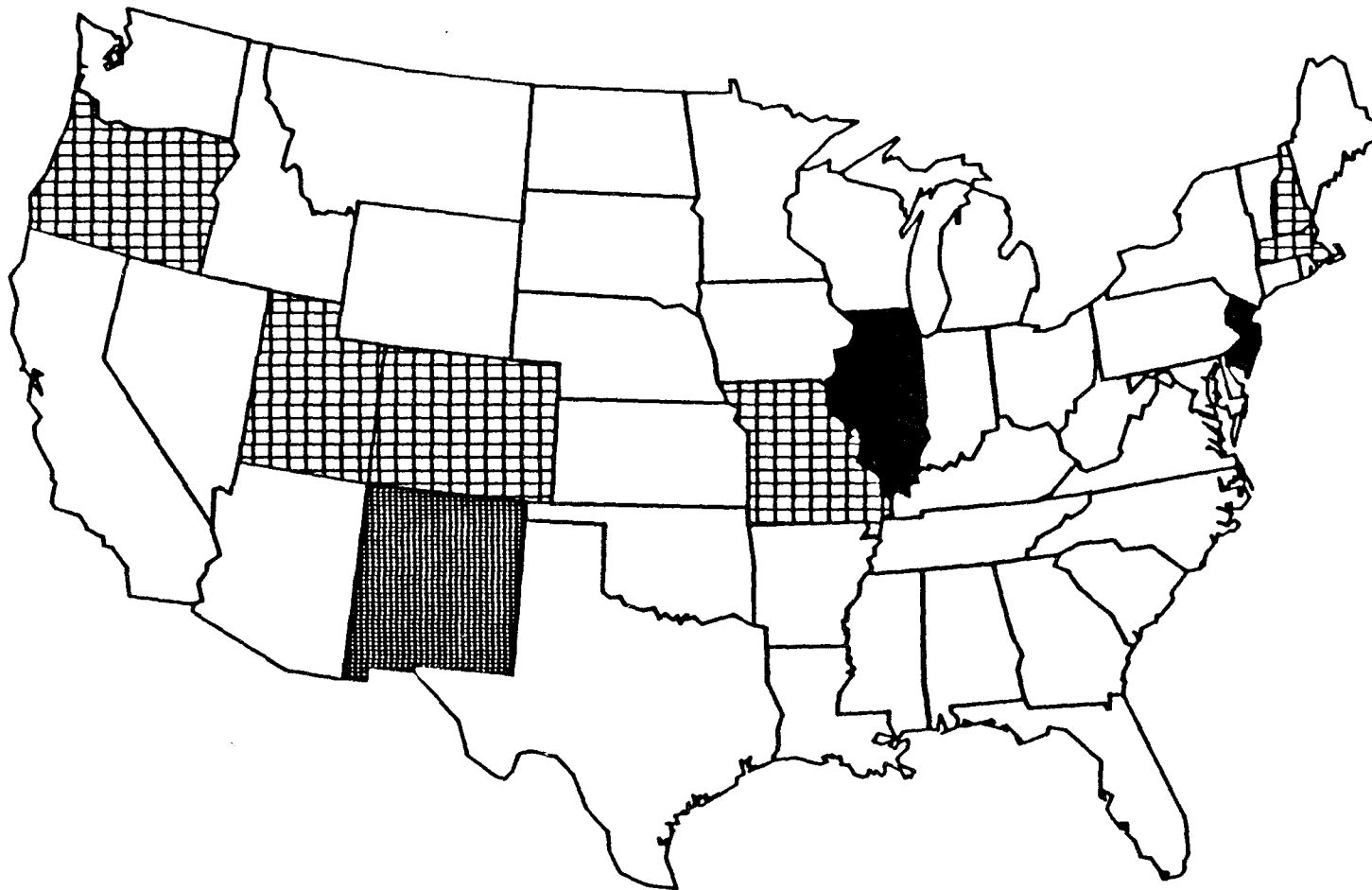


## 5. POTENTIAL FOR HUMAN EXPOSURE

### 5.1 OVERVIEW

Thorium is ubiquitous in our environment. Release of thorium to the atmosphere can occur both from natural and anthropogenic sources, and emissions from the latter sources can produce locally elevated atmospheric levels of thorium over the background. Windblown terrestrial dust and volcanic eruptions are two important natural sources of thorium in the air (Fruchter et al. 1980; Kuroda et al. 1987). Uranium and thorium mining, milling and processing, tin processing, phosphate rock processing and phosphate fertilizer production, and coal fired utilities and industrial boilers are the primary anthropogenic sources of thorium in the atmosphere (Hu and Kandaiya 1985; McNabb et al. 1979; Nakoaka et al. 1984; Sill 1977). The major industrial releases of thorium to surface waters are effluent discharges from uranium and thorium mining, milling and processing, tin processing, phosphate rock processing and phosphate fertilizer production facilities (Hart et al. 1986; McKee et al. 1987; Moffett and Tellier 1978; Platford and Joshi 1988). The primary sources of thorium at the Superfund sites are perhaps from the processing and extraction of thorium, uranium, and radium from ores and concentrates (EPA 1988a). At this time, elevated levels (higher than background) of thorium have been found at 16 out of 1177 National Priority List (NPL) hazardous waste sites in the United States (VIEW Database 1989). The frequency of these sites within the United States can be seen in Figure 5-1.

Data regarding the fate and transport of thorium in the air are limited. Wet and dry deposition are expected to be mechanisms for removal of atmospheric thorium. The rate of deposition will depend on the meteorological conditions, the particle size and density, and the chemical form of thorium particles. Although atmospheric residence times for thorium and compounds were not located, judging from residence times of other metals (e.g., lead) and their compounds, they are likely to be a few days. Thorium particles with small aerodynamic diameters (<10 micron aerodynamic diameter) will travel long distances from their sources of emission. In water, thorium will be present in suspended matters and sediment and the concentration of soluble thorium will be low (Platford and Joshi 1987). Sediment resuspension and mixing may control the transport of particlesorbed thorium in water. The concentration of dissolved thorium in some waters may increase due to formation of soluble complexes with carbonate, humic materials, or other ligands in the water (LaFlamme and Murray 1987). Thorium has been found to show significant bioconcentration in lower trophic animals in water, but the bioconcentration factors decrease as the trophic level of aquatic animals increases (Poston 1982; Fisher et al. 1987). The fate and mobility of thorium in soil will be governed by the same principles as in water, In most cases, thorium will remain strongly sorbed to soil and its mobility will be very slow (Torstenfelt 1986). However, leaching into groundwater is possible in some soils with low sorption capacity and the ability to form soluble complexes. The plant/soil transfer ratio for thorium is less than 0.01 (Garten 1978), indicating that it will not bioconcentrate in plants from soil. However, plants grown at the edge of



FREQUENCY     1 SITE     2 SITES     4 SITES

FIGURE 5-1. FREQUENCY OF SITES WITH THORIUM CONTAMINATION

## 5. POTENTIAL FOR HUMAN EXPOSURE

impoundments of uranium tailings containing elevated levels of thorium had a plant/soil concentration ratio of about 3 (Ibrahim and Whicker 1988).

