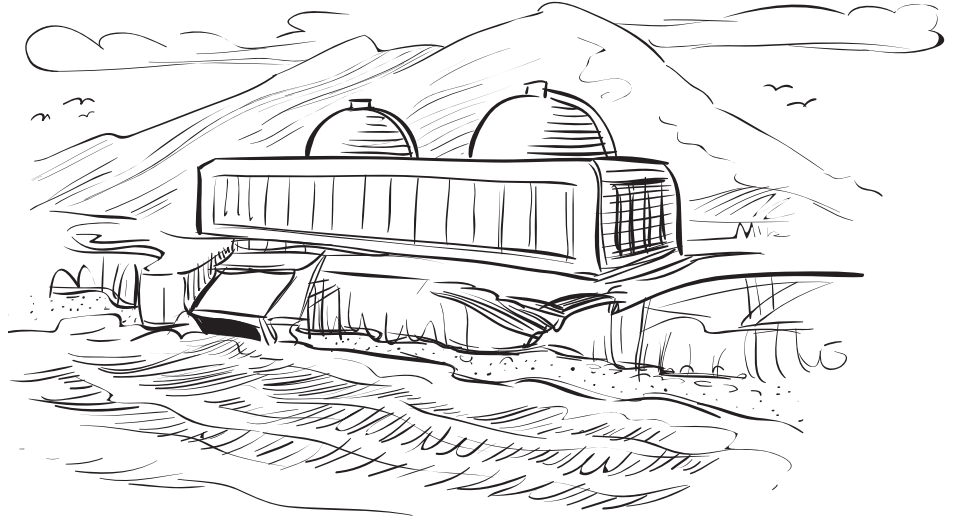




## Nonrenewable Energy Source: NUCLEAR

### TERMS IN GLOSSARY

chain reaction  
 containment vessel  
 control rod  
 fissionable  
 fuel rod  
 nuclear fission  
 nuclear fusion  
 nuclear reactor  
 plutonium  
 radioactive  
 reactive  
 reactor core  
 spent fuel  
 subatomic particle  
 thorium  
 uranium



**This nuclear power plant uses ocean water for cooling; it does not need traditional cooling towers.**

**T**HE ATOMIC AGE WAS BORN in 1939 when physicists burst apart the nucleus of a uranium atom, releasing a tremendous amount of energy as heat and light. They called this reaction nuclear fission. (Fission means “to split.”)

Nuclear fission’s first job was to make atomic bombs during World War II (in the 1940s). However, we soon learned how to control the energy from nuclear fission so we could use it to produce electricity. Today, nuclear energy is used widely for electricity generation. It is also used to power Navy submarines and some aircraft carriers.

### THE NUCLEAR RESOURCE

Nuclear energy is the energy trapped inside atoms, those tiny particles from which all matter is made.

#### The Energy of Atoms and Molecules

In nature, atoms are bonded together into molecules, which in turn are bonded into various types of matter. It takes a great deal of energy to hold these molecules together.

Every atom is made up of even tinier “subatomic” particles, including the protons and neutrons in the atom’s nucleus (central part). The energy that holds these subatomic nuclear particles together is significantly greater than the energy that holds molecules together.

### POWER SKETCH: A Natural Nuclear Reactor

**N**uclear power plants depend on fissionable materials, which include radioactive elements. These materials will release the energy bound in their atoms in a nuclear chain reaction. In most cases, the radioactive element used is uranium. Uranium is so reactive that it will, under very special circumstances, produce its own atomic reaction without any human help. At the Oklo mine in the West African country of Gabon, a deposit of “spent” uranium was found deep underground. This uranium had at one time spontaneously become a natural “nuclear reactor.” Millions of years ago, it began its own self-sustaining chain reaction that lasted about 500,000 years!

Making nuclear energy can be roughly compared to burning wood. When we burn wood, we produce energy by breaking the electron bonds between atoms and between molecules. If we stand beside a blazing bonfire we feel the energy of this chemical reaction as heat and see the energy as light. Similarly, when we produce a nuclear reaction, we break the bonds between protons and neutrons within the nucleus of each atom, releasing enormous amounts of energy – considerably more than our bonfire.

### Uranium Nucleus is “Easy” to Split

Most of the elements found on Earth have stable nuclei (plural of nucleus). This means they don’t split apart easily. But some elements, such as uranium, have unstable nuclei, which causes these elements to give off small particles (to “radiate”). One type of uranium, Uranium 235 (U-235) is especially unstable.\*

### Uranium: Fuel for Nuclear Power

Uranium is very hard and dense. That is, it has a lot of mass per given volume. Whereas one gallon of milk weighs about 8 pounds, one gallon of uranium weighs 150 pounds.

