Environmental Science, 1e

SUSTAINING YOUR WORLD

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12

Nonrenewable Energy Resources

Section 3

What Are the Advantages and Disadvantages of Using Nuclear Power?

12.3 What Are the Advantages and Disadvantages of Using Nuclear Power?

CORE IDEAS AND SKILLS

- Understand how a nuclear fission reaction works, and describe the nuclear fuel cycle.
- Explain the advantages and disadvantages of using nuclear power.
- Discuss the future of nuclear power.

KEY TERMS

nuclear fission nuclear fusion

Plus 5 Checkpoints

12.3 What Are the Advantages and Disadvantages of Using Nuclear Power?

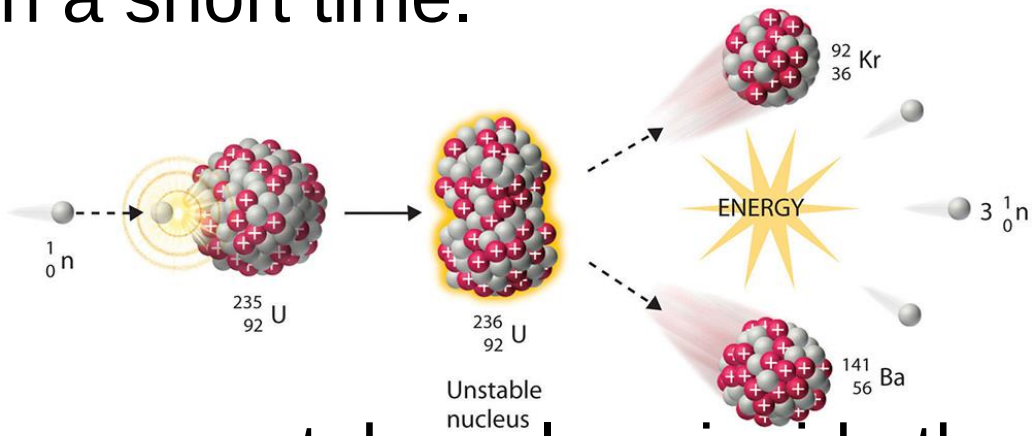
- Nuclear power has a low environmental impact, but its use has been limited by:
  - A low net energy, high costs, fear of accidents, and long-lived radioactive wastes
  - Its role in spreading nuclear weapons technology

Nuclear Fission Generates Power

- Like fossil fuels, nuclear power falls under the category of nonrenewable energy resources.
- Nuclear power requires the mineral uranium-235, which is mined from limited ores in Earth's crust.
- The world's three leading producers of nuclear power are, in order, the United States, France, and Russia.
- Inside both nuclear and fossil-fuel power plants, water is boiled to produce steam that spins a turbine and generates electricity. In fossil-fuel power plants, fossil fuels are burned to produce heat to boil water.
- Nuclear power production involves a more complex and costly process. A controlled nuclear fission reaction is carried out to provide the necessary heat.

Nuclear Fission Generates Power

- Nuclear fission occurs when a neutron is used to split a large nucleus into two or more smaller nuclei.
- Each fission reaction releases neutrons, which results in a chain reaction that releases an enormous amount of energy in a short time.