The atmospheric mass concentration of thorium ranged from 0.2-1.0 ng/m<sup>3</sup>, with a mean value of 0.3 ng/m<sup>3</sup> in air samples collected from 250 sites in the United States (Lambert and Wilshire 1979). In another study, the mean activity concentrations of thorium-228, thorium-230, and thorium-232 in New York City air were 36 aCi/m<sup>3</sup> (aCi = 10<sup>-18</sup> Ci), 36 aCi/m<sup>3</sup>, and 37 aCi/m<sup>3</sup>, respectively (Wrenn et al. 1981). The average population-weighted concentrations of thorium-232 and thorium-230 in United States community water supplies derived both from surface and groundwater were less than 0.01 pCi/L and less than 0.04 pCi/L, respectively (Cothorn 1987; Cothorn et al. 1986). The maximum concentration of thorium-232 in several fruits, vegetables and other type of foods from New York City was reported to be less than 0.01 pCi/g (Fisenne et al. 1987). The daily intakes of thorium-230 and thorium-232 for residents of New York City were estimated to be 0.17 and 0.11 pCi, respectively. Significant exposure to thorium requires special exposure scenarios (Fisenne et al. 1987). People who consume foods grown in high background areas, reside in homes with high thorium background levels, or live near radioactive waste disposal sites may be exposed to higher than normal background levels of thorium. Workers in uranium, thorium, tin, and phosphate mining, milling, and processing industries, and gas mantle manufacture may also be exposed to higher than normal background levels of thorium (Bulman 1976; Hannibal 1982; Hu et al. 1984; Kotrappa et al. 1976; Metzger et al. 1980).

### 5.2 RELEASES TO THE ENVIRONMENT

#### 5.2.1 Air

Releases of thorium to the atmosphere can occur from both natural and anthropogenic sources. The release of thorium in volcanic ash containing as much as 0.116 pCi/g (1.06 µg/g) of thorium-232 was reported by Fruchter et al. (1980). Increased concentrations of thorium in rain water following a volcanic eruption have also been observed (Kuroda et al. 1987). Since the average level of thorium in soil is about 6 µg/g of thorium (Harmsen and De Haan 1980), windblown terrestrial dust is also a likely natural source of thorium in the atmosphere. Since coal contains 0.5-7.3 µg/g thorium (Nakaoka et al. 1984), burning of coal for power generation produces thorium in the fly ash and is a manmade source of this chemical in the atmosphere. The amount of thorium in the fly ash from coal-burning power plants depends on the nature of coal burned and the emission control devices of the plant, but concentrations usually range from 4.5-37 µg/g (Abel et al. 1984; Coles et al. 1979; Tadmor 1986; Weissman et al. 1983). However, the concentrations of all natural radioactive isotopes in (including thorium isotopes) the stack effluents from coal-fired power plants are usually much lower than those from the natural background concentrations of these radionuclides (Nakaoka et al. 1984; Roeck et al. 1987). Similarly, fly ash

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from oil- and peat-fired power plants can also be atmospheric sources of thorium (Mustonen and Jantunen 1985).

Thorium-230 has been detected in air dust from uranium ore processing and mill tailings. These concentrations of thorium-230 (a decay product of uranium-238) may be particularly high in ore crushing areas (Sill 1977). Similarly, processing of thorium ores is expected to be an atmospheric source of thorium. Elevated levels of thoron (thoron or radon-220 originating from thorium-232) daughters, such as bismuth-212 and polonium-216, were present at a former thorium and rare-earth extraction facility waste site, although the concentrations of thorium in air particulate samples were not significant (Jensen et al. 1984). Since phosphate ores usually contain thorium-230, phosphate-ore processing plants are also atmospheric sources of thorium-230 (Metzger et al. 1980; McNabb et al. 1979). The by-products obtained during processing of tin ores usually contain thorium-232. Therefore, tin processing industries are sources of atmospheric thorium-232 emissions (Hu et al. 1981, 1984; Hu and Kandaiya 1985).

EPA (1984) estimated that about 0.2 Ci of thorium-230 is annually emitted into the air from uranium mill facilities, coal-fired utilities and industrial boilers, phosphate rock processing and wet-process fertilizer production facilities, and other mineral extraction and processing facilities. About 0.084 Ci of thorium-234 from uranium fuel cycle facilities and 0.0003 Ci of thorium-232 from underground uranium mines are emitted into the atmosphere annually (EPA 1984).

### 5.2.2 Water

The acidic leaching of uranium tailing piles in certain areas is a source of thorium-230 in surface water and groundwater (Moffett and Tellier 1978; Platford and Joshi 1988). The contamination of surface waters and benthic organisms by thorium-230 (a decay product of uranium-238) from uranium mining and milling operations and from radium and uranium recovery plants has been reported (Hart et al. 1986; McKee et al. 1987). Similarly, effluents from thorium mining, milling, and recovery plants are expected to be sources of thorium in water. Other industrial processes that are expected to be sources of thorium contamination into water are phosphorus and phosphate fertilizer production and processing of some tin ores. Since both phosphate rocks and the tailings from tin ore processing contain thorium mainly as thorium-230 and thorium-232, respectively (see Section 5.2.1), discharges of processed or unprocessed effluents and leaching from tailing piles can be sources of thorium in water. Leaching from landfill sites containing uranium and thorium may result in the contamination of surface water and groundwater with thorium (Cottrell et al. 1981).

