

only partially successful in removing wastes and contaminants from the incoming waters. Some operate only primary treatment facilities, consisting of gravity settlement chambers. These remove the more massive suspended solids, but very little of the finer solids, and hardly any of the dissolved solids. Most of the rest of the facilities include secondary treatment involving some kind of biological oxidation. Such plants may remove from 50% to 95% of the oxygen demand from the wastes, but usually have lower efficiencies for the removal of nitrates, phosphates, and trace metals. The large portion of the oxygen demand removed from the incoming sewage by the treatment plant does not disappear. Some is oxidized to harmless end products in the process, but the rest is simply transferred into sewage sludge, which must itself be disposed of.

Sludge disposal remains a major problem for many large cities. For many years, New York City and other coastal cities dumped digested sewage sludge into designated dumping grounds within coastal waters. In New York's case, this was a site approximately 12 miles out to sea. As a result of potential hazards to marine life and the public health, the city terminated such dumping. Land disposal can involve significant problems in odor generation and/or ground-water contamination. Some of the sludge is now being incinerated.

Another municipal activity that generates chemical contamination in some regions is the road and street salting done in the winter to improve traffic safety. The salt corrodes metals, damages plants, shrubs, and trees, and increases the salinity of the receiving waters. However, the environmental contamination from street salting appears generally acceptable in comparison to the alternative, i.e., impassable and unsafe roadways.

#### **Radiological contamination resulting from nuclear fission reactions**

This section discusses the types and sources of anthropogenic radioactive contaminants in the environment derived from military and civilian applications of nuclear fission. The sources for these materials are quite different from those that emit the chemical contaminants described in previous parts of this chapter. In general, the mass concentrations of radionuclides released are too low to result in any chemical toxicity following their uptake; the focus of concern is, therefore, on their radiobiological effects. Radiological contamination may be quite pervasive, since radionuclides follow the same environmental and metabolic pathways as do the stable nuclides of the same element. While there is no question that the total amount of radioactive material in the world has been increased by human activity, the radiation dose to the general population from natural sources is much greater than that from anthropogenic environmental releases. Natural sources account for approximately 97% of the per capita annual dose in the United States due to environmental radioactivity (i.e., not including medical diagnostic or therapeutic procedures).<sup>3</sup> However, any exposure above background level is considered deleterious to some degree, since radioactivity can alter genetic materials.

Contaminant radionuclides are generated as fission products and by neutron activation. In the latter process, bombardment by neutrons induces radioactivity in elements in air, water, soil, or in structural materials. The main anthropogenic source of environmental radioactivity during the past 50 years has been nuclear-weapons testing. Use of nuclear energy for electric-power generation has added a relatively small increment, and the industrial and medical uses of radionuclides have added still smaller amounts.

**Nuclear-Weapons Testing.** The basic fuel for nuclear weapons is either uranium-235 ( $^{235}\text{U}$ ), which is naturally occurring, or plutonium-239 ( $^{239}\text{Pu}$ ), which is produced from  $^{238}\text{U}$  by neutron capture. Contamination due to testing involves the release of: (1) unfissioned  $^{235}\text{U}$  or  $^{239}\text{Pu}$ ; (2) hundreds of different fission-product nuclides having half-lives ranging from fractions of a second to years, the most hazardous of which are iodine-131 ( $^{131}\text{I}$ ), cesium-137 ( $^{137}\text{Cs}$ ), strontium-89 ( $^{89}\text{Sr}$ ), and strontium-90 ( $^{90}\text{Sr}$ ); and (3) products formed by neutron activation of air, water, soil, and the metal casings that surround the weapons. The most extensive series of atmospheric tests occurred in the 1950s and early 1960s, and resulted in the release of about 20 megacuries (MCi) of  $^{90}\text{Sr}$ , 30 MCi of  $^{137}\text{Cs}$ , 5 MCi of  $^{14}\text{C}$ , and 3000 MCi of  $^3\text{H}$  into the environment.<sup>4</sup> Some atmospheric testing has been done by France, China, and India; the contribution since 1972 due to these is about 5% of the amount produced in the earlier test series. A number of proposals have been advanced for the use of peaceful nuclear explosions for various purposes, such as releasing natural gas from underground sources, building harbors, and excavating for canals. If detonated in the atmosphere, these explosions would also release both fission and neutron activation products; the amounts of each would depend upon the particular type of explosive device used and the composition of the soil and rock surrounding the site.

**Nuclear-Power Reactors.** In power reactors, controlled fission is used to generate electricity. The first nuclear central power station began operation in 1957 in Pennsylvania. At the end of the twentieth century, nuclear power accounted for about 20% of the total U.S. electrical production. However, no new nuclear power reactors have been ordered since 1979, when a reactor failure occurred at one of the units at Three Mile Island in Pennsylvania. While the reactor itself was destroyed, there was no significant release of radioactivity or reactor fission products to the environment because of the effectiveness of the containment structure, which is a feature of all U.S. power reactors.