Uranium is found in many parts of the world, including the United States. We dig uranium-bearing rock (ore) from the ground just as we mine other minerals. There is a limited supply – though scarcity is less of an issue than it is for fossil fuels, since uranium is used in much smaller quantities. Uranium is, nevertheless, a nonrenewable resource.

*\*Elements other than uranium, notably plutonium and thorium, can also be used for nuclear fission. In most parts of the world plutonium is only used in weapons and not for the production of electricity. Thorium has been used successfully in experimental reactors. It is estimated to be three or four times more abundant than uranium, though its commercial practicality has not been proven.*



## GENERATING ELECTRICITY WITH NUCLEAR ENERGY

### A Nuclear Chain Reaction

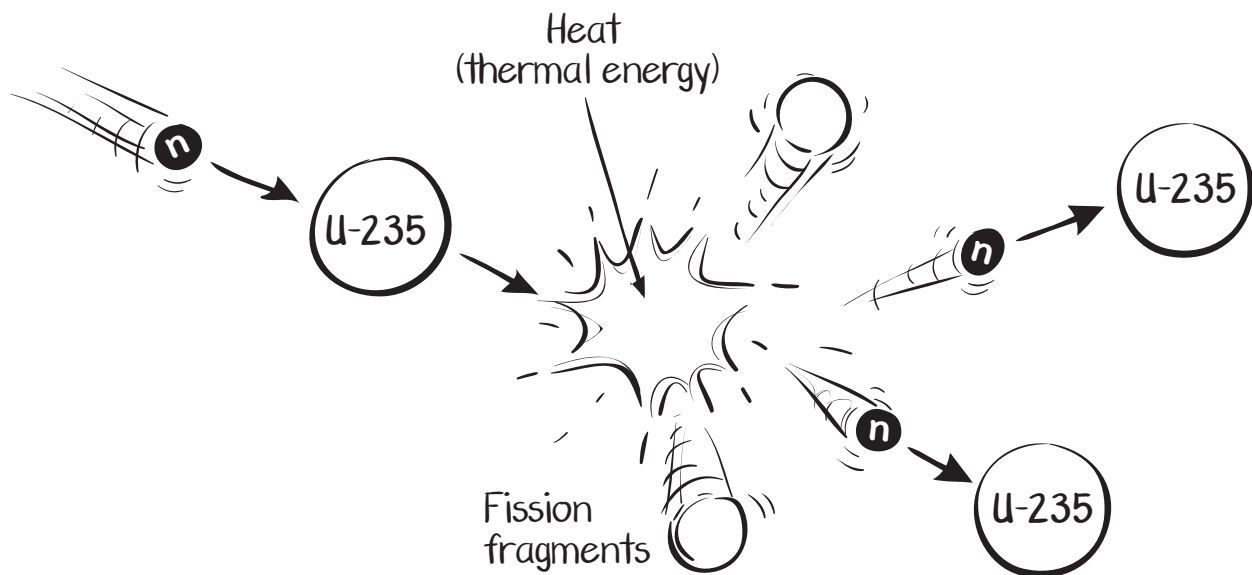
In a nuclear power plant the process of nuclear fission — splitting uranium nuclei — is accelerated. Controlled for safety, the process produces enough heat for steam to power a turbine generator.

For nuclear fission to occur, high-energy subatomic particles, neutrons, are caused to bombard the uranium atom's nucleus, breaking it apart. When the nucleus splits, it releases heat and light as well as neutrons. These particles strike other uranium atoms, splitting those as well. These, in turn, strike and split other atoms, and so on, producing a nuclear chain reaction.

