Environmental Science
Earth as a Living Planet

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Alternative renewable energy sources have a future in our urban environment. For example, the roofs of buildings can be used for passive solar collectors or photovoltaic systems. Patterns of energy consumption can be regulated through use of innovative systems such as pump storage to augment production of electrical energy when demand is high in urban areas.

Alternative energy sources such as solar and wind are perceived by many environmentalists as being linked more closely with nature than are fossil fuels, nuclear energy, or even water power. This is because solar and wind energy development requires less human modification of the environment. Solar and wind energy allow us to live more in harmony with the environment, and thus we feel more connected to the natural world.

We are seriously considering alternative energy today because we value environmental quality. Recognizing that burning fossil fuels causes many serious environmental problems and that petroleum will soon become too available, we are trying to increase our scientific knowledge and improve our technology to meet our energy needs for the future while minimizing environmental damage. Our present science and technology can lead to a sustainable energy future, but we will need to change our values and our behavior to achieve it.

**KEY TERMS**

- active solar energy systems
- alternative energy
- biomass
- fuel cells
- geothermal energy
- nonrenewable energy
- passive solar energy systems
- photovoltaics
- renewable energy
- solar collectors

**STUDY QUESTIONS**

1. What types of government incentives could be used to encourage use of alternative energy sources? Would such widespread use impact our economic and social environment?
2. Your town is near a large river that has a nearly constant water temperature of 15°C (59°F). Could the water be used to cool buildings in the hot summer? How? What would be the environmental effects?
3. Which has greater potential for energy production, wind or water power? Which costs more environmental problems? Why?
4. What are some of the problems associated with producing energy from biomass?
5. It is the year 2050, and natural oil and gas are rare and expensive. People are increasingly using solar and wind energy. Describe the problems associated with these energy sources.
6. What are some of the problems associated with using nuclear power?

**FURTHER READING**


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**Chapter 20**

**Nuclear Energy and the Environment**

As one of the alternative to fossil fuels, nuclear energy generates a lot of controversy. After reading this chapter, you should understand:

- What nuclear fission is and what the basic components of a nuclear power plant are.
- What nuclear fission is and what the three major types are.
- Why it is important to know the type of radiation and the half-life for a particular radionuclide.
- What the basic facts of the nuclear fuel cycle are, and how each is related to our environment.
- How radionuclides affect the environment and the health of radioactive materials in the environment.
- What the breeder reactor is, and why it is important for the future of nuclear energy.
- What the relationships between radiation dosage and health are.
- What we have learned from accidents at nuclear power plants.
- How we might safely dispose of high-level radioactive materials.
- What the future of nuclear power is likely to be.
- That nuclear power produces electric energy without emitting air pollution or contributing to global warming.

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Indian Point nuclear power plants, on the Hudson River within 20 miles of New York City, must be relicensed, and this is creating a major controversy about whether the kind of power plants should be near homes of millions of people.
CASE STUDY

Indian Point: Should a Nuclear Power Plant Operate Near One of America’s Major Cities?

In 1974, the first of three nuclear reactors was built at Indian Point Nuclear Power Plant in Buchanan, New York, 38 km (24 miles) north of New York City (Figure 20.1). Indian Point’s second reactor was built two years later, and a third two years after that. The power plant has been in operation since then, with a capacity of 7,000 megawatts.

The plant’s license was renewed in 2013 and 2015, and under U.S. law nuclear power plants must be relicensed. Twenty million people live within 60 km (30 miles) of this power plant, and this makes considerable concern.

The National Regulatory Commission (NRC) announced the beginning of the process of relicensing Indian Point Nuclear Power Plant on May 2, 2007. By 2008, the relicensing of the plant had become a regional controversy, opposed by New York State government, environmental groups, and a number of non-governmental environmental organizations. The plant has operated for 32 years, so what is the problem?

The discussion of public opinion about nuclear power plants suggests a dilemma for the United States. This chapter explores nuclear power reactions, radiation, accidents, waste management, and the future of nuclear power.

20.1 Nuclear Energy

Nuclear energy is the energy of the atomic nucleus. Two nuclear processes can be used to release that energy to do work: fission and fusion. Nuclear fission is the splitting of atomic nuclei, and nuclear fusion is the fusing, or combining, of atomic nuclei. A product of both fission and fusion reactions is the release of enormous amounts of energy. (You may wish to review the discussion of matter and energy in A Closer Look 8.1.)

Nuclear energy for commercial use is produced by the splitting of atoms in nuclear reactors, which are devices that produce controlled nuclear fission. In the United States, almost all of these reactors use a form of uranium fuel. Nuclear fusion is not yet used commercially, although it has been accomplished in experimental fusion reactors.

Most recently, a transformer burned in the second unit in April 2007, and radioactive water leaked into ground water, and the source of the leak was difficult to find. Proponents of nuclear power say: What’s the problem? These are minor problems and there has been no major one. As far as can tell, the plant is safe.

But others, like New York State’s attorney general Andrew Cuomo, believe the location is too dangerous, and he has asked the Nuclear Regulatory Commission to deny Indian Point’s relicensing, saying that it has a "long and troubling history of problems." The controversy at Indian Point illustrates the worldwide debate about nuclear energy. With growing concern about the use of fossil fuel, there are calls for increased use of nuclear power, accompanied by long-standing fears of its use. This chapter provides a basis for you to decide whether nuclear power could be, and should be, a major supplier of energy in the future.

The Energy Policy Act of 2005 promulgates nuclear energy and recommends that the United States start the process of building new nuclear power plants by 2010. Nuclear energy is one of the cleanest, most abundant, and potentially lowest-cost power sources currently available. There are two main approaches to generating nuclear power: fission and fusion. Fission reactors are used to produce nuclear fuel, which can eventually replace fossil fuel. Therefore, nuclear power, which does not contribute to global warming, may one day be used as a major source of energy, partly or even totally. Fossil fuel, safety, and storage of waste can be resolved.

The discussion of public opinion about nuclear power suggests a dilemma for the United States. This chapter explores nuclear power reactions, radiation, accidents, waste management, and the future of nuclear power.

Fission Reactors

The first human-controlled nuclear fission, demonstrated in 1942 by Italian physicist Enrico Fermi at the University of Chicago, led to the development of nuclear power to produce electricity. Today, in addition to power plants to supply electricity to homes and industry, nuclear reactors power submarines, aircraft carriers, and icebreaker ships. Russia is building ships that contain reactors to provide electric power to the ships' icebreakers, and the United States is designing reactors for deep-sea mining operations.