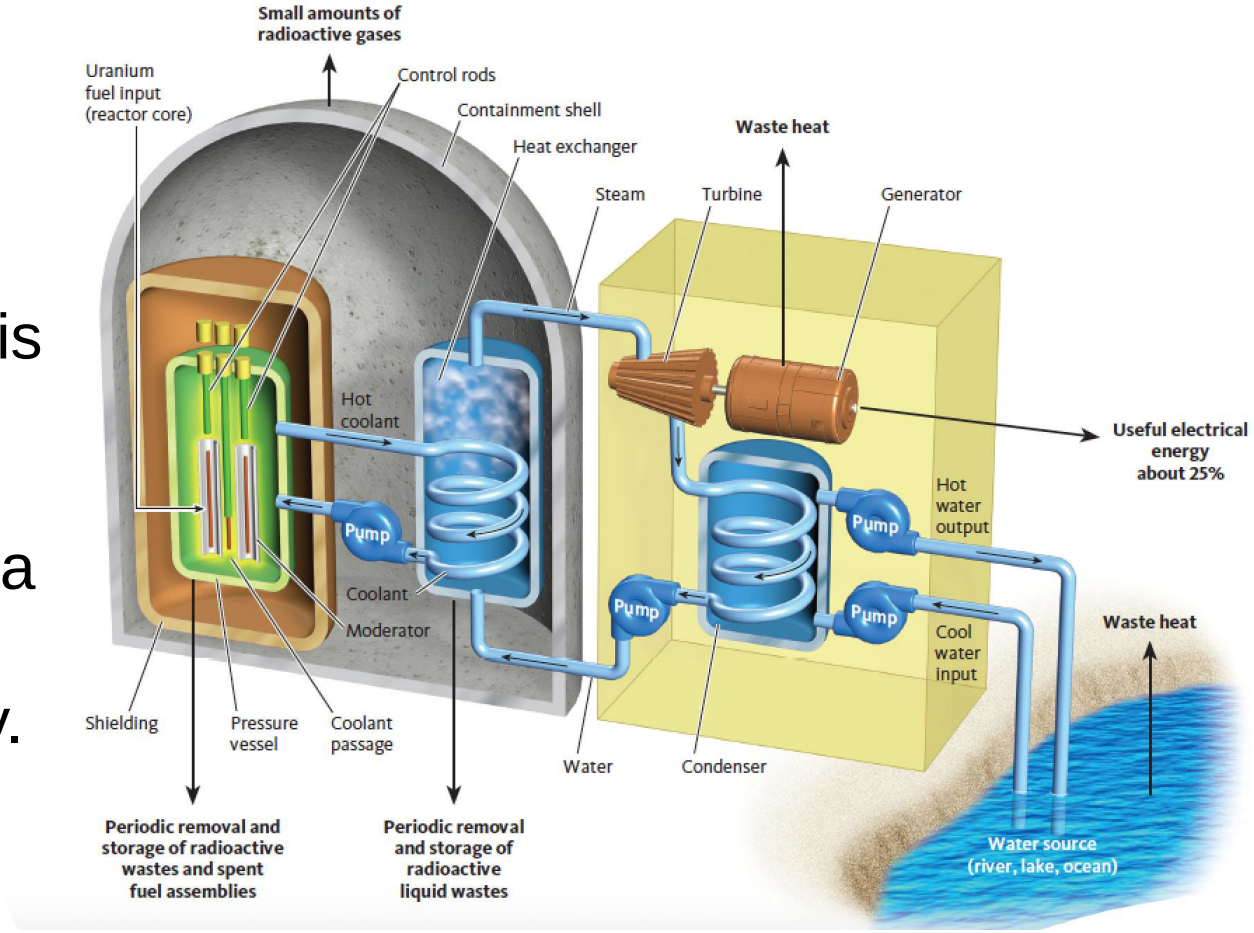
- The whole process takes place inside the reactor of a nuclear power plant

How Does a Nuclear Fission Reactor Work?- OVERVIEW-

- Controlled nuclear fission: a neutron is used to split a large nucleus into two or more smaller nuclei
  - Carried out in light-water reactor
  - Fueled by uranium ore
  - Enormous amount of energy released in short time
  - Heat used to generate electricity

Electricity from Nuclear Fuel

Nuclear-Generated Electricity: Intense heat produced by nuclear reactions within the core of this power plant is used to convert water to steam, which spins a turbine that generates electricity.



NUCLEAR FISSION REACTORS

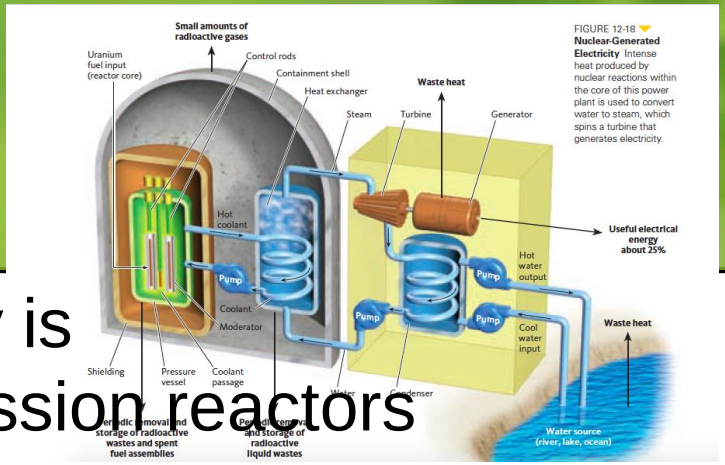


FIGURE 12-18 **Nuclear-Generated Electricity** Intense heat produced by nuclear reactions within the core of this power plant is used to convert water to steam, which spins a turbine that generates electricity.

- Most nuclear-generated electricity is produced by light-water nuclear fission reactors
- The fuel for this type of reactor is made from uranium ore. After the uranium ore is mined, it is enriched to increase the concentration of its fissionable material (uranium-235) to about 5%.
- Enriched uranium-235 is processed into small pellets of uranium dioxide Each pellet, about the size of a pencil eraser, contains as much energy as a ton of coal.
- Large numbers of pellets are packed into closed pipes called fuel rods. The rods are bundled together in fuel assemblies and placed in the reactor core.

NUCLEAR FISSION REACTORS

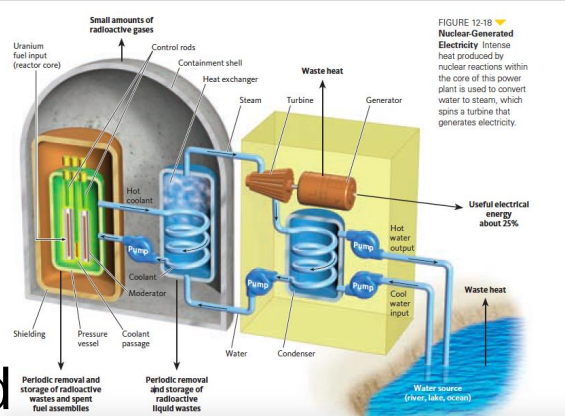


FIGURE 12-18 **Nuclear-Generated Electricity** Intense heat produced by nuclear reactions within the core of this power plant is used to convert water to steam, which spins a turbine that generates electricity.

