1. PUBLIC HEALTH STATEMENT

This public health statement tells you about strontium and the effects of exposure.

The Environmental Protection Agency (EPA) identifies the most serious hazardous waste sites in the nation. These sites make up the National Priorities List (NPL) and are the sites targeted for long-term federal cleanup activities. Strontium and strontium-90 have been found in at least 102 and 12 of the 1,636 current or former NPL sites, respectively. However, the total number of NPL sites evaluated for strontium and strontium-90 are not known. As more sites are evaluated, the sites at which strontium and strontium-90 are found may increase. This information is important because exposure to strontium and strontium-90 may harm you and because these sites may be sources of exposure.

When a substance is released from a large area, such as an industrial plant, or from a container, such as a drum or bottle, it enters the environment. This release does not always lead to exposure. You are exposed to a substance only when you come in contact with it. You may be exposed by breathing, eating, or drinking the substance, or by skin contact. External exposure to radiation may occur from natural or man-made sources. Naturally occurring sources of radiation are cosmic radiation from space or radioactive materials in soil or building materials. Man-made sources of radioactive materials are found in consumer products, industrial equipment, atom bomb fallout, and to a smaller extent from hospital waste and nuclear reactors.

If you are exposed to strontium, many factors determine whether you'll be harmed. These factors include the dose (how much), the duration (how long), and how you come in contact with it. You must also consider the other chemicals you're exposed to and your age, sex, diet, family traits, lifestyle, and state of health.

1.1 WHAT IS STRONTIUM?

Strontium is a natural and commonly occurring element. Strontium can exist in two oxidation states: 0 and +2. Under normal environmental conditions, only the +2 oxidation state is stable

enough to be important. Pure strontium is a hard, white-colored metal, but this form is not found in the environment. Rather, strontium is usually found in nature in the form of minerals. Strontium can form a variety of compounds. Strontium compounds do not have any particular smell. There are two types of strontium compounds, those that dissolve in water and those that do not. Natural strontium is not radioactive and exists in four stable types (or isotopes), each of which can be written as ^{84}Sr, ^{86}Sr, ^{87}Sr, and ^{88}Sr, and read as strontium eighty-four, strontium eighty-six, etc. All four isotopes behave the same chemically, so any combination of the four would have the same chemical effect on your body.

Rocks, soil, dust, coal, oil, surface and underground water, air, plants, and animals all contain varying amounts of strontium. Typical concentrations in most materials are a few parts per million (ppm). Strontium ore is found in nature as the minerals celestite ($SrSO_4$) and strontianite ($SrCO_3$). After the strontium is extracted from strontium ore, it is concentrated into strontium carbonate or other chemical forms by a series of chemical processes. Strontium compounds, such as strontium carbonate, are used in making ceramics and glass products, pyrotechnics, paint pigments, fluorescent lights, medicines, and other products. For more information, see Chapter 5.

Strontium can also exist as radioactive isotopes (see Chapter 4). ^{90}Sr, or strontium ninety, is the most hazardous of the radioactive isotopes of the chemical element strontium. ^{90}Sr is formed in nuclear reactors or during the explosion of nuclear weapons. Each radioactive element, including strontium, constantly gives off radiation, and this process changes it into an isotope of another element or a different isotope of the same element. This process is called radioactive decay. ^{90}Sr gives off beta particles (sometimes referred to as beta radiation) and turns into yttrium ninety (^{90}Y); ^{90}Y is also radioactive and gives off radiation to form zirconium ninety (^{90}Zr), which is a stable isotope. The radioactive half-life is the time that it takes for half of a radioactive strontium isotope to give off its radiation and change into a different element. ^{90}Sr has a half-life of 29 years.

^{90}Sr has limited use and is considered a waste product. The radioactive isotope ^{89}Sr is used as a cancer therapeutic to alleviate bone pain. ^{85}Sr has also been used in medical applications. For more information about the properties and use of radioactive strontium, see Chapters 4 and 5.

