dry deposition (at the point of maximum impact) near a MSW incinerator in Vermont. Their estimate was between 468 and 2,275 years, depending upon the ambient concentration of beryllium in the soil. Other quantitative data regarding the relative significance of these sources was not available.

Beryllium has been identified in 353 soil and 193 sediment samples collected from 535 NPL hazardous waste sites, where it was detected in some environmental media (HazDat 2002).

6.3 ENVIRONMENTAL FATE

6.3.1 Transport and Partitioning

Beryllium in air is attached to particulate matter whose residence time in air is dependant upon particle size. A study of stack emissions from coal combustion reported that most beryllium is found on particles with diameters of $<2.5 \mu\text{m}$ (Gladney and Owens 1976). Particles of this size can remain airborne for approximately 10 days (Gladney and Owens 1976). The transport of beryllium from the atmosphere to terrestrial and aquatic surfaces occurs through wet and dry deposition (EPA 1987). By analogy to other elements, a typical dry deposition velocity may be estimated for beryllium particles over vegetative surfaces as 0.25 cm/second (EPA 1987). The dry deposition rate of aerosol particles is a function of particle size, wind speed, and surface roughness. The process of wet deposition of airborne beryllium consists of wash-out and rain-out; wash-out involves the scrubbing of particles from the air by rain and rain-out involves their attachment to aerosols in clouds. The portion of beryllium particles transported from the atmosphere by wet deposition has not been estimated. Beryllium was detected but not quantified in rainwater from Fresno, California, which suggests that transport of beryllium from the atmosphere to terrestrial and aquatic surfaces occurs by wet deposition (Salo et al. 1986). Beryllium containing soil can be resuspended in the atmosphere as a result of wind action.

Beryllium is carried to rivers, lakes, and oceans by the process of land erosion. The amount of beryllium transported to surface waters from the land by wind-blown soil is estimated to be relatively small (Merrill et al. 1960). Acid deposition has been shown to accelerate chemical weathering of soil and bedrock into drainage outflow, increasing the mobility of beryllium (Jagoe et al. 1993). The estimated residence time of beryllium in ocean water, before it is removed from the aquatic phase by sedimentation or other removal processes, is between 150 and 570 years (Bowen 1979; Merrill et al. 1960).

Beryllium binds strongly to soil fulvic acid; binding increases with increasing pH. Beryllium also forms complexes with marine fulvic acids at nearly neutral pH values (Esteves Da Silva et al. 1996a). However, beryllium has a much stronger affinity for clay minerals than for organic matter. Beryllium is usually associated in soil with aluminum sites on clay minerals rather than with iron oxides (Lum and Gammon 1985). It tends to displace divalent cations with smaller charge-to-ionic radius ratios (Fishbein 1981). For pH values $\#6$, the distribution of beryllium between solution and solids is related to sorption at surface sites. At pH values >6 , the solute concentration of beryllium is strongly controlled by the solubility of $\text{Be}(\text{OH})_2$ (Aldahan et al. 1999).

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The sediment-water distribution coefficients (K_d) for beryllium are very high indicating a very low mobility in sediments. At pH values >6 , K_d values are very high for most soils and sediments. For Lake Michigan sediments, K_d ranged between 10^5 and 10^6 (Hawley et al. 1986). Beryllium may accumulate in the surface organic layer of the sediment profile; however, there is no indication as to whether the organic matter content of sediment affects K_d (Lum and Gammon 1985). The presence of organic matter did not significantly affect the K_d for saline systems (You et al. 1989); in seawater, K_d is, on average, between 316,000 and 794,000 (Hawley et al. 1986).

In highly alkaline soils, the mobility of beryllium may increase as a result of the formation of soluble hydroxide complexes, such as $[\text{Be}(\text{OH})_4]^{2-}$ (Callahan et al. 1979; Cotton and Wilkinson 1980). In acidic soils (e.g., forest ecosystems), dissolved Be^{2+} has been found to be the prevailing beryllium species in the soil solution, and it should be relatively mobile in these environments (Krám et al. 1998). However, leaching would not be expected to occur in less acidic soils (Hayes and Traina 1998).

The concentration of beryllium in plants is very low (see Section 6.4.4). Soluble forms of beryllium must be present for uptake to occur in plants. For collard seedlings, beryllium remains in the roots, and only small portions were translocated to above ground portions (Kaplan et al. 1990). Romney and Childress (1965) examined uptake of ^7Be in beans, barley, sunflowers, and tomato plants. Over 95% of ^7Be was found in the roots; very little was translocated to the foliage and fruits (Romney and Childress 1965). The Enrichment Ratio (ER) of beryllium in oat grain and in alfalfa grown in both microcosms and field plots amended with beryllium containing fly ash was 1 (Tolle et al. 1983).

Beryllium does not bioconcentrate in aquatic organisms. A measured bioconcentration factor (BCF) of 19 was reported for beryllium in bluegill fish (EPA 1980). Other investigators have reported a BCF of 100 for freshwater and marine plants, vertebrates, and fish (Callahan et al. 1979). Comparisons of the beryllium levels in bottom-feeding biota and surface sediments from Lake Pontchartrain, Louisiana, indicate similar, but somewhat lower, beryllium concentrations in biota (Byrne and DeLeon 1986). Very low bioaccumulation for beryllium was observed in southern toads (*Bufo terrestris*) exposed directly to elevated levels of beryllium and other trace metals from a coal fly ash basin (Hopkins et al. 1998). No evidence of the bioaccumulation of beryllium in the food chain of humans was located in the literature (Fishbein 1981).

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6.3.2 Transformation and Degradation

As an element, beryllium does not degrade in the environment; it can only change its form.

