5. POTENTIAL FOR HUMAN EXPOSURE

5.1 OVERVIEW

Radium is a naturally-occurring metal that is almost ubiquitous in soils, water, geologic materials, plants, and foods at low concentrations. The utilization of radium, uranium, and fossil fuels has resulted in the redistribution of radium in the environment by way of air, water, and land releases. The concentration of radium in natural water is usually controlled by adsorption-desorption reactions with minerals and rocks and by the solubility of radium-containing minerals. In addition, radium is constantly being produced by the radioactive decay of its precursors, uranium, and thorium. Radium does not degrade other than by radioactive decay at rates which are specific to each of four naturally-occurring isotopes. The concentrations of radium-226 and radium-228 in drinking water are generally low, but there are specific geographic regions where high concentrations of radium occur due to geologic sources. Radium may be bioconcentrated and bioaccumulated by plants and animals, and it is transferred through food chains from lower trophic levels to humans.

The frequency of NPL hazardous waste sites in the United States at which radium has been found at higher than background levels can be seen in Figure 5-l.

5.2 RELEASES TO THE ENVIRONMENT

5.2.1 Air

The combustion of coal may be the most important mechanism for releasing radium into the atmosphere. The mean concentration of radium-226 in coal is on the order of 1 pCi/g (0.04 Bq/g). When combusted, radium may volatilize, then condense onto coal fly ash particles, which in turn may be released from power plants as fugitive emissions. The concentrations of radium-226 in fly ash have ranged from 1 to 10 pCi/g (0.04 to 0.4 Bq/g) (Coles et al. 1978; Eisenbud and Petrow 1964; Morris and Bobrowski 1979).

The radium-228 content of fly ash has varied from 1.8 to 3.1 pCi/g (0.07 to 0.12 Bq/g) (Eisenbud and Petrow 1964). If it is assumed that the total radium content of fly ash is 5 pCi/g (0.19 Bq/g), and that 1% of the ash generated at all coal-fired power plants in the United States escapes into the atmosphere, then an order-of-magnitude estimate of the amount of radium released each year would be 2.2 Ci (81,000,OOO kBq) (Roy et al. 1981). Eisenbud and Petrow (1964) estimated that a single lOOO-megawatt coal-fired power plant will discharge about 28 mCi (1,037,OOO kBq) of total radium per year. Radium-226 has been detected in soils in industrial regions at levels up to 8.1 pCi/g (0.30 Bq/g) (Jaworowski and Gryzbowska 1977).

FIGURE 5-1. Frequency of Sites with Radium Contamination

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Global releases of radium-226 by the combustion of coal have been estimated as 150 Ci (5,550,000,000 kBq) per year (Jaworowski et al. 1971). It has also been observed that radium-226 concentrations in glacial ice samples collected in Europe have increased by a factor of 100 during the last 80 years. The source of these elevated levels of radium may have been emissions from fossil fuels (Jaworowski et al. 1971).

Another potential source of atmospheric radium is particulate matter created by uranium mining and milling operations. However, no information was located on estimated releases or atmospheric concentrations.

5.2.2 Water

The most significant water-related releases of radium may be from the leaching of uranium mine tailings and from the release of ore-processing effluents generated by leaching, decantation, and filtration processes. Approximately 97 million tons of mine tailings that contain an estimated 60,000 Ci (2.2×10^9 kBq) of radium-226 have been stockpiled at the surface in the western United States (Kaufmann et al. 1976). It has been estimated that 10 million tons of uranium mine tailings are generated each year in Canada (Kalin 1988). Laboratory extraction studies (Havlik et al. 1968a, 1968b) have demonstrated that radium-226 may leach from solid wastes, particularly by acidic wastewaters. Surface runoff and leachate from uranium mine tailings have contained radium-226 ranging from 38 to 116 pCi/L (1.4 to 4.3 Bq/L) (Kalin 1988; Swanson 1985). Untreated uranium milling effluent has contained radium-226 at up to 2.2 μCi/L (81 kBq/L) (Sebesta et al. 1981). In the past, leachate from mine tailings containing radium-226 concentrations of 53 to 292 pCi/L (2 to 11 Bq/L) has been deep-well injected (Kaufmann *et* al. 1976). Approximately 2,000 to 3,000 Ci (74,000,000,000 to 111,000,000,000 kBq) of total radioactivity were released to the subsurface by two uranium mills in New Mexico. No information was located on the total amount of radium released to the environment by water-related discharges. As discussed in Section 5.4.2, however, concentrations of radium-226 and radium-228 found in surface and ground water sources have generally been low.

