section 2

Nuclear Energy

Reading Guide

What You'll Learn

- **Explain** how a nuclear reactor converts nuclear energy to thermal energy.
- **Describe** advantages and disadvantages of using nuclear energy to produce electricity.
- **Discuss** nuclear fusion as a possible energy source.

Why It's Important

Using nuclear energy to produce electricity can help reduce the use of fossil fuels. However, like all energy sources, the use of nuclear energy has advantages and disadvantages.

Review Vocabulary

nuclear fission: the process of splitting an atomic nucleus into two or more nuclei with smaller masses

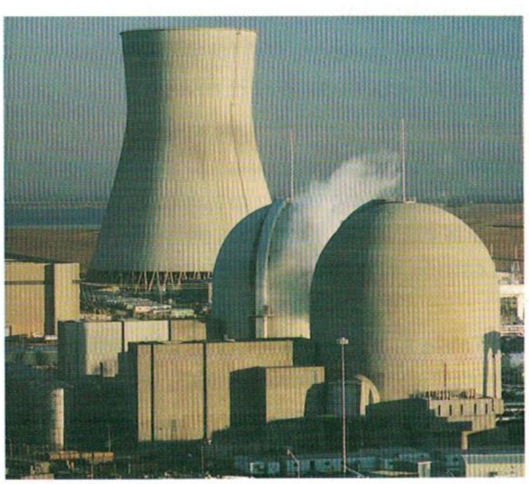
New Vocabulary

- nuclear reactor
- nuclear waste

Using Nuclear Energy

Over the past several decades, electric power plants have been developed that generate electricity without burning fossil fuels. Some of these power plants, such as the one shown in **Figure 11,** convert nuclear energy to electrical energy. Energy is released when the nucleus of an atom breaks apart. In this process, called nuclear fission, an extremely small amount of mass is converted into an enormous amount of energy. Today almost 20 percent of all the electricity produced in the United States comes from nuclear power plants. Overall, nuclear power plants produce about eight percent of all the energy consumed in the United States. In 2003, there were 104 nuclear reactors producing electricity at 65 nuclear power plants in the United States.

Figure 11 A nuclear power plant generates electricity using the energy released in nuclear fission. Each of the domes contain a nuclear reactor. A cooling tower is on the left.



Nuclear Reactors

A **nuclear reactor** uses the energy from controlled nuclear reactions to generate electricity. Although nuclear reactors vary in design, all have some parts in common, as shown in **Figure 12.** They contain a fuel that can be made to undergo nuclear fission; they contain control rods that are used to control the nuclear reactions; and they have a cooling system that keeps the reactor from being damaged by the heat produced. The actual fission of the radioactive fuel occurs in a relatively small part of the reactor known as the core.