6.3.2.1 Air

The atmospheric emission of beryllium during ore processing is likely to occur as: beryllium, beryllium ore dust, beryllium hydroxide, $\text{Be}(\text{OH})_2$; beryllium oxide, BeO ; sodium fluoroberyllate, $(\text{NH}_4)_2\text{BeF}_4$; and beryllium fluoride, BeF_2 (Fishbein 1981); from ceramic plants, atmospheric emissions are typically beryllium or beryllium oxide (Fishbein 1981). The form of beryllium emitted into the atmosphere from thermal processes is typically beryllium oxide (EPA 1998). It is unlikely that beryllium oxide in air will react with sulfur or nitrogen oxides to produce beryllium sulfates or nitrates.

6.3.2.2 Water

Beryllium exhibits only the +2 oxidation state in water. The reaction of beryllium in water is controlled by chemical speciation by which one species is converted to another. Beryllium is highly hydrated in acid solutions, which is a consequence of its high charge to size ratio. The speciation of beryllium in solution is: $[\text{Be}(\text{H}_2\text{O})_4]^{2+}$, $\text{Be}_2(\text{OH})^{3+}$, $\text{Be}_3(\text{OH})_3^{3+}$, and possibly $\text{Be}_3(\text{OH})_7^{3+}$ in acid solution (i.e., $\text{pH} \approx 6$); and $[\text{Be}(\text{OH})_4]^{2-}$ in basic solution (i.e., $\text{pH} > 8$) (Cotton and Wilkinson 1980). In the pH range of 6–8, typical of most waters, the speciation of beryllium is controlled by the formation solid beryllium hydroxide, $\text{Be}(\text{OH})_2$, which has a very low solubility (solubility product, $K_{\text{sp}} = 10^{-21}$). Table 6-4 illustrates several precipitation reactions for beryllium under a neutral environment.

Other transformations of environmental importance are the formation of insoluble basic carbonates, such as $(\text{BeCO}_3)_2\text{Be}(\text{OH})_2$, formed by reaction of dissolved carbonate with beryllium solutions and the formation of beryllium sulfate (i.e., BeSO_4) formed by reaction of soluble sulfates with beryllium solutions.

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Table 6-4. Precipitation of Beryllium Compounds in a Neutral (pH 6.5–9.5) Environment

<p>Ammonium tetrafluoroberyllate (Ammonium beryllium fluoride)</p> $(NH_4)_2BeF_4 \rightarrow 2[NH_4]^+_{aq} + [BeF_4]^{2-}_{aq}$ <p>Excess H₂O pH 7</p>	Remains soluble in a neutral environment
<p>Beryllium oxide</p> $BeO + H_2O \rightarrow Be(OH)_2$ <p>Excess H₂O pH 7</p>	Forms insoluble beryllium hydroxide in a neutral environment
<p>Beryllium hydroxide</p> $Be(OH)_2 \rightarrow \text{no reaction}$ <p>Excess H₂O pH 7</p>	Beryllium hydroxide is insoluble in a neutral environment
<p>Beryllium fluoride</p> $BeF_2 + 2 H_2O \rightarrow [BeF_2(H_2O)_2]_{aq} \text{ and other complexes}$ <p>Excess H₂O pH 7</p>	Remains soluble in a neutral environment
<p>Beryllium nitrate trihydrate</p> $Be(NO_3)_2 \cdot 3H_2O + 2MOH^a \rightarrow Be(OH)_2 + 2[M]^+_{aq} + 2[NO_3]^-_{aq} + 3H_2O$ <p>Excess H₂O pH 7</p>	Forms insoluble beryllium hydroxide in a neutral environment
<p>Beryllium sulfate tetrahydrate</p> $BeSO_4 \cdot 4H_2O + 2MOH^a \rightarrow Be(OH)_2 + 2[M]^+_{aq} + [SO_4]^{2-}_{aq} + 4H_2O$ <p>Excess H₂O pH 7</p>	Forms insoluble beryllium hydroxide in a neutral environment

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Table 6-4. Precipitation of Beryllium Compounds in a Neutral (pH 6.5–9.5) Environment (continued)

Beryllium oxalate trihydrate $\text{BeC}_2\text{O}_4 \cdot 3\text{H}_2\text{O} + 2\text{MOH}^{\text{a}} \longrightarrow \text{Be}(\text{OH})_2 + 2[\text{M}]^+_{\text{aq}} + [\text{C}_2\text{O}_4]^{2-}_{\text{aq}} + 3\text{H}_2\text{O}$	Forms insoluble beryllium hydroxide in a neutral environment
Excess H ₂ O pH 7	
Beryllium Basic Acetate ^b $\text{Be}_4\text{O}(\text{C}_2\text{H}_3\text{O}_2)_6 + 6\text{MOH}^{\text{a}} + \text{H}_2\text{O} \longrightarrow 4\text{Be}(\text{OH})_2 + 6[\text{M}]^+_{\text{aq}} + 6[\text{C}_2\text{H}_3\text{O}_2]^-_{\text{aq}}$	Forms insoluble beryllium hydroxide in a neutral environment
Excess H ₂ O pH 7	

Source: EPA 1998

^aMOH is a base; M in MOH signifies a cation such as sodium (Na) or potassium (K).

^bBeryllium basic acetate is not a true basic salt; it is a covalent compound.

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6.3.2.3 Sediment and Soil

Typical transformation processes for beryllium in soil include precipitation, complexation, and anion exchange. Important factors affecting the transformation of beryllium in soils and sediments include: pH, ionic strength (i.e., salinity), concentration and distribution of species, composition of the mineral matrix, organic matter, biological organisms, and temperature (see Section 6.3.1). Data suggesting the biotransformation of beryllium or its compounds in soil were not located.

6.3.2.4 Other Media

No data were located on the transformation of beryllium in media other than air, water, sediment, and soil in the literature.