- To regulate how much power is produced, plant operators use control rods, moving them into and out of the reactor core to absorb more or fewer neutrons.
- This slows down or speeds up the fission reaction.
- A coolant, usually fresh water, circulates through the core to prevent fuel rods and other components from melting and releasing massive amounts of radioactivity into the environment.
- An emergency core cooling system also protects against meltdowns.
- A containment shell made of thick, steel-reinforced concrete surrounds the reactor core. It is designed to keep radioactive materials from escaping into the environment if an internal explosion or a core meltdown occurs.
- It also protects the core from external threats such as weather disasters.

NUCLEAR FISSION REACTORS

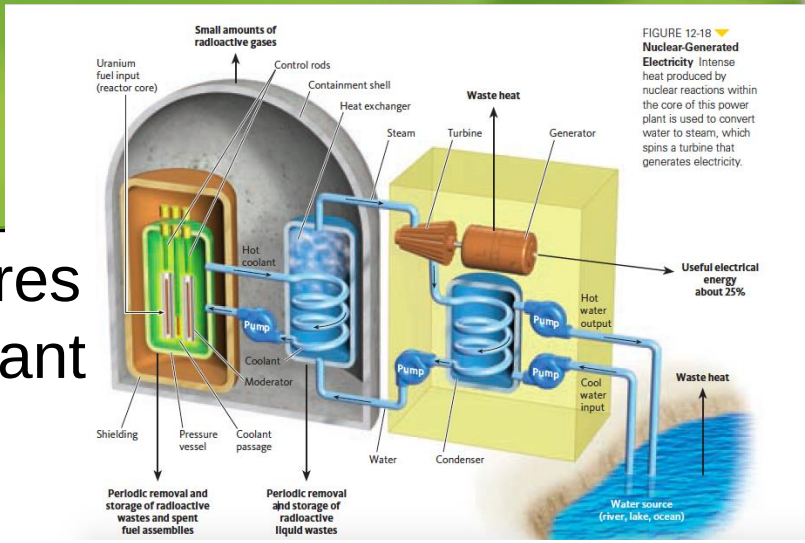


FIGURE 12-18 **Nuclear-Generated Electricity** Intense heat produced by nuclear reactions within the core of this power plant is used to convert water to steam, which spins a turbine that generates electricity.

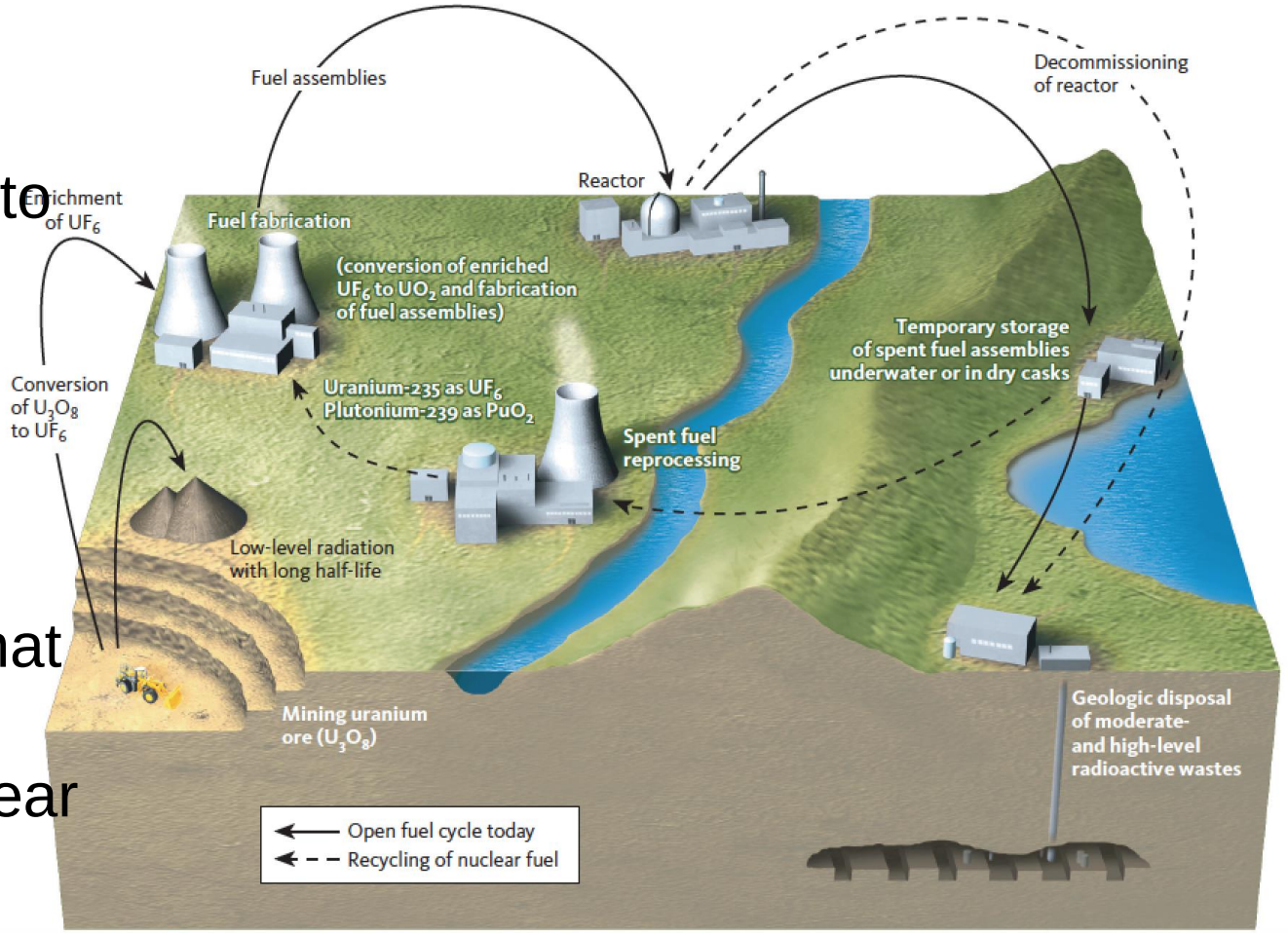
- The need for all these safety features means building a nuclear power plant can cost $10 billion or more.