5.2.3 Soils

Land releases of radium are related to atmospheric fallout of coal fly ash (see Section 5.2.1). For example, elevated radium-226 concentrations in snow have been detected near a coal-fired power plant in Poland (Jaworowski et al. 1971). Other land releases may include the disposal of coal fly ash, lime slurry derived from water softening processes, and uranium mine tailings and associated wind-blown dusts.

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However, no information was located on the total amount of land-released radium.

5.3 ENVIRONMENTAL FATE

Radium may be transported in the atmosphere in association with particulate matter. It exists primarily as a divalent ion in water, and its concentration is usually controlled by adsorption-desorption mechanisms at solid-liquid interfaces and by the solubility of radiumcontaining minerals. Radium does not degrade in water other than by radioactive decay at rates that are specific to each isotope. Radium may be readily adsorbed by earth materials; consequently, it is usually not a mobile constituent in the environment. It may be bioconcentrated and bioaccumulated by plants and animals, and it is transferred in food chains from lower trophic levels to humans.

5.3.1 Transport and Partitioning

5.3.1.1 Air

Radium may be transported in the atmosphere by the movement of particulate matter derived from uranium and coal utilization (see Section 5.2.1). These fugitive emissions would be subject to atmospheric dispersion, gravitational settling and wash-out by rain.

No data were located on the residence time of radium in the atmosphere or its deposition rate. However, data for other elements adsorbed to particulate matter indicate that the residence time for fine particles is about 1 to 10 days (EPA 1982b; Keitz 1980). Radium may, therefore, be subject to long-range transport in the atmosphere.

5.3.1.2 Water

Radium in water exists primarily as a divalent ion (Ra^{2+}) and has chemical properties that are similar to barium, calcium, and strontium. The solubility of radium salts in water generally increases with increased pH levels. The solubilities of radium sulfate and carbonate are low; the solubility constants for crystalline RaSO, and RaCO, have been estimated as 5.495×10^{-11} mole/L and 5.01×10^{-9} mole/L, respectively (Langmuir and Riese 1985). Radium nitrate, chloride, and iodate are very soluble in water (Ames and Rai 1978). However, the concentration of radium in water is usually controlled by adsorptiondesorption reactions at solid-liquid interfaces which are in turn influenced by pH (see Section 5.3.1.3) or by the dissolution and coprecipitation of minerals that contain radium (EPA 1985a; Langmuir and Riese 1985). The tendency for radium to coprecipitate with barite, and sparingly soluble barium sulfate, as $(BaRa)SO_4$ is well known. Moreover, water treatment by adsorption and water-softening techniques are thought

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to be effective in reducing radium in untreated drinking water (Watson et al. 1984). Therefore, it is likely that radium in water does not migrate significantly from the area where it is released or generated (EPA 1985a). Limited field data also support the generalization that radium is not mobile in groundwater (Kaufmann et al. 1976; Swanson 1985).

5.3.1.3 Aquifers, Sediments, and Soils

Radium in water may be readily adsorbed by sediments, soils, and aquifer components. It has been experimentally demonstrated that radium can be adsorbed by soils and sediments (Benes and Strejc 1986; Landa and Reid 1982), ferric hydroxide and quartz (Benes et al. 1984; Valentine et al. 1987), kaolinite and montmorillonite (Benes et al. 1985), and muscovite and albite (Benes et al. 1986).

Partition coefficients such as adsorption constants (K_d) describe the tendency of chemicals to partition to solid phases from water. Adsorption constants for inorganic ions such as Ra^{2+} cannot be predicted a priori because they depend on the type of adsorbent, the pH of the water, and the presence of other ions in solution. K_d values for sand have varied from 18 to 1,742 mL/g in the pH range of 7.4 to 8.3 (Benes et al. 1984; Valentine et al. 1987). K_d values for clay minerals and other common rock-forming minerals have ranged from 2,937 to 90,378 mL/g in alkaline solutions (Benes et al. 1985, 1986). Similarly, K_ds for soils in alkaline solutions have ranged from 214 to 467 mL/g (Ames and Rai 1978). Adsorption constants based on field studies with lake sediments have varied from 205 to 15,833 mL/g (Swanson 1985). The magnitude of these adsorption constants indicate that partitioning to solid surfaces is a major removal mechanism of radium from water. Swanson (1985) concluded that about 90% of the radium-226 released by uranium-mine effluent to two small lakes was adsorbed by the lake sediments and algae-detrital material.