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### 5.2.3 Soil

Thorium occurs naturally in the earth's crust at an average lithospheric concentration of 8-12  $\mu\text{g/g}$  (ppm). The typical concentration range of naturally-occurring thorium in soil is 2-12  $\mu\text{g/g}$ , with an average value of 6  $\mu\text{g/g}$  (Harmsen and De Haan 1980). Manmade sources of thorium contamination in soil are mining, milling and processing operations and uranium, thorium, tin and phosphate fertilizer production (Chong et al. 1985; Hu and Kandaiya 1985; Joshi 1987; McNabb et al. 1979; Sill 1977). The two principal processes that can contaminate soil from these industries are precipitation of airborne dusts and land disposal of uranium or thorium-containing wastes.

According to EPA (1988a), the primary sources of thorium at the Superfund sites are processing and extraction of thorium, uranium and radium from ores or ore-concentrates. The following radioactive waste Superfund sites have been found to contain one or more isotopes of thorium (VIEW 1989): Shpack and adjacent landfills, Norton, MA; Maywood Chemical Co., Sears Property, Maywood, NJ; W.R.Grace and Co., Wayne, NJ; West Chicago Sewage Treatment Plant, W. Chicago, IL; Reed-Keppler Park, West Chicago, IL; Kerr-McGee (Residential Areas), W. Chicago, IL; Kress Creek and the West Branch of the DuPage River, W. Chicago, IL; United Nuclear Corp., Church Rock, NM; Homestake Mining Co., Milan, NM; Kearsarge Metallurgical Corp., Conway, NH; Naval Air Engineering Center, Lakehurst, NJ; Teledyne Wah Chang, Albany, OR; Woodland Route 72 Dump, Woodland Township, NJ; Weldon Spring Quarry, St. Charles City, MO; Monticello Radioactivity-Contaminated Properties, Monticello, UT; Uravan Uranium Project, Montrose City, CO. Disposal of incandescent lights and lanterns containing thorium-232 will be an additional source of thorium at waste disposal sites.

## 5.3 ENVIRONMENTAL FATE

Thorium occurs in nature in four isotopic forms, thorium-228, thorium-230, thorium-232, and thorium-234. Of these, thorium-228 is the decay product of naturally-occurring thorium-232, and both thorium-234 and thorium-230 are decay products of natural uranium-238. To assess the environmental fate of thorium, these isotopes of thorium with the exception of thorium-234 which has short half-life (24.1 days), should be considered.

### 5.3.1 Transport and Partitioning

Data regarding the transport and partitioning of thorium in the atmosphere are limited. Release of atmospheric thorium from mining, milling, and processing operations of thorium will mainly consist of thorium-232 particulate matter. Emissions from mining, milling, and processing of uranium and the airblown dust from uranium tailing piles will contribute to the presence of thorium-230 as an atmospheric particulate aerosol. The aerodynamic diameters of both thorium-230 and thorium-232 in atmospheric aerosols are greater than 2.5  $\mu\text{m}$ . The aerodynamic diameter of

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thorium-228, however, is less than 1.6  $\mu\text{m}$  (Hirose and Sugimura 1987) and may travel longer distances than both thorium-230 and thorium-232. Like other particulate matter in the atmosphere, thorium will be transported from the atmosphere to soil and water by wet and dry deposition.

The deposition of thorium through snow and rain water has been observed (Jiang and Kuroda 1987). Dry deposition of thorium through impaction and gravitational settling has also been observed (see Section 5.2.3). The atmospheric residence time of thorium depends on the aerodynamic diameter of the particles. Those with small diameters are likely to be transported longer distances. For example, high thorium-228/thorium-232 activity ratios observed in surface air of the Western North Pacific Ocean are thought to be due to long distance transport of small particles of thorium-228 (Hirose and Sugimura 1987).

The dry deposition velocity of lead-212, a thoron (thoron or radon-220 itself originating from thorium-232) decay product has been reported to be in the range 0.03-0.6 cm/set (Bigu 1985; Rangarajan et al. 1986). These low deposition velocities indicate that the thoron daughter, stable lead, may have a long residence time in the atmosphere with respect to dry deposition.

Thorium discharged as  $\text{ThO}_2$  into surface waters from mining, milling, and processing will be present as suspended particles or sediments in water because of the low solubility of thorium in water (Platford and Joshi 1986). Other soluble thorium ions will hydrolyze at pH above 5 forming  $\text{Th}(\text{OH})_4$  precipitate or hydroxy complexes, e.g.,  $\text{Th}(\text{OH})_2^{+2}$ ,  $\text{Th}_2(\text{OH})_2^{+6}$ ,  $\text{Th}_3(\text{OH})_5^{+7}$  (Bodek et al. 1988; Hunter et al. 1988; Milic and Suranji 1982). The hydroxy complexes will be adsorbed by particulate matter in water, e.g., goethite ( $\alpha\text{-FeOOH}$ ), with the result that most of the thorium will be present in suspended matter or sediment, and the concentration of soluble thorium in water will be low (Hunter et al. 1988; Sheppard 1980). The adsorption of thorium to suspended particles or sediment in water depends on the particle size, and the adsorption and subsequent removal from aqueous phase is expected to be higher for finer grained particles (Carpenter et al. 1987). The residence times for thorium with respect to removal by adsorption onto particles were reported to be shorter in nearshore waters than in deeper waters, probably because of the availability of more adsorbents (particulate matter). The residence time may vary from 1 day to 70 days (Cochran 1984). The scavenging rate varied seasonally and was inversely related to the sediment resuspension rate. Therefore, the removal rate was found to be dependent on both sediment resuspension rate and the concentration of iron and manganese compounds (good adsorption properties) in water (Cochran 1984).

The transport of thorium in water is principally controlled by the particle flux in the water, i.e., most of the thorium will be carried in the particle-sorbed state (Santschi 1984), and sediment resuspension and mixing may control the transport of particle-sorbed thorium in water (Santschi

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et al. 1983). Although the concentration of dissolved thorium is low in most waters, its value could be higher in some waters. For example, the concentration of dissolved thorium in an alkaline lake was up to 4.9 dpm/L (2.21 pCi/L) compared to about  $1.3 \times 10^{-5}$  dpm/L ( $0.59 \times 10^{-5}$  pCi/L) in sea water (LaFlanune and Murray 1987). The dissolved thorium concentration can increase by the formation of soluble complexes. The anions or ligands likely to form complexes with thorium in natural water are  $\text{CO}_3^{2-}$  and humic materials, although some of the thorium-citrate complexes may be stable at pH above 5 (LaFlamme and Murray 1987; Miekeley and Kuchler 1987; Platford and Joshi 1986; Raymond et al. 1987; Simpson et al. 1984).

