

5. POTENTIAL FOR HUMAN EXPOSURE

5.1 OVERVIEW

Boron is a naturally-occurring element found combined with other elements throughout the environment. Boron is neither transformed nor degraded in the environment, although changes in the specific form of boron and its transport may occur, depending on environmental conditions. It is estimated that natural weathering is a significant source of environmental boron.

Ingestion of boron from food (primarily fruits and vegetables) and water is the most frequent route of human exposure, but occupational exposures to boron dusts may be significant. Boron is also a component of several consumer products, including cosmetics medicines and insecticides. Populations residing in areas of the western United States with natural boron-rich deposits may be exposed to higher-than-average levels of boron.

The EPA has identified 1,177 NPL sites. Boron, borate, and borax have been found at 21, 1, and 1, respectively, of the sites evaluated for these chemicals. However, we do not know how many of the 1,177 NPL sites have been evaluated for the presence of these chemicals. As more sites are evaluated by the EPA, these numbers may change (View 1989). The frequency of these sites within the United States can be seen in Figure 5-1.

5.2 RELEASES TO THE ENVIRONMENT

Borates are widespread, naturally-occurring substance found mainly as an inorganic compound in sediments and sedimentary rock. It is released to the environment slowly in low concentrations by weathering processes. Although few data are available quantifying boron releases from industrial sources, it is estimated that natural weathering releases more boron to the environment worldwide than do these industrial sources (Butterwick et al. 1989).

Releases of boron to the environment occur from the production and use of boron and boron-related compounds. However, neither boron nor boronrelated compounds are listed on the Section 313 toxic chemical list and, therefore, are not included in the Toxics Release Inventory (TRI).

5.2.1 Air

Borates are released to air from natural and industrial sources. Natural sources include oceans, volcanoes, and geothermal steam (Graedel 1978). Boron compounds are released from anthropogenic sources such as coalfired and geothermal steam power plants, chemical plants, and rockets as well as manufacturing facilities producing fiberglass and other products (EPA 1987c; Graedel 1978; Hollis et al. 1988; Lang et al. 1986; Rope et al. 1988; Stokinger 1981). No quantitative data regarding boron releases to air were located.

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5.2.2 Water

Natural weathering of boron-containing rocks is a major source of boron compounds in water (Butterwick et al. 1989). The quantity of boron released varies widely with the geographic variations in boron-rich deposits. In the United States, the area richest in natural boron deposits is the Mojave Desert in California (Butterwick et al. 1989; Stokinger 1981).

Boron compounds are released to water in municipal sewage from perborates in detergents, and in waste waters from coal-burning power plants, copper smelters, and industries using boron. Borate levels above background may be present in runoff waters from areas where boron-containing fertilizers or herbicides were used (Butterwick et al. 1989; Nolte 1988; Waggott 1969). An average concentration of 1 mg boron/L was reported in sewage effluents in California (Butterwick et al. 1989). No other quantitative data regarding boron releases to water in the United States were located. However, Waggott (1969) reported that boron concentrations in municipal sewage in a treatment plant in England ranged from 2.5 to 6.5 mg/L, releasing between 130 and 240 kg boron/day.

Boron has been detected in surface water and groundwater at hazardous waste sites. Data from the Contract Laboratory Program (CLP) Statistical Database indicate that boron occurred at about 20% of the sites at a geometric mean concentration of 156 ppb (0.156 mg boron/L) in positive samples of groundwater and at about 5% of the sites at a geometric mean of 1,177 ppb (1.177 mg boron/L) in surface water (CLPSD 1989).

5.2.3 Soil

Boron is naturally released to soil and water by rainfall, weathering of boron-containing minerals, desorption from clays and by decomposition of boron-containing organic matter. Man-made sources include application of boron-containing fertilizers or herbicides, application of fly ash or sewage sludge as a soil amendment, the use of waste water for irrigation or land disposal of boron-containing industrial wastes (Butterwick et al. 1989; Hollis et al. 1988; Mumma et al. 1984; Nolte 1988; Rope et al. 1988).

No quantitative data were located regarding man-made releases of boron compounds to soil. However, Mumma et al. (1984) reported that the boron concentration in sewage sludges from 23 U.S. cities ranged from 7.1 to 53.3 mg/kg. Landfilling or land application is a common disposal method for these sludges.

Data from the CLP Statistical Database indicate boron was detected in soil at about 5% of hazardous waste sites at a geometric mean concentration of 8,055 ppm in positive samples (CLPSD 1989). However, earlier data from the CLPSD (1980-1983) indicate a geometric mean concentration of boron of 21 mg/kg and a maximum concentration of 320 mg/kg (Eckel and Langley 1988), essentially equivalent to reported background levels of boron in soil. Clarification of

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the discrepancy in the data is necessary in order to compare boron levels at hazardous waste sites to background levels.

