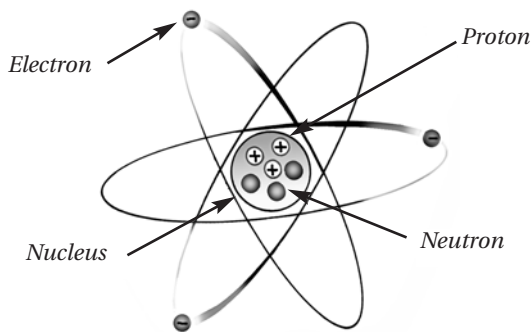


# Nuclear Energy

## What is nuclear energy?

Nuclear energy is derived from **atoms**. Atoms are particles that make up matter. They are very tiny; in fact, in one drop of water there are more than 1,000,000,000,000,000,000,000 (one sextillion) atoms. An atom is mostly empty space, but at its center is its **nucleus** surrounded by a cloud of moving **electrons**. Almost all of the atom's mass is in its nucleus which is made of **protons** and **neutrons**. It would take nearly 2,000 electrons to equal the size of one proton. Protons, neutrons, and electrons are all atomic particles.



*Model of an Atom's Structure*

Protons have a **positive** electric charge, electrons have a **negative** electric charge, and neutrons are **neutral**, they have no electric charge. Objects with like electric charges repel one another and objects with differing charges attract one another. Because the protons in the nucleus of the atom are positively charged, and the electrons moving around the nucleus are negatively charged, they attract each other, and the force of this attraction helps to hold the atom together. An atom usually has the same number of electrons floating around the outside of the nucleus as it has protons in the nucleus.

Atoms can have different numbers of protons and neutrons but are classified according to the number of protons found in the nucleus. Atoms with one proton are called hydrogen atoms, helium atoms have two protons, carbon atoms have six protons, and so on to the last naturally occurring atom, uranium, which has 92 protons.

## How is nuclear energy released from an atom?

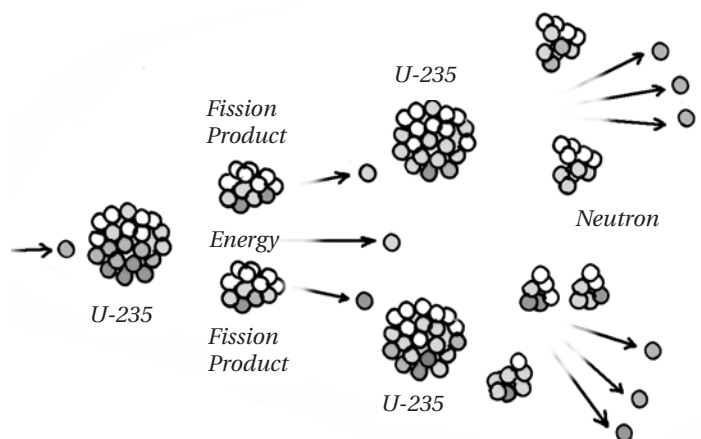
Nuclear energy is released from an atom through nuclear **fission** or nuclear **fusion**. In the fission process, commonly used in today's nuclear reactors, a nucleus of a target material such as Uranium-235 is bombarded by a neutron which is absorbed. The absorbed neutron causes the atom's nucleus to split apart or "fission" into two

atoms of lighter weight, releasing energy, neutrons and radioactivity. Fission then is the splitting of atoms. Fission reactions produce enormous amounts of heat which turns water into steam for generating electricity. The heat is produced from the collision of fissioned particles with other atoms, converting kinetic energy into heat.

In the second process of releasing energy from the atom, the nuclei of atoms are joined through "fusion," resulting in the creation of a third element, a free neutron, and nucleus. Heat is produced when the free neutron collides with other atoms. The sun and stars get their energy from the fusion of hydrogen to produce helium. Scientists have been attempting to imitate this process for many years, but it requires extremely high temperatures. Although scientists have been unable to develop a container capable of holding such extremely hot material, one of the more promising efforts involves containing the material within a magnetic field, while it is being heated to the required temperature.

## What is a chain reaction?

The release of two or three neutrons in fission is very important. These neutrons can make other Uranium-235 nuclei fission, releasing more neutrons which are absorbed by new atoms causing them to fission, releasing more heat and neutrons. The repeating of this process over and over is a chain reaction, and can continue as long as Uranium-235 nuclei and neutrons are present. Because heat energy is produced whenever a nucleus fissions, a chain reaction is a continuous source of heat energy.



