Uranium (Nuclear)

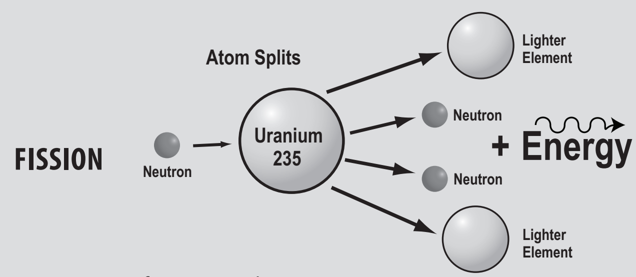
Uranium at a Glance, 2015

Classification:
- nonrenewable

Major Uses:
- electricity

U.S. Energy Consumption:
- 8.337 Q
- 8.56%

U.S. Energy Production:
- 8.337 Q
- 9.47%



Data: Energy Information Administration

What Is Uranium?

Uranium is a naturally occurring radioactive element, that is very hard and heavy and is classified as a metal. It is also one of the few elements that is easily fissioned. It is the fuel used by nuclear power plants.

Uranium was formed when the Earth was created and is found in rocks all over the world. Rocks that contain a lot of uranium are called uranium ore, or pitch-blende. Uranium, although abundant, is a **nonrenewable** energy source.

Three **isotopes** of uranium are found in nature, uranium-234, uranium-235, and uranium-238. These numbers refer to the number of neutrons and protons in each atom. Uranium-235 is the form commonly used for energy production because, unlike the other isotopes, the nucleus splits easily when bombarded by a neutron. During fission, the uranium-235 atom absorbs a bombarding neutron, causing its nucleus to split apart into two atoms of lighter mass.

At the same time, the fission reaction releases thermal and radiant energy, as well as releasing more neutrons. The newly released neutrons go on to bombard other uranium atoms, and the process repeats itself over and over. This is called a **chain reaction**.

What Is Nuclear Energy?

Nuclear energy is energy that comes from the **nucleus** of an atom. Atoms are the particles that make up all objects in the universe. Atoms consist of neutrons, protons, and electrons.

Nuclear energy is released from an atom through one of two processes: nuclear **fusion** or nuclear **fission**. In nuclear fusion, energy is released when the nuclei of atoms are combined or fused together. This is how the sun produces energy (see *Solar*, page 39).

In nuclear fission, energy is released when the nuclei of atoms are split apart. Nuclear fission is the only method currently used by nuclear plants to generate electricity.

History of Nuclear Energy

Compared to other energy sources, nuclear energy is a very new way to produce energy. It wasn't until the early 1930s that scientists discovered that the nucleus of an atom is made up of protons and neutrons. Then in 1938, two German scientists split the nucleus of the atom apart by bombarding it with a neutron—a process called fission. Soon after, a Hungarian scientist discovered the chain reaction and its ability to produce enormous amounts of energy.

During World War II, nuclear fission was first used to make a bomb. After the war, nuclear fission was developed for generating electricity.

The first nuclear power plant came online in Shippingport, PA in 1957. Since then, the industry has experienced dramatic shifts in fortune. Through the mid 1960s, government and industry experimented with demonstration and small commercial plants. A period of rapid expansion followed between 1965 and 1975.

No new plants, however, were ordered after the 1970s until recently, as a result of public opposition, as well as building costs, problems with siting a waste repository, and lower demand for power. Today, there is renewed interest in nuclear power to meet future demand for electricity and plans for new plants are underway.

Uranium Fuel Cycle

The steps—from mining the uranium ore, through its use in a nuclear reactor, to its disposal—are called the **uranium fuel cycle**.

▪ Mining

Uranium ore can be mined using conventional surface and underground mining methods, but these techniques is no longer used in the U.S. Uranium can also be mined using solution mining techniques. **In situ leaching**, or solution mining, dissolves uranium ore while it is still in the ground using a weak chemical solution. The chemical-ore solution is then pumped to the surface. In 2016, six in situ leach plants were operating in the United States.

▪ Milling

At the mill, conventionally mined ore is crushed and treated with an acid solution that separates the uranium ore from the rock. If in situ leaching was used, the uranium is already dissolved in solution. The chemical-ore solution undergoes further treatments to separate the uranium as a precipitate. Uranium is collected and dried as uranium oxide (U_3O_8) concentrate. The concentrate is a powder called **yellowcake**. This process of removing uranium from the ore is called uranium milling.