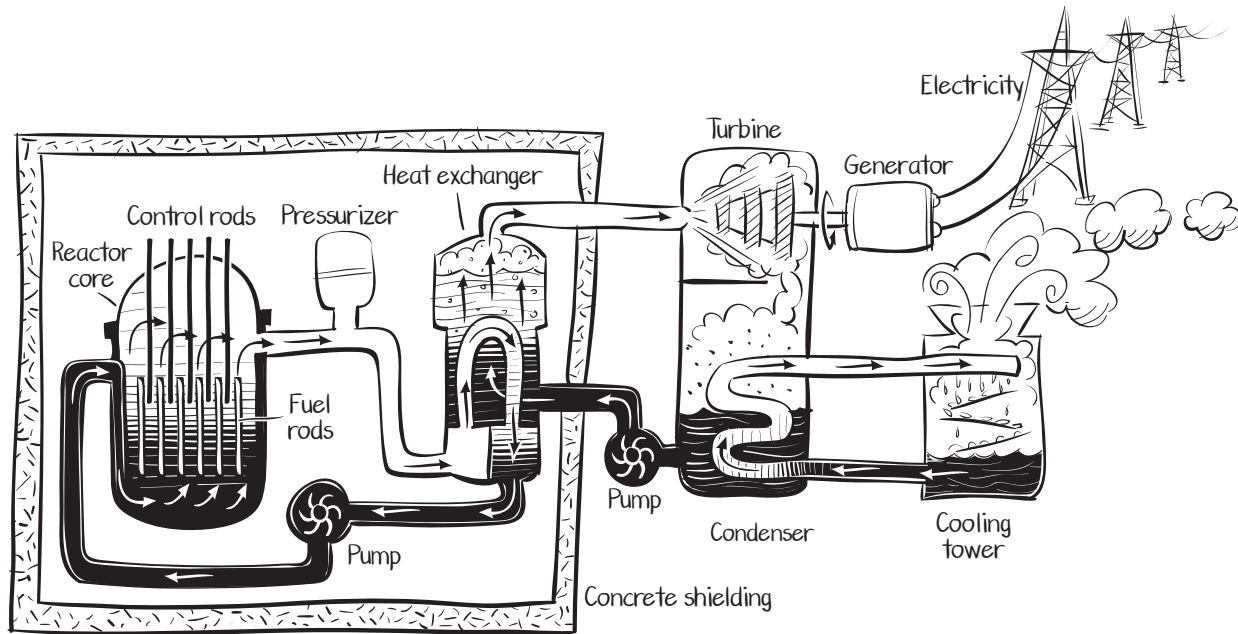
The amount of energy produced by splitting one uranium nucleus isn't much. However, because uranium is so dense, one pound of uranium has billions and billions of nuclei. Once we start a chain reaction, a LOT of energy is released. In a nuclear power plant, this reaction is carefully controlled to allow just the right release of heat energy needed to produce electricity.

### STAR-STRUCK URANIUM

Uranium was produced in the fiery destruction of ancient stars. These stars exploded to provide "dust," which clustered together to make planets, including Earth. Uranium is one of the star-born elements of Earth.



Starting a nuclear chain reaction



A nuclear power plant

### Preparing the Nuclear Fuel

At a nuclear fuel processing plant, the natural uranium is “enriched” — a mechanical process that increases the U-235 concentration by about 4 percent to make the uranium more useful.\* The enriched uranium is formed into pellets the size of the tip of your little finger. (Each pellet contains the energy equivalent of a pick-up truck full of coal, 150 gallons of oil, or a house-sized container of natural gas.) The pellets are loaded into long metal fuel rods.

### Inside a Nuclear Power Plant

Many fuel rods are placed into a reactor core, interspersed with moveable control rods holding a material that absorbs neutrons. Pushed in or out of the core, the control rods govern the size of the reaction (and, therefore, the amount of energy produced).

\*When used in nuclear weapons, the U-235 concentration must be enriched by 85-90 percent. The much lower concentration used in a nuclear power plant is calculated to avoid a sustained explosive reaction.

The fission reaction is started with high-energy neutrons from uranium inserted into the reactor. These neutrons bombard the pellets, splitting some of the uranium nuclei. This releases more neutrons, causing the chain reaction that produces heat and light.

A liquid or gas flows past the fuel rods in the reactor core, carrying some of the heat to a heat exchanger. (See “Heat Exchangers,” page 53.) In the heat exchanger, this heat is transferred to water that boils and makes steam to spin the turbines. The rest of the system works like a traditional steam-driven power plant.

### **Nuclear Power Safety and Nuclear Waste**

Uranium requires caution through many stages. It is less hazardous in its natural state than later; but danger of inhaling or swallowing exists while it is mined and milled, and dangers increase as it is enriched (made more radioactive), fashioned into pellets, and stored for use.

The amount of waste produced from nuclear reactors is small in comparison to the energy produced. The waste from one person’s lifetime use of nuclear power has been estimated to occupy the space of a soda can, whereas waste from coal power over that time can be 68 tons of solids and 77 tons of carbon dioxide.

Nuclear waste, even in small doses, is lethal and remains hazardous for tens of thousands of years. Though quantities created at a given time are small, they build up over time, so that 72 storage facilities in the U.S. hold an estimated 50,000 tons of used (spent) fuel.