The removal of Ra^{2+} by adsorption has been attributed to ion exchange reactions, electrostatic interactions with potential determining ions at mineral surfaces, and surface-precipitation with $BaSO_4$. The adsorptive behavior of Ra^{2+} is similar to that of other divalent cationic metals in that it decreases with an increase in pH and is subject to competitive interactions with other ions in solution for adsorption sites. In the latter case, Ra^{2+} is more mobile in groundwater that has a high total dissolved solids (TDS) content. It also appears that the adsorption of Ra^{2+} by soils and rocks may not be a completely reversible reaction (Benes et al. 1984, 1985; Landa and Reid 1982). Hence, once adsorbed, radium may be partially resistant to removal, which would further reduce the potential for environmental release and human exposure.

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5.3.1.4 Plants and Animals

Transfer from soil to plants. Radium in the soil may be readily absorbed by plants, depending on the specific plant type and soil (Rayno 1983). Elevated concentrations of radium-226 above background levels have been detected in areas where radium and/or uranium was mined or processed (Kalin 1988; Rayno 1983; Tracy et al. 1983; Watson et al. 1984). The partitioning of radium-226 to plants from soils has been estimated by measuring the ratio of radium activity (or concentration) in the plant mass to that in the host soil. Soil-plant transfer coefficients or concentration factors have ranged from 1.1×10^{-3} to 6.5 (Rayno 1983; Tracy et al. 1983). Watson et al. (1984) concluded that a reasonable radium-226-concentration factor for fruits is 3×10^{-3} and that 0.1 describes the partitioning of radium-226 to forage and hay. An unweighted mean concentration factor for grain was 0.63. No information was located on soil-to-plant transfers for radium-228; however, its properties in this regard may be similar to those of radium-226.

Transfer from plants to cattle. There is a potential for human exposure to radium by the consumption of beef and milk derived from cattle who graze on forage grown in soils containing radium. The mean ratio of radium-226 in milk to that in the animal's diet has been estimated to be 3.8×10^{-3} (Watson et al. 1984). A similar ratio or transfer coefficient for flesh was 6.8×10^{-3}.

Transfer from water to aquatic organisms. Aquatic organisms such as fish, snails, clams, and algae can bioaccumulate radium from water. Bioconcentration factors (BCFs) for fish living in streams or lakes receiving uranium-processing waste effluent have ranged from 1 to 60 for flesh portions, and from 40 to 1,800 in bone samples (Markose et al. 1982; Swanson 1985). It has been proposed that bottom-feeding organisms ingest suspended solids containing adsorbed radium, then are in turn consumed by larger predatory fish.

5.3.2 Transformation and Degradation

5.3.2.1 Air

Pure metallic radium oxidizes when exposed to air, but radium compounds suspended in air are not subject to transformation or degradation mechanisms.

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5.3.2.2 Water

Radium in water exists as a stable divalent ion; it probably does not hydrolyze nor is it significantly influenced by oxidation-reduction reactions (Ames and Rai 1978). The solubility of radium salts is increased with increasing pH levels.

5.3.2.3 Soil

Radium in soils and sediment does not biodegrade nor participate in any chemical reactions that transform it into other forms. The only degradation mechanism operative in air, water, and soil is radioactive decay. Radium has 16 known isotopes (see Chapter 3), but only 4 occur naturally (Radium-223, -224, -226, and -228). The half-life of radium-226 is 1,620 years. The half-lives of radium-228, radium-223, and radium-224 are 5.77 years, 11.4 days, and 3.64 days, respectively.

5.4 LEVELS MONITORED OR ESTIMATED IN THE ENVIRONMENT

Radium is a naturally-occurring metal and is almost ubiquitous at low concentrations in air, water, soil, rocks, and food. The median concentrations of radium-226 and radium-228 in drinking water are generally low, but there are geographic areas where higher concentrations of radium are known to occur. The utilization of coal and uranium has resulted in re-distributing radium in the environment, but the overall effects appear to be small. Estimated levels of average human exposure to radium of non-occupational populations are presented in Table 5-l.