Nuclear fission produces much more energy than other sources, such as burning fossil fuels. One kilogram (2.2 lb) of uranium oxide produces heat equivalent to approximately 60 metric tons of coal, making uranium an important source of energy in the United States and the world.

Three types, or isotopes, of uranium occur in nature: uranium-235, which accounts for approximately 0.7% of natural uranium, uranium-238, which makes up about 99.3% of natural uranium, and uranium-234, which makes up about 0.6%. Uranium-235 and uranium-236 are two radioactive isotopes of uranium. However, uranium-235 is the only naturally occurring fissile (or fissionable) material; therefore, it is essential to the production of nuclear energy. Processing uranium (called enrichment) to increase the concentration of uranium-235 from 0.7% to about 3% produces enriched uranium, which is used as fuel for the nuclear fission reactor. Radium is explained and related terms are defined in A Closer Look 20.1.

Fission reactors used uranium-235 by neutron bombardment. The fission reaction produces neutrons, fission fragments, and heat. The released neutrons strike other 235 atoms, releasing more neutrons, fission products, and heat. The neutrons released are fissioning and must be slowed down slightly, or moderated, to increase the probability of fission. In light-water reactors, the most commonly used in the United States, ordinary water is used as the moderator. As the process continues, a chain reaction develops as more and more neutrons are split, releasing more neutrons and more heat. A chain reaction in its early stages is described as subcritical; when the reactivity is increased, the reactivity increases. Further addition of fuel rods into the core stops the fission reaction. The construction of the coolant is to remove the heat produced by the fission reactor. This is an important point: the rate of generation of heat in the fuel. Neutrons from a reactor core are moderated. A meltdown generally refers to a nuclear accident in which the nuclear fuel becomes too hot that it forms a molten mass that breaches the containment of the reactor and contaminates the outside environment with radioactivity.

Other parts of the nuclear power supply system are the primary coolant loops and pumps, which circulate the coolant through the reactor, extracting heat produced by
Radioactive Decay

To many people, radiation is a subject shrouded in mystery. They fear exposure to it, learning from an early age that nuclear energy must be dangerous because radiation and the atomic bomb can cause widespread human suffering. One thing that makes radiation scary is that we cannot see it, taste it, smell it, or feel it. In this feature, we try to demystify some aspects of radiation by discussing the process of radioactivity.

Radioactive Decay

Radioactive decay is a natural process that has been going on since the creation of the universe. Understanding the process of radiation involves understanding the radioisotope, which is a form of a chemical element that spontaneously undergoes radioactive decay. During the decay process, the radioisotope changes into one isotope to another and emits one or more forms of radiation.

You may recall from Chapter 5 that isotopes are variants of an element that have the same atomic number (the number of protons in the nucleus) but vary in their atomic mass (the number of neutrons plus protons in the nucleus). For example, two isotopes of uranium are 235U and 239U. The atomic number for both isotopes of uranium is 92 (from Table 5.1); however, the atomic mass numbers are 235 and 238. The two different uranium isotopes may be written as uranium-235 and uranium-238 or 235U and 238U.

An important characteristic of a radioisotope is its half-life, the time required for half of a given amount of the isotope to decay to a stable form. For example, uranium-235 has a half-life of 710 million years, and uranium-238 has a half-life of 4.5 billion years. Other radioisotopes have even shorter half-lives, for example, polonium-216 has a half-life of about 3 minutes, and radon has a half-life of about 3.8 days. Other radioisotopes have even shorter half-lives, for example, polonium-216 has a half-life of about 3 minutes, and radon has a half-life of about 3.8 days. Other radioisotopes have even shorter half-lives, for example, polonium-216 has a half-life of about 3 minutes, and radon has a half-life of about 3.8 days.

The main point here is that each radioisotope has its own unique and lasting half-life. Isotopes with very short half-lives are present for only a brief time, whereas those with long half-lives remain in the environment for long periods. Table 20.1 illustrates the general pattern for decay in terms of the elapsed half-lives and the percentage remaining. For example, suppose we start with 15 polonium-218 and half of a half-life of approximately 3 minutes. After an elapsed time of 6 minutes, 50% of the polonium-218 remains. After 5 elapsed half-lives, or 30 minutes, only 6% is still present, and after 10 elapsed half-lives (30 minutes), 0.1% is still present. Where has the polonium gone? It has decayed to lead-214, another radioactive isotope, which has a half-life of about 27 minutes. The decay process of changes associated with the decay process is often known as a radioactive decay chain. You may wonder where the lead-214 came from. The answer is that it is formed from decay of the polonium-218.

The half-life of a radioisotope is the time required for half of the isotope to decay to a stable form. The elapsed time is the time required for half of the isotope to decay to a stable form. The elapsed time is the time required for half of the isotope to decay to a stable form. The elapsed time is the time required for half of the isotope to decay to a stable form.
Radiation Emitting Elements | Radiation Emitting | Half-life
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Uranium-234 | Alpha, Beta, Gamma | 8.1 days
Thorium-234 | Beta, Gamma | 9.9 days
Protactinium-234 | Beta, Gamma | 43.8 days
Uranium-233 | Alpha, Beta, Gamma | 2.26 billion years
Thorium-232 | Alpha, Beta, Gamma | 14.1 billion years
Radium-226 | Alpha, Beta, Gamma | 1600 years
Radon-222 | Alpha, Beta | 3.8 days
Plutonium-239 | Beta, Gamma | 14 days
Lead-214 | Alpha, Beta, Gamma | 28.8 days
Radium-224 | Alpha, Beta, Gamma | 19.7 days
Plutonium-238 | Alpha, Beta, Gamma | 0.0000001576 seconds
Lead-210 | Alpha, Beta, Gamma | 5.0 days
Radium-210 | Alpha, Beta, Gamma | 138.4 days
Lead-206 | None | Stable

**Figure 20.3** Uranium-238 decay chain. (Source: J. Scherer, ed., Radiometric Dating, 2nd printing [American Institute of Professional Geologists, 1985].)

**Figure 20.4** Comparison of (a) a fossil fuel power plant and (b) a nuclear power plant with a boiling water reactor. Radcliffe-on-Trent, located in Nottinghamshire, England, and the nuclear power station 4) is located in Leibstadt, Switzerland. (Source: American Nuclear Society, Nuclear Power and the Environment, 1973.)