Quantities of radioactive strontium, as well as other radioactive elements, are measured in units of mass (grams) or radioactivity (curies or becquerels). Both the curie (Ci) and the becquerel (Bq) tell us how much a radioactive material decays every second. The becquerel is a new international unit known as the SI unit, and the curie is an older unit; both are used currently. A becquerel is the amount of radioactive material in which 1 atom transforms every second. One curie is the amount of radioactive material in which 37 billion atoms transform every second; this is approximately the radioactivity of 1 gram of radium. For more information on radiation, see Appendix D and the glossary, Chapter 10, at the end of this profile or the *ATSDR Toxicological Profile for Ionizing Radiation.*

1.2 WHAT HAPPENS TO STRONTIUM WHEN IT ENTERS THE ENVIRONMENT?

Stable and radioactive strontium compounds in the air are present as dust. Emissions from burning coal and oil increase stable strontium levels in air. The average amount of strontium that has been measured in air from different parts of the United States is 20 nanograms per cubic meter (a nanogram is a trillion times smaller than a gram). Most of the strontium in air is in the form of stable strontium. Very small dust particles of stable and radioactive strontium in the air fall out of the air onto surface water, plant surfaces, and soil either by themselves or when rain or snow falls. These particles of strontium eventually end up back in the soil or in the bottoms of lakes, rivers, and ponds, where they stay and mix with stable and radioactive strontium that is already there.

In water, most forms of stable and radioactive strontium are dissolved. Stable strontium that is dissolved in water comes from strontium in rocks and soil that water runs over and through. Only a very small part of the strontium found in water is from the settling of strontium dust out of the air. Some strontium is suspended in water. Typically, the amount of strontium that has been measured in drinking water in different parts of the United States by the EPA is less than

1 milligram for every liter of water (1 mg/L). ^{90}Sr in water comes primarily from the settling of ^{90}Sr dust out of the air. Some ^{90}Sr is suspended in water. In general, the amount of ^{90}Sr that has been measured in drinking water in different parts of the United States by EPA is less than one-tenth of a picocurie for every liter of water (0.1 pCi/L or 0.004 Bq/L).

Strontium is found naturally in soil in amounts that vary over a wide range, but the typical concentration is 0.2 milligrams per kilogram (kg) of soil (or 0.2 mg/kg). The disposal of coal ash, incinerator ash, and industrial wastes may increase the concentration of strontium in soil. Generally, the amount of ^{90}Sr in soil is very small and is only a fraction of the total concentration of strontium in soil. Higher concentrations of ^{90}Sr in soil may be found near hazardous waste sites, radioactive waste sites, and Department of Energy facilities located around the United States. A major portion of stable and radioactive strontium in soil dissolves in water, so it is likely to move deeper into the ground and enter groundwater. However, strontium compounds may stay in the soil for years without moving downward into groundwater. In the environment, chemical reactions can change the water-soluble stable and radioactive strontium compounds into insoluble forms. In some cases, water-insoluble strontium compounds can change to soluble forms. For more information about the transport properties of stable and radioactive strontium in the environment, see Chapter 6.

1.3 HOW MIGHT I BE EXPOSED TO STRONTIUM?

Strontium is found nearly everywhere in small amounts, and you can be exposed to low levels of strontium by breathing air, eating food, drinking water, or accidentally eating soil or dust that contains strontium. Food and drinking water are the largest sources of exposure to strontium. Because of the nature of strontium, some of it gets into fish, vegetables, and livestock. Grain, leafy vegetables, and dairy products contribute the greatest percentage of dietary strontium to humans. The concentration of strontium in leafy vegetables, such as cabbage, grown in the United States is less than 64 mg in a kg of the fresh vegetables (i.e., 64 ppm). For most people, the intake of strontium will be moderate. More information about strontium exposure can be found in Chapter 6.

^{90}Sr is found nearly everywhere in small amounts from past nuclear accidents and fallout from nuclear explosions. You can be exposed to low levels of ^{90}Sr by eating food, drinking water, or accidentally eating soil or dust that contains ^{90}Sr. Food and drinking water are the largest sources of exposure to ^{90}Sr. Because of the nature of ^{90}Sr, some of it gets into fish, vegetables, and livestock. Grain, leafy vegetables, and dairy products contribute the greatest percentage of dietary ^{90}Sr to humans. The concentration of ^{90}Sr in fresh vegetables grown in the United States is less than 9 pCi (or 0.3 Bq) in 1 kg of dried vegetables (in a hot oven). The intake of radioactive strontium for most people will be small. You can take in more ^{90}Sr if you eat food that was grown on a radioactive strontium-contaminated hazardous waste site. More information about radioactive strontium exposure can be found in Chapter 6.

1.4 HOW CAN STRONTIUM ENTER AND LEAVE MY BODY?

Both stable strontium and radioactive strontium enter and leave the body in the same way.