The transport of thorium from water to aquatic species has been reported. The bioconcentration factor (concentration in dry organism/concentration in water) (dry weight basis) in algae may be as high as  $975 \times 10^4$ , but the maximum value in zooplankton (calanoids and cyclopoids) may be  $2 \times 10^4$  (Fisher et al. 1987). Fisher et al. (1987) suggested that sinking plankton and their debris may account for the sedimentation of most of the thorium from oceanic surface waters. The highest observed thorium bioconcentration factor in the whole body of rainbow trout (Salmo gairdneri) was 465 (Poston 1982). The succeeding lower bioconcentration factors in higher trophic animals indicates that thorium will not biomagnify in the aquatic environment. It was also noted that the majority of thorium body burden in fish is in the gastrointestinal tract (Poston 1982).

The mobility of thorium in soil will be governed by the same principles as in water. In most soil, thorium will remain strongly sorbed onto soil and the mobility will be very slow (Torstenfelt 1986). The presence of ions or ligands ( $\text{CO}_3^{2-}$ , humic matter) that can form soluble complexes with thorium should increase its mobility in soil. The contamination of groundwater through the transport of thorium from soil to groundwater will not occur in most soils, except soils that have low sorption characteristics and have the capability to form soluble complexes. Chelating agents produced by certain microorganisms (Pseudomonas aeruginosa) present in soils may enhance the dissolution of thorium in soils (Premuzic et al. 1985).

The transport of atmospherically deposited thorium from soil to plants is low. The soil to plant transfer coefficients (concentration in dry plant to concentration in dry soil) were estimated to be  $10^{-4}$  to  $7 \times 10^{-3}$  by Garten (1978) and  $0.6 \times 10^{-4}$  for thorium-232 by Linsalata et al. (1989). The root systems of grasses and weeds adsorb thorium from the soil but the transport of thorium from the root to the aboveground parts of the plant is not very extensive, as indicated by 100-fold higher concentrations of all three isotopes (thorium-228, thorium-230, and thorium-232) in the root than in the aboveground parts of the plant (Taskayev et al. 1986). However, Ibrahim and Whicker (1988) showed that under certain conditions, vegetation can accumulate thorium-230, as indicated by the plant/soil concentration ratio (dry weight) of 1.9-2.9 for mixed grasses, mixed forbs and sagebrush plants

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grown at the edge of uranium tailings impoundments. Vegetation concentration ratios for thorium-232 (a concentration ratio of about 0.1) and thorium-228 (a maximum concentration ratio of about 0.4) were lower than that of thorium-230. It was postulated that the acidity and wet conditions at this site enhanced the solubility of thorium in soil and that the difference in solubility was responsible for the difference in plant uptake of the three thorium isotopes (Ibrahim and Whicker 1988). However, it is possible that the observed difference in the uptake of the three isotopes by plants is due to a difference in the chemical compounds formed by the isotopes, making one more leachable than the other (therefore more available for uptake) under the prevailing local conditions (also see Section 5.6).

### 5.3.2 Transformation and Degradation

#### 5.3.2.1 Air

Thorium may change from one chemical species to another in the atmosphere (such as  $\text{ThO}_2$  to  $\text{Th}(\text{SO}_4)_2$ ) as a result of chemical reactions, but nothing definitive is known about the atmospheric chemical reactions of thorium. The chemical forms in which thorium may reside in the atmosphere are also not known, but it is likely to be present mostly as  $\text{ThO}_2$ .

#### 5.3.2.2 Water

The principal abiotic processes that may transform thorium compounds in water are complexation by anions/organic ligands and hydroxylation. The increase in the mobility of thorium through the formation of soluble complexes with  $\text{CO}_3^{2-}$ , humic materials, and other anions or ligands and the decrease in the mobility due to formation of  $\text{Th}(\text{OH})_4$  or anionic thoriumhydroxide complexes were discussed in Section 5.3.1.2. In a model experiment with seawater at pH 8.2 and freshwater at pH 6 and pH 9, it was estimated that almost 100% of the thorium resides as hydroxo complexes (Boniforti 1987);

#### 5.3.2.3 Soil

No published data were located referencing biotic transformation of thorium in soil. Abiotic transformation processes that can convert immobile thorium in soil into mobile forms through the formation of complexes were discussed in Section 5.3.1.3.

## 5.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT

### 5.4.1 Air

The level of thorium in air have not been measured as frequently as it has for uranium. The concentration of thorium in the atmosphere of the South Pole measured in 1970 ranged between 18 and 83  $\text{fg}/\text{m}^3$ , with a mean value of 59  $\text{fg}/\text{m}^3$  (1  $\text{fg} = 10^{-15}$  g). The origin of thorium in the polar



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atmosphere was speculated to be either crustal weathering or the ocean water (Zoller et al. 1974). The thorium level in the air of Algonquin Park, Ontario, Canada was reported to be  $7.1 \text{ pm}^3$  (Sheppard 1980). The level of thorium measured in 1969 in East Chicago, IN, a heavily polluted industrial area, was  $1.3 \text{ ng/m}^3$  compared to a value of  $0.27 \text{ ng/m}^3$  at a rural location in Michigan (Niles, MI) (Dams et al. 1970). The air particulate samples collected from 250 sites in the United States by the National Air Surveillance Network (NASN) of EPA during 1975 and 1976 were analyzed for thorium-232 by neutron activation analysis. The measured concentrations at 250 urban and nonurban sites in the United States ranged from 0.2-1.0  $\text{ng/m}^3$ , with a mean concentration of  $0.3 \text{ ng/m}^3$  (Lambert and Wilshire 1979). The mean concentrations of thorium-228, thorium-230 and thorium-232 in New York City air (sample collected on the roof above the 14th floor) were  $36 \text{ aCi/m}^3$  ( $\text{aCi} = 10^{-18} \text{ Ci}$ ),  $36 \text{ aCi/m}^3$ , and  $37 \text{ aCi/m}^3$ , respectively (Wrenn et al. 1981).

The air concentrations of thorium and other airborne radioactivity near a former thorium and rare-earth extraction facility in the United States were measured. The maximum radioactivity due to all three isotopes of thorium at a site about 450 feet from the primary waste pile was  $0.66 \text{ fCi/m}^3$ . Although the background thorium radioactivity was not reported, the total radioactivity at a site about 4000 feet south of the waste pile was about 3.5 times lower than a site 450 feet from the pile (Jensen et al. 1984).