6.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT**6.4.1 Air**

Beryllium in the ambient air is measured at many local, state, and national air monitoring stations across the United States. The data are available from the Storage and Retrieval of Aerometric Data database (EPA 1987). The detection limit for aerometric determination of beryllium is 0.03 ng/m^3 , and annual averages at most of these monitoring stations are listed below this concentration. Measurements at 100 U.S. locations indicated an average daily beryllium concentration of $<0.5 \text{ ng/m}^3$ (Drury et al. 1978; Fishbein 1981). Between 1982 and 1992, annual averages of beryllium in air ranged from 0.02 to 2 ng/m^3 in the urban Detroit, Michigan area. The ambient concentrations of beryllium were quite similar for all land use categories (e.g., residential, commercial, and industrial). In 1985, in Jacksonville, Florida, beryllium was below the limit of detection in air (Del Delumyea et al. 1997).

The ambient concentration of beryllium found in air near power stations in Castellon, Spain ranged from not detected to 1.61 ng/m^3 (Boix et al. 2001). Beryllium concentrations in atmospheric particulate samples in and around a beryllium processing facility near Navi Mumbai, India were $0.48 \pm 0.42 \text{ ng/m}^3$ (N#397). The levels of beryllium during the monsoon season were comparatively lower and often were below the detection limit (Thorat et al. 2000).

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6.4.2 Water

Beryllium was detected in 2,760 out of 50,000 U.S. Geological Survey ambient surface water monitoring stations through the year 1988 with a mean concentration of 1.9 µg/L (Eckel and Jacob 1988). The National Drinking Water Contaminant Occurrence Database (NDOD), which contains data from ambient water supplies, lists the number of detections of beryllium in surface water at several locations around the United States. In lakes/reservoirs, dissolved beryllium was detected at 13 of 137 sites (9.5% of sites) with an average concentration of 1.1±0.4 µg/L (EPA 2001). In spring waters, dissolved beryllium was detected at 4 of 66 sites (6.1% of sites) with an average concentration of 99.3±42.1 µg/L (EPA 2000a). In other surface waters, dissolve beryllium was detected at 227 of 1,539 sites (14.7% of sites) with an average concentration of 20.8±36.1 µg/L; total beryllium was detected at 182 of 943 sites (19.3% of sites) with an average concentration of 4.4±35.1 µg/L (EPA 2001). The median total beryllium concentration of Great Lakes water samples ranged from <4 to 120 ng/L. The percentage of beryllium in suspended particulates of Great Lakes water samples ranged from 2 to 88% and averaged about 50% (Rossmann and Barres 1988). Beryllium concentrations measured in the Houston Ship Channel ranged from 8 to 24 ng/L (Saleh and Wilson 1999). The concentration of total beryllium in seawater ranges from 0.02 to 0.9 ng/L, with an average of <0.5 ng/L (Measures and Edmond 1986; Merrill et al. 1960).

The NDOD lists the number of detections of beryllium in groundwater water at several locations around the United States. In groundwater, dissolved beryllium was detected at 262 of 4,177 sites (6.6% of sites) with an average concentration of 13.0±50.3 µg/L; total beryllium was detected at 30 of 334 sites (9.0% of sites) with an average concentration of 1.7±1.8 µg/L (EPA 2000a). The median concentration of beryllium in groundwater samples taken around the Denver, Colorado metropolitan area in 1993 was measured at <1 µg/L (Bruce & McMahon 1996). Beryllium has been identified in 376 groundwater samples collected from 535 NPL hazard waste sites, where it was detected in some environmental media (HazDat 2002).

Rainwater in Australia had an average beryllium concentration of 0.05–0.08 µg/L (Meehan and Smythe 1967) and an upland environment in Great Britain had an average concentration of <0.06 µg beryllium/L (Neal et al. 1992).

The average concentrations of beryllium in bottled and tap water in the United States were <0.1 and 0.013 µg/L, respectively. Table 6-5 summarizes some selected data on the beryllium content of drinking water (Vaessen and Szteke 2000).

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6.4.3 Sediment and Soil

Beryllium is the 44th most abundant element in the Earth's crust. The average beryllium concentration in the Earth's crust is approximately 2–5.0 mg/kg (Drury et al. 1978; Griffiths and Skilleter 1990; Krám et al. 1998; Mason and Moore 1982; Reeves 1986). Beryllium occurs in silicate minerals and feldspar minerals. The greatest known concentrations of beryllium are found in certain pegmatite bodies. Beryllium ores can contain several thousand mg beryllium per kg solid (Fishbein 1981). Shacklette and Boerngen (1984) reported the average and range of beryllium concentrations in soils and other surficial materials in the conterminous United States as 0.63 and <1–15 mg/kg, respectively. Frink (1996) summarized several different studies and reported that the most likely concentration of beryllium in uncontaminated soils (in the Northeast United States) ranges from <1 to 7 mg/kg. The average concentrations of beryllium in the O or A horizons (sandy loam) and the B horizon (clay) in Maryland were 0.71 and 0.46 mg/kg respectively (Sparling and Lowe 1996). The average and range of beryllium concentrations in Florida soils were 0.46 mg/kg and 0.01–5.92, respectively (Chen et al. 1999). The average beryllium concentration in California soils was measured as 1.14 mg/kg (Chen et al. 1999). There are few beryllium rich soils in the United States, and these areas are in sparsely settled areas that are not important for food production (Griffitts and Skilleter 1990). The concentration of beryllium in soil around beryllium processing facilities in Navi Mumbai, India ranged from 1.42 to 2.75 µg/g (Thorat et al. 2000). These levels were comparable to background levels reported in the literature.

In bottom sediments of the Detroit River and western Lake Erie, concentrations of beryllium ranged from 0.1 to 3.8 µg/g beryllium (Lum and Gammon 1985). The beryllium levels in the sediments of Lake Pontchartrain, Louisiana were 0.05–0.5 µg/kg (dry weight) (Byrne and DeLeon 1986). The concentration of beryllium in sediments from the Neosho River in southeastern Kansas ranged from 0.52 to 1.1 µg/g dry weight in 1992 (Allen et al. 2001). Beryllium has been identified in 353 soil and 193 sediment samples collected from 535 NPL hazardous waste sites, where it was detected in some environmental media (HazDat 2002).