If a person breathes in vapors or dust containing a chemical form of strontium that is soluble in water, then the chemical will dissolve in the moist surface inside the lungs and strontium will enter the bloodstream relatively quickly. If the chemical form of strontium does not dissolve in water easily, then particles may remain in the lung for a time. When you eat food or drink water that contains strontium, only a small portion leaves the intestines and enters the bloodstream. Studies in animals suggest that infants may absorb more strontium from the intestines than adults. If a fluid mixture of a strontium salt is placed on the skin, the strontium will pass through the skin very slowly and then enter the bloodstream. If the skin has scratches or cuts, strontium will pass through the skin much more quickly.

Once strontium enters the bloodstream, it is distributed throughout the body, where it can enter and leave cells quite easily. In the body, strontium behaves very much like calcium. A large portion of the strontium will accumulate in bone. In adults, strontium mostly attaches to the surfaces of bones. In children, whose bones are still growing, strontium may be used by the body to create the hard bone mineral itself. As a result the strontium will be stored in the bone for a long time (years). Because of the way bone grows, strontium will be locally dissolved from

bone and recirculate through the bloodstream, where it may be reused by growing bone, or be eliminated. This process accounts for the slow removal of strontium from the body.

Strontium is eliminated from the body through urine, feces, and sweat. Elimination through urine may occur over long periods, when small amounts of strontium are released from bone and do not get recaptured by bone. When strontium is taken in by mouth, the portion that does not pass through the intestinal wall to enter the bloodstream is eliminated through feces during the first day or so after exposure.

See Chapter 3 for further information.

1.5 HOW CAN STRONTIUM AFFECT MY HEALTH?

To protect the public from the harmful effects of toxic chemicals and to find ways to treat people who have been harmed, scientists use many tests.

One way to see if a chemical will hurt people is to learn how the chemical is absorbed, used, and released by the body. In the case of a radioactive chemical, it is also important to gather information concerning the radiation dose and dose rate to the body. For some chemicals, animal testing may be necessary. Animal testing may also be used to identify health effects such as cancer or birth defects. Without laboratory animals, scientists would lose a basic method to get information needed to make wise decisions to protect public health. Scientists have the responsibility to treat research animals with care and compassion. Laws today protect the welfare of research animals, and scientists must comply with strict animal care guidelines.

There are no harmful effects of stable strontium in humans at the levels typically found in the environment. The only chemical form of stable strontium that is very harmful by inhalation is strontium chromate, but this is because of toxic chromium and not strontium itself. Problems with bone growth may occur in children eating or drinking unusually high levels of strontium, especially if the diet is low in calcium and protein. Ordinary strontium salts are not harmful when inhaled or placed on the skin.

Animal studies showed that eating or drinking very large amounts of stable strontium can be lethal, but the public is not likely to encounter such high levels of strontium. In these unusually high amounts, so much strontium was taken into bone instead of calcium that growing bones were weakened. Strontium had more severe effects on bone growth in young animals than in adults.

It is not known whether stable strontium affects reproduction in people. The effect of stable strontium on reproduction in animals is not known. The Department of Health and Human Services has determined that strontium chromate is expected to be a carcinogen, but this is because of chromium. There is no information that any other form of stable strontium causes cancer in humans or animals.

The harmful effects of radioactive strontium are caused by the high energy effects of radiation. Since radioactive strontium is taken up into bone, bone itself and the soft tissues nearby may be damaged by radiation released over time. Because bone marrow is the essential source of blood cells, blood cell counts may be reduced if the dose is too high. This has been seen in humans who received injections of radioactive strontium (^{89}Sr) to destroy cancer tissue that had spread to the bone marrow. Lowered blood cell counts were also seen in animals that breathed or swallowed radioactive strontium. Numerous problems occur when the number of blood cells is too low. A loss of red blood cells, anemia, prevents the body from getting sufficient oxygen, resulting in tiredness. A loss of platelets may prevent the blood from clotting properly, and may result in abnormal bleeding, especially in the intestines. A loss in white blood cells harms the body's ability to fight infectious disease.

Radiation damage may also occur from exposure to the skin. Medically, radioactive strontium probes have been used intentionally to destroy unwanted tissue on the surface of the eye or skin. The eye tissues sometimes become inflamed or abnormally thin after a long time. Thinning of the lower layer of the skin (dermis) has also been reported in animal studies as a delayed effect.

It is not known whether exposure to radioactive strontium would affect human reproduction. Harmful effects on animal reproduction occurred at doses that were more than a million times higher than typical exposure levels for the general population.