Spent fuel is still radioactive. It must be handled carefully and stored safely in a secure place. (“Secure place” is a matter of controversy; see “Considerations,” pages 130–131.) Radioactivity decreases over time; some estimate a 99 percent drop in 40 years. But decrease does not mean elimination; the waste remains dangerous for many generations.

### **Nuclear Fuel Recycling**

A portion of the spent fuel is removed periodically from the reactor, about every 18 months; each nuclear pellet may last 5 years.

After removal, the fuel still retains most of its energy. If recycled (reprocessed), it could be reused in a modern, efficient plant. Some say present supplies could fire our nuclear plants for 40 years, with reprocessing, during which the volume of waste would shrink. Some countries reprocess their used fuel, but not the U.S.

### **NUCLEAR FUSION**

**N**uclear *fusion* (as opposed to nuclear *fission*) is another form of atomic energy. Nuclear fusion means several smaller nuclei are “fused” to form a larger nucleus. When this happens, a huge amount of energy is given off as heat and light. This process is what makes our sun produce heat and light, making it a natural nuclear reactor. Nuclear fusion is very appealing as an energy source, because it uses less fuel and creates less radioactive material than nuclear fission. However, scientists have not yet learned how to control fusion reactions that produce usable energy. So despite 50 years of effort, engineers haven’t yet found a practical way to use a fusion reaction.

One reason nuclear fuel is not recycled in the U.S. is because a reprocessing byproduct is plutonium, usable in weapons. High cost of reprocessing is another deterrent. Other countries – notably Russia, France, and Japan – have government-supported reprocessing facilities.

### **Nuclear Power Around the World**

In some parts of the world, mainly in industrialized countries such as the U.S., nuclear plants have not been built in several years, although support has grown recently for building more. In Asia, particularly China, South Korea, and India, electricity production from nuclear power plants is expected to increase.



### **CONSIDERATIONS**

- Nuclear power is among the most controversial issues of our age. By wide agreement, great care is necessary in producing, using, and storing fissionable materials. Opponents of nuclear power say that the inherent dangers of using fissionable materials outweigh all benefits. But proponents maintain that safety has sufficiently improved, over time, to make nuclear energy an acceptable part of our energy mix.
- Nuclear power plants emit no carbon. For this reason proponents refer to it as clean energy and promote its use as a way to combat global climate change. Opponents of nuclear power do not believe it should be considered “clean” – even though it’s carbon-free – because of waste and safety issues.
- With nuclear energy, a huge amount of electricity can be produced from very little fuel. One nuclear power plant can produce hundreds to thousands of megawatts of baseload power.
- In the U.S., nuclear power plant back-up safety systems helped to avoid several nuclear power plant disasters, such as 1979’s contained accident at Three Mile Island in Pennsylvania. Nuclear power advocates point to this as demonstrating the effectiveness of the industry. Opponents say that these incidents will continue to occur and show the dangers that might not be avoided the “next time around.”
- Additional concerns voiced by nuclear power development opponents is vulnerability of nuclear power plants to sabotage or terrorist attacks.

- Cost factors occasion further controversy. Proponents of nuclear energy argue that its fuel costs are less than for fossil fuel plants, and that domestic nuclear power means less dependence on foreign oil. Opponents respond that costs are high at the beginning (construction) and end (decommissioning); waste management and disposal are costly; substantial water is needed for cooling; and discharge of cooling water can be harmful to marine life.
- The regulatory system in the U.S. includes inspectors at each nuclear plant. It also encourages the power plant operators to identify and correct safety problems. For example, routine examinations of a nuclear facility in Ohio in 2002 found a potentially dangerous situation that caused the Nuclear Regulatory Commission (a U.S. government agency) to order a check of 68 similar nuclear plants. Some say that shows a careful approach. Others say it evidences danger.
- “Spent” rods of used nuclear fuel are typically stored at the power plant that produced them. The U.S. government built a disposal facility and containers for spent nuclear fuel deep under the Nevada desert, but use of this facility has been stalled by controversy. Experts disagree over whether this facility, or others like it that may be built, is an adequate solution for the protection of public safety and the environment.
- A bottom-line question of our time is whether the hazards of nuclear power development and the attendant long-term waste problems are outweighed by the alternatives. A build-up of nuclear power facilities can replace fossil fuel facilities in far less time than it takes to develop other methods of avoiding greenhouse gas emissions. Policy makers must weigh the hazards of nuclear waste into the future against the need to gain control of pollution and climate change now.