Table 6-5. Beryllium Content of Drinking Water

Product	Number of samples	Content ($\mu\text{g}/\text{kg}$)		Technique	Reference
		Mean	Range		
Mineral water (bottled)					
Spain:					
Lanjaron	3	—	0.12±0.01	IEF	Capitan et al. 1989
Ortigosa del Monte	3	<0.6	<0.06	IEF	Capitan et al. 1989
United States:					
All samples	72	<0.1	<0.1–5.2	ICP	Allen et al. 1989
Domestic samples ^a	18	<0.1	<0.1–0.2	ICP	Allen et al. 1989
European samples ^b	54	<0.1	<0.1–5.2	ICP	Allen et al. 1989
Poland:					
Nieszawa	3	0.17	—	ET-AAS	Szczepaniak and Szymanski 1996
Zywiec Zdrój	3	0.15	—	ET-AAS	Szczepaniak and Szymanski 1996
Tap Water					
Spain-Granada	3	—	0.09±0.01	IEF	Capitan et al. 1989
Germany-Mainz	—	0.008 ^c	<0.005±0.009	ET-AAS	Reichert 1973
Germany-Weisbeden	—	—	0.034±0.002	ET-AAS	Sauer and Lieser 1986

Table 6-5. Beryllium Content of Drinking Water (continued)

Product	Number of samples	Content ($\mu\text{g}/\text{kg}$)		Technique	Reference
		Mean	Range		
Saudi Arabia-Riyadh (schools)	59	1.24 ^c	0.4–2.17	ICP-MS	Al-Saleh 1996
The Netherlands	266	<0.1	<0.1–0.2	—	Fonds et al. 1987
	91	<0.05	<0.05–0.21	ICP-MS	Van de Veld-Koerts et al. 1994
United States	—	0.013 ^c	0.01–0.7	—	APHA 1992

Source: Vaessen and Szteke 2000

^anine brands

^b28 brands

^carithmetic mean

— = Not specified; ET-AAS = electrothermal atomic absorption spectrometry; ICP = inductively coupled plasma spectroscopy; ICP-MS = inductively coupled plasma mass spectrometry; IEF = ion exchange fluorimetry

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6.4.4 Other Environmental Media

The beryllium concentration in several foods, fruits, and fruit juices from around the world are shown in Tables 6-6 and 6-7. The median concentration of beryllium in the 38 foods listed in Table 6-6 is 22.5 µg/kg fresh weight (excluding kidney beans) and the range of concentrations is <0.1–2,200 µg/kg fresh weight. The highest concentrations (in µg/kg fresh weight) were reported for kidney beans (2,200), crisp bread (112), garden peas (109), parsley (77), and pears (65). The average concentration of beryllium in fruit and fruit juices listed in Table 6-7 is 13.0 µg/L, and the concentrations ranged from not detected to 74.9 µg/L.

The beryllium concentration in the tissue of bottom fish (e.g., English sole or *Parophrys vetulus*) from Commencement Bay, Tacoma, Washington was 6 µg/kg (Nicola et al. 1987). Beryllium levels in oysters and clams in Lake Pontchartrain, Louisiana were 0.051 and 0.083–0.38 µg/g dry weight, respectively (Byrne and DeLeon 1986). A U.S. FDA survey of concentrations of beryllium and other elements in oysters and clams collected from U.S. coastal areas in use for shellfish production ranged from not detected to 0.002 mg/kg wet weight (Capar and Yess 1996). In 1991, the concentration of beryllium in mussels species from the Neosho River, Kansas were 0.02–0.04, not detected–0.02, 0.03, and 0.02–0.04 µg/g dry weight for pimpleback (n=3) sampled at Cottonwood River; Kansas, monkeyface (n=2) sampled at Humboldt, Kansas; monkeyface (n=1) sampled at Leroy, Kansas; and monkeyface (n=4) sampled at Oswego, Kansas, respectively (Allen et al. 2001).

The concentration of beryllium in pipping black-crowned night herons from Pea Patch Island in Delaware Bay, a major shipping area that receives anthropogenic releases of toxic substances, ranged from not detected to 0.028 µg/g dry weight. At Middle Island (a coastal reference site without contamination located in Rehoboth Bay, Delaware), the concentration of beryllium in pipping black-crowned night herons ranged from not detected to 0.021 µg/g dry weight (Ratter et al. 2000).

Beryllium has been detected in orchard leaves and in various trees and shrubs in the United States at concentrations of 26 and <1 µg/kg, respectively (IARC 1980). The beryllium content of macrohydrophytes derived from various habitats in Poland ranged from 0.7 to 136.6 µg/g. The beryllium concentrations varied with the plant species and the particular degree of water contamination in their respective environments (Sarosiek and Kosiba 1993). Beryllium levels were below detection limits (not

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Table 6-6. Beryllium Content of Various Fresh Foods