▪ Conversion

The next step in the cycle is the conversion of the solid yellowcake into a gas called uranium hexafluoride, or UF_6. The uranium hexafluoride is then shipped to a **gaseous diffusion plant** for enrichment.

▪ Enrichment

Because less than one percent of uranium ore contains uranium-235, the form used for energy production, uranium must be processed to increase its concentration. This process—called enrichment—increases the percentage of uranium-235 from 0.7 to three to five percent, the percentage required for reactor fuel. It typically takes place at a gaseous diffusion plant where the uranium hexafluoride is pumped through filters that contain very tiny holes. Because uranium-235 has three fewer neutrons and is one percent lighter than uranium-238, it moves through the holes more easily. This method increases the percentage of uranium-235 as the gas passes through thousands of filters. The enriched fuel is then converted into uranium dioxide (UO_2) in the form of a black powder.

▪ Fuel Fabrication

The enriched uranium is taken to a fuel fabrication plant where it is prepared for the nuclear reactor. Here, the uranium is made into a solid ceramic material and formed into small, barrel-shaped pellets. These ceramic fuel pellets can withstand very high temperatures, just like the ceramic tiles on the space shuttle. Fuel pellets are about the size of a pencil eraser, yet each one can produce as much energy as 149 gallons of oil. The pellets are sealed in 12-foot metal tubes called **fuel rods**. Finally, the fuel rods are bundled into groups called fuel assemblies.

▪ Nuclear Reactor

The uranium fuel is now ready for use in a nuclear **reactor**. The reactor is the center of the nuclear power plant. Fissioning takes place in the reactor core. Surrounding the core of the reactor is a shell called the reactor pressure vessel. To prevent heat or radiation leaks, the reactor core and the vessel are housed in an airtight containment building made of steel and concrete several feet thick.

The reactor core houses about 200 fuel assemblies. Spaced between the fuel assemblies are movable **control rods**. Control rods absorb neutrons and slow down the nuclear reaction. Water also flows through the fuel assemblies and control rods to remove some of the heat from the chain reaction.

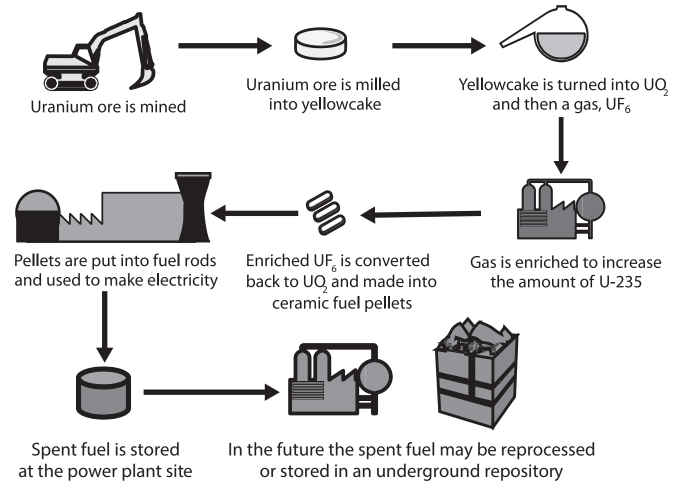
The nuclear reaction generates heat energy just as burning coal or oil generates heat energy. Likewise, the heat is used to boil water into steam that turns a **steam generator** to produce electricity. Afterward, the steam is condensed back into water and cooled. Some plants use a local body of water for cooling; others use a structure at the power plant called a **cooling tower**.

▪ Spent (Used) Fuel Storage

Like most industries, nuclear power plants produce waste. One of the main concerns about nuclear power plants is not the amount of waste created, which is quite small compared to other industries, but the radioactivity of some of that waste. The fission process creates radioactive waste products. After about three cycles, these waste products build up in the fuel rods, making the chain reaction more difficult to carry out. Utility companies generally replace one-third of the fuel rods every 12 to 18 months to keep power plants in continuous operation.