5.4.1 Air

Dust samples collected from the atmosphere of New York City were found to contain radium-226 at 8×10^{-5} pCi/m^3 (3.0×10^{-6} Bq/m^3) and radium-228 at 1.5×10^{-4} pCi/m^3 (5.6×10^{-6} Bq/m^3) (Eisenbud and Petrow 1964). No other published data on ambient concentrations of radium in the atmosphere were located.

5.4.2 Water

Radium is a naturally-occurring and fairly ubiquitous metal at low concentrations in water and rock-forming minerals. It has been estimated that the total mass of radium-226 in the earth's oceans is about 150 tons (Fremlin and Abu Jarad 1980). The occurrence of radium in ground, surface, and finished (treated) drinking water has been assessed (Aieta et al. 1987; Cech et al. 1988; EPA 1985a; Hess et al. 1985; Longtin 1988; Lucas 1985; Michel and Cothern 1986; Watson et al. 1984). In general, shallow wells tend to have lower radium-226 concentrations than deeper wells, and the total content in municipal

Isotope	Medium	Typical Concentration In Medium	Assumed Rate of Intake of Medium	Assumed Fraction Absorbed	Estimated Intake[a] (pCi/kg/day)	Estimated Intake[a] (mBq/kg/day)
Radium-226	Air	8×10^{-5} pCi/m^{3b}	20 m^3/day	0.2	5×10^{-6}	1.9×10^{-4}
Radium-228	Air	1.5×10^{-4} pCi/m^{3b}	20 m^3/day	0.2	9×10^{-6}	3.3×10^{-4}
Radium-226	Water	0.9 pCi/L^c	2 L/day	0.2^d	0.005	0.19
	Water	10 pCi/L^e	2 L/day	0.2	0.057	2.1
Radium-228	Water	1.4 pCi/L^c	2 L/day	0.2	0.008	0.30
	Water	6.4 pCi/L^f	2 L/day	0.2	0.037	1.4
Radium-226	Food	0.6 pCi/kg^g	2 kg/day	0.2	0.003	0.11

[a]Assuming a 70-kg adult.
[b]Eisenbud and Petrow (1964). Air samples collected in New York City.
[c]Mean concentration from Longtin (1988).
[d]See Section 2.3.1.2
[e]Mean concentration of noncompliance water (Hess et al. 1985).
[f]Estimated mean of noncompliance water assuming that the ratio $^{228}Ra/^{226}Ra$ is 0.64 (Lucas 1985).
[g]Estimated from Eisenbud (1973) and Bortoli and Gaglione (1972).

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(treated) water supplies is lower than that in raw well water (Watson et al. 1984). The radium content of surface water is usually very low. Radium-226 generally ranges from 0.1 to 0.5 pCi/L (0.004 to 0.019 Bq/L) (Hess et al. 1985). Based on 990 random samples of drinking water from ground water sources, the average population-weighted concentrations of radium-226 and radium-228 in the United States (excluding Hawaii) were about 0.91 pCi/L (0.034 Bq/L) and 1.41 pCi/L (0.052 Bq/L), respectively (Longtin 1988). Approximately 90% of these samples contained radium-226 at less than 1 pCi/L (0.04 Bq/L); similarly, about 90% contained radium-228 at less than 1 pCi/L (0.04 Bq/L). (These were not necessarily the same water sources.) However, there were approximately 200 public water supplies with radium-226 activities after treatment that were in excess of the regulatory maximum contaminant level (MCL) of 5 pCi (0.19 Bq) total radium/L (Hess et al. 1985). The mean radium-226 activity of the supplies in excess of the MCL was about 10 pCi/L (0.37 Bq/L).

A survey on the occurrence of radium-228 in municipal water supplies in Illinois, Iowa, Missouri, and Wisconsin indicated that the activity of this isotope may range from 0.3 to 32.0 pCi/L (11.1 to 1,180 mBq/L) (Lucas 2985), while Michel and Cothern (1986) reported *that* typical concentrations are less than 1 pCi/L (37 mBq/L).

There are few data on the occurrence of radium-224 in water. It has been speculated that the activity of this isotope could approach 30 to 40 pCi/L (1,110 to 1,480 mBq/L) (EPA 1985a).