Product	Number of samples	Concentration (μg Be/kg fresh weight)		Technique	Reference
		Mean	Range		
Bananas, pulp	400	4.2	ND–18	—	Cowgill 1981
Beans	3	0.07	ND–0.07	F	Meehan and Smythe 1967
Beans, kidney	—	2,200 ^a	—	ICP-AES	Awadallah et al. 1986
Cabbage	1	0.2	—	F	Meehan and Smythe 1967
Cabbage	95	0.091	ND–0.50	ICP-MS	Bibak et al. 1999
Cane sugar:					
brown	—	30	—	—	Hamilton and Minski 1973
demerara	—	6	—	—	Hamilton and Minski 1973
refined	—	2	—	—	Hamilton and Minski 1973
granulated	—	0.2	—	—	Hamilton and Minski 1973
Carrots, raw	—	<25	—	—	Wolnik et al. 1984
Clams, hardshell	31	2 \pm 3	—	ICP-AES	Caper and Yess 1996
Clams, softshell	10	<2	—	ICP-AES	Caper and Yess 1996
Crabs	6	15	10–20	F	Meehan and Smythe 1967
Crisp bread	—	112 ^a	—	Flame AAS	Zorn and Diem 1974 ^b
Coriander	—	34 ^a	—	ICP-AES	Awadallah et al. 1986
Corn, field	—	<25	—	—	Wolnik et al. 1984
Dill	—	59 ^a	—	ICP-AES	Awadallah et al. 1986
Egg plant (aubergine)	—	26 ^a	—	ICP-AES	Awadallah et al. 1986
Fish, whole:					
Mullet	8	11	1.6–19	F	Meehan and Smythe 1967
Blackfish	4	11	3.7–18	F	Meehan and Smythe 1967
Fish, whole:					
Mullet	2	1.5	ND–2.6	F	Meehan and Smythe 1967
Blackfish	1	0.4	—	F	Meehan and Smythe 1967
Garden pea	—	109 ^a	—	ICP-AES	Awadallah et al. 1986
Green pepper	—	42 ^a	—	ICP-AES	Awadallah et al. 1986
Hen eggs, yolk	1	0.2	—	F	Meehan and Smythe 1967
Hen eggs, yolk, and white	1	0.06	—	F	Meehan and Smythe 1967
Honey					
Eucalyptus	—	0.18 \pm 0.09	—	ICP-MS	Bettinelli et al. 2000
Robinia	—	0.38 \pm 0.02	—	ICP-MS	Bettinelli et al. 2000

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Table 6-6. Beryllium Content of Various Fresh Foods (continued)

Product	Number of samples	Concentration (μg Be/kg fresh weight)		Technique	Reference
		Mean	Range		
Lettuce	—	16 ^a	—	Flame AAS	Zorn and Diem 1974
Meat	3	4	4–5	GC-ECD	Kaiser et al. 1972
Milk	100	0.2	ND–0.7	F	Meehan and Smythe 1967
Mushrooms	1	1.6	—	F	Meehan and Smythe 1967
Mushrooms, European wild	1,303	9	<5–36	ET-AAS	Seeger et al. 1984
Orange juices	—	<1	—	—	McHard et al. 1980
Oysters	59	0.6	0.2–5.4	F	Meehan and Smythe 1967
Oysters, east coast United States	93	<2	—	ICP-AES	Capar and Yess 1996
Oysters, west coast United States	40	<2	—	ICP-AES	Capar and Yess 1996
Parsley	—	77 ^a	—	ICP-AES	Awadallah et al. 1986
Peanuts, kernels	2	0.5	0.3–0.8	F	Meehan and Smythe 1967
Pears	—	65 ^a	—	ICP-AES	Awadallah et al. 1986
Potatoes	—	59 ^a	—	ICP-AES	Awadallah et al. 1986
Potatoes	—	33 ^a	—	Flame AAS	Zorn and Diem 1974
Potatoes	41	0.4–0.6	0.2–1.4	ET-AAS	Hofele et al. 1994
Rice	3	4	3–5	GC-ECD	Kaiser et al. 1972
Rice, peeled	—	72 ^a	—	Flame AAS	Zorn and Diem 1974
Tomatoes	1	0.2	—	F	Meehan and Smythe 1967
Tomatoes	—	17 ^a	—	Flame AAS	Zorn and Diem 1974
Vegetable marrow (pumpkin)	—	20 ^a	—	ICP-AES	Awadallah et al. 1986

^aOriginal data based on dry weight; concentrations are recalculated to fresh weight.

— = not specified; AAS = atomic absorption spectroscopy; AES = atomic emission spectroscopy; ET-AAS = electrothermal atomic absorption spectrometry; F = fluorimetry; GC-ECD = gas chromatography electron capture detection; ICP-AES = inductively coupled plasma-atomic emission spectroscopy; ICP-MS = inductively coupled plasma-mass spectrometry; ND = not detected

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Table 6-7. Beryllium Content of Various Fruits and Fruit Juices

Product	Number of samples	Mean ($\mu\text{g/L}$)	Range
Apple juice	4	22.5	ND–43.6
Citrus fruit			
Ruby red grapefruit	1	1.3	—
Lime	1	ND	—
Tangerine	1	0.8	—
Grape cultivars	3	4.4	<0.1–7
Lemon products			
CA lemon	1	17.4	—
Bottled lemon	1	17.0	—
Lemonade	1	55.3	—
Orange juice	5	2.8	ND–2.8
Papaya (pulp)	3	74.9	64.5–84.1
Pear (pulp)	1	37.3	—
Red currant	1	1.1	—
Stone fruit (pulp)			
Apricot	1	<0.1	—
Peach	1	ND	—
Plum	1	1.6	—
Prune	1	3.6	—
Sour cherry	1	1.5	—
Tomato sauce	2	42.4	39.8–45.0
Tropical fruit			
Banana	1	1.5	—
Kiwi	1	3	—
Mango	1	4.5	—
Pineapple	1	<0.1	—

Source: Barnes 1997

— = not specified; ND = not detected

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specified) in vegetation in the immediate vicinity of a municipal solid waste (MSW) incinerator near Catalonia, Spain (Meneses et al. 1999).

Beryllium levels of 0.47–0.74 μg per cigarette have been detected in three brands of German cigarettes; 2–10% of the beryllium was found in the cigarette smoke (Reeves 1986). In a literature review undertaken by Smith et al. 1997, yields of 0–0.0005 μg beryllium per cigarette have been reported for domestic cigarette brands. Beryllium was detected in only 4 of 12 studies in which it was a target element (Smith et al. 1997).

The beryllium concentration in coal ash is on average 46 mg/kg in the United States (Stadnichenko et al. 1961). Beryllium concentrations in ammonia, nitrate, and phosphorus fertilizers used in agriculture ranged from <0.2 to 13.5 $\mu\text{g/g}$ (Raven and Loeppert 1997).