The fuel that is taken out of the reactor is called **spent fuel**. This used fuel contains both radioactive waste products and unused fuel. The spent fuel is usually stored near the reactor in a deep pool of water called the spent fuel pool. The spent fuel cools and loses most of its radioactivity through radioactive decay. In three months, the spent fuel will lose 50 percent of its radiation; in one year, 80 percent; in 10 years, 90 percent. The spent fuel pool was intended as a temporary method for storing used nuclear fuel. However, there is no permanent storage solution yet for spent fuel, and space in fuel pools can run out quickly.

Uranium Fuel Cycle



The nuclear industry has designed dry cask storage as another temporary solution. Now, the spent fuel stays in the pool for five to seven years. Then, it is moved elsewhere on the nuclear power plant site to be stored in vaults or dry casks. Each of these methods for managing spent nuclear fuel puts the fuel into airtight, steel and concrete structures. The U.S. Nuclear Regulatory Commission has stated that it is safe to store spent fuel on site for at least 120 years. Eventually, the spent fuel will be reprocessed and/or transported to a permanent federal disposal site, although no permanent facilities exist at this time.

▪ Reprocessing

Spent fuel contains both radioactive waste products and unused nuclear fuel. In fact, the vast majority of the nuclear fuel remains unused when the fuel rod must be replaced. Reprocessing separates the unused nuclear fuel from the waste products so that it can be used in a reactor again.

Currently, American nuclear power plants store the spent fuel in spent fuel pools—without reprocessing. Reprocessing is more expensive than making new fuel from uranium ore. If uranium prices rise significantly or storage becomes a bigger problem, reprocessing may gain favor. Other countries, like France, reprocess some of their spent nuclear fuel.

Spent Fuel Repository

Most scientists believe the safest way to store nuclear waste is in rock formations deep underground called geological repositories. In 1982, Congress passed the Nuclear Waste Policy Act. This law directed the Department of Energy to site, design, construct, and operate America's first repository by 1998. The same law also established the Nuclear Waste Fund to pay for a permanent **repository**. People who used electricity from nuclear power plants would be charged 1/10 of one cent for each kilowatt-hour of electricity they used.

What Is Radiation?

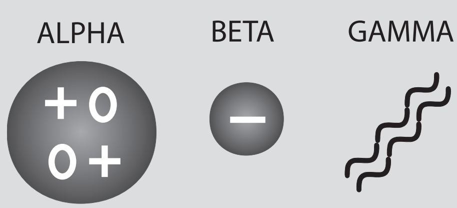
Radiation is energy released by atoms. It is very powerful and moves very fast. Not all atoms are radioactive. Some atoms—the radioactive ones—have more neutrons than protons, making them unstable. In a natural process called **radioactive decay**, these atoms give up their energy and nuclear particles and become stable.

Radiation cannot be touched, seen, or heard, but it is around us all the time. Natural sources of radiation include cosmic rays from outer space, minerals in the ground, and radon in the air. Man-made sources of radiation include the x-ray equipment used by doctors, smoke detectors, old color television sets, and luminous dial clocks. Nuclear waste is another kind of man-made radiation that usually contains higher than natural concentrations of radioactive atoms.

Atoms emit radiation in the form of tiny particles, called alpha and beta radiation, and in the form of rays, called gamma radiation. Alpha radiation is the slowest moving type of radiation and can be blocked by a sheet of paper or the outer layer of skin on your body. Beta radiation is faster and lighter than alpha radiation and can pass through about an inch of water or skin. Gamma radiation is different from alpha and beta radiation because it is an electromagnetic wave, just like radio waves, light, and x-rays. Gamma radiation has no weight and moves much faster than alpha and beta radiation. It takes several inches of lead, several feet of concrete, or a large amount of water to stop gamma rays. It can easily pass through the human body as medical x-rays do.

Alpha, beta, and gamma radiation are called ionizing radiation because they can produce electrically charged particles, called **ions**, in the things that they strike. (Visible light and radio waves are non-ionizing forms of radiation.) Ionizing radiation can be harmful to living things because it can damage or destroy cells. The used fuel from nuclear power plants is called high-level nuclear waste because of its dangerous levels of radiation.