Nuclear reactors are part of the nuclear waste problem and not a long-term solution to the energy problem. One way for nuclear power to be sustainable for at least hundreds of years would be the use of a process known as breeding. Breeder reactors are designed to produce new nuclear fuel. They do this through a process in which they transform waste or low-grade uranium into fissile material. Breeder reactors, of constructed in sufficient numbers (several thousand), could supply about half the energy presently produced by fossil fuels for about 2,000 years. Breeding is apparently the future of nuclear power, if sustainability in terms of nuclear fuel is the objective. Bringing breeder reactors "online" to produce safe nuclear power will take planning, research, and advanced reactor development. Also, fuel for the breeder reactors will have to be recycled, as reactor fuel must be replaced.

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Chapters and heat exchangers are space generators, which use a pressurized fluid to make steam (Figure 20.1). In light-water reactors, water is used as the coolant as well as the moderator. In heavy-water reactors, heavy water (deuterium oxide) is used as a coolant. A design philosophy has emerged in the nuclear industry to build less complicated, smaller reactors that are safer. Large nuclear power plants, which produce about 1,000 MW of electric power, require an extensive set of pumps and cooling equipment to ensure that adequate cooling is available in the reactor. Smaller reactors can be designed with cooling systems that work by gravity and as a result are not as vulnerable to pump failure caused by power loss. Such cooling systems are said to have passive safety, and the reactors are said to be passively safe. Another approach is the use of helium gas to cool reactors that have specially designed fuel capsules capable of withstanding temperatures as high as 1,500°C (about 2,730°F). The idea is to design the fuel assembly so that it cannot hold sufficient fuel to reach this temperature and thus cannot experience a core meltdown.

**Sustainability and Nuclear Power**

Sustainability with respect to nuclear power has two aspects: (1) nuclear power's role in creating alternative fuel supplies and (2) the sustainability of nuclear fuel itself. In the first case, nuclear energy can be used to produce hydrogen from water or methane, to supply fuel cells in automobiles. Using hydrogen would help the United States transition from its dependence on oil to a less environmentally damaging energy source (hydrogen). This is a central theme of sustainability that has the objective of meeting our energy needs in the future without harming the environment. The second aspect of sustainability with respect to nuclear power has to do with nuclear fuel. This is especially important because uranium-fueled nuclear power is a nonrenewable resource. Nuclear power plants are becoming safer and more economical. Although we have not begun building any nuclear power plants in over 20 years, new nuclear power plants provide an increasing amount of electrical energy. Since the early 1990s, America's nuclear plants have added over 23,000 MW, equivalent to 23 large fossil-fueled power plants. This increase is the result of more efficient use of existing nuclear power plants and the lower cost of energy production from nuclear plants. 10

Our present light-water reactors use uranium very inefficiently. Only about 1% of the uranium is used in the reactor, the other 99% ends up as waste. Therefore, our current reactors are part of the nuclear waste problem and not a long-term solution to the energy problem. One way for nuclear power to be sustainable for at least hundreds of years would be the use of a process known as breeding. Breeder reactors are designed to produce new nuclear fuel. They do this through a process in which they transform waste or low-grade uranium into fissile material. Breeder reactors, if constructed in sufficient numbers (several thousand), could supply about half the energy presently produced by fossil fuels for about 2,000 years. Breeding is apparently the future of nuclear power, if sustainability in terms of nuclear fuel is the objective. Bringing breeder reactors "online" to produce safe nuclear power will take planning, research, and advanced reactor development. Also, fuel for the breeder reactors will have to be recycled, as reactor fuel must be replaced.
every few years. What is needed is a new type of breeder reactor, comprising an entire system that includes reactor, fuel cycle (especially recycling and reprocessing of fuel), and less production of waste. Such a new reactor is possible, but will require redesigning our national energy policy and turning energy production in new directions. It remains to be seen whether this will happen.

**Pebble-Bed Reactors**

A new type of gas-cooled reactor, called a pebble reactor, has been suggested and is being designed and developed in South Africa, but none has yet been built or operating anywhere in the world. The design uses fuel elements called pebbles that are about the size of a billiard ball (Figure 20.6). The pebbles have an outer graphite shell with an interior containing about 15,000 sandgrain-size particles of nuclear fuel (uranium oxide). Approximately 300,000 pebbles are loaded into a metal container shielded by a layer of graphite. Approximately 100,000 more graphite pebbles are interspersed with the fuel pebbles to assist in controlling production of heat from the reactor. Fuel pebbles are fed into the core, continuously refilling the nuclear reactor. As each fuel pebble leaves the core, another is added from the storage container.

The analogy is a gumball machine, where one gumball is removed and another takes its place. This is a safety feature of the reactor because the core at any time has just the right amount of fuel necessary for optimal production of energy. The pebble-bed reactors will probably be modular, with each unit producing about 150 MW(e) power, which is about one-tenth of that produced by a large centralized nuclear power plant.

**Fusion Reactors**

In contrast to fission, which involves splitting heavy nuclei (such as uranium), fusion involves combining the nuclei of light elements (such as hydrogen) to form heavier ones (such as helium). As fusion occurs, heat energy is released (Figure 20.7). Nuclear fusion is the source of energy in our sun and other stars.

In a hypothetical fusion reactor, two isotopes of hydrogen—deuterium and tritium—are injected into the reactor chamber, where the necessary conditions for fusion are maintained. Products of the deuterium-tritium (DT) fusion include helium, producing 20% of the energy released, and neutrons, producing 80% of the energy released (Figure 20.8).

Several conditions are necessary for fusion to take place. First, the temperature must be extremely high—approximately (60 million degrees Celsius for DT fusion). Second, the density of the fuel elements must be sufficiently high. At the temperature necessary for fusion, nearly all streams of their electrons, forming a plasma. Plasma is an electrically neutral material consisting of positively charged nuclei, ions, and negatively charged electrons.

Then, the plasma must be confined for a sufficient time to ensure that the energy released by the fusion reactions exceeds the energy supplied to maintain the plasma. The potential energy available when and if fusion reactor power plants are developed is nearly inexhaustible. One gram of DT fuel (from a water and lithium fuel supply) has the energy equivalent of 45 barrels of oil. Deuterium can be extracted economically from ocean water, and tritium can be produced in a reaction with lithium in a fusion reactor. Lithium can be extracted economically from abundant mineral supplies.

Many problems remain to be solved before nuclear fusion can be used on a large scale. Research is still in the first stage, which involves basic physics, testing of possible fuels (mostly DT), and magnetic confinement of plasma.
20.2 Nuclear Energy and the Environment

The nuclear fuel cycle includes the processes involved in producing nuclear power from the mining and processing of uranium to controlled fission, the reprocessing of spent nuclear fuel, the decommissioning of power plants, and the disposal of radioactive waste. Throughout the cycle, radiation can contaminate the environment. (Figure 20.9). To understand the environmental effects of radiation, it is useful to be acquainted with the units used to measure radiation and the amounts or doses. These are explained in a Closer Look 20.2.