*Nuclear fission causes a chain reaction producing a continuous source of heat energy.*

## Why do we use uranium?

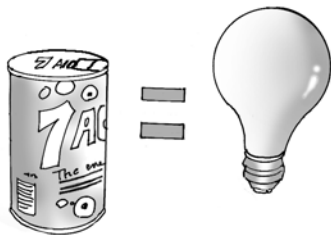
**Uranium**, which is naturally radioactive, occurs in nature as either **Uranium-235** or **Uranium-238**. (The number refers to the element's atomic mass or the number of protons plus neutrons in the nucleus.) Less than one percent of naturally occurring uranium is Uranium-235, with more than 99 percent being Uranium-238. It is U-235 which fissions, releasing energy. Thus, the ability of uranium to fission or to be transformed into a fissionable element is why uranium is used in nuclear reactors. U-235 is only mildly radioactive, and no extraordinary precautions are necessary when handling fuel rods that have not yet been used.

Uranium occurs naturally in the earth's crust. Uranium oxide is more abundant than gold and silver, and about as common as tin. In 2002, Canadian and Australian uranium mines accounted for over 50 percent of the world's total uranium production.

Uranium, used to generate electricity, has virtually no other beneficial use. But in a nuclear power plant it produces large quantities of energy from very small amounts of fuel while occupying a minimal amount of acreage. These small sites are ideal to provide the vast amounts of electricity needed for densely populated and heavily industrialized areas.

A uranium **fuel pellet**, approximately the size of the tip of your finger, is equivalent to 17,000 cubic feet (481 cubic meters) of natural gas, or 1,780 pounds (807 kilograms) of coal, or 149 gallons (564 liters) of oil.

If you were to burn a 100-watt light bulb continuously for one year it would consume 876 kWh of electricity. To generate that amount of electricity you would need 876 lbs (397 kg) of coal, or 324-377 lbs. (147 to 171 kg) of natural gas, or 508 lbs. (230 kg) of oil, but only 0.0007 lbs. (.0003 kg) of uranium enriched to 4 percent for use in a commercial nuclear reactor. Clearly, the storage of nuclear fuel, both prior to electric generation and the waste fuel, is a fraction of the area required for other fuels.



*According to the Nuclear Energy Institute, "an individual's lifetime share of the amount of used nuclear fuel generated by America's nuclear power plants, which provide 20 percent of the country's electricity, would not fill a single soft drink can."*

## How is fission accomplished in a nuclear reactor?

Nuclear reactors are composed of three principal parts: **reactor vessel**, **core** and **control rods**. The reactor vessel, a tank-like container weighing more than 500 tons (454 mtons) with steel walls six to nine inches (15 to 23 cm) thick, is located at the base of the reactor building. The core, located at the bottom of the reactor vessel, holds the fuel assemblies. Control rods are inserted into the core to regulate the rate of fission. The control rods are able to do this because of their cadmium or boron composition (materials that absorb neutrons). The absorption of neutrons controls the rate of fission. To slow the reaction, the control rods are inserted farther into the core. This decreases the number of neutrons that collide with uranium atoms, thus slowing the reaction. The actual operation of the core involves the consumption of Uranium-235, the subsequent creation of fission by-products and the production of **plutonium**. Energy released by fission is transferred to water, turning it to steam. From this point on, nuclear power plants operate just like fossil fueled power plants.

## What is spent fuel?

When the fuel assemblies can no longer efficiently sustain a fission reaction (approximately three years), they are removed from the core. The "**spent fuel**" as it is called, contains unused nuclear fuel and **radioactive nuclear waste**. The spent fuel is stored in pools—steel-lined, concrete vaults filled with water; or in dry casks—massive, above-ground concrete and/or steel containers, at the nuclear power plant until it can be reprocessed or disposed of. Water is used to both cool the fuel and absorb radiation. Most spent fuel loses about 50 percent of its radioactivity after three months and about 80 percent after one year.

## How do you isolate and store radioactive waste from land, water and air?

Several methods are being developed to isolate and safely store radioactive nuclear waste. One method proposed includes reprocessing the spent fuel. The used fuel would be transported to reprocessing plants where the still unused nuclear fuel would be separated from the radioactive material that needs to be safely stored.

The low-level or high-level material can be fused into a glass or ceramic solid, which is impervious to air and water, and buried in deep, stable, underground geologic formations. These storage areas would be constantly monitored.