Radioactive strontium may cause cancer as a result of damage to the genetic material (DNA) in cells. An increase in leukemia over time was reported in individuals in one foreign population who swallowed relatively large amounts of ^{90}Sr (and other radioactive materials) in river water contaminated by a nuclear weapons plant. Cancers of the bone, nose, and lung (in the case of a breathing exposure), and leukemia were reported in animal studies. In addition, skin and bone cancer were reported in animals that received radiation at high doses to the skin. The International Agency for Research on Cancer (IARC) has determined that radioactive strontium is carcinogenic to humans, because it is deposited inside the body and emits beta radiation. The EPA has determined that radioactive strontium is a human carcinogen.

To learn more about the health effects of exposure to stable or radioactive strontium, see Chapter 3.

1.6 HOW CAN STRONTIUM AFFECT CHILDREN?

This section discusses potential health effects from exposures during the period from conception to maturity at 18 years of age in humans.

Children are exposed to stable strontium in the same manner as adults: usually in small amounts in drinking water and food. Young children who have more hand-to-mouth activity or who eat soil may accidentally eat more strontium. Infants and children with active bone growth absorb more strontium from the gut than adults.

Excess stable strontium causes problems with growing bone. For this reason, children are more susceptible to the effects of stable strontium than adults who have mature bone. Children who eat or drink unusually high levels of stable strontium may have problems with bone growth, but only if the diet is low in calcium and protein. Children who drink milk, especially milk fortified

with vitamin D, are not likely to have bone problems from exposure to excess stable strontium. The amount of stable strontium that is usually taken in from food or water or by breathing is too low to cause bone problems in children. No developmental studies in humans or animals examined the effect on the fetus when the mother takes in excess strontium. However, no problems are expected with fetal bone growth because only small amounts of strontium are transferred from the mother across the placenta to the fetus. Evidence suggests that stable strontium can be transferred from the mother to nursing infants through breast milk, but the presence of calcium and protein in milk protects against bone problems during nursing.

Children take in, use, and get rid of radioactive strontium in the same ways as stable strontium. Children are likely to be more vulnerable than adults to the effects of radioactive strontium because relatively more goes into bone when it is growing. Also, children are potentially more vulnerable than adults to radiation damage because they keep radioactive strontium in bone for a longer time.

Children would be expected to have the same types of effects from exposure to radioactive strontium as exposed adults. Children can be exposed to radioactive strontium at levels higher than background without showing increases in cancer rates. Evidence from one foreign population showed that children who drank water containing unusually high levels of radioactive strontium for 7 years showed an increase in leukemia. High levels of radioactive strontium cause more bone damage and higher bone cancer rates when animals are exposed before birth or as juveniles rather than as adults. In humans and animals, radioactive strontium can be transferred into milk or across the placenta into the fetus.

1.7 HOW CAN FAMILIES REDUCE THE RISK OF EXPOSURE TO STRONTIUM?

If your doctor finds that you have been exposed to significant amounts of strontium, ask whether your children might also be exposed. Your doctor might need to ask your state health department to investigate. Public health officials may publish guidelines for reducing exposure to strontium when necessary.

It is possible that higher-than-normal levels of stable strontium may occur naturally in soil in some places or that higher levels of radioactive strontium may be found in soil near hazardous waste sites. Some children eat a lot of dirt. You should prevent your children from eating dirt. Make sure they wash their hands frequently, and before eating. If you live near a hazardous waste site, discourage your children from putting their hands in their mouths or from engaging in other hand-to-mouth activities.

Since strontium is so common in the environment, and is naturally present in food and water, we cannot avoid being exposed to it. For several reasons, having a balanced diet with sufficient vitamin D, calcium, and protein will be protective by reducing the amount of ingested strontium that is absorbed.

1.8 IS THERE A MEDICAL TEST TO DETERMINE WHETHER I HAVE BEEN EXPOSED TO STRONTIUM?

All people have small amounts of stable strontium in their bodies, mostly in bone. It can be measured in the blood, hair, feces, or urine. The amount is usually measured by its mass (grams). Measurements in urine can show whether you have been exposed recently to larger-than-normal amounts of strontium. Measurements in hair can reveal whether you were exposed to high amounts of strontium in the past. Most physicians do not test for strontium in their offices, but can collect samples and send them to a special laboratory. X-rays can show changes in bone that may occur from exposure to high amounts of strontium, but these changes may have other causes (a diet low in vitamin D or a high exposure to some other trace metal).

