

## 5. PRODUCTION, IMPORT/EXPORT, USE, AND DISPOSAL

### 5.1 PRODUCTION

Strontium is a naturally occurring element that makes up approximately 0.02–0.03% of the earth's crust. In nature, strontium is present in igneous rocks in amounts averaging 375 ppm. The principal strontium minerals of commercial interest are celestite ( $\text{SrSO}_4$ ) and strontianite ( $\text{SrCO}_3$ ). Strontium is also a minor component of other mineral deposits and may occur in or near sedimentary rocks associated with beds or lenses of gypsum, anhydrite, and rock salt; in veins associated with limestone and dolomite; or dispersed in shales, marls, and sandstones. In the United States, there are deposits of celestite in Texas, Washington, Arizona, Ohio, and California. The U.S. Geological Survey (USGS) estimated U.S. resources of celestite and strontianite at 2,500,000 tons, containing 1,130,000 tons of strontium (Adams 1975). However, domestic deposits of these minerals are not economically exploitable, and strontium has not been mined in the United States since 1959.

Celestite is converted to  $\text{SrCO}_3$ , the common commercial form of strontium. The black ash method (alternatively known as the calcining method) and the soda method (also known as direct conversion) are the two most common recovery techniques for strontium. The black ash method produces chemical grade strontium carbonates, which are 98% strontium carbonate and 2% byproducts and impurities. The soda ash method produces technical grade strontium carbonates, containing at least 97% strontium carbonate. The black ash method is the preferred means of strontium carbonate production because it yields a higher-grade product (USGS 1998).

During World War II, the U.S. government began stockpiling celestite for defense applications. In 1963, Congress determined that the stockpile was unnecessary, and by 1973, all of the stockpiled high-grade celestite was sold. The remaining low-grade celestite material, approximately 12,000 metric tons, has been listed by the Defense National Stockpile Center of the Defense Logistics Agency as valueless. In 1998, Congress authorized the remaining stockpile for disposal. The only U.S. strontium carbonate producer using celestite is the Chemical Products Corporation of Cartersville, Georgia. A number of U.S. companies manufacture strontium compounds from strontium carbonate. Mallinkrodt Inc. of St. Louis, Missouri, produces strontium chloride, and Rockwood Pigments Corporation of Beltsville, Maryland, produces strontium chromate. Production of other strontium compounds is on a limited scale (USGS 1998, 1999).

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Radioactive strontium, or  $^{89}\text{Sr}$  and  $^{90}\text{Sr}$ , does not occur in nature. It is the direct result of anthropogenic activity. As discussed in Chapter 4,  $^{89}\text{Sr}$  and  $^{90}\text{Sr}$  are produced by nuclear fission. Nearly all of the  $^{90}\text{Sr}$  generated in the United States is present in spent nuclear reactor fuel rods. These fuel rods are currently located at the commercial reactor facilities or at Department of Energy (DOE) facilities across the United States. After 1 year of decay of nuclear fuel rods,  $^{90}\text{Sr}$  represents 3.7% by mass of the total fission product inventory. A limited amount of  $^{89}\text{Sr}$  and  $^{90}\text{Sr}$  is produced for industrial, scientific, and medicinal applications through the process of fission product recovery. During the period of 1974–1984,  $^{90}\text{Sr}$  was recovered and converted into solid forms. Typically,  $^{90}\text{Sr}$  is combined with fluorine to produce strontium fluoride ( $^{90}\text{SrF}_2$ ) or with chlorine ( $\text{Cl}_2$ ) to produce strontium chloride ( $^{90}\text{SrCl}_2$ ). These solids were placed in double walled capsules to be used for commercial and medical applications.  $^{90}\text{Sr}$  is available from Pacific Northwest National Laboratory located at the DOE facility in Hanford, Washington. The Hanford inventory of  $^{90}\text{Sr}$  embodies one of the largest sources of this nuclide in the world (DOE 1996b, 1996c).