Thinking Critically

- 1. Most of the space in this power plant is taken up by equipment that . . .
- 2. The plant is located near water because . . .
- 3. The waste that escapes naturally from this plant doesn't appear to be harmful because . .
- **4. Make Judgments** Would you feel comfortable living near a nuclear power plant? Why or why not?

Nuclear Fuel Cycle

Nuclear Fuel Cycle: Using nuclear power to produce electricity involves a sequence of steps and technologies that together are called the nuclear fuel cycle.



Nuclear Fuel Cycle

- Building and running a nuclear power plant is only one part of the nuclear fuel cycle.
- This cycle includes the mining of uranium, processing and enriching the uranium to make fuel, using it in a reactor, and safely storing the resulting highly radioactive wastes for thousands of years until their radioactivity falls to safe levels.

Steps of the Nuclear Fuel Cycle -OVERVIEW-

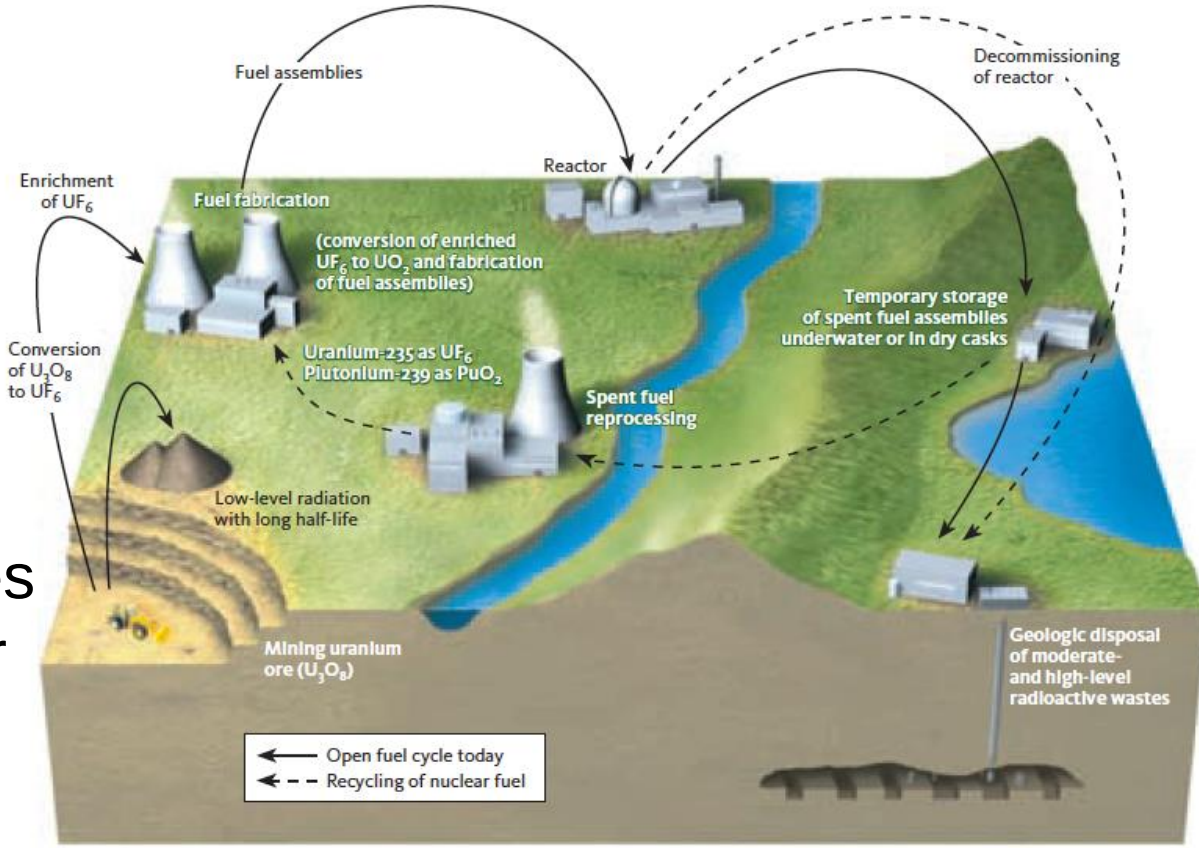
- Mine the uranium.
- Process and enrich the uranium to make the fuel.
- Use it in the reactor.
- Safely store the highly radioactive waste for thousands of years until the radioactivity falls to safe levels.
- Decommission the reactor.

