STRONTIUM

1. BACKGROUND

Strontium (atomic symbol Sr) is a silvery-white alkaline earth metal that exists in several stable (e.g., Sr-86 and Sr-88) and several radioactive (e.g., Sr-89 and Sr-90) isotopic states. Stable strontium and its salts have many industrial uses, such as providing the red color in pyrotechnic devices such as tracer bullets, distress signal rockets, flares, and fireworks. In medicine, strontium bromide has been used as a sedative, as an antiepileptic drug, and in the therapy for skin rashes.

Abundance. Stable strontium is the 15th most abundant element in nature and it is the most abundant trace element in seawater. Thus, it can become incorporated into all plants and animal tissues. The amount of strontium in natural fresh waters in the U.S. may vary from approximately 0.007 to 15 milligrams/liter (mg/L), averaging about 0.5 mg/L. The daily intake of strontium varies from about 1.8 to 2.0 mg/day. Of this a negligible quantity is supplied by air, approximately 60 to 90 percent by food, and the remaining 10 to 40 percent by water. Strontium is present naturally in many foods (e.g. spices, seafood, cereals, grains, and leafy vegetables).

Metabolism. There is some evidence that strontium is essential for growth of animals, especially for the calcification of bone and teeth. It would appear that the metabolism of strontium closely resembles that of calcium, especially with regard to bone. The gastrointestinal adsorption of strontium is described as poor, varying from approximately 5 to 25 percent of the ingested dose. The 70 kilogram standard man contains approximately 320 mg of strontium. The skeleton contains more than 99 percent of the strontium. The rest is distributed among soft tissues, the largest concentrations residing in the aorta, larynx, trachea, and lower gastrointestinal tract. When administered orally, it is excreted primarily in the feces. Strontium is also excreted in the sweat and in the milk of lactating females.

Health Aspects. The chemical toxicity of the stable isotopes of strontium is considered to be quite low. Strontium poisoning is rare and in most instances accidental. Current interest in the toxicity of strontium is related to the radioactive isotope, Sr-90, which is present in radioactive fallout as a fission product, remains available for an extended period because of its 28.1-year half-life, and has been implicated as a causative agent in bone cancer and leukemia.

2. Sr-90

Sr-90 is a radioactive isotope of strontium that is produced in nuclear fission with a relatively high yield of 3 to 4 percent [7000 gigabecquerels (GBq) (190 curies) of Sr-90 and 1.4×10^6 GBq (3.8×10^4 curies) of Sr-89 per kiloton]. Sr-90 is a beta emitter (546 KeV, no gammas) with a half-life of 28.1 years [specific activity 5217 becquerels/gram (Bq/g), or 141 curies (Ci)/g], Sr-89 is a beta emitter (1.463 MeV, gammas very rarely) with a half-life of 52 days (specific activity 28,200 Ci/g). Sr-89 is an important radiation hazard for a year or two after a nuclear weapon explosion.

The possible hazard of Sr-90[1], with its relatively long half-life and its chemical similarity to calcium, was recognized in the work with atomic energy carried out as part of the Manhattan District efforts. Initially, there was a concern about the Sr-90 in fallout from atmospheric tests of nuclear weapons. By the mid-1970's, there was a concern about potential nuclear facility accidents because of the Sr-90 inventory in power reactors, at fuel reprocessing plants and in high-level waste, as well as a continuing concern for the potential consequences of nuclear weapons use. Accidental or deliberate misuse of Sr-90 in research laboratories also can result in human exposure. The primary focus of concern was in the induction of bone cancer by the beta radiations. Wide-ranging investigations were initiated regarding the behavior of Sr-90 in the environment, especially in food and food chains, in aqueous media, and in a variety of organisms. This resulted in an enormous database on the radiobiology of strontium.

Releases of radioactive Sr-90 into the environment and exposures of human populations have occurred in several activities, practices, and events involving radiation sources. The main contribution to the collective doses to the world population in such cases has come from the testing of nuclear weapons in the atmosphere. This practice occurred from 1945 through 1980. Each nuclear test resulted in unrestrained release to the environment of substantial quantities of Sr-90. These were widely dispersed in the atmosphere and deposited everywhere on the earth’s surface. Approximately 622 petabecquerels (PBq) (16.8 million curies) of Sr-90 were produced and globally dispersed in atmospheric testing.