5.3 ENVIRONMENTAL FATE

5.3.1 Transport and Partitioning

Boron is a nonvolatile metalloid that occurs in combination with most of the other elements known (Cotton and Wilkinson 1980). Atmospheric boron may be in the form of particulate matter or aerosols as borides, boron oxides, borates, boranes, organoboron compounds, trihalide boron compounds, or borazines. Borates are relatively soluble in water, and will probably be removed from the atmosphere by precipitation and dry deposition (EPA 1987c). The half-life of airborne particles is usually on the order of days, depending on the size of the particle and atmospheric conditions (Nriagu 1979). No specific information on the fate of atmospheric boron was located.

Boron readily hydrolyzes in water to form the electrically neutral, weak monobasic acid H_3BO_3 and the monovalent ion $B(OH)_2^-$. In concentrated solutions, boron may polymerize, leading to the formation of complex and diverse molecular arrangements. Rai et al. (1986) concluded that because most environmentally relevant boron minerals are highly soluble in water, it is unlikely that mineral equilibria will control the fate of boron in water. Waggott (1969), for example, noted that boron is not significantly removed during the conventional treatment of waste water. Boron may, however, be co-precipitated with aluminum, silicon, or iron to form hydroxyborate compounds on the surfaces of minerals (Biggar and Fireman 1960).

Water borne boron may be adsorbed by soils and sediments. Adsorption-desorption reactions are expected to be the only significant mechanism that will influence the fate of boron in water (Rai et al. 1986). The extent of boron adsorption depends on the pH of the water and the chemical composition of the soil. The greatest adsorption is generally observed at pH 7.5-9.0 (Keren et al. 1981; Keren and Mezuman 1981; Waggott 1969). Bingham et al. (1971) concluded that the single most important property of soil that will influence the mobility of boron is the abundance of amorphous aluminum oxide. The extent of boron adsorption has also been attributed to the levels of iron oxide (Sakata 1987), and to a lesser extent, the organic matter present in the soil (Parks and White 1952), although other studies (Mezuman and Keren 1981) found that the amount of organic matter present was not important.

The adsorption of boron may not be reversible in some soils. The lack of reversibility may be the result of solid-phase formation on mineral surfaces (Rai et al. 1986), and/or the slow release of boron by diffusion from the interior of clay minerals (Griffin and Burau 1974).

Partition coefficients such as adsorption constants describe the tendency of a chemical to partition from water to solid phases. Adsorption constants for inorganic constituents such as a boron cannot be predicted a priori, but must be measured for each soil-water combination. Compilations of

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available data for boron are given elsewhere (Rai et al. 1986). In general, boron adsorption will be most significant in soils that contain high concentrations of amorphous aluminum and iron oxides and hydroxides such as the reddish Ultisols in the southeastern United States.

It is unlikely that boron is bioconcentrated significantly by organisms from water. A bioconcentration factor (BCF) relates the concentration of a chemical in the tissues of aquatic and terrestrial animals or plants to the concentration of the chemical in water or soil. The BCFs of boron in marine and freshwater plants, fish, and invertebrates were estimated to be less than 100 (Thompson et al. 1972). Experimentally measured BCFs for fish have ranged from 52 to 198 (Tsui and McCart 1981). These BCFs suggest that boron is not significantly bioconcentrated. Boron in water is completely absorbed by the human system, but it does not accumulate in body tissues (Waggott 1969). No other experimentally measured BCFs were located. LD

5.3.2 Transformation and Degradation

5.3.2.1 Air

There is no information available that suggests that particulate boron compounds are transformed or degraded in the atmosphere.

5.3.2.2 Water

Elemental boron is inert in the presence of water. Boron compounds rapidly transform to borates, the naturally occurring form of boron, in the presence of water. No further degradation is possible. Borate and boric acid are in equilibrium depending only on the pH of the water. If dissolved in atmospheric water, the standard borate-boric acid equilibria are established.

5.3.2.3 Soil

Most boron compounds are transformed to borates in soil due to the presence of moisture. Borates themselves are not further degraded in soil. However, borates can exist in a variety of forms in soil (see Section 5.2.3). Borates are removed from soils by water leaching and by assimilation by plants.

5.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT

5.4.1 Air

There are few studies made to estimate the concentration of boron-containing compounds in ambient air. This is partly due to difficulties of analysis at the low levels involved. Bertine and Goldberg (1971) estimated that approximately 11,600 tons of boron are injected into the atmosphere as a component of fly ash produced by coal combustion which was estimated to contain an average of about 75 mg/kg boron.