![Diagram of the nuclear fuel cycle including uranium mining, fabrication of fuel assemblies, reactor operation, spent fuel management, and decommissioning.]

**Radiation Units and Doses**

The units used to measure radioactivity are complex and somewhat confusing. Nevertheless, a modest acquaintance with them is useful in understanding and talking about the effects of radiation on the environment.

A commonly used unit for radioactive decay is the becquerel (Bq), which is the amount of radioactivity equal to 37 billion nuclear transformations per second. The curie is named for Marie Curie and her husband, Pierre, who discovered radium in 1898. They also discovered polonium, which they named after Marie's homeland, Poland. The harmful effects of radiation were not known at that time, and both Marie Curie and her daughter died of radiation-induced cancer. Her laboratory (Figure 20.10) is still contaminated today.

In the International System (SI) of measurement, the unit commonly used for radioactive decay is the becquerel (Bq), which is one radioactive decay per second. Units of measurement often used in discussions of radioactive isotopes, such as radium-222, are becquerels per cubic metre and picocuries per liter (pCi/l). A picocurie is one-thousandth (10^-12) of a curie. Becquerels per cubic meter or picocuries per liter are therefore measures of the number of radioactive decays that occur each second in a cubic meter or liter of air.

When dealing with the environmental effects of radiation, we are most interested in the actual dose of radiation delivered by radioactive isotopes. The dose is commonly measured in terms of rem (rad) are now. In the International System, the corresponding unit is the gray (Gy) and milligray (mGy). Rads and grays are the units of the absorbed dose of radiation; 1 rem is equivalent to 100 rads. Rads and grays are units of equivalent dose, or the absorbed dose, where 1 rives stands for air.

*Figure 20.9* Radiometric diagrams showing the nuclear fuel cycle for the U.S. nuclear energy industry: Distribution of isotopes, which are decayed to become and energy release, volume of high-level waste, and the central core of the plant. (Source: Office of Industry Relations, American Nuclear Industry, 1974.)

*Figure 20.10* Marie Curie in her laboratory.

...is received at higher elevations. Radiation from rocks and soils (such as granite and volcanic ash) containing radioactive minerals delivers about 0.3 to 1.2 mSv/year. The amount of radiation delivered from rocks, soils, and water may be much larger in areas where radon gas (a naturally occurring radioactive gas) seeps from radon in basements. As a result, mountainous areas that also have an abundance of granite rocks, such as Colorado, have a greater background radiation than the states that have a lot of limestone bedrock and are low in elevation, such as Florida. In spite of the general pattern, or locations in Florida where phosphate deposits occur, background radiation is above average because of a relatively high uranium concentration found in the phosphate rocks. The amount of radiation received by people from human sources is about 1.35 mSv/year. Two sources include naturally occurring radionuclides-40K and carbon-14, which are present in our bodies and produce about 0.35 mSv/year. Potassium is an important electrolyte in...
From the sky

Ozone layer

About 8,000 cosmic rays penetrate each of us every minute.

From the air

What we breathe

About 200 atoms of radioactive isotopes (radon, polonium, uranium, and isotopes) disintegrate in the lungs each minute, producing many Alpha, Beta, and Gamma radiation.

From our diet

What we eat

About 400 radioactive elements (mostly potassium and uranium) disintegrate in the body each minute.

Figure 20.10. The major sources of internal radiation are the air, the food we breathe, and the food we eat.

The United States-235 enrichment and fabrication of fuel assemblies also produce large amounts of fission products that must be carefully handled and disposed of.

Site selection and construction of nuclear power plants in the United States have been extremely controversial. The general public is concerned about the fact that the planned reactors are only a few miles away from our homes. This concern is understandable, given the potential risks associated with radioactive waste disposal and the possibility of accidents or natural disasters.

The power plant or reactor is the site most people are concerned about because it is the most visible part of the power plant. This is also the site of past accidents, including the Chernobyl disaster.

The Chernobyl accident, which occurred in the Chernobyl area, is a good example of the consequences of nuclear power plants.

Nuclear power plants are a significant source of radiation, and the potential dangers associated with them must be considered.

Patriot: "If it is not dangerous, why are we afraid of it?"

Figure 20.12. Sources of radiation received by people. The natural annual dose is 3.6 mSv per year, and the average dose from medical procedures is 0.2 mSv per year.

Effects of Radioisotopes

Radioisotopes are substances that emit ionizing radiation and are used in various medical and industrial applications. They can be used to treat cancer, study the function of organs, and sterilize medical equipment.

Radioisotopes are also used in agriculture, where they are used to improve crop yields and to study the growth of plants.

Radioisotopes are also used in the energy sector, where they are used to generate electricity.

Radioisotopes are also used in medicine, where they are used to detect and treat diseases.

Radioisotopes are also used in research, where they are used to study the behavior of subatomic particles.

Radioisotopes are also used in industry, where they are used to test the quality of products.

Radioisotopes are also used in defense, where they are used to develop nuclear weapons.

Radioisotopes are also used in the environment, where they are used to study the effects of pollution.

Radioisotopes are also used in space, where they are used to study the effects of radiation on humans.

Radioisotopes are also used in transportation, where they are used to study the effects of radiation on materials.

Radioisotopes are also used in the food industry, where they are used to study the effects of radiation on food.

Radioisotopes are also used in the pharmaceutical industry, where they are used to develop new drugs.

Radioisotopes are also used in the cosmetics industry, where they are used to study the effects of radiation on skin.

Radioisotopes are also used in the chemical industry, where they are used to study the effects of radiation on chemicals.

Radioisotopes are also used in the nuclear industry, where they are used to study the effects of radiation on nuclear reactors.

Radioisotopes are also used in the environmental industry, where they are used to study the effects of radiation on the environment.

Radioisotopes are also used in the educational industry, where they are used to study the effects of radiation on students.

Radioisotopes are also used in the entertainment industry, where they are used to study the effects of radiation on performers.

Radioisotopes are also used in the military industry, where they are used to study the effects of radiation on soldiers.

Radioisotopes are also used in the space industry, where they are used to study the effects of radiation on astronauts.

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Radioisotopes are also used in the military industry, where they are used to study the effects of radiation on soldiers.

Radioisotopes are also used in the space industry, where they are used to study the effects of radiation on astronauts.

Radioisotopes are also used in the medical industry, where they are used to study the effects of radiation on patients.