## 5.2 IMPORT/EXPORT

In 2001, 100% of celestite used in the United States was imported from Mexico. Of the 38,500 metric tons of strontium minerals and compounds imported in 2001, approximately 94% were imported from Mexico, 6% from Germany, and 2% from other countries. From the period of 1954–1974, demand for strontium imports (both mineral and compound) has steadily increased from approximately 3,200 to 16,000 metric tons. From 1994 to 2001, the importation of strontium minerals and compounds for consumption has remained relatively steady at approximately 31,000–38,500 metric tons. The apparent consumption of all strontium imports in the United States is 97%. The total export volume of strontium compounds during 1993–2001 was more than 20 times lower than the quantities of strontium minerals and compounds imported during the same period. Exports of strontium compounds has varied from 1,120 metric tons in 1994 to 1,040 metric tons in 2001 (USGS 1998, 1999, 2002).

## 5.3 USE

In 2001, more than 85% of all strontium consumed in the United States was used in the manufacture of ceramics and glass products, primarily in television faceplate glass and secondarily in ceramic ferrite magnets (strontium ferrite) and other ceramic and glass applications. All color televisions and other devices containing cathode-ray tubes (CRT) sold in the United States are required by law to contain

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strontium in the faceplate glass of the picture tube to block x-ray emissions. Major manufacturers of television picture tube glass incorporate about 8% by weight of strontium oxide (SrO) into the glass faceplate material. Strontium is added to the glass melt in the form of strontium carbonate. Upon heating and solidification, it is transformed to SrO. Other uses for strontium compounds include pyrotechnics (strontium nitrate), paint pigments (strontium chromate), fluorescent lights (strontium phosphate), getters in zinc production (strontium carbonate), alloy (strontium metal), and medicines (strontium chloride, strontium peroxide). Strontium metal has limited commercial use. One minor use of strontium is as an alloy material for the production of aluminum castings. Most commercial uses of strontium compounds and products use strontium carbonate as the feed material (Hibbins 1997; USGS 1999, 2002).

The radioactive isotope  $^{89}\text{Sr}$  (also known by the pharmaceutical brand name Metastron™) is used as a cancer therapeutic to alleviate bone pain.  $^{85}\text{Sr}$  has been used in medical applications, such as radiologic imaging of bones, in minor commercial applications, such in radioisotope thermoelectric generators (RTG), as a beta-particle standard source, and in instruments that measure thickness and density of materials (Murray 1994).  $^{90}\text{Sr}$  has been used in RTGs at remote locations (e.g., lighthouses) throughout the former Soviet Union (Alimov 2003). Many of these  $^{90}\text{Sr}$  RTGs in the former Soviet Union are completely unguarded against potential thieves or intruders, lacking such minimal security measures as fences or even signs warning of radioactive dangers. The biggest danger coming from these unprotected RTGs is their availability to terrorists who can use the radioactive materials (e.g.,  $^{90}\text{Sr}$ ) contained in them to make so-called “dirty bombs”, which are bombs that are triggered by standard explosives, but disperse radioactivity.

#### 5.4 DISPOSAL

Most nonradioactive strontium minerals, strontium compounds, and strontium-containing materials do not require special disposal and handling requirements. However, some chemical forms may be classified as hazardous materials if the compound is chemically reactive, flammable, or toxic. Care should be taken to read and understand all of the hazards, precautions, and safety procedures for each specific chemical form. In addition, all federal, state, and local laws and regulations should be investigated and subsequently followed with regard to disposal and handling of the specific chemical form of the strontium compound or material.

Radioactive strontium does require special disposal and handling requirements and is regulated by the Nuclear Regulatory Commission (USNRC). Radioactive waste-containing radioactive strontium can be

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grouped into three categories: low-level waste (LLW); high-level waste (HLW) and spent nuclear fuel; and mixed waste. As defined by the Nuclear Waste Policy Act, high-level radioactive waste is “the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentration.” However, most classifications of HLW also include spent nuclear fuel. Most HLW was generated from the production of plutonium. A small fraction is related to the recovery of enriched uranium from naval reactor fuel. This waste typically contains highly radioactive, short-lived high activity fission by-products as well as other long-lived isotopes, hazardous chemicals, and toxic heavy metals.  $^{90}\text{Sr}$  contamination is only a small fraction of the activity of HLW. Liquid HLW is typically stored in large underground tanks of either stainless steel or carbon steel, depending on whether they are acid or alkaline solutions. There are about 100 million gallons of high-level liquid waste stored in underground tanks in Washington, South Carolina, Idaho, and New York. These tanks contain a variety of radioactive liquids, solids, and sludges. Some of the liquid wastes have been solidified into glass, ceramic slag, salt cakes, and sludges (DOE 1996a; Murray 1994).