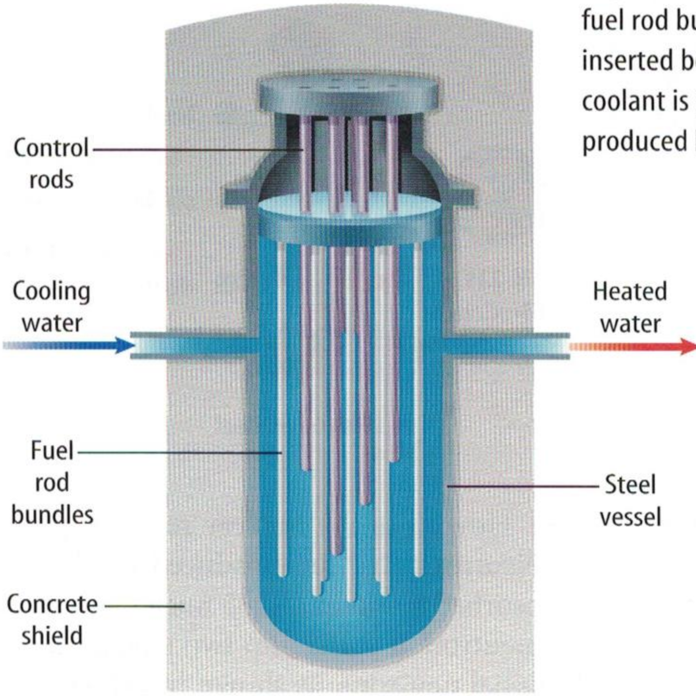
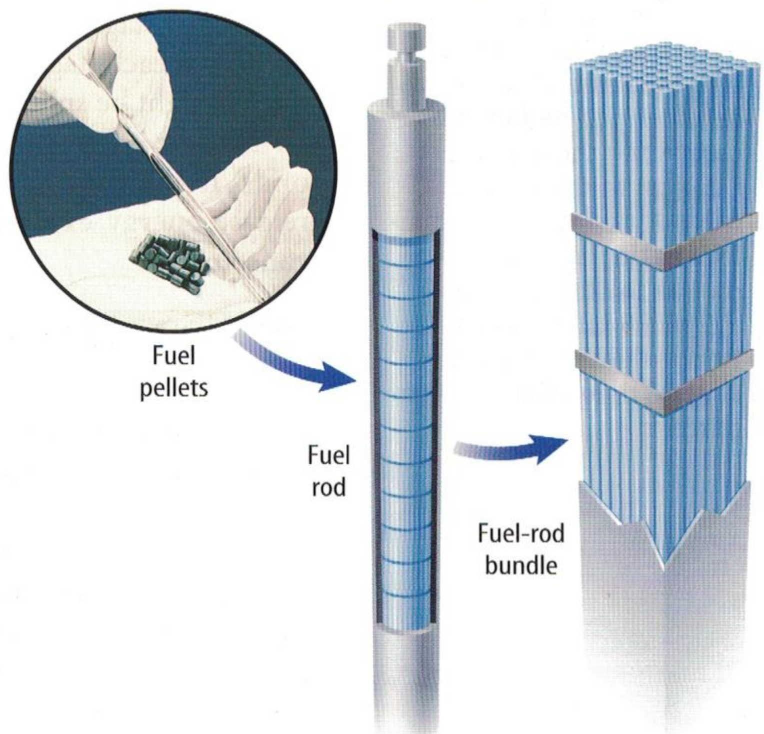


Figure 12 The core of a nuclear reactor contains the fuel rod bundles. Control rods that absorb neutrons are inserted between the fuel rod bundles. Water or another coolant is pumped through the core to remove the heat produced by the fission reaction.

Nuclear Fuel Only certain elements have nuclei that can undergo fission. Naturally occurring uranium contains an isotope, U-235, whose nucleus can split apart. As a result, the fuel that is used in a nuclear reactor is usually uranium dioxide. Naturally occurring uranium contains only about 0.7 percent of the U-235 isotope. In a reactor, the uranium usually is enriched so that it contains three percent to five percent U-235.

The Reactor Core The reactor core contains uranium dioxide fuel in the form of tiny pellets like the ones in **Figure 13.** The pellets are about the size of a pencil eraser and are placed end to end in a tube. The tubes are then bundled and covered with a metal alloy, as shown in **Figure 13.** The core of a typical reactor contains about a hundred thousand kilograms of uranium in hundreds of fuel rods. For every kilogram of uranium that undergoes fission in the core, 1 g of matter is converted into energy. The energy released by this gram of matter is equivalent to the energy released by burning more than 3 million kg of coal.

Figure 13 Nuclear fuel pellets are stacked together to form fuel rods. The fuel rods are bundled together, and the bundle is covered with a metal alloy.