Numerous measurements of the global disposition of Sr-90 (and cesium-137) and the occurrence of these and other fallout radionuclides in diet and the human body were made at the time the testing was taking place. The worldwide average effective dose from ingesting Sr-90 (1945 to date) is 97 microsieverts (µSv) [9.7 millirem (mrem)]. The worldwide average effective dose from inhaling Sr-90 (1945 to 1985) is 9.2 µSv (0.92 mrem).

<u>Intake</u>. The deposition of Sr-90 on land and the transfer to humans by ingestion is the most significant pathway for human exposure (i.e., worldwide pathway contribution is 79 percent). Long-term variation in the Sr-90 intake will depend on the composition of the individual's diet. For example, the major contributors of Sr-90 in the former Soviet diet were cereals and whole grain (UNSCEAR 1977). Milk and milk-byproducts are the major contributors of Sr-90 in western countries. Other food products that may contain Sr-90 include fruits, vegetables (carrots, cabbage, potatoes), meat, eggs, spices, and seafood. During the late 1960s, fish consumption contributed about 3 percent to the body burden of Sr-90 among the Japanese.

The National Academy of Sciences, in 1973, stated, in "Radionuclides in Food," that "Although Dairy products represented 58 percent of the dietary calcium, they provide less radiostrontium/g calcium than did any of the other items. If an attempt is made to reduce radiostrontium intake by eliminating milk from the diet and increasing the vegetable portion to make up the deficit of calcium, the resulting intake of Sr-90 is greater than that from the diet containing the milk products."

<u>Embryo/Fetal Deposition</u>. The rapid growth of the fetal and neonatal skeleton with its high proliferation of bone cells and the development of the hematopoietic system, which start about the fifth month <u>in utero</u>, cause the skeleton to be more sensitive to radiation from Sr-90 than at

---

[1] Actually most of the radiation damage from Sr-90 is caused by its daughter isotope yttrium-90. Y-90 has a half-life of only 64.2 hours, so it decays as fast as it is formed, and emits 2.27 MeV beta particles.

any other stage of life. However, Sr-90 ingested by the mother before pregnancy is generally not available for transfer to a future fetus. The total amount of strontium in the developing skeleton increases about 20-fold in the course of pregnancy. During the last 4 weeks before birth, the fetal skeleton accumulates the same amount of strontium as during all the previous months of pregnancy. Although strontium follows the calcium pathways in the mother's body, the metabolic processes can discriminate against strontium in favor of calcium; however, the ability of placental membranes to discriminate against strontium decreases during pregnancy. By the end of the pregnancy, the ability to discriminate against strontium has almost disappeared and strontium is passed on to the fetus in the same concentration as that present in the maternal circulation. The estimated lifetime radiation dose to the infant skeleton from a single ingestion of $3.7x10^4$ Bq (1 µCi) Sr-90 at six months and nine months of gestation is 600 6 milligray (mGy) [600 millirad(mrad)] and 18 mGy (1,800 mrad), respectively (NCRP Report No. 128).

Deposition of Sr-90 into deciduous teeth does not cease at birth. The dentine of the deciduous tooth continues to take up calcium, phosphorus, and strontium through the life of the tooth, typically 7 to 12 years depending on the type of tooth. Sr-90 will be deposited uniformly throughout the tooth if a constant dietary source is provided. Conversely, Sr-90 will be deposited in bands, in the dentine beneath the tooth enamel, if dietary Sr-90 is ingested as single acute doses. Dental mapping of the tooth can indicate when and how much dietary Sr-90 was ingested. American Dental Association staff are mapping Sr-90 deposition in exfoliated teeth obtained from Russian adults exposed to Sr-90 during the cold war.

3. ENVIRONMENTAL MONITORING

The concentrations of the radionuclides released into the environment from a nuclear facility are generally too low to be measurable except close to the nuclear facility and then for a limited number of radionuclides.