Spent nuclear fuels, such as fuel elements and irradiated targets used in nuclear reactors, are currently disposed of at the commercial nuclear power plants and DOE facilities where they were produced. Spent fuel is highly radioactive due to the large concentration of fission products and must be stored in special water-cooled pools that shield and cool the material. Most of the  $^{90}\text{Sr}$  remains trapped in the spent fuel rod matrix and is never released. Roughly all DOE spent fuel, about 3,000 metric tons, is stored at four sites: Hanford, Savannah River, Idaho National Engineering Laboratory, and West Valley, New York. Commercial reactors have generated more than 30,000 metric tons of spent fuel. The spent fuel from these facilities is stored at the more than 100 commercial nuclear reactor sites around the United States. The establishment of an HLW and spent fuel repository for both DOE and commercial waste is currently under evaluation at Yucca Flats, Nevada. It is not projected to be in operation until after the year 2010 (DOE 1996b; Eisenbud 1987; Murray 1994).

Mixed waste contains both radioactive and chemically hazardous materials such as toxic, corrosive, flammable, or explosive materials. The radioactive component may be either HLW or LLW. All liquid HLW is mixed waste, usually in the presence of organic solvents or heavy metals in addition to radioactive components. Disposal of mixed wastes is regulated by EPA under the Resource Conservation and Recovery Act (RCRA) and by the USNRC under the Atomic Energy Act. EPA and USNRC have developed special procedures on how to handle and dispose of this special category. DOE operates an incinerator in Oak Ridge, Tennessee that burns mixed hazardous radioactive wastes (DOE 1996a).

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Low-level waste is all radioactive waste that cannot be classified as HLW, spent fuel, or mixed waste. Low-level does not necessarily mean low radioactivity or low environmental hazards. However, the bulk of LLW has relatively little radioactivity and practically no transuranic elements. Thus, LLW usually does not require shielding from radioactivity or heat removal equipment. Most LLW is acceptable for near-surface land disposal. LLW types that may be contaminated with  $^{90}\text{Sr}$  include both wet and dry wastes. Examples of the physical form of LLW are spent ion exchange resins, filter sludges, filter cartridges, evaporator bottoms, compactable trash, non-compactable trash, irradiated components, ashes produced from the incineration of combustible material, contaminated detergents or solvents, organic liquids, and discarded contaminated equipment or tools. Of the LLW generated today, approximately 64% of the volume and 70% of the radioactivity are generated as a result of nuclear power plant activities or supporting fuel cycle operations. Other sources of LLW are industrial, academic, government, and medical. Radiostrontium contamination accounts for only a small fraction of the activity of LLW. LLW is typically packaged in drums or boxes and buried in shallow pits or trenches. Approximately 3 million cubic meters of LLW generated in the United States have been disposed of this way. LLW from DOE sources is currently disposed of at several DOE facilities across the United States. Only two sites accept non-DOE LLW, Barnwell, South Carolina and Richland, Washington. Over half of the LLW in the eastern United States is disposed of at the Barnwell site. As required by the Federal LLRW (Low Level Radioactive Waste) Policy Act in 1980 and in the 1985 amendments, states or interstate compacts are required to build facilities to contain LLW generated from sources within their boundaries. However, other than Barnwell, South Carolina and Richland, Washington sites, no other facility in the United States is currently accepting LLW from non-DOE sources. Currently, many generators store LLW on-site until additional facilities can be constructed in the future (DOE 1996a; Eisenbud 1987; Murray 1994).