The unit used to measure radiation is the rem and millirem (1/1000 of one rem). The average American is exposed to about 360 millirem a year from natural and man-made sources, a harmless amount. About 260 millirem of this total comes from natural (background) sources of radiation such as soil, rocks, food, and water. Another 55 millirem comes from medical x-rays and about 10 millirem from a variety of sources including mineral mining, burning fossil fuels, and consumer products such as old televisions and luminous dial clocks. Newer LCD or plasma televisions do not emit radiation. Radiation emitted from nuclear power plants accounts for only a tiny amount of exposure, only about 0.01 millirem of exposure per year.



The Department of Energy (DOE) originally looked at Yucca Mountain, Nevada, to be the site of a national spent nuclear fuel repository. In 2010, the DOE withdrew its Yucca Mountain application with the intention of pursuing new long-term storage solutions. A Blue Ribbon Commission was formed in January 2010. The commission's job is to provide recommendations for managing used nuclear fuel in the United States.

Until a final storage solution is found, nuclear power plants will continue storing used fuel at their sites in spent fuel pools or dry cask storage. In the meantime, a federal appeals court ruled in 2013 that the Department of Energy must stop collecting money for the Nuclear Waste Fund until a national repository site is chosen and construction has begun.

Nuclear Energy Use

Nuclear energy is an important source of electricity—third after coal and natural gas—providing 19.45 percent of the electricity in the U.S. today. There are 99 nuclear reactors in operation at 61 power plants in 30 states. Four new reactors are expected to come online in 2017 and 2018.

Nuclear energy now provides about 10.63 percent of the world's electricity. The U.S., France, China, Russia, South Korea, Germany, and Canada are world leaders. France generates over 83 percent of its electricity with nuclear power. Japan was a former leader in worldwide nuclear production. the Fukushima incident (see page 46) prompted Japanese authorities to temporarily halt nuclear power generation, and in 2014, produced no electricity from uranium. New safety measures have led to the gradual re-opening of Japan's nuclear power plants, with five facilities operational again in 2017.

Licensing Nuclear Power Plants

Nuclear power plants must obtain permits to start construction and licenses to begin operation. Researchers conduct many studies to find the best site for a nuclear power plant. Detailed plans and reports are submitted to the **Nuclear Regulatory Commission**, the Federal Government agency responsible for licensing nuclear power plants and overseeing their construction and operation.

When the builders of a nuclear power plant apply for a license, local hearings are held so people can testify and air their concerns and opinions. After a plant is built, the Nuclear Regulatory Commission places inspectors at the site to assure the plant is operating properly.

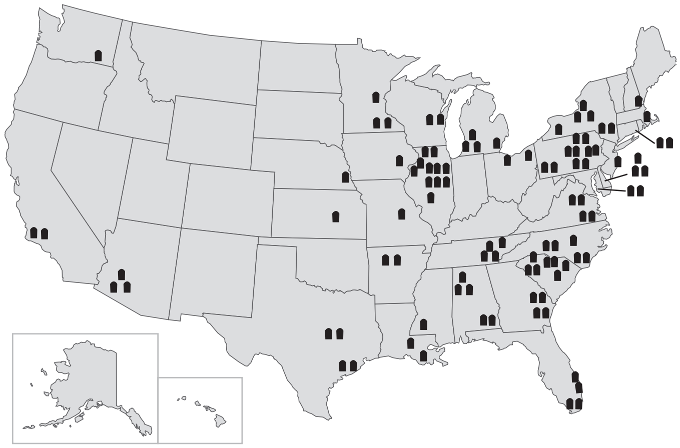
Economics of Nuclear Energy

Much of the cost of producing electricity at a nuclear plant comes not from the fuel source—uranium is a very small part of the operating cost—but from the cost of building and monitoring the plant. Nuclear plants have very high up-front costs because of the licensing, construction, and inspection requirements.

If you consider only the fuel costs and operating costs, nuclear electricity is about two and a half cents per kilowatt-hour (kWh). In comparison, the cost of producing electric power from new coal plants is approximately three and a half cents per kWh.