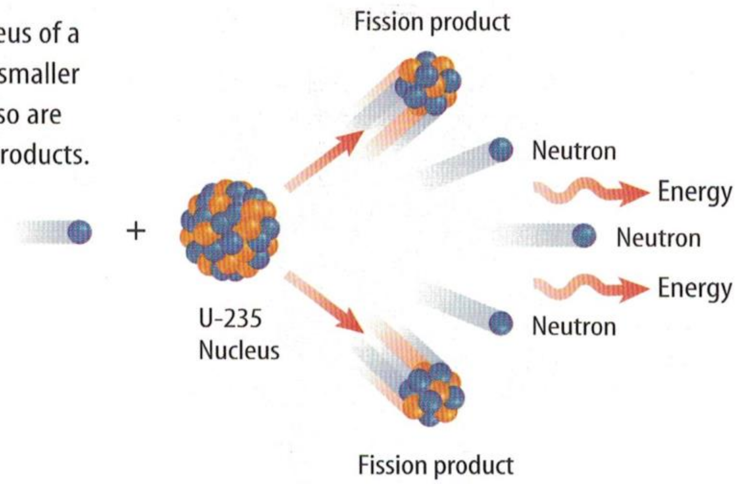


Figure 14 When a neutron strikes the nucleus of a U-235 atom, the nucleus splits apart into two smaller nuclei. In the process two or three neutrons also are emitted. The smaller nuclei are called fission products.
Explain *what happens to the neutrons that are released in this reaction.*

Nuclear Fission How does the nuclear reaction proceed in the reactor core? Neutrons that are produced by the decay of U-235 nuclei are absorbed by other U-235 nuclei. When a U-235 nucleus absorbs a neutron, it splits into two smaller nuclei and two or three additional neutrons, as shown in **Figure 14.** These neutrons strike other U-235 nuclei, causing them to release two or three more neutrons each when they split apart.

Because every uranium atom that splits apart releases neutrons that cause other uranium atoms to split apart, this process is called a nuclear chain reaction. In the chain reaction involving the fission of uranium nuclei, the number of nuclei that are split can more than double at each stage of the process. As a result, an enormous number of nuclei can be split after only a small number of stages. For example, if the number of nuclei involved doubles at each stage, after only 50 stages more than a quadrillion nuclei might be split.

Nuclear chain reactions take place in a matter of milliseconds. If the process isn't controlled, the chain reaction will release energy explosively rather than releasing energy at a constant rate.

Reading Check *What is a nuclear chain reaction?*

INTEGRATE Earth Science

Uranium-Lead Dating
Uranium is used to determine the age of rocks. As uranium decays into lead at a constant rate, the age of a rock can be found by comparing the amount of uranium to the amount of lead produced. Uranium-lead dating is used by scientists to date rocks as old as 4.6 billion years. Research other methods used to determine the age of rocks.

Controlling the Chain Reaction To control the chain reaction, some of the neutrons that are released when U-235 splits apart must be prevented from striking other U-235 nuclei. These neutrons are absorbed by rods containing boron or cadmium that are inserted into the reactor core. Moving these control rods deeper into the reactor causes them to absorb more neutrons and slow down the chain reaction. Eventually, only one of the neutrons released in the fission of each of the U-235 nuclei strikes another U-235 nucleus, and energy is released at a constant rate.

Nuclear Power Plants

Nuclear fission reactors produce electricity in much the same way that conventional power plants do. **Figure 15** shows how a nuclear reactor produces electricity. The thermal energy released in nuclear fission is used to heat water and produce steam. This steam then is used to drive a turbine that rotates an electric generator. To transfer thermal energy from the reactor core to heat water and produce steam, the core is immersed in a fluid coolant. The coolant absorbs heat from the core and is pumped through a heat exchanger. There thermal energy is transferred from the coolant and boils water to produce steam. The overall efficiency of nuclear power plants is about 35 percent, similar to that of fossil fuel power plants.

INTEGRATE Social Studies

Ukraine The worst nuclear accident in history occurred at the Chernobyl nuclear power plant in the Ukraine in 1986. Many people in the area suffered from radiation sickness. Use a map or atlas to find the location of the Ukraine. Write a description of the location in your Science Journal.

The Risks of Nuclear Power

Producing energy from nuclear fission has some disadvantages. Nuclear power plants do not produce the air pollutants that are released by fossil-fuel burning power plants. Also, nuclear power plants don't produce carbon dioxide.

The nuclear generation of electricity, however, has its problems. The mining of the uranium can cause environmental damage. Water that is used as a coolant in the reactor core must cool before it is released into streams and rivers. Otherwise, the excess heat could harm fish and other animals and plants in the water.