Radioisotopes are also used in the research industry, where they are used to study the effects of radiation on researchers.

Radioisotopes are also used in the agricultural industry, where they are used to study the effects of radiation on crops.

Radioisotopes are also used in the industrial industry, where they are used to study the effects of radiation on industries.

Radioisotopes are also used in the defense industry, where they are used to study the effects of radiation on defense systems.

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Radioisotopes are also used in the entertainment industry, where they are used to study the effects of radiation on performers.
food, the higher was the level of the isotope in their bodies (Figure 20.14). It is possible to predict the environmental pathways that radionuclides will follow because we know the normal pathways of nonradioactive isotopes with the same chemical characteristics. Our knowledge of biokinetics and of large-scale air and oceanic movements that transport radionuclides throughout the biosphere will also help us to understand the effects of radionuclides.

**Radiation Doses and Health**

The most important question in studying radiation exposure in people involves determining the point at which the exposure or dose becomes a hazard to health (see A Closer Look 20.3). Unfortunately, there are no simple answers to this seemingly simple question. We do know that a dose of about 5,000 mSv (5 sieverts) for a healthy adult is lethal, and health effects become apparent at lower doses. Exposure to 1,000-2,000 mSv is sufficient to cause health problems, including vomiting, fatigue, potential abortion of pregnancies of less than two months' duration, and temporary sterility in males. At 500 mSv, physiological damage is recorded. The maximum allowed dose of radiation per year for workers in industry is 50 mSv, which is approximately 30 times the average annual natural background level and 500 times the long-term natural background level. For continuous or frequent exposure, the limit for the general public is 1 mSv.

Most information concerning the effects of high doses of radiation on people comes from studies of the people who survived the atomic bomb detonations in Hiroshima and Nagasaki at the end of World War II. We also have information concerning people exposed to high levels of radiation (e.g., by uranium miners, workers who painted watch dials with luminous paint containing radium, and people treated with radium seeds implanted in their stomachs). Workers in mines who were exposed to high levels of radiation have been shown to suffer a significantly higher rate of lung cancer than the general population. Studies have shown that there is a delay of 10 to 25 years between the time of exposure and the onset of disease. Starting in about 1917 in New Jersey, approximately 2,000 young women were employed painting watch dials with luminous paint. To maintain a sharp point on their brushes, they licked them and as a result were swallowing radium, which was in the paint. By 1924, dentists in New Jersey were reporting cases of jaw bone, and within five years radium was known to be the cause. Many of the women died of anemia or bone cancer.

Although there is a vigorous and ongoing debate about the nature and extent of the relationship between radiation exposure and cancer mortality, most scientists agree that radiation can cause cancer. Some scientists believe that there is a linear relationship, such that any increase in radiation beyond the background level will produce an additional hazard. Others believe that the body is able to successfully handle and recover from low levels of exposure to radiation but that health effects (toxicity) become apparent beyond some threshold. The verdict is still out on this subject, but it seems prudent to take a conservative viewpoint and accept that there may be a linear relationship. Unfortunately, long-term chronic health problems related to low-level exposure to radiation are neither well known nor well understood.

Radiation has a long history in the field of medicine. Drinking waters that contain radioactive materials goes back to Roman times. By 1899, the adverse effects of radiation had been studied and were well known, and in that year, the first lawsuit for malpractice using X rays was filed. Because science had shown that radiation could destroy human cells, however, it was a logical step to conclude that drinking water containing radioactive material such as radon might help fight diseases such as stomach cancer. In the 1950s, it became popular to drink water containing radon, and the practice was supported by doctors, who stated that there were no known toxic effects. Although we now know that statement to be incorrect, radiotherapy, which uses radiation to kill cancer cells in humans, has been widely and successfully used for a number of years.
20.3 Nuclear Power Plant Accidents

Although the chance of a disastrous nuclear accident is considered very low, the probability that an accident will occur increases with every reactor put into operation. For example, according to the U.S. Nuclear Regulatory Commission's performance goal for a single reactor, the probability of a large-scale core meltdown in any given year should be no greater than 0.01% (one chance in 10,000). However, if there were 1,500 nuclear reactors (about four times the present world total), a meltdown could occur at 1.22 times the annual probability of 0.01%, or one every seven years. This is clearly an unacceptable risk. Increasing safety by about 10 times would reduce it to 1.22 times the most manageable risk, but the risk would still be appreciable because the potential consequences remain large.

Next, we discuss the two most well-known nuclear accidents, which occurred at the Three Mile Island and Chernobyl reactor. It is important to understand that these accidents resulted in harm from human error.

Three Mile Island

One of the most dramatic events in the history of U.S. radiation pollution occurred on March 28, 1979, at the Three Mile Island nuclear power plant near Harrisburg, Pennsylvania. The malfunction of a valve, along with human error, caused the core's water level, the major problem, to result in a partial core meltdown. Intense radiation was released into the atmosphere. The nuclear station was isolated from the immediate environment. Fortunately, the containment structure functions as designed, and only a relatively small amount of radiation was released into the environment. Exposure from the radiation emitted into the atmosphere has been estimated at 1 mSv, which is less than the amount of radiation required to cause acute toxic effects. Average exposure to radiation in the surrounding area is estimated to have been approximately 0.012 mSv, which is only about 1% of the normal background radiation received by people. However, radiation levels were much higher near the site. Within a week after the accident, 12 mSv/hour was measured at a meter near the site. By comparison, the average American receives about 2 mSv/year from natural radiation.

Because the long-term chronic effects of exposure to low levels of radiation are not well understood, the effects of Three Mile Island exposure, although apparently small, are difficult to estimate. However, the incident revealed many potential problems with the way U.S. society deals with nuclear power. Historically, nuclear power had been relatively safe, and the state of Pennsylvania was unprepared to deal with the accident. For example, there was not a state bureau for radiation help, and the state Department of Health did not have a single book on radiation medicine; the medical library had been dismantled two years earlier for budgetary reasons. One of the major impacts of the accident was that there was no state office of mental health, and no one in the Department of Health was allowed to sit in on important discussions following the accident.

Chernobyl

Lack of procedures to deal with a serious nuclear power plant accident was dramatically illustrated by events that began unfolding on the morning of Monday, April 28, 1986. Workers at a nuclear power plant in Sweden were searching for the source of a radiation leak in a private home. They concluded that it was not in the radiation that was leaking. Radium, the radioactive isotope, was coming from the Soviet Union by way of prevailing winds. Confronted, the Soviets announced that an accident had occurred at a nuclear power plant at Chernobyl two days earlier, on April 25 (Figure 20.15). This was the first notice of the world to the worst accident in the history of nuclear power generation.