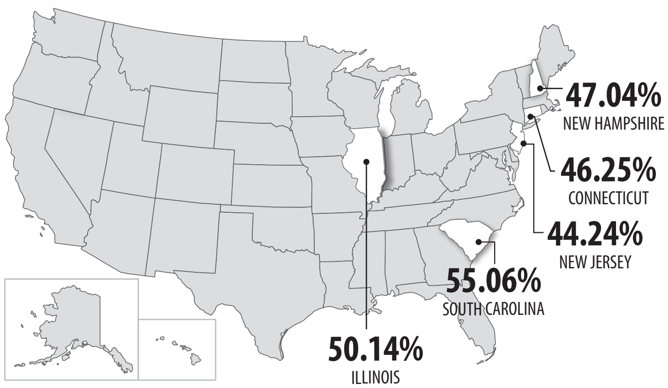
Uranium is an abundant natural resource that is found all over the world. Because uranium is an extremely concentrated fuel source, it

U.S. Nuclear Power Reactors, 2016



Data: Energy Information Administration

States with the Largest Percentage of Electricity Generated by Nuclear Energy, 2015



Data: Energy Information Administration

requires far less mining and transportation than other fuel sources for the energy it furnishes. At current rates of use, uranium resources could last over 100 years. A process called **breeding**, which converts uranium into plutonium—an even better fuel—could extend uranium reserves for thousands of years. Breeder reactors were tested in France, but they are not planned for use in this country.

Nuclear Energy and the Environment

Nuclear power plants have very little impact on the environment. Generating electricity from nuclear power produces no air pollution because no fuel is burned. Most of the water used in the cooling process is recycled.

In the future, using nuclear energy may become an important way to reduce the amount of carbon dioxide produced by burning fossil fuels and biomass. Carbon dioxide is considered the major greenhouse gas.

People are using more and more electricity. Some experts predict that we will have to use nuclear energy to produce the amount of electricity people need at a cost they can afford.

Whether or not we should use nuclear energy to produce electricity can often be a controversial and sometimes highly emotional issue.

Nuclear Safety

The greatest potential risk from nuclear power plants is the release of high-level radiation and radioactive material. In the United States, plants are specifically designed to contain radiation and radioactive material in the unlikely case of an accident. Emergency plans are in place to alert and advise nearby residents if there is a release of radiation into the local environment. Nuclear power plants have harnessed the energy from the atom for over 50 years in the United States.

In 1979, at the Three Mile Island facility in Pennsylvania, the top half of the uranium fuel rods melted when coolant to one reactor was cut off in error. A small amount of radioactive material escaped into the immediate area before the error was discovered. Due to the safety and containment features of the plant design, multiple barriers contained almost all of the radiation and no injuries or fatalities occurred as a result of the error. In response to the incident at Three Mile Island, the U.S. nuclear industry made upgrades to plant design and equipment requirements. Operator and staff training requirements were strengthened, and the U.S. Nuclear Regulatory Commission took on a greater role in emergency preparedness and routine inspections. Lessons learned from Three Mile Island were shared with the international nuclear industry.

In 1986, in the Ukraine (former Soviet Union) at the Chernobyl nuclear power plant, two steam explosions blew the top off of Unit 4. A lack of containment structures and other design flaws caused the release of a large amount of radioactive material into the local community. More than 200,000 people were evacuated from their homes and about 200 workers were treated for radiation sickness and burns. Several people were killed immediately or died shortly thereafter, with others suffering longer term medical ailments.

On March 11, 2011, an earthquake and resulting tsunami struck Japan, killing and injuring tens of thousands of people. Prior to that time, Japan generated a large percentage of its electricity from nuclear power. In the Fukushima prefecture (community), the Daiichi nuclear plant shut down as a result of the earthquake but suffered extraordinary damage from the tsunami. This damage included the loss of back-up power generation necessary to keep the reactor and the fuel rods contained in it cool. The release of some radioactive material required that residents within a 12 mile radius of the plant be evacuated. Residents living between 12 and 19 miles from the affected power plant were asked to evacuate voluntarily. The Japanese Nuclear and Industrial Safety Agency, the International Atomic Energy Agency, health organizations, and the nuclear energy industry continue to investigate the area as it is restored and residents return. These groups are also monitoring the impact of the radiation released from the Daiichi nuclear power plant both on the local environment and around the world.

Nuclear energy remains a major source of electricity in the United States and around the globe. The safe operation of nuclear power plants is important to quality of life and to the health and safety of individuals worldwide.