A quite different exposure scenario occurred when a power reactor failed at Chernobyl in the Ukraine in 1986, which was then in the Soviet Union. This reactor had no containment structure. As a result, about 1000 cases of acute radiation poisoning occurred, including 28 early fatalities. There were approximately 95,000 persons within 3 km of the reactor who were exposed to quite high radi-

ation. About 135,000 people living within 30 km were evacuated about 10 days later. A radioactive cloud moved downwind into central and northern Europe and the fallout from the cloud caused somewhat elevated radiation exposures to many millions. Within the next 10 years, there were several thousand cases of thyroid tumors in downwind populations in Ukraine and Belarus that were attributable to radioactive iodine (in dairy products), that delivers a concentrated radiation dose to the thyroid. The exposed populations are being monitored to determine the extent of the elevation that will actually occur for tumors at other organs of the body with longer lag times.

While there may be future generations of nuclear power reactors in the U.S. at some time, that time is at least several decades in the future. The fraction of the electrical power supply generated by nuclear fission can be expected to decline as some of the older units reach their economically useful lifetime and are retired, decommissioned, and dismantled.

In the meantime, there is a growing inventory of spent fuel rods stored under water in tanks maintained at nuclear power plants. In 2002, the U.S. Congress endorsed the Department of Energy's plan to transfer high-level power plant wastes to an underground storage facility at Yucca Mountain in Nevada as a secure long-term repository. A brief summary outline of the nuclear power industry follows.

### **Nuclear fuel cycle**

All power reactors currently in use in the U.S. use  $^{235}\text{U}$  for fuel. Contaminants may be released into the environment at a number of steps in the fuel cycle.

**Mining.** Uranium is mined both underground and in open pits. In order to protect workers in underground areas, the radioactive radon gas, which diffuses into the mine air, and its daughter products are vented into the atmosphere outside the mine. While locally high radioactivity levels may occasionally result, the releases generally do not contribute significantly to community exposures. Analogous to the case of ragweed discussed earlier in this chapter, anthropogenic activity results in an increase in what is essentially a natural contaminant. In this case, it is radon gas.

**Milling.** Milling involves crushing of the ore and the use of chemical methods to extract, concentrate, and purify the uranium into a semirefined oxide,  $\text{U}_3\text{O}_8$ . The major contaminant problem in this step is the large amount of residual solids. This waste material, known as tailings, occupies as much volume as the material taken into the mill. These solids contain most of the radium originally present in the ore. There were over 80 million metric tons of tailings occupying over 2100 acres of land in the United States, this inventory that is being reduced by removal to more secure locations. The radiation and radioactive dust from the

tailings piles constitute contamination from natural sources that are redistributed and localized in areas that generally are closer and more accessible to human populations than are the ores in the mines. As a result, the radiation levels in cities near piles of tailings may be higher than normal. In addition, in some towns in the western United States, these tailings, which resemble construction sand, were used for landfill and incorporated into construction materials. Their high radium content resulted in high radon levels in many buildings.

Milling operations use large amounts of water, which often became contaminated with nonradioactive chemicals and with small amounts of uranium, radium, and their decay products. Discharges to streams resulted in local contamination problems.

**Refining and Conversion.** In this step, the uranium concentrate ( $\text{U}_3\text{O}_8$ ) is chemically purified. The uranium to be enriched in its  $^{235}\text{U}$  content is converted into a volatile hexafluoride,  $\text{UF}_6$ . Some nonradioactive liquid wastes and acid gases may be released in these chemical conversion processes.

**Enrichment.** The concentration of  $^{235}\text{U}$  in natural uranium is approximately 0.7%. Most reactors operate more efficiently with higher amounts. Thus, in enrichment, the concentration of  $^{235}\text{U}$  in the  $\text{UF}_6$  is increased to approximately 2%–4%, by multistage gaseous diffusion or centrifugation. Large amounts of electric power and cooling water are consumed in these processes.

**Fuel Fabrication.** Enriched  $\text{UF}_6$  is converted into a dioxide powder,  $\text{UO}_2$ , made into pellets and loaded into alloy tubing, which is then formed into individual fuel-rod elements. Up to this point in the fuel cycle, environmental contamination problems are minimal, and are similar to those of the chemical industry in general. Although dusts and fumes of natural uranium are mildly radioactive, they have been well controlled. The greatest potentials for general environmental contamination are associated with power production and fuel reprocessing.

**Power Production.** Various types of reactors may be used to convert heat into electrical power. Modern reactors are primarily of two types: pressurized-water reactors (PWR) or boiling-water reactors (BWR). In both, water is used as both the coolant and the moderator of the fission reaction. In the boiling-water reactor, water is heated as it passes through the reactor core and steam is produced. The steam passes through turbines and is then condensed for return to the reactor. In the pressurized-water reactor, the water pumped through the core is maintained at a high pressure to prevent it from boiling in the core. Rather, the water, which leaves the core at about  $318^\circ\text{C}$ , passes through a steam generator unit, where its heat is transferred to the water-steam loop that passes through the turbines. The nature and amount of any atmospheric discharges depend upon reactor type, operating his-