It is speculated that the system that supplied cooling water for the Chernobyl reactor failed as a result of human error, causing the temperature of the reactor core to rise to over 2,000°C (about 5,000°F), melting the uranium fuel. Explosions removed the top of the building, leading to the release of radioactive material into the atmosphere. The radioactive iodine was quickly dispersed throughout the atmosphere. There were no radioactive iodine sickens, and it is difficult to determine the causes of the radiation sickness.

In the days following the accident, nearly 8 million people in the Northern Hemisphere received varying amounts of radiation from Chernobyl. With the exception of the 30-km zone surrounding Chernobyl, the world's human exposure was relatively small. Even in Europe, where exposure was higher, it was considered low because the radiation received during one year.

In the 30-km zone, approximately 115,000 people were evacuated, and in 1990, 24,000 people were evacuated to have received an average radiation dose of 0.35 Sv (410 mSv). This group of people is being fully cared for.

It was expected, based on research from Japanese bomb survivors, that approximately 123,000 people would likely be exposed to the radiation. However, this was not the case because the radiation received was less than the radiation received during one year.

In 1990, an international effort was underway to help those affected by the accident. The United Nations Development Programme and the World Bank were working to provide assistance to the affected communities.

The accident at Chernobyl had serious consequences, including contamination of the environment, economic losses, and public health issues. The area around Chernobyl has been designated a "relocation zone," and the local population has been evacuated. The accident resulted in the evacuation of thousands of people from the area, and many have been unable to return to their homes.

The disaster at Chernobyl has had far-reaching implications, including changes in nuclear policy and international cooperation. The incident has also raised questions about the safety of nuclear power and the need for improved regulatory frameworks.

The impact of the Chernobyl disaster on public opinion has been significant. The event has led to a decline in support for nuclear energy and a rise in support for renewable energy sources.

20.3.1 Nuclear Power Plant Accidents

For a very long time unless some far is the first to store the radioactive waste. For example, the city of Dnipropetrovsk, 5 km from Chernobyl, is a "ghost city." Over 50,000 people were evacuated from the city, and the population of the city was 48,000 today. The city is abandoned, with blocks of vacant apartment buildings and running vehicles. People are trying to grow new vegetation to transform the urban land back to green fields.

According to one estimate, Chernobyl will ultimately be responsible for approximately 16,000 deaths worldwide. The radiation received during the first year of the incident caused 3,000 deaths. The human exposure was relatively small. Even in Europe, where exposure was higher, it was considered low because the radiation received during one year.

The accident at Chernobyl had serious consequences, including contamination of the environment, economic losses, and public health issues. The area was declared a "relocation zone," and the local population was evacuated. The accident resulted in the evacuation of thousands of people from the area, and many have been unable to return to their homes.

The disaster at Chernobyl has had far-reaching implications, including changes in nuclear policy and international cooperation. The incident has also raised questions about the safety of nuclear power and the need for improved regulatory frameworks.

The impact of the Chernobyl disaster on public opinion has been significant. The event has led to a decline in support for nuclear energy and a rise in support for renewable energy sources.

Advocates of nuclear power have argued that nuclear power is safer than other sources of energy. They say that the number of additional deaths caused by air pollution resulting from burning fossil fuels is much greater than the number of lives lost through nuclear accidents.

The Chernobyl disaster has led to increased awareness of the risks associated with nuclear power. The incident has also raised questions about the adequacy of safety regulations and the need for increased oversight of nuclear facilities.
example, the 16,000 deaths that might eventually be attributed to Chernobyl are fewer than the number of deaths caused each year by air pollution from burning coal. Those arguing against nuclear power state that as long as people build nuclear power plants and manage them, there will be the possibility of accidents. We can build nuclear reactors that are safer, but people will continue to make mistakes, and accidents will continue to occur.

20.4 Radioactive-Waste Management

Examination of the nuclear fuel cycle (Figure 20.9) illustrates some of the sources of waste that must be disposed of as a result of using nuclear energy to produce electricity. Radioactive wastes are by-products that must be expected when electricity is produced at nuclear reactors, they may be grouped into three general categories: low-level waste, transuranic waste, and high-level waste. In addition, the tailings from uranium mines and mills must also be considered hazardous. In the western United States more than 20 million metric tons of abandoned tailings will continue to produce radiation for at least 100,000 years.

Low-Level Radioactive Waste

Low-level radioactive waste contains sufficiently low concentrations or quantities of radioactivity that it does not present a significant environmental hazard if properly handled. Low-level waste includes a wide variety of items, such as residues or solutions from chemical processing, solid or liquid plant waste, sludges, and acids; and slightly contaminated equipment, tools, plastic, glass, wood, and other materials.

Low-level waste has been buried in near-surface burial areas in which the hydrologic and geologic conditions were adequate to ensure that the migration of radioactive materials would not occur. However, monitoring has shown that several of the U.S. sites for disposal of low-level radiation have not provided adequate protection for the environment, and leaks of liquid waste have polluted groundwater. Of the original six burial sites, three had closed permanently by 1979 due to unexplained leaks, financial problems, or lack of license. As of 1995, only two remaining government low-level nuclear waste repositories remained in operation in the United States, one in Washington and the other in South Carolina. In addition, there is a private facility in Utah run by Envirocare that accepts low-level waste. Construction of new burial sites, such as the Ward Valley site in southeastern California, has been met with strong public opposition, and controversy remains as to whether low-level radioactive waste can be disposed of safely.

Transuranic Waste

Transuranic waste is composed of human-made radioactive elements heavier than uranium. It is produced in part by neutron bombardment of uranium in reactors and includes plutonium, americium, and curium. Most transuranic waste is industrial trash, such as clothing, rags, tools, and equipment, that has been contaminated. The waste is low-level in terms of intensity of radioactivity, but plutonium has a long half-life and requires isolation from the environment for about 200,000 years. Most transuranic waste is generated from the production of nuclear weapons and, more recently, from cleanup of former nuclear weapons facilities.

Some nuclear weapons transuranic wastes, as of 2000, are being transported to a disposal site near Carlsbad, New Mexico. The waste is isolated at a depth of 655 m (2,150 ft) in salt beds (rock salt) that are several hundred meters thick (Figure 20.16). Rock salt at the New Mexico site has several advantages.

The salt is about 225 million years old, and the area is geologically stable, with very little seismic activity. The salt has no flowing groundwater and is easy to mine. Encapsulated salt in the salt about 10 m wide and 4 m high is used for disposal. Rock salt flows slowly into mined openings. The waste-filled spaces in the storage facility will be finally closed by the slow-moving salt in 75 to 200 years, sealing the waste.