The concentration of thorium in rainwater over Fayetteville, AR, ranged from 2.8-123  $\text{fCi/L}$  for thorium-228, 1.7-123  $\text{fCi/L}$  for thorium-230, and 0.8-118  $\text{fCi/L}$  for thorium-232. The peak values in thorium concentrations correlated well with the 1980 eruption of Mount St. Helen and the 1982 eruption of El Chichon (Jiang et al. 1986; Jiang and Kuroda 1987; Salaymeh and Kuroda 1987).

The natural decay of uranium-238 and thorium-232 will produce radon-222 and thoron (radon-220). The indoor air levels of radon (radon-222) and thoron (radon-220) daughters arising from some building materials and the soil, have been reported by several authors. It was generally believed that the effective dose equivalent from radon-220 (thoron) daughters (originating from thorium-232) might average about one-fifth of that due to radon-222 daughters (originating from uranium-238) in the temperate regions (Schery 1985). However, more recent measurements at varied indoor locations within the United States and Germany have shown that the potential alpha energy concentrations from radon-220 daughters may be as high as 60% of that originating from radon-222. It has also been shown that the concentrations of thoron (radon-220) and radon-222 daughters in the indoor air are dependent on the air exchange rate in the dwellings and that the indoor concentrations are about 3-4 times higher than the outdoor concentrations (Keller and Folkerts 1984; Schery 1985).

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### 5.4.2 Water

Compared to uranium, relatively less information was located on the levels of thorium in natural waters. The concentrations of dissolved thorium in water with high pH (more than 8) are expected to be very low, and the concentration may increase with the decrease of pH (Harmsen and De Haan 1980). Cothorn et al. (1986) reported thorium-232 concentrations rarely exceed 0.1 pCi/L in natural waters, but that the concentrations of thorium-230, a progeny of uranium-238, may be as high as 0.4 pCi/L. In a natural surface water in Austria, the concentration of thorium (isotope undefined) was reported to be 1.24-2.90 µg/L (Harmsen and De Haan 1980). The concentration of thorium (isotope undefined but probably thorium-230) in water under low pH conditions which may occur from the leaching of uranium tailings may be as high as 38 mg/L (Harmsen and De Haan 1980). The individual concentrations of thorium-228, -230, and -232 in an area of Great Bear Lake in Canada contaminated with mine wastes (silver and uranium mines) were less than 0.5 pCi/L (Moore and Sutherland 1981). The concentrations of thorium-228, -230, and -232 in a highly alkaline (pH of about 10) lake (Mono Lake) in California have been reported to be as high as 1.02, 1.41, and 0.7 pCi/L, respectively (Anderson et al. 1982; Simpson et al. 1982).

The concentrations of thorium in seawater at various depths and locations have been reported by several authors. Because of the very low concentrations of thorium and the differences in location and the varying characteristics of the water, the reported results are different. The concentration of total thorium in seawater ranges from  $4 \times 10^{-5}$  to less than 0.5 µg/kg (Greenberg and Kinston 1982; Sheppard 1980) and the world average concentration in seawater is 0.05 µg/L (Harmsen and De Haan 1980). The concentrations of the individual isotopes thorium-232, thorium-230, and thorium-228 in seawater have been reported to range from 0.00023-0.032, 0.014-0.72, and 0.023-3.153 fCi/L, respectively (Anderson et al. 1982; Hirose 1988; Huh and Bacon 1985; Livingston and Cochran 1987; Simpson et al. 1982). The concentrations of thorium in sediments are much higher than in seawater. In several sediments, concentrations of thorium-232, thorium-230, and thorium-228 ranged from 0.52-1.96, 1.01-30.77, and 0.36-1.93 pCi/g, respectively (Huh et al. 1987; Yang et al. 1986).

Thorium has also been detected in groundwaters. In groundwater in Austria, concentrations ranged from 0.5-2.90 µg/L (Harmsen and De Haan 1980). Briny groundwater from a well in Palo Duro Basin, WA, contained 0.009, 0.1, and 0.59 pCi/L of thorium-232, thorium-230, and thorium-228, respectively (Laul et al. 1987). In a California well, thorium-230 was detected at a concentration as high as 1.3 pCi/L (Aieta et al. 1987). The average population-weighted concentrations of thorium-232 and thorium-230 in United States community water supplies derived from both surface water and groundwater are less than 0.01 pCi/L and less than 0.04 pCi/L, respectively (Cothorn 1987; Cothorn et al. 1986).

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### 5.4.3 Soil

The typical concentration range of thorium in soil is 2-12  $\mu\text{g/g}$  (ppm), with an average value of 6  $\mu\text{g/g}$  (Harmsen and De Haan 1980). The thorium content of soil normally increases with an increase in clay content of soil (Harmsen and De Haan 1980). The thorium contents in most soils from the Superfund sites listed in Section 5.2.3 were above background levels. The soil concentrations of thorium-232 at the Reed-Keppler Park, W. Chicago, IL, site and the Kerr-McGee Residential areas in W. Chicago, IL, were 11,000 and 16,000 pCi/g, respectively (EPA 1988a). Soils near processing and milling operations, and concentrations of uranium and thorium ores, phosphate ores, and tin ores may contain thorium at concentrations higher than the background levels. Higher concentrations of thorium in soils near uranium ore crushing facilities have been reported (Jensen et al. 1984; Sill 1977).

### 5.4.4 Other Media

Because concentrations of thorium in foods are very low, very few data exist. The thorium-232 content in fresh fruits, vegetables, and tea was determined (in pCi/g), and the values are listed in Table 5-1. Vegetables grown in an area of high natural activity in Brazil had the following concentrations of thorium ( $\mu\text{g/g}$  in dry sample) (Linsalata et al. 1987): brown beans, 0.011; potato, 0.0019; zucchini, 0.011; corn, 0.0022; carrot, 0.0074; and sweet potato, 0.0027. These authors did not observe rapid transport of thorium-232 from soil to the edible parts of the plants.

The concentrations of thorium in both hard and soft tissues of humans have been determined by a few authors. The concentration of thorium-232 in the blood of normal populations (not occupationally or otherwise known to be exposed to levels higher than background level of thorium) in the United Kingdom was 2.42  $\mu\text{g/L}$ . The thorium-232 level in the urine of the same population was below the detection limit of 0.001  $\mu\text{g/L}$ , although the concentration in the urine of exposed workers ranged from less than 0.001-2.24  $\mu\text{g/L}$ . The highest value (2.24  $\mu\text{g/L}$ ) was found in a worker in the thorium nitrate gas mantle industry (Bulman 1976; Clifton et al. 1971).