Data on the presence of radon in groundwater can be used as a guide to the presumably corresponding presence of radium in the same source. Based on descriptions of aquifer composition or lithology and data from state water-resource agencies, counties with potentially high levels of radon in groundwater have been identified by Michel (1987). These estimates indicate that the U.S. counties with the highest levels of radium would be found in many areas of the Western third of the country, including large areas of California, Nevada, Idaho, and Montana. Wisconsin and Minnesota would also have high levels. In the East, the Appalachian Mountain region including almost all of Maine and New Hampshire would have high levels, as well as a large section of central Florida. It is important to note that quantitative estimates are not available, and the potentially "high" values for radon and radium imply only a comparison to other areas, not necessarily a risk to human health or the environment.

5.4.3 Soil

The mean concentration of radium-226 in 356 surface soil samples collected from 0 to 6 cm in 33 states was 1.1 pCi/g (0.041 Bq/g) (Myrick et al. 1981). This mean concentration is very similar to those reported

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for typical igneous rocks (1.3 pCi/g or 0.048 Bq/g), sandstone (0.71 pCi/g or 0.026 Bq/g), shale (1.1 pCi/g or 0.041 Bq/g), and limestone (0.42 pCi/g or 0.016 Bq/g) (Eisenbud 1973). The concentration of radium-226 in soils in Northern Italy was reported to average 0.72 pCi/g [range: 0.08 to 3.8 pCi/g (0.003 to 0.14 Bq/g)] (DeBortoli and Gaglione 1972), excluding regions with extremely high levels of natural radioactivity (no data presented).

The concentrations of radium-226 in soils that were contaminated by mining or milling activities have ranged from less than 1 to 3,700 pCi/g (0.037 to 137 Bq/g) (Kalin 1988; Landa 1984; Tracy et al. 1983). No information was located on the occurrence of the other radium isotopes in soil or rocks.

The presence of uranium in soil can be used as an indication of occurrence of radium and radon in the same location. Based on geological reports and data synthesized from the National Uranium Resource Evaluation (NURE) program, areas with potentially high radon levels in soil gas have been identified by Michel (1987). These areas would have correspondingly high soil radium levels, although quantitative estimates are not available. These uranium "hot spots" occur with more frequency in the Western third of the United States, and include large areas of California and Idaho. High concentrations have been found in Wisconsin and Minnesota and a very dense area has been identified in western Missouri/eastern Kansas. In the East, high levels appear generally along the Appalachian mountains and near industrialized sites. High levels have also been found in the northern to central sections of Florida.

5.4.4 Other Media

Radium-226 may occur in many different foods, and reported activities have varied considerably. The mean radium-226 contents of diets in 11 cities in the United States were estimated to be 0.52 to 0.73 pCi/kg of food consumed (0.019 to 0.027 Bq/kg) (Eisenbud 1973). Estimates of the mean concentrations of radium-226 in milk and beef are 0.23 pCi/L (0.009 Bq/L) and 0.22 pCi/kg (0.008 Bq/kg) (fresh weight), respectively, in the United States (Watson et al. 1984). No information was located on the occurrence of radium-228 in food.

5.5 GENERAL POPULATION AND OCCUPATIONAL EXPOSURE

Major sources of exposure to radium by the general population are the consumption of drinking water and food (Table 5-l). Of the many radionuclides found in nature, radium is considered to be one of the most important because of its wide occurrence in groundwater, and because it, like calcium, is retained in bone tissues (Aieta et al. 1987). Bone cancer is the greatest health risk from exposure to radium.

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Based on assumptions about the concentration of radium in drinking water provided by utilities, the size of the population consuming this water, and the associated risk of cancer, Hess et al. (1985) estimated that the average concentration of radium in drinking water may cause cancer in 941 persons per year in the United States. The risk of exposure to radium in food is uncertain because of the variability in diets and in the radium-226 content of foods. It has been estimated that the yearly intake of radium-226 for food in New York City is on the order of 640 pCi (24 Bq) (Eisenbud 1973).

Levels of occupational exposure to radium are difficult to assess. Workers who are occupationally exposed to radium through the mining and processing of uranium are also probably exposed simultaneously to uranium itself, thorium, and radon by inhalation and probably dermal exposure. Nielson and Rogers (1981) suggested that inhalation exposures during uranium mining and milling operations involving crushing, grading, or blasting are the most significant routes of exposure. There is also some concern about ingesting dust at processing plants (Dixon 1985). It has also been suggested that inhalation of fugitive emissions from mine tailings could be locally significant (Ruttenber et al. 1984), but radium-specific data were not located.