The New Mexico disposal site is important because it is the first geologic disposal site for radioactive waste in the United States. It is a pilot project that will be evaluated very carefully. Safety is the primary concern. Procedures to transport the waste to the disposal site as safely as possible and place it underground in the disposal facility have been established. Because the waste will be hazardous for many thousands of years and there are uncertainties concerning future cultures and languages, clear warnings above and below-ground have been created. The site is slowly marked to help ensure that human interaction in the future is avoided.

High-Level Radioactive Waste

High-level radioactive waste consists of commercial and military spent nuclear fuel, uranium and plutonium derived from military reprocessing, and other radioactive weapons materials. It is extremely toxic, and a sense of urgency surrounds its disposal as the total volume of spent fuel accumulates. As presented in the United States, the thousands of metric tons of high-level waste are being stored at more than a hundred sites in 40 states. Seventy-two of the sites are commercial nuclear reactors.

Storage of high-level waste is at best a temporary solution, and serious problems with radioactive waste have occurred where it is being stored. Although improvements in storage tanks and other facilities will help, eventually some sort of disposal program must be initiated. Some scientists believe the geologic environment can best provide safe containment of high-level radioactive waste. Others disagree and have criticized proposals for long-term disposal of high-level radioactive waste underground. A comprehensive geologic disposal development program should have the following objectives:

- Identification of sites that meet broad geologic criteria of ground stability and slow movement of groundwater with long flow paths to the surface.
- Intensive subsurface exploration of possible sites to positively determine geologic and hydrologic characteristics.
- Predictions of behavior of potential sites based on present geologic and hydrologic situations and assumptions for future changes such as climate, groundwater flow, erosion, and ground movements.
- Evaluation of risk associated with various predictions.
- Political decision making based on risks acceptable to society.

Yucca Mountain Nuclear Waste Depository

In the United States, one of the focal points for debates over nuclear wastes is the plan to store them deep in the earth at Yucca Mountain, Nevada. The Nuclear Waste Policy Act of 1982 initiated a high-level nuclear waste disposal program. The Department of Energy has given the responsibility to investigate several potential sites and make a recommendation. The 1982 act was amended in 1987; the amendment, along with the Energy Power Act of 1992, specified that high-level waste was to be disposed of underground in a deep, geologic waste repository. It was also specified that the Yucca Mountain site in Nevada was to be the only site evaluated. The site remains controversial, and no nuclear wastes have been stored there. The earlier that waste might be deposited there is 2017. Costs to build the facility have reached $77 billion. If the site is suitable, then it could accept high-level waste as early as 2010. Following are some of the key issues being addressed by the Department of Energy at the Yucca Mountain site:

- Assessment of the probability and consequences of volcanic eruptions.
- Evaluation of the earthquake hazard.
- Estimation of changes in the storage environment over long periods of time.
- Estimation of the time the waste may be contained and the types and rates of radiation that may escape from deteriorated waste containers.
- Evaluation of how heat generated by the waste may affect moisture in and around the repository and the design of the repository.
- Characterization of groundwater flow near the repository.
- Identification and understanding of major geological processes that control the transport of radioactive materials.

One of the problems is just getting the present amount of nuclear waste from power plants to this site.
It does not cause the kinds of air pollution or emit greenhouse gases that cause acid rain (see Chapter 23).

If breeder reactors are developed for commercial use, the amount of fuel available will be greatly increased.

Those in favor of nuclear power argue that it is safer than other means of generating power and that we should build many more nuclear power plants in the future. This argument is predicated on the misunderstanding that such power plants would be considerably safer than those being used today. That is, if we standardize nuclear reactors and make them safer and smaller, nuclear power could provide much of our electricity in the future, although the possibility of accidents and the disposal of spent fuel are concerns.

The argument against reviving nuclear power is based on political and economic considerations as well as scientific uncertainty concerning safety issues. Opponents point out that about 161 million Americans—more than half the population—live within 75 miles of one of the 104 nuclear power plants in the United States. Those opposed to expanding nuclear power argue that converting from coal-burning plants to nuclear power plants for the purpose of reducing carbon dioxide emissions would require an enormous investment in nuclear power to make a real impact. This is true. Also, critics say, given the fact that safer nuclear reactors are only just being developed, there will be a time lag. As a result, nuclear power is not likely to have a real impact on environmental problems, such as air pollution, acid rain, and potential global warming, before at least the year 2050. Furthermore, uranium ore is a fuel conventional nuclear reactors is limiting.

The International Nuclear Energy Association estimates that if nuclear power plants were to remain at the level they were in 2004, there would be 85 years of uranium fuel from known reserves. But if nations attempt to build many new power plants in the next decade, known reserves of uranium would be used up much more quickly. Nuclear power therefore only becomes a long-term energy source through breeder reactors.

Another argument against nuclear power is that some countries may be interested in nuclear power as a path to nuclear weapons. Reprocessing used nuclear fuel from a power plant produces plutonium that can be used to make nuclear bombs. There is concern that rogue nations with nuclear power could divert plutonium to make weapons, or may sell plutonium to others. Even terrorists, who would make nuclear weapons.

Until 2001, the politics of nuclear energy was heating up. Nearly all energy scenarios were based on the expectation that nuclear power would continue to grow slowly or perhaps even decline in the coming years. Since the Chernobyl incident, however, many countries in Europe have been reevaluating the use of nuclear power, and in some instances the number of nuclear power plants being built has been significantly reduced. Indeed, in Germany...
Critical Thinking Questions

1. How might you interpret figure 20.17, which shows the percentage of people in the United States who favored building more nuclear power plants from 1975 to 2002? What do you think the effects of nuclear accidents and the California energy crisis of 2001 have been on the number of people who favor building new power plants?

2. Try to construct arguments for those who would strongly favor nuclear power and contrast them with the arguments of those who would strongly oppose it.

where about one-third of the country's electricity is produced by nuclear power, the decision has been made to shut down all nuclear power plants in the next 25 years at they become obsolete.

Nuclear power produces about 7% of the energy used in the United States today. As mentioned earlier, there have been no new orders for nuclear power plants in the United States. Nevertheless, research and development into the smaller, safer nuclear power plants and breeder reactors are going forward. In addition, the Nuclear Power Act of 2005 suggests that nuclear power use should be increased in the future. The nuclear option is again being evaluated in light of the environmental problems associated with fossil fuel. However, the benefits of nuclear power must be balanced with the safety and waste disposal issues that have made nuclear energy an uncertain option for many people. The full impact of what began in 1942, when the first atomic bomb was tested, is still to be determined.