Nuclear Fuel Cycle

Figure 12-17 shows, via the dashed lines, two possible alternatives for nuclear fuel rods used in nuclear power

- 1. How are the two processes different?
- 2. The United States doesn't currently use the reprocessing route for its spent nuclear rods. Infer why.
- (Keep these responses in mind and to look for the reasons as you continue the lesson.)

FIGURE 12-17
Nuclear Fuel Cycle Using nuclear power to produce electricity involves a sequence of steps and technologies that together are called the nuclear fuel cycle.



Nuclear Power Presents Environmental Challenges

- Using nuclear power has some advantages, but it also has disadvantages and challenges.
- As long as a reactor is operating safely, the power plant itself has a fairly low environmental impact and little risk of an accident. However, when considering the entire nuclear fuel cycle, potential environmental impacts increase significantly.
- Those who support nuclear power claim that increased use of this energy resource could greatly reduce CO2 emissions. As a result, it could help slow climate change.
- Scientists point out that this is only partially correct.

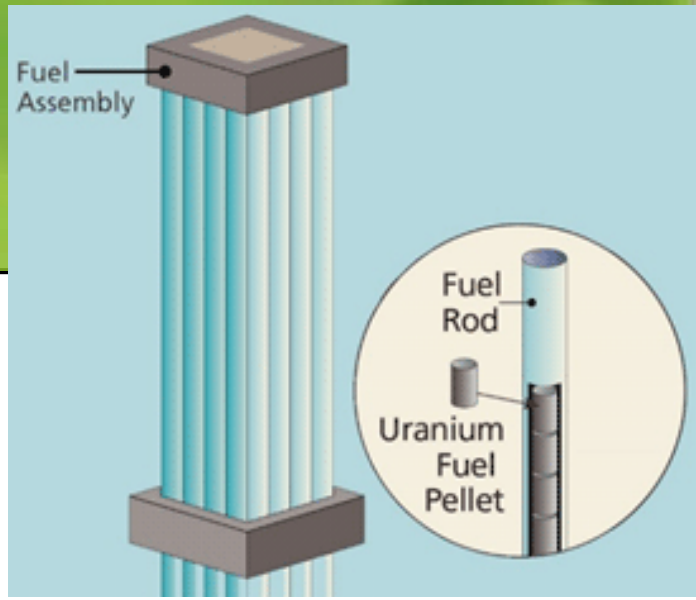
Nuclear Power Presents Environmental Challenges

- While nuclear plants are operating, they do not emit CO2. However, during the 10 years it typically takes to build a plant, large amounts of CO2 are emitted, especially in the manufacturing of huge quantities of construction cement.
- Every other step in the nuclear fuel cycle also results in the release of CO2 .
- Such emissions may be much lower than emissions from coal-burning power plants, but they still contribute to atmospheric warming and climate change.

Nuclear Power Presents Environmental Challenges

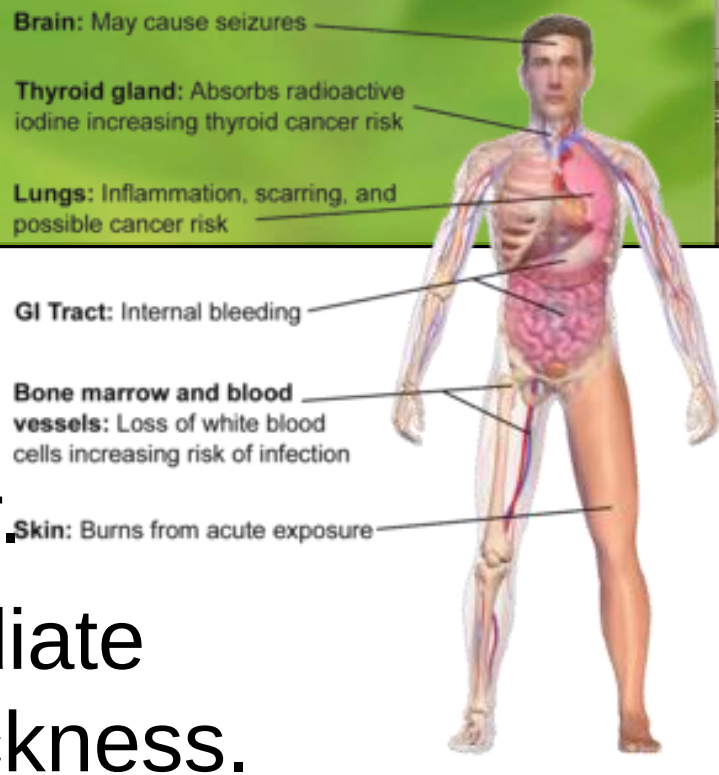
- Nuclear power plants do not emit air pollutants as long as the plant operates without problems.
- Modern plants perform with little risk, but many of the nuclear reactors in the United States are aging.
- The average age of nuclear plants in the United States is 34 years, and worldwide it is 25 years.
  - * Note* Our text was written in 2015- You could add 5 years to the ages given
- Plants are licensed to operate for 40 years and can request a 20-year extension before the plant is shut down.