6.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE

The general population is exposed to trace amounts of beryllium by inhalation of air and ingestion of drinking water and food. If the average concentration of beryllium in air is assumed to be <0.03 ng Be/ m^3 (see Section 6.4.1), and it is further assumed that a normal U.S. adult inhales approximately 20 m^3 of air per day, then the inhalation exposure for a U.S. adult would be approximately <0.6 ng Be/day. This value may be somewhat higher for persons living near sources of beryllium emission. Similarly, if the concentration of beryllium in average U.S. drinking water is 0.5 $\mu\text{g/L}$ (see Section 6.4.2), and the consumption rate of drinking water by a normal adult is assumed to be 2 L/day, the exposure from drinking water would be 1 μg per day. Reliable data regarding the daily exposure rate to beryllium from food consumption are lacking. It has been estimated that the daily intake of beryllium from U.S. food is 0.12 μg (EPA 1987). This estimate is based on an arbitrary value for beryllium content of a total diet sample of 0.1 ng per g food and a daily consumption of 1,200 g of food (EPA 1987). In a study examining the trace element concentrations of foodstuffs in Tarragona, Spain, beryllium was below the detection limit (0.02 $\mu\text{g/g}$) in the following food groups: meat, seafood, cereals, seeds, vegetables, roots/tubers, fruits, milk, dairy products, eggs, and sugar (Llobet et al. 1998). In another study examining the trace element concentrations of food samples via hospital diets in Japan, the average daily intake of beryllium was determined to be 84.4 $\mu\text{g/day}$ (Muto et al. 1994). Other investigators have reported the total daily intake of beryllium in the range of 5–100 $\mu\text{g/day}$ (Emsley 1998; Tsalev and Zaprianov 1984; Vaessen and Szteke 2000).

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The mean concentration of beryllium in urine of about 500 nonoccupationally exposed individuals in the United States according to the 3rd National Health and Nutrition Examination Survey was 0.22 µg/g of creatinine (Paschal et al. 1998). Other studies reported mean urinary beryllium concentrations ranging from <0.03 to 0.4 µg/L for persons not occupationally exposed (Apostoli and Schaller 2001). Tsalev and Zaprianov (1984) reported that approximately 10 µg Be/day is excreted (on average) in human feces. Using the estimated daily fecal concentration, the exposure to beryllium by this method is within the range of estimates determined from total diet studies as discussed previously. Beryllium concentrations in other human tissues and fluids are: blood 0.01–3.6 µg/L, bone 3 µg/kg, hair 5–8 µg/kg, liver 2 µg/kg, muscle 0.8 µg/kg, nails <10 µg/kg, plasma or serum <4 µg/L, and tooth <0.01 µg/kg (Emsley 1998; Tsalev and Zaprianov 1984).

In a study of German cigarettes, tobacco was found to contain 0.47–0.74 µg beryllium per cigarette and 2–10% passes into the smoke during smoking (Reeves 1986). Some cigarettes contain small amounts of beryllium, and increases of blood and urine beryllium have been associated with smoking (Tsalev and Zaprianov 1984). In another review focusing on cigarettes from the United States, yields of 0–0.0005 µg Be per cigarette have been reported in 4 of 12 studies of smoke measurements; however, 8 of 12 studies failed to detect beryllium at any concentration (Smith et al. 1997). Nevertheless, smokers may have a higher probability of exposure to beryllium than the nonsmoking population.

People who work in industries where beryllium is present have a greater probability of inhalation exposure than nonoccupational groups. The estimated daily-weighted average beryllium exposure levels for some workers in a plant that extracted and produced beryllium metal were >50 µg/m³ during the mid-1960s. Beryllium exposure levels were >30 µg/m³ during the mid-1970s. After 1977, this plant complied with the OSHA maximum TWA concentration of 2 µg/m³ (Kriebel et al. 1988a). The TWA personal air concentration for beryllium in a precious metal refinery in 1983 ranged from 0.22 to 42.3 µg/m³ (Cullen et al. 1987). Recent occupational exposure measurements of beryllium at the Rocky Flats Environmental Technology Site in Colorado were conducted in the main beryllium production building. Mean concentrations of beryllium were measured for area and breathing zone monitors as 0.16 and 1.04 µg/m³, respectively (Stange et al. 1996a). At the Cardiff Atomic Weapons Establishment in the United Kingdom, annual mean area and personal sampling concentration ranges of beryllium were from 0.02–0.32 and 0.09–0.72 µg/m³, respectively, over the period from 1961 to 1997 (Johnson et al. 1999).

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Workers who do not change their work clothes at the end of the work day can increase the probability of home contamination with beryllium. Fabrics experimentally exposed at a beryllium production worksite contained up to 2.8 mg Be/m² (NIOSH 1995). Workers' family members may be exposed when workers come home wearing beryllium-contaminated clothing. Resuspended beryllium dust concentrations in air from unwashed clothing can reach levels of 0.64 µg/m³. The shaking of contaminated clothes can administer an inhalation dose of approximately 17 µg beryllium (NIOSH 1995). In another study, beryllium concentrations in machine shop workers' personal vehicles were measured. The highest concentrations of beryllium were measured on the driver's floor of the workers' vehicles at 19 µg/Be/foot² (Sanderson et al. 1999).

It is likely that dental technicians who work with beryllium-containing dental alloys without using appropriate handling safeguards may be exposed to higher levels of beryllium than the normal population (Bauer et al. 1988).

A National Occupational Exposure Survey conducted by NIOSH during 1981–1983 estimated that 13,869 workers were potentially exposed to beryllium and 7,045 workers to beryllium compounds in the workplace (NIOSH 1989a).

6.6 EXPOSURES OF CHILDREN

This section focuses on exposures from conception to maturity at 18 years in humans. Differences from adults in susceptibility to hazardous substances are discussed in 3.7 Children's Susceptibility.