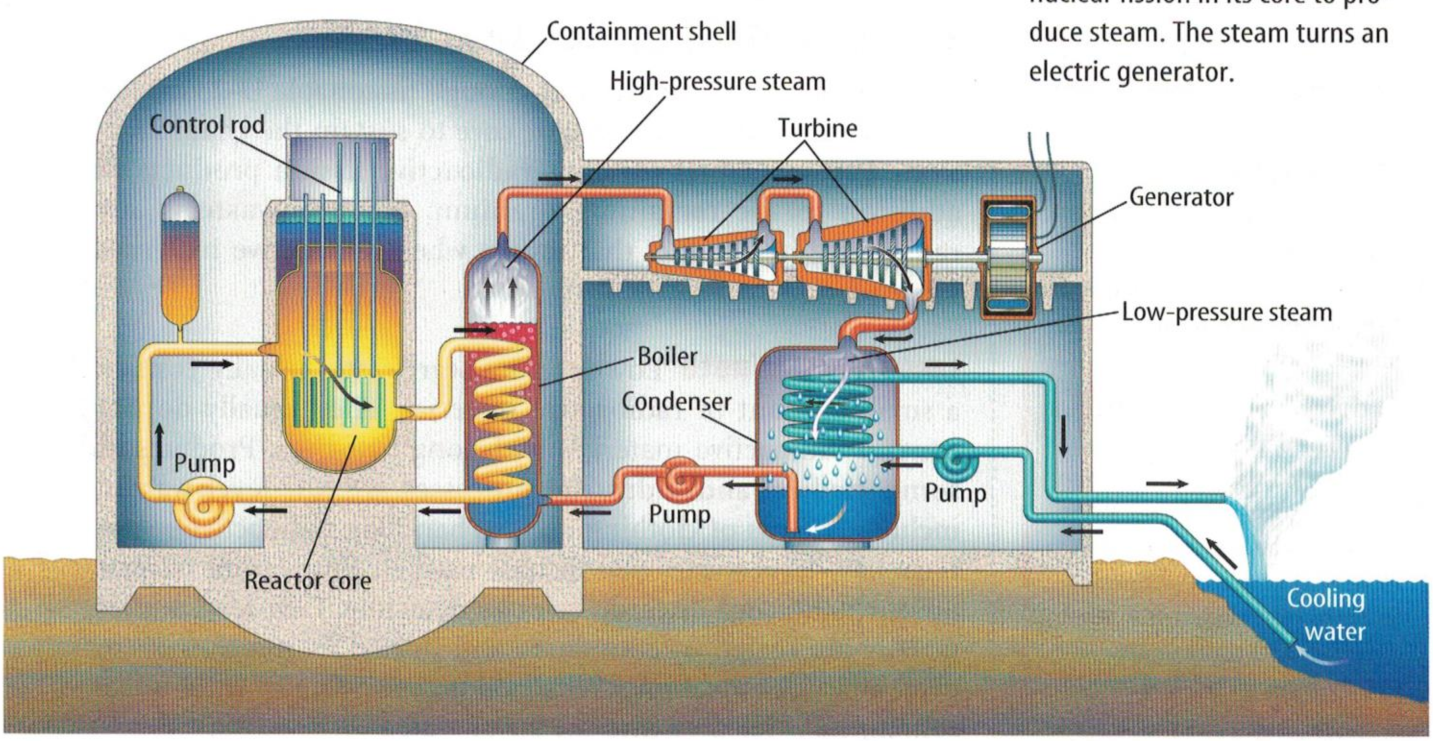


Figure 15 A nuclear power plant uses the heat produced by nuclear fission in its core to produce steam. The steam turns an electric generator.

Figure 16 An explosion occurred at the Chernobyl reactor in the Ukraine after graphite control rods caught fire. The explosion shattered the reactor's roof.

The Release of Radioactivity One of the most serious risks of nuclear power is the escape of harmful radiation from power plants. The fuel rods contain radioactive elements with various half-lives. Some of these elements could cause damage to living organisms if they were released from the reactor core. Nuclear reactors have elaborate systems of safeguards, strict safety precautions, and highly trained workers in order to prevent accidents. In spite of this, accidents have occurred.

For example, in 1986 in Chernobyl, Ukraine, an accident occurred when a reactor core overheated during a safety test. Materials in the core caught fire and caused a chemical explosion that blew a hole in the reactor, as shown in **Figure 16.** This resulted in the release of radioactive materials that were carried by winds and deposited over a large area. As a result of the accident, 28 people died of acute radiation sickness. It is possible that 260,000 people might have been exposed to levels of radiation that could affect their health.