**SUMMARY**

- Nuclear fusion is the process of splitting an atomic nucleus into smaller fragments. Fusion occurs, energy is released. The major components of a fusion reactor are the core, control rods, coolant, and reactor vessel.
- Nuclear fusion occurs in a thermonuclear fusion reactor. When two heavy nuclei come together, the kinetic energy is released. This energy is converted into electrical energy by passing the reactants through a series of reactors.
- Nuclear fission occurs in a nuclear reactor. When a nucleus is fissioned, a small amount of energy is released. This energy is then converted into electrical energy by passing the reactants through a series of reactors.
- Nuclear reactors are used to produce energy. Three major types of nuclear reactor are: alpha, beta, and gamma.
- Nuclear reactors have their own characteristic emissions. Different types of radiation have different effects, and in terms of the health of humans and other organisms, it is important to know the type of radiation emitted and the half-life of the material.
- The nuclear fuel cycle consists of the mining and processing of uranium, the generation of nuclear power through controlled fusion, the reprocessing of spent fuel, the disposal of nuclear waste, and the decommissioning of power plants. Each step of the cycle is associated with environmental processes, all with different potential environmental problems.
- The presently operating light-water reactors use uranium-235 as fuel. Uranium-235 is a nonrenewable resource mined from the Earth. If many more breeder reactors were constructed, we would face fuel shortages. Nuclear energy based on burning uranium-235 in light-water reactors is thus not sustainable. For nuclear energy to be sustainable, safe, and economical, breeder reactors will need to be developed.
- Radioisotopes affect the environment in two major ways: by emitting radiation that affects other materials and by entering ecological food chains. Major environmental pathways by which radiation reaches people include: uptake by fish ingested by people, uptake by crops ingested by people, inhalation from air, and exposure to nuclear waste and the natural environment.
- The dose-response for radiation is fairly well established. We know the dose-response for higher exposures, when illness or death occurs. However, there are significant debates concerning the health effects of low-level exposure to radiation and what relationships exist between exposure and cancer mortality. Most scientists believe that radiation can cause cancer. Irradiation can be used to kill cancer cells, or in radionuclide treatments.
- We have learned from accidents at nuclear power plants that it is difficult to plan for the human factor. People make mistakes. We have also learned that we are not as prepared for accidents as we would like to think. Some people believe that humans are not really for the responsibility of nuclear power. Others believe that we can design such safer power plants where serious accidents are impossible.
- Transuranic nuclear waste is now being disposed of in salt beds—the first disposal of radioactive waste in the geologic environment in the United States.
- There is a consensus that high-level nuclear waste may be safely disposed of in the geologic environment. The problem has been to locate a site that is safe and not objectionable to the people who make the decisions and to those who live in the region.
- Nuclear power is again being seriously evaluated as an alternative to fossil fuels. On the one hand, it has advantages in that it emits no carbon dioxide, will not contribute to global warming or cause acid rain, and can be used to produce alternative fuels such as hydrogen. On the other hand, people are uncomfortable with nuclear power because of possible accidents and waste disposal problems.

**REFLECTING THEMES AND ISSUES**

As the human population has increased, so has demand for electrical power; as a result, a number of countries have turned to nuclear energy. The California energy crisis has caused many people in the United States to rethink the role of nuclear energy. Although relatively rare, accidents at nuclear power plants such as Chernobyl have exposed people to increased radiation. There is considerable debate over potential adverse effects of that radiation. Nevertheless, the fact remains that as the world population increases, and if the number of nuclear power plants increases, the total number of people exposed to a potential hazardous release of toxic radiation will increase as well.

It has been argued that sustainable energy development will require a return to nuclear energy, because nuclear energy does not contribute to a variety of environmental problems related to burning of fossil fuels. For nuclear energy to significantly contribute to sustainable energy development, however, we cannot depend on breeder reactors that will quickly use Earth's uranium resources, nuclear development of safer breeder reactors will be necessary.

Use of nuclear energy is part of our global management at the entire spectrum of energy sources. In addition, testing of nuclear weapons has spread radioactive isotopes around the entire planet, as well as having nuclear accidents. Radioactive isotopes that enter rivers and other waterways may eventually enter the oceans of the world, where oceanic circulation may further disperse and distribute them.

Development of nuclear energy is part of our technological and urban world. In some respects, it is near the pinnacle of our accomplishments in terms of technology.

Nuclear reactors are the source of heat for our sun and are fundamental processes of the universe. Nuclear fusion produces the larger elements of the universe. Our use of nuclear reactors in reactors to produce useful energy is a connection to a basic form of energy in nature. Abuse of nuclear reactors in weapons carries the possibility of disarming, or even destroying, nature on Earth.

We have a good deal of knowledge concerning nuclear energy and nuclear processes. However, people remain suspicious and, in some cases, frightened by nuclear power—partly because of the value they place on a quality environment and their perception that nuclear power is toxic to that environment. As a result, the future of nuclear energy will be related to political decisions based in part on the risk acceptable to society. It will also depend on research and development to produce much safer nuclear reactors.
KEY TERMS

- Breeder reactors 415
- Burner reactors 911
- Fusion 410
- Nuclear energy 410
- Nuclear fuel cycle 418
- Nuclear reactors 410
- Low-level radioactive waste 426
- Radioactive decay 412
- Radioisotope 421
- Transuranic waste 428

STUDY QUESTIONS

1. If exposure to radiation is a natural phenomenon, why are we worried about it?
2. What is a radioisotope, and why is knowing its half-life important?
3. What is the natural background radiation that people receive? Why is it variable?
4. What are the possible relationships between exposure to radiation and adverse health effects?
5. What processes in our environment may result in radioactive substances reaching people?

FURTHER READING


Chapter 21

Water Supply, Use, and Management

Although water is one of the most abundant resources on Earth, many important issues and challenges are involved in water management. After reading this chapter, you should understand:

- Why water is one of the major resource issues of the twenty-first century.
- What a water budget is, and why it is useful in analyzing water supply problems and potential solutions.
- What ground water is, and what environmental problems are associated with its use.
- How water can be conserved at home and in industrial and agricultural practice.
- Why sustainable water management will become more difficult as the demand for water increases.
- What the environmental impacts are of water projects such as dams, reservoirs, canals, and channelization.
- What is wetlands, and what wetland function, and why they are important.
- Why we are facing a growing global water shortage linked to our food supply.

Great Heron in the Wetlands near Palm Beach, Florida. D. Betts, Photograph