The thorium-232 concentration in rib bones from several control humans from the United States ranged from less than 0.1-72 ng/g (ppb) and were found to increase-with age (Lucas et al. 1970). A similar increase in thorium concentration with age was seen in bones (primarily vertebral wedges) of a Colorado population (Wrenn et al. 1981). The level of thorium-232 in rib bones of individuals in the United Kingdom not occupationally exposed to thorium ranged from 0.8-163.8 ng/g, with a mean value of 28.7 ng/g in dry ash (Clifton et al. 1971). The concentration of thorium in the fibula of a Thorotrast patient was reported to be 2.0  $\mu\text{g/g}$  (ppm) (Edgington 1967). Singh et al. (1985) reported more recent measurements of isotopic concentrations of thorium in different human bones from the general population of Colorado and Pennsylvania. These values are shown in Table 5-2. The authors concluded that the concentrations of thorium-230 in ribs

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**TABLE 5-1. Thorium-232 Content in Fresh Fruits, Vegetables, and Tea<sup>a</sup>**

Food	Concentration in pCi/g (wet weight)
Apples	$\leq 6.9 \times 10^{-3}$
Asparagus	$\leq 9.8 \times 10^{-2}$
Bananas	$\leq 8.2 \times 10^{-3}$
Bell peppers	$\leq 6.7 \times 10^{-3}$
Brazil nut	$< 7 \times 10^{-3}$ to $9 \times 10^{-3}$
Broccoli	$\leq 3.6 \times 10^{-3}$
Cabbage	$\leq 3.3 \times 10^{-3}$
Carrots	$\leq 4.2 \times 10^{-3}$
Celery	$\leq 9.0 \times 10^{-3}$
Cucumbers	$\leq 2.9 \times 10^{-3}$
Egg plant	$\leq 3.3 \times 10^{-3}$
Grapefruit	$\leq 9.8 \times 10^{-3}$
Green beans	$\leq 4.9 \times 10^{-3}$
Green tea	$2 \times 10^{-3}$ to $3 \times 10^{-3}$
Irish potatoes	$\leq 3.9 \times 10^{-3}$
Lettuce	$\leq 2.8 \times 10^{-3}$
Oranges	$\leq 4.1 \times 10^{-3}$
Pears	$\leq 8.5 \times 10^{-3}$
Raisins	$\leq 1.2 \times 10^{-2}$ ; $2 \times 10^{-3}$ to $3 \times 10^{-3}$
Sesame seed	$1 \times 10^{-2}$
Soybean	$1 \times 10^{-3}$
Sweet potatoes	$\leq 7.5 \times 10^{-3}$
Tangelos	$\leq 2.3 \times 10^{-3}$
Tangerines	$4.7 \times 10^{-3}$
Tomatoes	$\leq 1.1 \times 10^{-2}$
Turnips	$\leq 2.6 \times 10^{-3}$
Yellow squash	$\leq 3.9 \times 10^{-3}$

<sup>a</sup>Source: Oakes et al. 1977; Kobashi and Tominaga 1985.

**TABLE 5-2. Thorium Levels in Bones of Colorado and Pennsylvania Residents<sup>a</sup>**

Source of bone	Mean Th Levels [(pCi/kg) wet weight] in Residents from Two Locations					
	Colorado			Pennsylvania		
	Th-232	Th-230	Th-228	Th-232	Th-230	Th-228
Ribs	0.50	1.57	1.0	0.20	0.54	1.19
Vertebrae	0.096	0.96	0.88	0.10	0.27	1.31
Sternum	ND <sup>b</sup>	ND <sup>b</sup>	0.02 <sup>b</sup>	0.33	0.63	2.73

<sup>a</sup>Source: Singh et al. 1985.

<sup>b</sup>Only one sample analyzed.

ND = not detected; Th = thorium.

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of the Colorado population were significantly higher (statistically), probably because of exposure to uranium tailings, than those from the Pennsylvania population.

The levels of thorium in the tissues of a hard-rock miner, a uranium miner, and the levels in two uranium millers (thorium-230 is a decay product of uranium-238, and thorium-238 and thorium-232 are impurities in uranium) were compared with the levels in the 50th percentile for the general population (Singh et al. 1987; Wrenn et al. 1981). These data are given in Table 5-3. The levels of thorium-230 in the hard-rock miner were about 10 times higher than the median levels in most tissues of the general population. In the case of the uranium miner and millers, the values were more than two orders of magnitude higher than the median tissues levels in the general population.

Wrenn et al. (1981) determined the median concentrations of thorium-228, thorium-230, and thorium-232 in the lungs of smokers and nonsmokers; the respective values were 0.22, 0.56, and 0.43 pCi/kg for smokers and 0.37, 0.84, and 0.60 pCi/kg for nonsmokers. The investigators concluded that cigarette smoking had no effect relative to increasing the concentration of thorium isotopes in lungs.

### 5.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE

The general population will be exposed to thorium through the inhalation of air and ingestion of food and drinking water containing trace amounts of the chemical. Because the concentration of thorium is normally very low in air, drinking water, and foods (see Section 5.4), few studies were located that determined the daily human intake of thorium. According to Cothorn (1987), the estimated daily intakes of thorium-230 in the United States population through inhalation of air and ingestion of drinking water are 0.0007 and less than 0.06 pCi, respectively. The corresponding values for thorium-232 are 0.0007 and less than 0.02 pCi. Cothorn (1987) assumed that the intake from food would be negligible. Based on these values, the total daily intakes of thorium-230 and thorium-232 are expected to be less than 0.06 and less than 0.02 pCi, respectively. However, other authors estimated the contribution of food to the total human thorium intake may not be negligible and may be the most significant. Based on a survey of the levels of thorium in air, water, and food, Fisenne et al. (1987) estimated the daily intake of thorium-230 and thorium-232 by New York City residents. The daily dietary, water, and inhalation intake of thorium-230 was estimated to be 0.164, 0.005, and 0.0003 pCi, respectively, giving a total daily intake of 0.17 pCi. The corresponding estimated values for thorium-232 are 0.110, 0.002, and 0.0002 pCi, with a total daily intake being 0.112 pCi. From the measured values of thorium in feces and the assumed values for uptake and elimination rates, Linsalata et al. (1985) estimated a daily ingestion intake of thorium-232 for New York residents to be about 0.08 pCi or 0.7  $\mu\text{g}$ . This value is considerably smaller than the value estimated by Fisenne et al. (1987). The value from Linsalata et al. (1985) is again