In the United States, power plants are designed to prevent accidents such as the one that occurred at Chernobyl. But many people still are concerned that similar accidents are possible.

The Disposal of Nuclear Waste

After about three years, not enough fissionable U-235 is left in the fuel pellets in the reactor core to sustain the chain reaction. The spent fuel contains radioactive fission products in addition to the remaining uranium. **Nuclear waste** is any radioactive by-product that results when radioactive materials are used.

Low-Level Waste Low-level nuclear wastes usually contain a small amount of radioactive material. They usually do not contain radioactive materials with long half-lives. Products of some medical and industrial processes are low-level wastes, including items of clothing used in handling radioactive materials. Low-level wastes also include used air filters from nuclear power plants and discarded smoke detectors. Low-level wastes usually are sealed in containers and buried in trenches 30 m deep at special locations. When dilute enough, low-level waste sometimes is released into the air or water.

ScienceOnline

Topic: Storing Nuclear Wastes

Visit gpscience.com for Web links to information about storing nuclear wastes.

Activity Obtain a map or sketch an outline of the United States. Mark the locations of the nuclear waste sites that you found. What do these locations have in common? Why do you think these locations were chosen over other sites that were closer to the nuclear waste generating sites?

High-Level Waste High-level nuclear waste is generated in nuclear power plants and by nuclear weapons programs. After spent fuel is removed from a reactor, it is stored in a deep pool of water, as shown in **Figure 17.** Many of the radioactive materials in high-level nuclear waste have short half-lives. However, the spent fuel also contains materials that will remain radioactive for tens of thousands of years. For this reason, the waste must be disposed of in extremely durable and stable containers.

Reading Check *What is the difference between low-level and high-level nuclear wastes?*

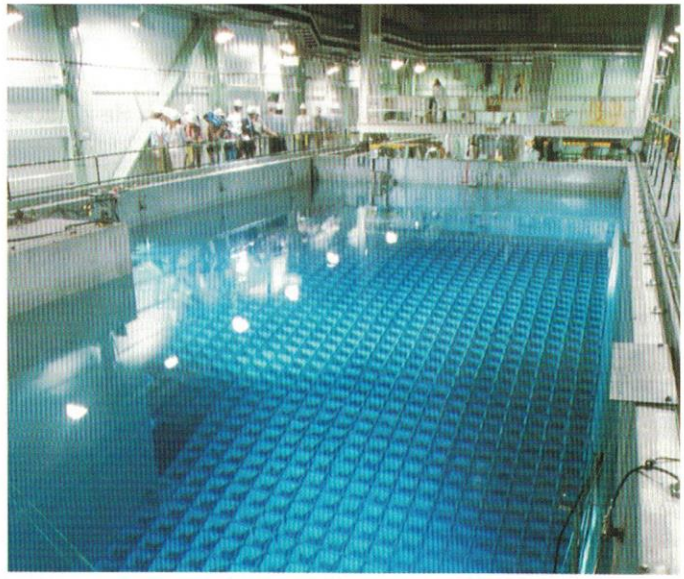


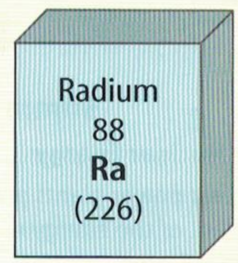
Figure 17 Spent nuclear fuel rods are placed underwater after they are removed from the reactor core. The water absorbs the nuclear radiation and prevents it from escaping into the environment.

One method proposed for the disposal of high-level waste is to seal the waste in ceramic glass, which is placed in protective metal-alloy containers. The containers then are buried hundreds of meters below ground in stable rock formations or salt deposits. It is hoped that this will keep the material from contaminating the environment for thousands of years.

Applying Science

Can a contaminated radioactive site be reclaimed?