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5.4.2 Water

Boron is widely distributed in surface water and groundwater. Average surface water concentration in the United States is about 0.1 mg boron/L (Butterwick et al. 1989; EPA 1986b), but concentrations vary greatly, depending on boron content of local geologic formations and anthropogenic sources of boron (Butterwick et al. 1989). A survey of U.S. surface waters detected boron in 98% of 1,577 samples at concentrations ranging from 0.001 to 5 mg boron/L. Mean concentrations calculated for the 15 drainage basins in the continental United States ranged from 0.019 mg boron/L in the Western Great Lakes Basin to 0.289 mg boron/L in the Western Gulf Basin (Butterwick et al. 1989). The concentration of boron in sea water is about 4.5 mg/L (Butterwick et al. 1989; EPA 1986b).

Several studies have measured boron concentrations in water in those areas of California with boron-rich deposits. Reported high boron concentrations in surface waters ranged from 15 mg boron/L in coastal drainage waters to 360 mg boron/L in a boron-rich lake (Butterwick et al. 1989; Deverel and Millard 1988). Mean boron concentration in a California river ranged from 0.30 to 0.50 mg boron/L over a 20-year period (Butterwick et al. 1989). Reported boron concentrations in groundwater in the San Joaquin Valley ranged from 0.14 to 120 mg boron/L with a median concentration of about 4 mg boron/L (Butterwick et al. 1989; Deverel and Millard 1988). Waggott (1969) reports that groundwater boron concentrations greater than 100 mg/L are common in California.

Drinking water surveys generally do not report boron concentration. However, concentrations of boron in tap water have been reported in a range of 0.007-0.2 mg/L in the United States and England (Choi and Chen 1979; Waggott 1969), and the National Inorganics and Radionuclides Survey completed in 1987 reported relatively widespread occurrence of boron in 989 public water supplies (NIRS 1987). Boron concentrations ranged from less than 0.005 to greater than 2 mg/L, with concentrations of up to 0.4 mg/L in 90% of systems (NIRS 1987). A survey of 969 public water supply systems showed 99% contained boron at less than 1 mg/L. The maximum level measured was 3.28 mg/L (McCabe et al. 1970).

5.4.3 Soil

Background boron levels in U.S. soils were reported at a geometric mean concentration of 26 mg/kg with a maximum concentration of 300 mg/kg (Eckel and Langley 1988). Boron was detected in soils in Idaho at geometric mean concentrations of 4.6-9.8 mg/kg (Rope et al. 1988) and in sediments of Puget Sound (Malins et al. 1984).

Boron is an essential nutrient for plants. Boron soil concentrations for optimum plant growth reportedly range from 0.1 to 0.5 mg/kg for several plant species (Butterwick et al. 1989).

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5.4.4 Other Environmental Media

Boron is assimilated by plants from soil and is therefore a natural constituent of many foods, mainly fruits and vegetables. The amount of boron absorbed varies considerably among different plant species (Butterwick et al. 1989). The Food and Drug Administration (FDA) has set a tolerance limit of 8 ppm boron for citrus fruit (21 CFR 180.271).

Boron compounds are present in several consumer products. Sodium borate and boric acid are widely used in cosmetics. Over 600 cosmetic products, including makeup, skin and hair care preparations, and shaving creams, contain these compounds at concentrations of up to 5% (Beyer et al. 1983). These compounds have also been used in insecticide powders for roach control, in medicines applied to the skin at concentrations up to 5% (Beyer et al. 1983) and in some laundry products (Butterwick et al. 1989; Stokinger 1981; Waggott 1969).

5.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE

Human exposure to borates may occur through ingestion of food and water or insecticides used to control cockroaches, powders or dusts, inhalation of boron-containing or absorption of boron from cosmetics or medical preparations through mucous membranes or damaged skin. The most appreciable boron exposure to the general population is likely to be ingestion of food and to a lesser extent in water. Estimates of average daily boron ingestion by humans range from 10 to 25 mg (Beyer et al. 1983; Waggott 1969).

Occupational exposure to boron compounds may be higher. Workers in industries producing or using boron or boron compounds may be exposed by inhalation to boron-containing dusts or gaseous boron compounds due to process upsets or faulty equipment. Dermal absorption of boron may also occur if damaged skin is in contact with these materials, but this is considered a minor pathway (Stokinger 1981).