5.6 POPULATIONS WITH POTENTIALLY HIGH EXPOSURES

The populations at greatest risk of exposure from the consumption of drinking water with a high radium content are located in the Piedmont and Coastal Plain province in New Jersey, North Carolina, South Carolina, and Georgia and parts of Minnesota, Iowa, Illinois, Missouri, and Wisconsin (Hess et al. 1985; Longtin 1988). It has been estimated that about 600,000 people consume water with radium-226 concentrations in excess of the MCL (5 pCi/L or 0.19 Bq/L) in Illinois, Iowa, Missouri, and Wisconsin. Isolated occurrences of high radium-226 have also been detected in Arizona, New Mexico, Texas, Mississippi, Florida, and Connecticut. There is also a high probability of exposure to high radium-228 concentrations in many of the states listed above in addition to parts of California, Colorado, Idaho, Montana, New Mexico, and Wyoming (Michel and Cothern 1986).

It has been suggested that uranium miners and millers who are in chronic contact with dust are at risk. However, such workers are simultaneously exposed to several radionuclides and no generalization specific to radium can be made.

5.7 ADEQUACY OF THE DATABASE

Section 104(i)(5) of CERCIA, 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

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health effects of radium 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 radium.

The following categories of 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 known, would reduce or eliminate the uncertainties of human health assessment. Each data need discussion highlights the availability, or absence, of the relevant exposure information. A statement that reflects the importance of identified data needs is also included. In the future, these 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. Although some of the physical and chemical properties of radium and radium compounds have not been determined, many of those that are needed to evaluate its behavior in the environment are known. The adsorption-desorption behavior of radium with geologic materials depends on the specific system under study and should be determined on a case-by-case basis. Also, thermodynamic and kinetic data for solid solution formation are scarce. Research in this area would facilitate modeling the fate of radium in water.

Production, Import, Use, and Disposal. Radium is apparently used only in small quantities (e.g., in laboratories) in the United States. The quantities discharged to the environment from this source are probably insignificant compared to naturally-occurring radium. However, data on actual amounts of radium currently in use and amounts disposed of as waste would be useful in estimating human exposure potential.

Environmental Fate. Studies of releases of radium that result from uranium mining and processing would be helpful to fully assess the total amount and environmental fate of radium released to the environment. Field data on the mobility of radium in groundwater would also be helpful in attempts to predict its potential for occurrence in sources of drinking water at remote sites.

Bioavailability from Environmental Media. Data on the absorption of radium from environmental media via inhalation, oral, and dermal exposure would be useful in determining potential risks for organisms (humans, animals and plants) that have been exposed to radium in air, soil, or natural waters.

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Food Chain Bioaccumulation. The existing information indicates that radium may be transferred through the food chain from lower trophic levels to humans. Additional monitoring studies in areas where radium occurs naturally at high concentrations in soil would be helpful to determine if this pathway is a significant route of exposure. The transfer of radium-228 from soils through the food chain has not been assessed.

Exposure Levels in Environmental Media. The concentration of radium-226 in drinking water has been the subject of numerous studies, and average values are reasonably well known. It appears that emphasis could be given to monitoring radium-226 concentrations in regions where high concentrations are expected to occur ("hot spots"), such as regions with high levels of natural radioactivity, in the vicinity of uranium mining and milling operations, and at NPL and other hazardous waste sites. Information on the occurrence of radium in the atmosphere would also be useful in helping to predict exposure via inhalation.

The occurrence of radium-228 has not been as well established, and additional data would be helpful, particularly in geologic regions where high concentrations are likely. There is virtually no information on the occurrence and levels of radium-223 and radium-224 in drinking water. The occurrence and levels of any of the isotopes of radium in food are highly variable, and additional data would facilitate exposure estimates.

Exposure Levels in Humans. There is no information available on the general background levels of radium in human tissue. Information on these levels, especially in the skeleton, would be especially useful as a means to monitor continuing exposure to radium.

Exposure Registries. A national exposure registry for persons exposed to radium was not located but would be useful in relating factors such as age, sex, season, geography, regulations, environment and other factors to measured exposure concentrations and health outcomes.

5.7.2 On-going Studies

The EPA is presently conducting a survey called the National Inorganics and Radionuclides Survey (NIRS). This study has been ongoing since 1981, and preliminary reports have been published. These data are still being analyzed for the establishment of revised interim drinking water regulations.