In the early 1900s, with the discovery of radium, extensive mining for the element began in the Denver, Colorado, area. Radium is a radioactive element that was used to make watch dials and instrument panels that glowed in the dark. After World War I, the radium industry collapsed. The area was left contaminated with 97,000 tons of radioactive soil and debris containing heavy metals and radium, which is now known to cause cancer. The soil was used as fill, foundation material, left in place, or mishandled.



Identifying the Problem

In the 1980s, one area became known as the Denver Radium Superfund Site and was cleaned up by the Environmental Protection Agency. The land then was reclaimed by a local commercial establishment.

Solving the Problem

1. The contaminated soil was placed in one area and a protective cap was placed over it. This area also was restricted from being used for residential homes. Explain why it is important for the protective cap to be maintained and why homes could not be built in this area.
2. The advantages of cleaning up this site are economical, environmental, and social. Give an example of each.

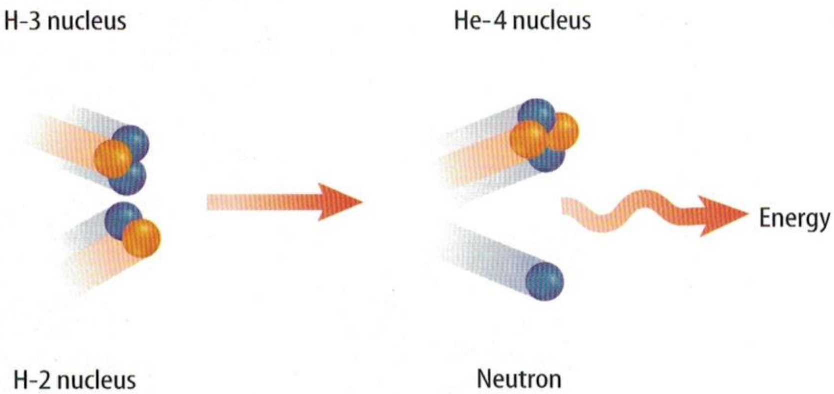


Figure 18 In nuclear fusion, two smaller nuclei join together to form a larger nucleus. Energy is released in the process. In the reaction shown here, two isotopes of hydrogen come together to form a helium nucleus.
Identify *the source of the energy released in a fusion reaction.*

Nuclear Fusion

The Sun gives off a tremendous amount of energy through a process called thermonuclear fusion. Thermonuclear fusion is the joining together of small nuclei at high temperatures, as shown in **Figure 18.** In this process, a small amount of mass is converted into energy. Fusion is the most concentrated energy source known.

An advantage of producing energy using nuclear fusion is that the process uses hydrogen as fuel. Hydrogen is abundant on Earth. Another advantage is that the product of the reaction is helium. Helium is not radioactive and is chemically nonreactive.

One disadvantage of fusion is that it occurs only at temperatures of millions of degrees Celsius. Research reactors often consume more energy to reach and maintain these temperatures than they produce. Another problem is how to contain a reaction that occurs at such extreme conditions. Until solutions to these and other problems are found, the use of nuclear fusion as an energy source is not practical.

section 2 review

Summary

Using Nuclear Energy

- Nuclear power plants produce about eight percent of the energy used each year in the United States.

Nuclear Power Plants

- Nuclear reactors use the energy released in the fission of U-235 to produce electricity.
- The energy released in the fission reaction is used to make steam. The steam drives a turbine that rotates an electric generator.

The Risks of Nuclear Energy

- Nuclear power generation produces high-level nuclear wastes.
- Organisms could be damaged if radiation is released from the reactor.
- Nuclear waste is the radioactive by-product produced by using radioactive materials.

Self Check

1. **Explain** why a chain reaction occurs when uranium-235 undergoes fission.
2. **Describe** how the chain reaction in a nuclear reactor is controlled.
3. **Compare** the advantages and disadvantages of nuclear power plants and those that burn fossil fuels.
4. **Describe** the advantages and disadvantages of using nuclear fusion reactions as a source of energy.
5. **Think Critically** A research project produced 10 g of nuclear waste with a short half-life. How would you classify this waste and how would it be disposed of?

Applying Math

6. **Use Percentages** Naturally occurring uranium contains 0.72 percent of the isotope uranium-235. What is the mass of uranium-235 in 2,000 kg of naturally-occurring uranium?

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