In the future, radioactive wastes will be stored in federal repositories. Currently in the U.S., the main repository being developed is Yucca Mountain in Nevada.

### What does the term “meltdown” mean?

Ceramic fuel pellets and the metal fuel pins housing the uranium will melt at temperatures exceeding 5,000°F (2,760°C). During normal operations a reactor core is cooled by water circulating through the reactor vessel, keeping the reactor’s temperature well below the melting point of the fuel. For a **meltdown** to occur, the cooling water would have to be lost from around the fuel for an extended period of time allowing the pins and pellets to overheat. Nuclear power plants are designed to prevent this, with many independent cooling systems that operate automatically.

### What safety precautions are taken at nuclear power plants?

Nuclear power plants are monitored for radiation and are designed with safety systems which “take control” in the event of an accident. Other safety features of nuclear plants are: cooling systems which pump water into the core to keep it cool; the **containment building**, a large dome-shaped, thick-walled steel and concrete building which can prevent the escape of radiation should a problem develop; and an automatic procedure which inserts the control rods into the core to stop the chain reaction.

Because of the dilute quantities of Uranium-235 used in commercial nuclear reactors, nuclear explosions are impossible. It requires at least 90 percent Uranium-235 or Plutonium-239 to produce a nuclear explosion similar to that of nuclear weapons.

The U. S. Nuclear Regulatory Commission (NRC), and the Canadian Nuclear Safety Commission (CNSC) are responsible for the regulation of nuclear power plants in North America. Both agencies go to great lengths to prevent nuclear accidents. The NRC requires nuclear plant operators to undergo three or more years of extensive training and examination. The agencies also administer strict construction, maintenance and safety regulations.

### What is the future of nuclear energy?

In 2001 the U.S. nuclear energy industry drafted a long-term plan for the industry’s future. The foundation of that plan was adding 50,000 megawatts of new nuclear electric generating capacity by 2020. In addition, the industry included plans to add 10,000 megawatts of capacity through increased efficiency of its existing 103 nuclear power plants.

A **megawatt** is a unit of electrical power generally used to define the size of an electricity generating power plant. One megawatt equals 1,000 kilowatts. The average nuclear power plant is about 1,000 megawatts, so the industry foresees 50 new nuclear power plants, or a greater number of smaller plants generating less than 1,000 megawatts.

Since the beginning of nuclear energy in the 1940s, the U.S. and Canada have led the development of three generations of nuclear energy. Generation I in the 1950s and ‘60s included the demonstration of early prototype reactors. Generation II in the 1970s and ‘80s included the construction of commercial power reactors, including the light water reactor (LWR) of which there are two types—the boiling water reactors (BWRs) and pressurized water reactors (PWRs); and the Canada Deuterium Uranium (CANDU) a pressurized-heavy-water, natural-uranium power reactor.

At the beginning of 2003, 32 countries worldwide were operating 441 nuclear plants for electricity generation. Thirty-two new nuclear plants were under construction in 11 countries. Today 103 commercial nuclear power plants in the U.S. generate about 20 percent of the nation’s electricity each year. Sixteen CANDU reactors generate 15 percent of the electricity in Canada. These reactors are generating electricity in a reliable, environmentally safe and affordable manner without emitting noxious gases into the atmosphere.

While the Generation II and III nuclear power plant designs provide acceptable electricity supplies, advanced designs in the nuclear energy system will increase the opportunities for the use of emission-free, sustainable nuclear energy. To explore these opportunities, the U.S. Department of Energy’s Office of Nuclear Energy, Science and Technology, laid out a plan to engage governments, industry and the research community worldwide in a wide-ranging discussion on the development of next-generation nuclear energy systems. This plan resulted in the formation of the Generation-IV International Forum (GIF), a group whose member countries are interested in jointly defining the future of nuclear energy research and development.

### What is the Generation IV Technology Roadmap?

In January, 2000, the Generation-IV International Forum, consisting of ten countries, met together with a goal to develop future generation nuclear energy systems. This forum embraced systems that can be licensed, constructed, and operated to provide competitively priced and reliable energy products while satisfactorily addressing nuclear safety, waste, and public concerns. The primary objective for these new nuclear energy systems—known as **Generation IV Systems**— is to have them available for use and construction before the year 2030.