The only chance of detecting reactor-generated Sr-90 is in the nuclear power plant effluents themselves. Any Sr-90 detected in environmental samples can most likely be attributed to fallout from nuclear weapons testing. To differentiate reactor-generated fission products from those of nuclear weapons fallout, counting of strontium-containing environmental samples is required several times over a period of a week followed by fitting the counted data to Sr-89, Sr-90, and the ingrowth of yttrium-90 (Y-90). However, this methodology only works if there is sufficient Sr-89 relative to Sr-90 in the sample.

U.S. Nuclear Regulatory Commission (NRC)-licensed nuclear power plant operators are required to monitor gaseous and liquid emissions. Regulatory Guide 1.21 recommends that "...a quarterly analysis for strontium-89 and strontium-90 should be made on a composite of all filters from each sampling location collected during the quarter." The sensitivity is such that the analysis for radioactive material in particulate form should be sufficient to permit measurement of a small fraction of the activity which would result in annual exposures of 0.15 mSv (15 mrem) to any organ of an individual in an unrestricted area.

Each nuclear power plant in the United States is required to file an effluents report annually. In this report, information about the types and quantities of radionuclides that are released to the environment, as well as the dose impact on the environment, is reported. The licensee maintains an environmental monitoring program that is reviewed regularly by NRC. To keep track of these releases, the plants take frequent radiological samples. For example, a total of

1261 analyses on 981 environmental samples was taken in 1997 at Salem/Hope Creek. No strontium-90 was found in any samples acquired in 1997.

4. HEALTH EFFECTS OF Sr-90

Animal experiments indicate that bone sarcoma and tumors of the soft tissue near the bone may be important endpoints in the human exposure to radiostrontium at high doses [thousands of rads (tens of grays) average skeletal dose]. However, these same experiments also suggest that lifespan, cancer incidence, and genetic effects are unlikely to be influenced at the low doses expected from normal environmental exposures.

Although very small increases in cancer incidence attributable to internal deposition of Sr-90 from world-wide fallout is theoretically possible, no statistically significant excess of biological effects from Sr-90 exposures has been demonstrated. Whatever excess of incidence that could be present is masked by the variation in incidence among the population groups studied, the differences in methods of recording of data, and the normal statistical fluctuations of the data for such groups.

Studies from the United Kingdom have reported increases in mortality from leukemia among young persons, especially under age 10, living near certain nuclear facilities (Sellafield). The reasons for this pattern are not clear, although there were no corresponding increases in total cancer.

Risk estimates in humans from exposure to Sr-90 are 1 bone sarcoma per 10^4 person Gy (with lower and higher limits of 0 and 6) and 3 leukemias per 10^4 person Gy (with lower and higher limits of 0 and 8) for populations exposed to radiostrontium at low doses and dose rates (NCRP Report No. 110).

Chernobyl. Apart from the substantial increase in thyroid cancer after childhood exposure, there is no evidence of a major public health impact related to the ionizing radiation 14 years after the reactor accident at Chernobyl. 8 PBq (216,000 curies) of Sr-90 were released from Chernobyl reactor unit 4 in April 1986. No increases in overall cancer incidence or mortality that could be associated with radiation exposure have been observed. The risk of leukemia, one of the most sensitive indicators of radiation exposure, has not been found to be elevated even in the accident recovery workers or in children (UNSCEAR 2000, Annex J).

5. CANCER MORTALITY NEAR NRC-LICENSED NUCLEAR POWER REACTORS

A survey of cancer rates was conducted by the National Institutes of Health (NIH)(1990 NIH Survey) in populations living near nuclear facilities in the United States. This study encompassed all 62 nuclear facilities that went into service before 1982. Relative risk of mortality was compiled for 16 classes of cancer and five age groups for each county in which a nuclear power reactor resides (study county). Data also were compiled for two adjacent counties for comparative purposes (control counties). There is no evidence to suggest that the occurrence of leukemia or any other form of cancer was generally higher in the study counties than in the control counties. For childhood leukemia, the relative risk, comparing the study counties with their control counties, before plant startup, was 1.08, whereas after startup, it was 1.03. For leukemia all ages, the relative risks were 1.02 before startup and 0.98 after startup.

The observed comparisons provided no evidence of any cause-effect relationship between particular facilities and cancer occurrence in nearby populations. However, if any excess cancer risk was present in counties with nuclear facilities, it was too small to be detected by the methods employed in the 1990 NIH survey.