Dealing with Radioactive Nuclear Wastes



- Uranium lasts only 3 to 4 years before it's spent (useless) and must be replaced.
  - Spent rods are too hot and radioactive to throw away:
  - Researchers found that 10 years after being removed from a reactor, a single spent fuel rod assembly can still emit enough radiation to kill a person standing 1 meter (39 inches) away in less than three minutes

Dealing with Radioactive Nuclear Wastes



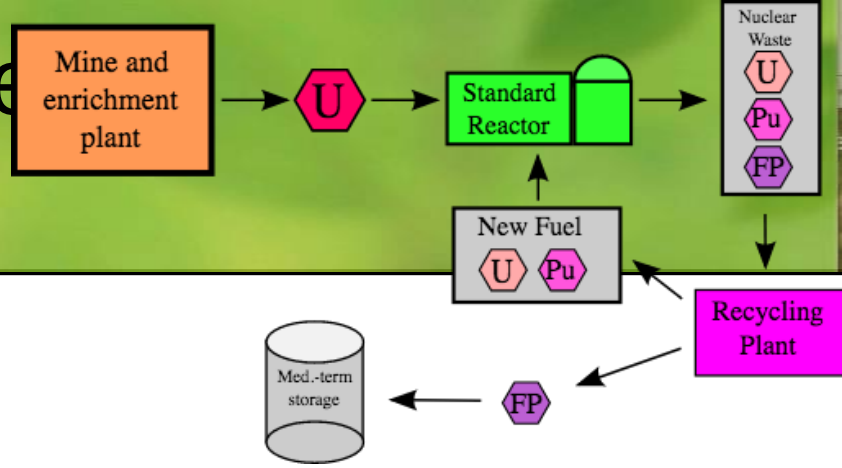
Selected Risks from Radiation Sickness

- Human exposure to even low levels of radiation over a long period can cause cancer.
- High doses can cause immediate death or delayed radiation sickness.
  - Symptoms of radiation sickness include weakness, burns, reduced organ function, nausea, and hair loss.

Dealing with Radioactive Nuclear Wastes

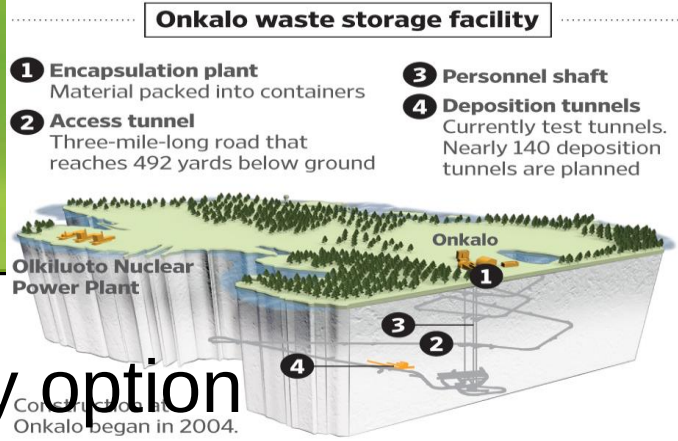
- Spent rods must be stored safely for 10,000–240,000 years
- After removal, they are stored in water-filled pools for several years then transferred to dry cask storage (this only lasts about 20 years, just a fraction of time needed for safe disposal)
- Security at storage sites is also a concern. One study warns that the waste storage pools and dry casks at two-thirds of the United States' commercial nuclear reactors are especially vulnerable to sabotage or terrorist attack.

Dealing with Radioactive Nuclear Wastes



- Reprocessing an option but very costly
  - Removes radioactive plutonium which a nation or terrorist can then use to make bombs.
  - Reduces storage time from 240,000 to 10,000 (Comparison: Modern humans only evolved 200,000 years ago)
  - US Spent billions of dollars on this but abandoned it in 1977- a few other countries still reprocess their nuclear fuel

Dealing with Radioactive Nuclear Wastes



- Deep burial for thousands of years is the safest but most costly option
- And scientists are still not able to verify that deep burial is the answer. After 60 years of research, there is no widely accepted or tested way to store such waste safely for thousands of years. As research continues, these deadly wastes are building up. In the United States, about 78% of nuclear waste is stored in pools and 22% is stored in dry casks. This practice takes care of waste for 100 years at very most.
- Still no acceptable method of handling