Borate dusts have been monitored in workplace air. Reported concentrations of borax dust in different areas of a large borax mining and refining plant ranged from 1.1 to 14.6 mg/m³ (Garabrant et al. 1985) and the mean boric acid/boron oxide dust concentration in a boric acid manufacturing plant was 4.1 mg/m³ (Garabrant et al. 1984). These values indicate that permissible exposure limits (PELs) set by OSHA, or threshold limit values (TLVs) recommended by the ACGIH, for boron-containing dusts in workplace air (Table 7-1) may, at times, be exceeded. Other industries include manufacture of fiberglass and other glass products, cleaning and laundry products, fertilizers, pesticides, and cosmetics (U.S. Borax and Chemical Corporation 1991; Stokinger 1981). Median normal values of boron in human blood (9.76 µg/100 g) and urine samples from these workers (720 µg boron/L) were reported (Stokinger 1981). Boron was not detected in a national survey of human adipose tissue (Stanley 1986). The National Institute for Occupational Safety and Health (NIOSH) estimated that the number of workers potentially exposed to boron increased from 6,500 in the early 1970s (NOHS 1989) to 35,600

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in the early 1980s (NOES 1989). Neither the NOHS nor the NOES databases contain information on the frequency, concentration, or duration of exposures of workers to any of the chemicals listed therein. These surveys provide only estimates of the number of workers potentially exposed to chemicals in the workplace. Sittig (1985) reports that NIOSH estimated the number of workers potentially exposed to borax at 2,490,000, to boron oxide at 21,000, and to boron trifluoride at 50,000.

5.6 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

The populations living in areas of California and other western states with boron-rich geological deposits have potentially high exposure to boron from drinking water and locally grown foods (Butterwick et al. 1989). Individuals using boron-containing cosmetics or medicines extensively, especially on damaged skin, may be exposed to higher-than-normal levels of boron (Beyer et al. 1983). Infants may be at risk in homes where boric acid containing roach powder on floor parameters is used to control cockroaches.

Workers in industries producing or using boron-containing materials also have potentially high exposure as noted above (Section 5.5). People living in the vicinity of waste sites are also at risk of higher-than-normal exposure levels.

5.7 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 boron is available. Where adequate information is not available, ATSDR, in conjunction with the 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 boron.

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 or eliminate the uncertainties of human health assessment. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed.

5.7.1 Data Needs

Physical and Chemical Properties. The solubilities of many boron minerals are not known precisely, but this lack of detailed information may not be a major limitation, since it appears unlikely that mineral equilibria significantly influence the fate of boron in the environment.

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Production, Import/Export, Use, and Disposal. The production volume and uses of boron and boron compounds are well documented (Ferguson et al. 1982; HSDB 1989; U.S Bureau of Mines 1989). However, data on disposal methods and volume would allow better estimation of human exposure to boron from this source.

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 Toxics Release Inventory (TRI), which contains this information for 1987, became available in May of 1989. However, neither boron nor boron-related compounds are currently listed in the database. This database will be updated yearly and should provide a list of industrial production facilities and emissions.

Environmental Fate. The only quantifiable mechanism that influences the fate of boron is soil adsorption (Rai et al. 1986). Additional research with soils that do not have significant quantities of aluminum and iron oxide may provide a more comprehensive view of the mobility of boron in the environment.

Bioavailability from Environmental Media. Boron compounds can be absorbed following inhalation of contaminated workplace air, ingestion of contaminated food, or through damaged skin (Draize and Kelley 1959; Wong et al. 1964). The most significant routes of exposure near hazardous waste sites are likely to be through drinking boron-contaminated water and ingestion of locally grown food (Beyer et al. 1983; Butterwick et al. 1989; CLPSD 1989). While exposure can occur by these routes, quantitative data on amounts absorbed or are bioavailable would be useful in clarifying the toxic potential of boron in humans.

Food Chain Bioaccumulation. Only one study was located where boron bioconcentration was actually measured (Tsui and McCart 1981). Future research may be helpful, but it appears that boron is not significantly bioconcentrated. There are no data on the biomagnification of boron in the food chain, but it is not likely that bioaccumulation is a major environmental concern.

Exposure Levels in Environmental Media. Data on boron levels in surface water and soil are extensive (Butterwick et al. 1989; Eckel and Langley 1988; EPA 1986b), but additional data on air, food, and drinking water concentrations of boron would be useful in increasing the accuracy of human exposure estimates.

Exposure Levels in Humans. Normal levels of boron in human blood and urine have been reported (Stokinger 1981). Additional data on blood and/or urine concentrations in individuals with potentially high exposure to boron would be useful in assessing the magnitude of human exposure.

Exposure Registries. No exposure registries for boron were located. This compound is not currently one of the compounds for which a subregistry has been established in the National Exposure Registry. The compound will be

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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 compound.

5.7.2 On-going Studies

No information was located on any on-going studies on the fate, transport, or potential for human exposure for boron.