Children are not small adults. A child's exposure may differ from an adult's exposure in many ways. Children drink more fluids, eat more food, breathe more air per kilogram of body weight, and have a larger skin surface in proportion to their body volume. A child's diet often differs from that of adults. The developing human's source of nutrition changes with age: from placental nourishment to breast milk or formula to the diet of older children who eat more of certain types of foods than adults. A child's behavior and lifestyle also influence exposure. Children crawl on the floor, put things in their mouths, sometimes eat inappropriate things (such as dirt or paint chips), and spend more time outdoors. Children also are closer to the ground, and they do not use the judgment of adults to avoid hazards (NRC 1993).

Specific information on the exposure of children to beryllium is limited. An x-ray health survey was conducted in 1948 in the neighborhood surrounding a beryllium manufacturing facility in Lorain, Ohio.

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In this survey, 2,000 children were examined, and none of the children exhibited signs of chronic berylliosis disease (AEC 1948). As with adults in the general population, small exposures in children occur from normal ingestion of food and drinking water and inhaling air. These exposures may be higher in areas with naturally high beryllium soil levels, and near beryllium processing sites, electric power plants, and waste sites containing beryllium. A study by Krachler et al. (1999a) provides suggestive evidence that beryllium is transferred across the placenta and excreted via breast milk. The levels of beryllium in umbilical cord serum and in colostrum were higher than in maternal serum. The average concentrations of beryllium in the umbilical cords of healthy newborn children were measured for arterial (1.3 µg/L), venous (0.8 µg/L), and mixed (0.6 µg/L) sera (Krachler et al. 1999b). No information on beryllium levels in amniotic fluid, meconium, or neonatal blood was located.

At waste sites, beryllium that is found in excess of natural background levels is most likely to be in soil, and presents a special hazard for young children. Hand-to-mouth activity and eating contaminated dirt will result in oral exposure to beryllium. The hazard in this case depends on the form of beryllium present at the waste site. Beryllium in soil at waste sites is almost entirely in the form of insoluble oxides and hydroxides of beryllium which would be expected to be less available than more soluble forms (see Section 6.3.1).

Other home exposures are unlikely since no household products or products used in crafts, hobbies, or cottage industries contain significant amounts of beryllium except in copper-beryllium wire, which is used in and around the home in electronics or other electrical devices.

Beryllium exposure to children from parents' work clothes, skin, hair, tools, or other objects from the workplace is possible if the parent uses beryllium at work. In a report to Congress by NIOSH, several historical cases of home contamination by beryllium were reported (NIOSH 1995). The most recent case was in 1992, suggesting that cases of beryllium home contamination may still be occurring. The majority of these cases were from the contamination of machinist workers' clothing with beryllium dust (NIOSH 1995).

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6.7 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

Several populations are at high risk for beryllium exposure. Individuals with the highest risk include people who are occupationally exposed to beryllium from manufacturing, fabricating, or reclaiming industries. There have been no reports of diseases attributable to beryllium exposure as a result of beryllium ore mining operations (Eisenbud and Lisson 1983; EPA 1987; Hamilton and Hardy 1974). People living near beryllium-emitting industries may be at a slightly increased risk of beryllium exposure due to contact with beryllium-contaminated dust within the household, as opposed to ambient air levels. Occupationally exposed workers who carry beryllium dust on their clothes from the workplace to their home may increase the risk of beryllium exposure to their family members (EPA 1987). However, it is common today for beryllium industries to provide and launder employee's work clothes. The National Emission Standard for Hazardous Air Pollutants (NESHAPS) restricts the amount of beryllium emitted into the environment by industries that process beryllium ores, metals, oxides, alloys, or wastes. The NESHAPS can be met by complying with either a 10 g per 24-hour emission limit or by meeting an ambient air concentration of 0.01 $\mu\text{g}/\text{m}^3$ of air averaged over a 30-day period (EPA 1982). Machine shops machining alloys containing #5% beryllium by weight are excluded from regulation under the NESHAPS emission standard (see 40 CFR Part 61, subpart C 61.30(b) 2001). No new cases of beryllium disease in people living near beryllium-processing industries have been reported in the past several years, probably because the past exposures were relatively high compared to present levels of beryllium in the ambient and workplace air (EPA 1987; NIOSH 1995).

Individuals may be exposed to high levels of beryllium from implanted dental prostheses (EPA 1987). The highest concentration of beryllium released from base metal alloy used as dental crowns measured in an artificial oral environment was 8 $\mu\text{g}/\text{day}$ per crown (Tai et al. 1992). The mantles of some lanterns used by campers contain approximately 600 μg of beryllium, and most of the beryllium becomes airborne during the first 15 minutes when a new mantle is used (Fishbein 1981). Therefore, people who camp outdoors and use these mantles are possibly exposed to higher than normal levels of beryllium. A small percentage of the population is sensitive to very low concentrations of beryllium, but there is no evidence that sensitivity develops at beryllium concentrations present in food or water, or that sensitivity is aggravated by ingestion of beryllium. No other special groups at risk were identified (EPA 1980).

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6.8 ADEQUACY OF THE DATABASE

Section 104(I)(5) of CERCLA, as amended, directs the Administrator of ATSDR (in consultation with the Administrator of EPA and agencies and programs of the Public Health Service) to assess whether adequate information on the health effects of beryllium is available. Where adequate information is not available, ATSDR, in conjunction with the National Toxicology Program (NTP), is required to assure the initiation of a program of research designed to determine the health effects (and techniques for developing methods to determine such health effects) of beryllium.

The following categories of possible data needs have been identified by a joint team of scientists from ATSDR, NTP, and EPA. They are defined as substance-specific informational needs that if met would reduce the uncertainties of human health assessment. This definition should not be interpreted to mean that all data needs discussed in this section must be filled. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed.