Decommissioning Old Nuclear Power Plants

- Modern plants perform with little risk, but many of the nuclear reactors in the United States are aging. The average age of nuclear plants in the United States is 34 years, and worldwide it is 25 years.
- Plants are licensed to operate for only 40 years and can request a 20-year extension before the plant is shut down
- Over half the commercial nuclear reactors operating worldwide in 2014 will have to be decommissioned by 2025. New nuclear reactors can not be built fast enough to replace the aging reactors that must be retired

Decommissioning Old Nuclear Power Plants

- Three ways to decommission or retire an aging power plant
  - Dismantle plant and safely store the radioactive materials
  - Enclose plant behind a physical barrier with full-time security until a storage facility has been built
  - Enclose the plant in a concrete and steel tomb
    - Monitor this for thousands of years
- Regardless of the method chosen, the high cost of retiring nuclear plants adds to the enormous cost of the nuclear fuel cycle and reduces its already low net energy.
- Even if all the nuclear power plants in the world were shut down tomorrow, their high-level radioactive wastes and components would need to be safely contained for thousands of years.

Nuclear Accidents Spread Uncertainty

- Loss of coolant water causes a meltdown in the reactor core.
  - Without the cooling water, the core of the reactor can experience a meltdown. Explosions and meltdowns can release radioactivity into the environment. Between 1952 and 2015, 34 serious nuclear “incidents” or “accidents” occurred worldwide
  - Three Mile Island (United States)
  - Chernobyl (Ukraine)
  - Fukushima Daiichi (Japan)

INTERPRET VISUALS
Visiting Chernobyl

FIGURE 12-21
Return to Chernobyl Tourists visit Pripyat, a town in the Chernobyl Exclusion Zone, 25 years after the 1986 accident. The man wearing the gas mask brought it along as a prop to have his picture taken in it. The area has been declared safe enough for day tours.

- Figure 12-21 shows people who are visiting the Chernobyl Exclusion Zone, an area that remains radioactive but has been opened for day tours.
- Consider the dilapidated appearance of the structure in which the visitors stand and study the apparel they wear.
- 1. Why are the people wearing protective clothing years after the accident?
- 2. Why would people want to go into an area like this?
- 3. Would you take this tour into the Exclusion Zone? Explain your answer.

ARTS IN SCIENCE
Nuclear Incidents in the News

Screen these videos of the 1979 ABC & CBS News report on the incident at Three Mile Island, which can be viewed https://www.youtube.com/watch?v=Ev6IJOlROto

https://youtube.com/watch?v=2VRdkTvv878

- 1. If I saw this report on television at the time, I would have thought that . . .
- 2. If I lived near Three Mile Island, I would have . . .
- 3. After hearing about the incident at Three Mile Island, my view of nuclear power would have been . . .
- 4. Evidence that leads me to say this report was balanced and based on facts/sensational and based on hearsay include . . .

Art Imitates Life
Three Mile Island & “China Syndrome”

Watch the Original Movie Trailer:

https://www.youtube.com/watch?v=bIGH1AfIS18

The movie, released about the same time as the Three Mile Island incident, centered on a similar, fictional accident at a nuclear power plant in California. Prompts:

1. I think that the movie was realistic in that it…

2. The point of view the movie’s producers had in mind was…

3. I believe/do not believe that something like this could happen now because…

4. The movie makes me more/less concerned about nuclear power because..

Experts Disagree about the Future of Nuclear Power

- Proponents of nuclear power:
  - No CO_2 emissions during plant operation
  - Research potentially cheaper/safer reactors
  - Develop nuclear fusion
  - Continue subsidies
- Opponents of nuclear power:
  - Risk of accidents
  - Damage to environment
  - Nuclear weapons

FIGURE 12-22

The Nuclear Fuel Cycle	
Advantages	**Disadvantages**
Low environmental impact (without accidents)	Low net energy
Emits one-sixth as much CO_2 as coal	Higher overall cost
Low risk of accidents in modern plants	Produces long-lived, harmful radioactive wastes
	Promotes availability of nuclear weapons

Government Subsidies and Spending

- The U.S. government has provided large research and development subsidies, tax breaks, and loan guarantees to the nuclear industry for more than 50 years.
- It has assumed most of the financial burden of developing ways to store radioactive wastes.
- In addition, the government has provided accident insurance guarantees because insurance companies refuse to insure fully any nuclear reactor against the effects of a catastrophic accident.

Government Subsidies and Spending

- Since 1948, the U.S. government has spent $95 billion on nuclear energy research and development.
- This is more than four times the amount spent on research and development for all forms of renewable energy combined.
- Many people question the need for continuing taxpayer support for nuclear power, especially since its energy output is not increasing.

Safety Concerns

- A serious safety concern related to commercial nuclear power is the spread of nuclear weapons technology.
- In the international marketplace, the United States and eight other countries have been selling commercial and experimental nuclear reactors and uranium fuel enrichment and purification technology for decades.
- Much of this information and equipment can be used to produce bomb-grade uranium and plutonium for use in nuclear weapons.