TABLE 5-3. Thorium Isotopic Concentration in Three Occupational Cases and the General Population of Grand Junction, Colorado (pCi/kg)

	Uranium Miner <sup>a</sup>			Hard Rock Miner <sup>a</sup>			Uranium Miller <sup>b</sup>			50th Percentile for the General Population <sup>a</sup>		
	Th-228	Th-230	Th-232	Th-228	Th-230	Th-232	Th-228	Th-230	Th-232	Th-228	Th-230	Th-232
Lung	1.1±0.18	54.0±0.81	1.4±0.13	0.70±0.24	12.0±0.79	0.61±0.18	0.49	141	2.35	0.21	0.88	0.37
Lymph nodes	NA	NA	NA	12.0±2.4	37.0±3.9	4.6±1.4	168	1687	31.7	4.8	13.0	8.1
Liver	0.25±0.04	32.0±0.36	0.12±0.2	0.05±0.01	0.82±0.07	0.06±0.02	0.73	120	0.09	0.08	0.13	0.07
Spleen	0.69±0.18	32.0±1.0	0.80±0.15	0.06±0.02	1.5±0.16	0.12±0.04	1.81	1.81	0.38	0.06	0.13	0.09
Bone	0.24±0.3	132.0±1.1	0.42±0.06	0.54±0.13	10.0±0.40	0.32±0.07	1.47	86.9	0.31	0.54	0.89	0.20
Kidney	0.11±0.05	10.0±0.40	0.09±0.04	0.09±0.02	1.4±0.15	0.11±0.04	0.82	2.80	0.18	0.09	0.23	0.07

<sup>a</sup>Wrenn et al. 1981.

<sup>b</sup>Singh et al. 1987; the averages of two samples are given.

NA = not analyzed; Th = thorium.

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considerably smaller than the daily dietary, water, and inhalation intakes of 2.24, 0.02, and 0.02  $\mu\text{g}$ , respectively, as estimated for residents of Bombay, India (Dang et al. 1986). It can be concluded from the above discussion that the total intake of thorium by the United States population may vary depending on the thorium content in the consumed food and that no firm United States average thorium intake value is yet available. The importance of the intake of thorium from foods is overshadowed by the relative absorption of thorium by lung compared with its uptake by gut (see Chapter 2).

Occupational exposures to higher levels of thorium isotopes occur primarily to workers in uranium, thorium, tin, and phosphate mining, milling, and processing industries, radium dial workers, and gas lantern mantle workers. From the measurement of airborne thorium concentrations in workplaces of the uranium and thorium industry, it was concluded that radioactive dust, particularly from crushing areas, represents an important route of exposure (Hannibal 1982; Kotrappa et al. 1976). It has also been reported that exposure of workers in the fertilizer industry to natural radioactivity may increase by 100% over normal background (Metzger et al. 1980). Measuring external gamma radiation dosages to a person working 8 hours/day has shown that monazite and xenotime storage rooms of Amang upgrading plants (tin processing) on the west coast of Malaysia exhibited exposure rates exceeding the ICRP recommended maximum value of 5 rem/year (Hu et al. 1984). From the radioactivity released by a burning gas mantle (contains thorium), it was concluded that the user would be at minimal risk unless the person was in a small unventilated room (Leutzelschwab and Googins 1984). However, workers in the gas mantle manufacturing industry are expected to be exposed to higher concentrations of radioactivity than the normal population.

Workers are exposed to higher levels of thorium and other radionuclides in certain thorium industries, as indicated by the measured exhaled breath and tissue levels of these chemicals. The significantly higher level of radon-220 (a decay product of thorium-232) in the exhaled breath of some thorium plant workers (Mayya et al. 1986) is indirect evidence of higher thorium intakes. Similarly, other authors have found higher tissue and body fluid levels (compared to background) of thorium in workers in the thorium processing industry (Clifton et al. 1971; Mausner 1982; Twitty and Boback 1970), workers in the radium dial industry (Keane et al. 1986), in uranium mill crushermen (Fisher et al. 1983), and in uranium and hard rock miners and uranium millers (Singh et al. 1987; Wrenn et al. 1981).

Thorium-doped glass is also used in the production of some camera lenses (Waligorski et al. 1985). A relatively recent measurement has shown that the external dose rate from exposure to a camera lens can be 10 times higher (as high as 9.25 mrem/hour at the front glass surface of the lens) than previously reported (Waligorski et al. 1985). Therefore, professional photographers and workers in the thorium-doped photographic lens



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manufacturing industry may be at slightly higher risk of exposure to thorium and its daughter products from inhalation and/or external radiation.

### 5.6 POPULATIONS WITH POTENTIALLY HIGH EXPOSURE

The three groups of the general population that have the potential of exposure to thorium and its decay products at levels higher than background are people who consume large amounts of foods grown in high background areas, people who reside in homes built with high thoron (radon-220)-emitting building materials and constructed on soil with high background levels of thorium, and people who live near radioactive waste disposal sites. Linsalata et al. (1987) analyzed vegetables grown in two areas near Sao Paulo, Brazil, that contained high natural radioactivity, and found the thorium is not bioaccumulated in the vegetables but maintained a mean concentration ratio (concentration in dry vegetable/concentration in dry soil) of  $10^{-4}$ . Root vegetables (e.g., carrots and potatoes) showed lower concentration ratios than zucchini and beans. Therefore, it can be concluded that vegetables grown in these soils would contain more thorium than vegetables grown in soil with normal background levels.

Linsalata et al. (1985) also estimated that the intake of thorium by populations residing in these parts of Brazil was 6-10 times higher than the population in New York City, as indicated by the analysis of human bones from the two areas. The concentration of thorium in human bones was found to be 100 times higher in high background monazite areas in India than in areas with normal thorium concentration in soils (Pillai and Matkar 1987).

The building construction materials that contain higher levels of thorium-232 are granite, clay bricks and certain kinds of concrete blocks and gypsum, particularly the materials in which waste products from uranium mining and milling industry are used (Beretka and Mathew 1985; Ettenhuber and Lehmann 1986; Hamilton 1971). Ettenhuber and Lehmann (1986) reported that the indoor gamma radiation dose equivalent in buildings made from bricks and concrete is mainly due to radon-222 (originating from uranium) and radon-220 (originating from thorium-232), and can be over 7 times higher than outdoors.