6.8.1 Identification of Data Needs

Physical and Chemical Properties. The relevant physical and chemical properties of beryllium are known (see Section 4.2). Additional information regarding the chemical forms of beryllium in coal fly ash and aerosols produced by specific industrial processes, and the mode by which beryllium compounds are incorporated into biological systems would be useful. Additional information about the chelation of beryllium (especially about chelating agents that may be used in the development of beryllium-specific chelation therapy) would also be useful.

Production, Import/Export, Use, Release, and Disposal. Data regarding the production, import/export, and use of beryllium and beryllium compounds are available (see Sections 5.1 through 5.3). According to the Emergency Planning and Community Right-to-Know Act of 1986, 42 U.S.C. Section 11023, industries are required to submit chemical release and off-site transfer information to the EPA. The TRI is updated yearly and provides a list of industrial production facilities and emissions.

As reported in Tables 6-2 and 6-3, the most significant amount of beryllium and beryllium compounds from production and use facilities is disposed of on land. Little is known about the methods used for land disposal of beryllium, except that small amounts of beryllium waste are discharged into public sewers

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(TRI99 2002). Additional data examining the method used for land disposal of beryllium waste and the routes by which beryllium might find its way from land disposal sites into groundwater would be useful.

Environmental Fate. For solids, there is a need to determine uptake factors into edible portions of plants and not just adherence to the root structure. Dry or wet deposition from the atmosphere to soil and water can occur. Little experimental data on the particle size and residence time of beryllium and beryllium compounds present in the ambient atmosphere are available. Additional data examining the possible chemical transformation reactions of beryllium and its half-life in air would be useful. Data regarding the dominant types of sorption mechanisms for beryllium (e.g., ion exchange vs. chemical sorption) for different mineral and environmental conditions are limited. Additional information elucidating the fate of beryllium with respect to its chemical speciation in soil is necessary.

Bioavailability from Environmental Media. Although the absorption of specific beryllium compounds from skin contact, inhalation, and ingestion have been studied in animals (see Section 3.3.1), the bioavailability of beryllium or its compounds from contaminated air, water, soil, or plant material may differ significantly from the studied values. Additional information on the dependence of absorption of beryllium on such parameters as chemical form, extent of sorption in the host medium, and other possible variables would be useful.

Food Chain Bioaccumulation. Beryllium does not bioconcentrate to high levels in aquatic animals (EPA 1980), although the bioconcentration in bottom-dwelling animals may be higher than non bottom-dwelling animals (Byrne and DeLeon 1986). There is no evidence of biomagnification of beryllium within terrestrial or aquatic food chains (Fishbein 1981). Further studies establishing the biomagnification potential for beryllium would be useful. Data regarding the intake of beryllium from food are lacking (Vaessen and Szteke 2000; Wolnik et al. 1984). The accuracy of the available database of beryllium in foods is questionable (Vaessen and Szteke 2000). More reliable concentration information is needed on levels of beryllium in food stuff to reduce or eliminate the uncertainties in estimating the dietary intake of beryllium (Vaessen and Szteke 2000). Such information would be important in assessing the contribution of food to the total intake of beryllium from different pathways.

Exposure Levels in Environmental Media. Some data on the levels of beryllium in air and drinking water are available. Limited data regarding the ambient concentration of beryllium near beryllium-containing hazardous waste sites in the United States are available. These monitoring data are important for assessing the potential health risk for individuals living near the waste sites (Eckel and

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Langley 1988). Nationwide monitoring data determining the levels of beryllium in U.S. drinking water at a detection limit <10 ng/L would be useful. Reliable and more recent monitoring data for the levels of beryllium in air, drinking water, soil (particularly at NPL sites), and food would be useful in estimating exposure from each source. Remedial investigations and feasibility studies conducted at the NPL sites contaminated with beryllium will add to the available database on exposure levels in environmental media. Investigations at these sites will also increase the current knowledge regarding the transport and transformation of beryllium at hazardous waste sites.

Exposure Levels in Humans. Beryllium levels in the urine and lung of both the control and occupationally exposed populations are available (Kanarek et al. 1973; Stiefel et al. 1980). No data on the beryllium levels in body tissues or fluids of populations living near hazardous waste sites or coal-fired power plants are available. Such information would be useful in assessing exposure levels for this population. Further studies regarding the possibility of increased exposure to beryllium via dental implants may be useful.

Exposures of Children. Children will be exposed to beryllium in the same manner as adults in the general population (i.e., ingestion of food and water, and inhalation of air).

Child health data needs relating to susceptibility are discussed in Section 3.12.2 Identification of Data Needs: Children's Susceptibility.

Exposure Registries. The Beryllium Case Registry (BCR) was established at Massachusetts General Hospital, Boston, Massachusetts in 1952 and taken over by NIOSH in the late 1970s. Since its transfer to NIOSH, no additional cases were added. Presently, the BCR is not an active registry. This element is not currently one of the compounds for which a subregistry has been established in the National Exposure Registry. The element will be considered in the future when chemical selection is made for subregistries to be established. The information that is amassed in the National Exposure Registry facilitates the epidemiological research needed to assess adverse health outcomes that may be related to the exposure to this element.

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6.8.2 Ongoing Studies

The Federal Research in Progress (FEDRIP 2001) database provides additional information obtainable from a few ongoing studies that may fill in some of the data needs identified in Section 6.8.1. These studies are summarized in Table 6-8.

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Table 6-8. Ongoing Studies on Human Exposure to Beryllium

Investigator	Affiliation	Subject	Sponsor
Peters, EL	Chicago State University	Fluctuating asymmetry in isopods as indicator of hazardous metals in urban area	National Institute of General Medical Sciences
Grew, ES	University of Maine	Beryllium in antarctic ultrahigh-temperature granulite-facies rocks and its role in partial melting of the lower continental crust	NSF

Source: FEDRIP 2001

NSF = National Science Foundation