If a person has been exposed to radioactive strontium, special tests can be used to measure radioactive strontium in blood, feces, or urine. These tests are most useful when done soon after exposure, since radioactive strontium quickly enters into bone and takes many years to be completely removed from bone. Radioactive strontium can be measured by its mass (in grams) or by its radiation emissions. These emissions, which differ for the various isotopes of strontium, are used to tell the amount of radioactive strontium (in curies or bequerels) and the radiation dose that it gives to your body (in sieverts or rem). In a procedure that is similar to

being x-rayed, specialized equipment can measure radioactive strontium that has been incorporated into bone.

For more information, please read Chapters 3 and 7.

1.9 WHAT RECOMMENDATIONS HAS THE FEDERAL GOVERNMENT MADE TO PROTECT HUMAN HEALTH?

The federal government develops regulations and recommendations to protect public health. Regulations can be enforced by law. Federal agencies that develop regulations for toxic substances include the Environmental Protection Agency (EPA), the Occupational Safety and Health Administration (OSHA), the Food and Drug Administration (FDA), and the U.S. Nuclear Regulatory Commission (USNRC).

Recommendations provide valuable guidelines to protect public health but cannot be enforced by law. Federal organizations that develop recommendations for toxic substances include the Agency for Toxic Substances and Disease Registry (ATSDR), the National Institute for Occupational Safety and Health (NIOSH), and the FDA.

Regulations and recommendations can be expressed in not-to-exceed levels in air, water, soil, or food that are usually based on levels that affect animals; they are then adjusted to help protect people. Sometimes these not-to-exceed levels differ among federal organizations because of different exposure times (an 8-hour workday or a 24-hour day), the use of different animal studies, or other factors.

Recommendations and regulations are also periodically updated as more information becomes available. For the most current information, check with the federal agency or organization that provides it. Some regulations and recommendations for strontium include the following:

EPA recommends that drinking water levels of stable strontium should not be more than 4 milligrams per liter of water (4 mg/L).

The Department of Energy (DOE) established derived air concentrations (DAC) for workplace exposure to radiation at DOE facilities. The DAC ranges from 0.000000002 microcuries per milliliter (μCi/mL) ($2x10^{-9}$ μCi/mL of air = 70 μBq/mL of air) for radioactive particles remaining in the lung for 100 days to 0.000000008 μCi/mL ($8x10^{-9}$ μCi/mL of air = 300 μBq/mL of air) for radioactive particles remaining in the lung for less than 10 days. The USNRC established an annual intake limit of 20 μCi (7 MBq) for on-the-job exposure to ^{90}Sr in air.

EPA set standards for the concentration of ^{90}Sr in community water supplies. The average annual concentration of ^{90}Sr in water supplies should not exceed 8 pCi/L (0.3 Bq/L). EPA also established maximum contaminant levels (MCLs) in drinking water for radionuclide activities to protect against harmful effects of ^{90}Sr. For beta particles like strontium, the MCL is 4 mrem per year ($4x10^{-5}$ Sv per year). The USNRC set a workplace value of 31 μCi (1.1 MBq) for the amount of ^{90}Sr that can be taken in by mouth in a year without any harmful effects.

More information on regulations and guidelines is available in Chapter 8.

1.10 WHERE CAN I GET MORE INFORMATION?

If you have any more questions or concerns, please contact your community or state health or environmental quality department, your regional Nuclear Regulatory Commission office, or contact ATSDR at the address and phone number below.

ATSDR can also tell you the location of occupational and environmental health clinics. These clinics specialize in recognizing, evaluating, and treating illnesses resulting from exposure to hazardous substances.

Toxicological profiles are also available on-line at www.atsdr.cdc.gov and on CD-ROM. You may request a copy of the ATSDR ToxProfiles CD-ROM by calling the information and technical assistance toll-free number at 1-888-42ATSDR (1-888-422-8737), by email at atsdric@cdc.gov, or by writing to:

Agency for Toxic Substances and Disease Registry
Division of Toxicology
1600 Clifton Road NE
Mailstop F-32
Atlanta, GA 30333
Fax: 1-770-488-4178

For-profit organizations may request a copy of final profiles from the following:

National Technical Information Service (NTIS)
5285 Port Royal Road
Springfield, VA 22161
Phone: 1-800-553-6847 or 1-703-605-6000
Web site: http://www.ntis.gov/