New Nuclear must meet 5 criteria to be environmentally and economically acceptable.

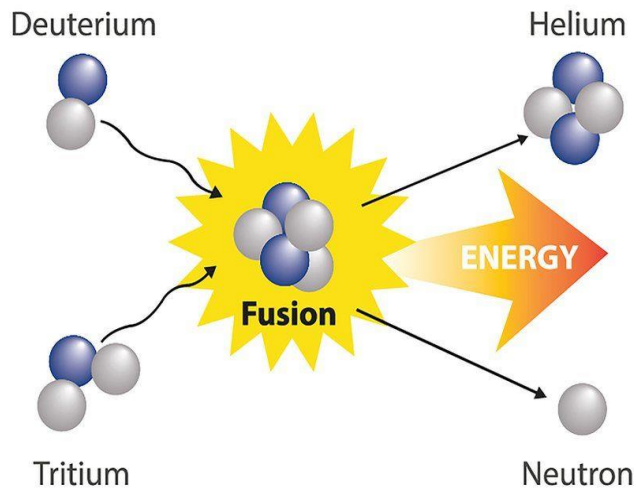
- **1.** Reactors must be built so that a runaway chain reaction is impossible.
- **2.** Fuel used in reactors and methods of fuel enrichment and fuel reprocessing must not lend themselves to production of nuclear weapons.
- **3.** Spent fuel and dismantled structures must be easy to dispose of without burdening future generations with harmful radioactive waste.

New Nuclear must meet 5 criteria to be environmentally and economically acceptable.

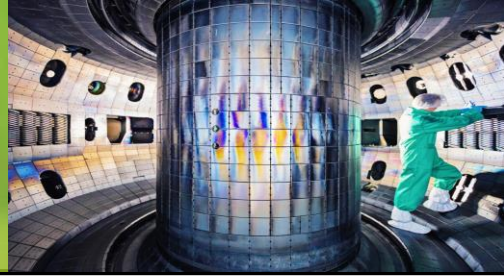
- **4.** Taking its entire fuel cycle into account, nuclear power must generate a net energy high enough to eliminate the need for government subsidies, tax breaks, or loan guarantees to compete in the open marketplace.
- **5.** The entire nuclear fuel cycle must generate fewer greenhouse gas emissions than other energy alternatives

Is Nuclear Fusion the Answer?

- In **nuclear fusion**, the nuclei of two isotopes of a light element, such as hydrogen, are forced together at extremely high temperatures until they fuse to form a heavier nucleus, releasing tremendous energy in the process.
- Some scientists hope controlled nuclear fusion can provide a limitless source of energy with fewer risks.

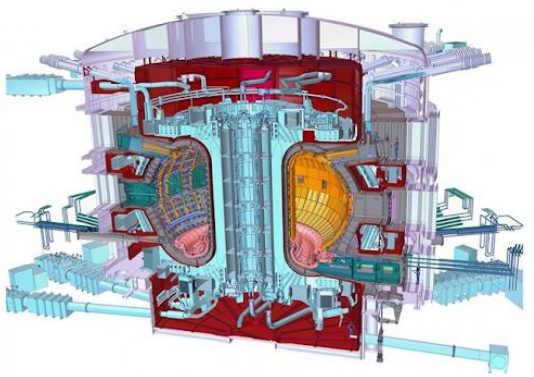


Other Possibilities of Nuclear Fusion



- Fusion power also might be used
  - to destroy toxic wastes,
  - to supply electricity for desalinating water, and
  - to help produce hydrogen fuel as a clean-burning energy source.
- In the United States, after more than 50 years of research and a $25 billion investment (mostly by the government), controlled nuclear fusion is still in its infancy. None of the tested approaches have been able to produce more energy than they used.

The Power of the Future



- In 2006, the United States, China, Russia, Japan, South Korea, India, and the European Union agreed to invest $12.8 billion in a joint effort to build a large-scale experimental nuclear fusion reactor by 2026. This will determine if fusion can produce net energy at an affordable cost.
- By 2014, the estimated cost of this project had doubled and was far behind schedule.
- Unless there is an unexpected scientific breakthrough, some skeptics say, “Nuclear fusion is the power of the future—and always will be.”

12.3 Summary

- Nuclear fission of uranium-235 fuel in a power plant produces heat that can be used to produce electricity.
- The nuclear fuel cycle describes all aspects of producing energy from nuclear fission reactions.
- Nuclear power emits fewer air pollutants and much less CO2 than burning coal.
- Because of its low net energy and high cost, the nuclear fuel cycle must be subsidized to compete in the marketplace.
- Nuclear power plant accidents are rare, but major accidents have released radioactive materials into the environment. Because of this risk and the high cost of the nuclear fuel cycle, some countries are phasing out their use of nuclear power.

12:3 Quick Check of Core Ideas and Skills

Change these FALSE statements to make them true.

- • During nuclear fission, atoms are heated to release energy.
- • The fuel for nuclear fission reactions is the element aluminum.
- • One problem with nuclear fission is the production of the reactors.
- • One advantage of nuclear power is that it produces less carbon monoxide than coal powered plants.