GIF selected six Generation IV systems that would meet challenging technology goals. Those recommended comprise the nuclear reactor and its energy conversion systems as well as the necessary facilities for the entire fuel cycle, from ore extraction to final waste disposal.

By selecting six systems technology goals can be reached; the mission of electricity generation, and hydrogen and

process heat production may be adequately addressed; and individual needs can be met since no one system may be sufficient to accommodate the range of national priorities and interests of the GIF countries.

### **Advanced-design nuclear power plants and the future!**

*(Adapted from the Nuclear Energy Institute, used by permission.)*

The nuclear energy industry has been developing and improving reactor technology for over four decades. Most of the plants built using this proven technology are virtually one-of-a-kind, custom designs. Such designs are not economically cost effective and they take a considerable amount of time to construct.

For future nuclear plants, the industry is firmly committed to developing standardized designs that will incorporate the latest technologies, be easier to operate and faster to build. These plants will achieve even higher safety ratings than today's plants.

Standardization simply means that reactors will be built in families of the same design, except for limited site-specific differences. Standardization will reduce construction and operating costs, and lead to greater efficiencies and simplicity in all aspects of nuclear plant operations, including safety, maintenance, and personnel training.

Future plants are called "evolutionary" designs because they build directly on a previous design and on the experience and lessons learned from plants already operating around the world. The "evolutionary" designs optimize the light water reactor, producing a plant that is simpler, easier to operate and maintain, and costs less to build. Safety studies indicate that these designs will be able to meet safety goals that are more than 100 times better than current plants.

In 1999, the Nuclear Regulatory Commission completed the certification process for a mid-size, 600-megawatt, nuclear power plant. The goal will be to achieve even greater simplification in nuclear plant designs as a way of reducing costs and enhancing safety. Utility requirements for performance, operation, maintenance and construction were developed for these passive designs, just as they were for the evolutionary designs.

The smaller 600-megawatt facility incorporates improved automatic safety features. It has several large tanks of emergency cooling water inside the containment structure above the reactor vessel. Should an emergency occur, pressure and gravity would force this water into the vessel to cool the core. Compared to today's 1000-megawatt plants, this smaller plant will need 50 percent less building volume, 50 percent fewer valves, 80 percent fewer pipes, 35 percent fewer large pumps, and 70 percent less control cable.

Because of their simplicity, the smaller plants can be built much faster. Quick construction is possible because many systems and subsystems will be assembled in the factory, not on the plant site.

Since today's nuclear plants were designed and built, there have been tremendous strides in many technological areas. Electronic control systems are a good example. Today's nuclear power plants have miles of control cable. New plant designs will greatly reduce the amount of cabling required through the use of multiplexed, digital control systems, including state-of-the-art fiber optic technology. The new control systems are more compact, easier to operate, and thus safer. They're also simpler, which cuts construction time and cost.

### **Nuclear Facts**

The average electricity production cost in 2002 for nuclear energy was 1.71 cents per kilowatt-hour; for coal fired plants, 1.85 cents; for oil, 4.41 cents; and for gas, 4.06 cents.

Of all energy sources, nuclear energy has the lowest impact on the environment. It is the most eco-efficient because it produces the most electricity in relation to its minimal environmental impact. Nuclear energy is the world's largest source of emission-free energy. No controlled air pollutants, such as sulfur, particulates, or greenhouse gases are produced at a nuclear power plant. Thus, the use of nuclear energy helps to keep the air clean, preserve Earth's climate, avoid ground-level ozone formation, and prevent acid rain.

Even if you lived right next door to a nuclear power plant you would still receive less radiation each year than you would receive in just one round-trip flight from New York to Los Angeles.

You would have to live near a nuclear power plant for over 2,000 years to get the same amount of radiation exposure that you get from a single diagnostic medical x-ray.

Since March, 1993, 175 metric tons of uranium from weapons have been transformed into fuel for nuclear power plants. That's the equivalent of 7,000 dismantled nuclear weapons. This is the result of the United States and the Russian Federation signing an agreement on the disposition and purchase of 500 metric tons of highly enriched uranium from dismantled Russian nuclear weapons.

Nearly 4,000 hospital-based nuclear medicine departments across the country perform more than 10 million nuclear medicine patient procedures each year.

In 1963, the U.S. Food and Drug Administration approved the irradiation of wheat, flour and potatoes; in 1983, spices and seasonings; in 1985, pork; in 1986, fruits and vegetables; in 1990, poultry; and in 1997, red meat.