The effect of soil on the level of thorium and its decay products in indoor air has been discussed by Gunning and Scott (1982). Homes near the Elliot Lake (Canada) uranium mines were suspected to contain higher than normal levels of thoron (radon-220) and its daughters, because of higher levels of thorium in the surface soil and building materials used in the town. The ratio of the concentration of decay products of thoron (radon-220) to radon-222 found in these homes was 0.3. Therefore, the concentrations of thoron in decay products originating from thorium-232 inside the homes were lower than radon-222 decay products originating from uranium-238, and the levels were insignificant compared with the remedial action limit of 20 mWL (1 WL is the concentration of short-lived radon decay

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products that will result in  $1.3 \times 10^5$  MeV of potential alpha energy per liter of air) (Gunning and Scott 1982).

The concentrations of thorium-232 in soil from several residential lots near the Kerr-McGee ore processing facilities in W. Chicago, IL, have been determined to be up to 16,000 pCi/g (EPA 1988a). Therefore, homes built on such lots or homes that are close to other radioactive disposal sites may be sources of higher thorium exposure.

Both cigarette tobacco and its smoke contain thorium (Munita and Mazzilli 1986; Neton and Ibrahim 1978) (see Section 5.2.1). However, the effect of cigarette smoking on potential thorium exposure remains unclear. Joyet (1971) analyzed the lungs of 10 autopsied smokers and two nonsmokers. In 5 of 10 smokers, the lungs contained significantly higher levels of thorium than the nonsmokers, and the thorium levels in the residual five were not significantly different from the nonsmokers. Limited data suggest that cigarette smoking has no effect on the concentration of thorium isotopes in the lungs (Wrenn et al. 1981).

### 5.7 ADEQUACY OF THE DATABASE

Section 104(i)(5) of CERCLA, 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 thorium 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 thorium.

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 Identification of Data Needs

Physical and Chemical Properties. Some of the physical and chemical properties (i.e.,  $K_{ow}$ ,  $K_{oc}$  and Henry's law constant) that are often used in the estimation of environmental fate of organic compounds are not useful or relevant for most inorganic compounds including thorium and its compounds. Relevant data concerning the physical and chemical properties, such as solubility, stability, and oxidation-reduction potential of thorium salts and complexes have been located in the existing literature. Production, Use, Release, and Disposal. In the absence of experimental or estimated population exposure data, information concerning

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production volume, uses, release, and disposal are sometimes useful indicators of potential population exposure. For example, if the production volume of a chemical is high, it is likely that the release of the chemical in the workplace and in the environment will be high. The exposure of population groups to a certain substance is dependent on its use pattern. The frequency of general population exposure will be high for substances that have widespread uses in homes. The production volumes and their past and future trends of the commercially important thorium compounds are known. The use pattern of thorium and compounds is well described in the literature. It is also known that occupational groups are most susceptible to thorium exposure. Data regarding the amounts of thorium disposed in the past, the present rates of disposal, and future disposal trends in the United States were not located. These data would be helpful in determining the potential for and extent of general population exposure to thorium. The current disposal and storage methods for thorium or its byproducts must be efficient in order to meet the NRC and EPA guidelines and regulations regarding their release into the accessible environment and exposure of the general population.

According to the Emergency Planning and Community Right-to-Know Act of 1986 (EPCRTKA), (§313), (Pub. L. 99-499, Title III, §313), industries required to submit release information to the EPA. The Toxics Release Inventory (TRI), which contains release information for 1987, became available in May of 1989. This database will be updated yearly and should provide a more reliable estimate of industrial production and emission.

Id

**Environmental Fate.** It can be concluded from the transport characteristics that surface water sediment will be the repository for atmospheric and aquatic thorium. Normally, thorium compounds will not transport long distances in soil. They will persist in sediment and soil. There is a lack of data on the fate and transport of thorium and its compounds in air. Data regarding measured particulate size and deposition velocity (that determines gravitational settling rates), and knowledge of the chemical forms and the lifetime of the particles in air would be useful.

**Bioavailability from Environmental Media.** The absorption and distribution of thorium as a result of inhalation and ingestion exposures have been discussed in Sections 2.3.1 and 2.3.2. However, quantitative data relating physical/chemical properties, such as particle size, chemical form of thorium, and degree of adsorption with the bioavailability of thorium in inhaled air particles and inhaled and/or ingested soil particles are lacking. Such studies would be useful in assessing potential thorium toxicity to people living near a hazardous waste site.

**Food Chain Bioaccumulation.** Information about bioaccumulation in fish and food exists, as does information on the levels of thorium in various foods. Existing data in the literature indicate that thorium does not biomagnify in predators due to consumption of contaminated prey organisms.

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**Exposure Levels in Environmental Media.** Because of the paucity of data on the levels of thorium in air, water, and food, there are conflicting reports on the importance of each medium to the total human dietary intake of this substance. Data on the levels of thorium in foods grown in contaminated areas, particularly in the vicinity of hazardous waste sites, are limited, and further development of these data will be useful. There is also a lack of air monitoring data around hazardous waste sites.

**Exposure Levels in Humans.** Although some data on the levels of thorium in human tissues exists, neither consensus values of the background levels for thorium in human tissues nor its levels in tissues of populations residing in the vicinity of hazardous waste sites were located. Conflicting data also exist regarding the level of thorium in the lungs of smokers and nonsmokers. Further research would be useful to provide conclusive evidence regarding the effect of cigarette smoking on thorium content in the lung. In addition, there are no reliable data on urinary and fecal excretion of thorium in general populations in the United States. The skeleton is the main organ for the accumulation of thorium, yet there are also no reliable data on macro and micro distribution of thorium in human bone necessary to quantify its body burden.

**Exposure Registries.** No exposure registries for thorium 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 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 exposure to this compound.

### 5.7.2 On-going Studies

According to the Federal Research in Progress Database, Perry and Tsao at the Lawrence Berkeley Laboratory are studying the chemical species and transport of thorium in soil. In other on-going projects, Krey et al. at Environmental Measurements Laboratory in New York are studying the daily intake of thorium, and McInroy et al. at Los Alamos National Laboratory are studying the tissue levels of thorium in the general population and occupationally exposed individuals.