Exploring Nuclear Energy

Student Guide

NEED

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Putting Energy into Education

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ENERGY

What Is Energy?

Energy makes change. It does things for us. Energy is used to move cars along the road and boats on the water. We use energy to bake cakes in the oven, keep ice frozen in the freezer, and light our homes. Energy helps our bodies grow and allows our minds to think. Scientists define energy as the ability to do work.

Energy is found in different forms, such as light, heat, sound, and motion. There are many forms of energy, but they can all be put into two categories: potential and kinetic.

Potential Energy

Potential energy is stored energy and the energy of position. Potential energy includes:

- Chemical energy is stored in the bonds of atoms and molecules. Fossil fuels such as coal, oil, and natural gas contain chemical energy that was stored in the organic material from which they were formed millions of years ago. Biomass, is any living or recently living organic material that can be used as a fuel. Biomass contains stored chemical energy produced from the sun through the process of photosynthesis.
- Stored gravitational energy is the energy of position or place. A rock on top of a hill contains potential energy because of its position. If a force pushes the rock, it rolls down the hill because of the force of gravity. The potential energy is converted into kinetic energy until it reaches the bottom of the hill and stops.
- Nuclear energy is energy stored in the nucleus of an atom—the energy that holds the nucleus together. The energy can be released when the nuclei are combined or split apart.

Kinetic Energy

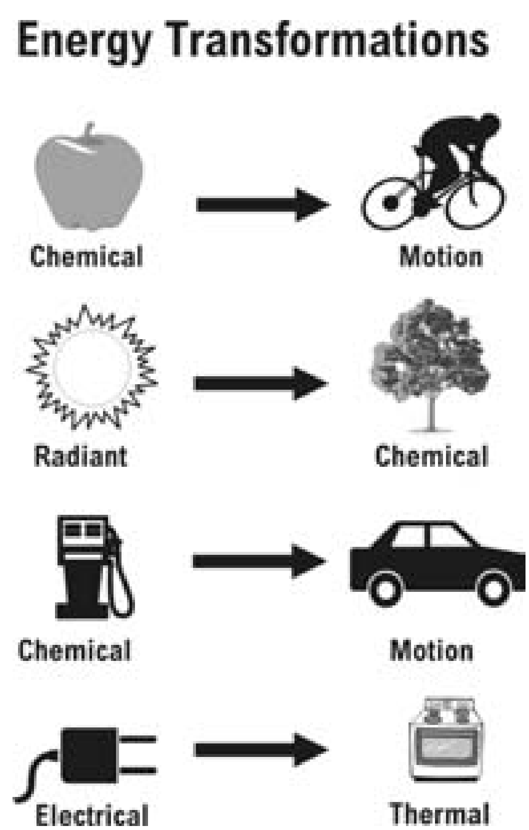
Kinetic energy is energy in motion; it is the motion of electromagnetic and radio waves, electrons, atoms, molecules, substances, and objects. Forms of kinetic energy include:

- Electrical energy is the movement of electrons. Everything is made of tiny particles called atoms. Atoms are made of even smaller particles—electrons, protons, and neutrons. The movement of electrons in a wire is called current. Lightning is another example of electrical energy.
- Radiant energy is electromagnetic energy that travels in waves. Radiant energy includes visible light, x-rays, gamma rays, and radio waves. Light is one type of radiant energy. Solar energy is an example of radiant energy.
- Thermal energy is the internal energy in substances; it is the vibration and movement of the atoms and molecules within substances. The more thermal energy in a substance, the faster the atoms and molecules vibrate and move. Geothermal energy is an example of thermal energy.
- Sound is the movement of energy through substances in longitudinal (compression/rarefaction) waves. Sound is produced when a force causes an object or substance to vibrate; the energy is transferred through the substance in a longitudinal wave.
- Motion is the movement of objects and substances from one place to another. Objects and substances move when a force is applied to them. Wind is an example of motion energy.

Law of Conservation of Mass and Energy

The Law of Conservation of Mass and Energy is not about saving energy. This law states that neither mass nor energy are created or destroyed. However, they can change from one form to another.

A car engine, for example, burns gasoline, converting the chemical energy in the gasoline into useful mechanical energy or motion; some of the energy is also converted into light, sound and heat. Photovoltaic (solar) cells convert radiant energy into electrical energy. Energy changes form, but the total amount of energy in the universe remains the same.



Energy Efficiency

Energy efficiency is the amount of useful energy produced by a system compared to the energy input. A perfect energy-efficient machine would convert all of the energy put into it into useful work, which is technologically impossible at this time. Converting one form of energy into another form always involves a loss of usable energy—usually in the form of heat—from friction and other processes. This 'waste heat' dissipates quickly and is very difficult to recapture.

Power plants that use steam to spin turbines to produce electricity (coal, natural gas, biomass, nuclear) convert about 35 percent of the chemical or nuclear energy in the fuel into electricity. A hydropower plant, on the other hand, converts about 95 percent of the kinetic energy in the water flowing through the system into electricity.

Most energy transformations are not very efficient. For example, a typical car converts only about 15 percent of the energy in gasoline into work. The human body is another example of a low efficiency "machine." Your body's fuel is food. Food gives you the energy to move, breathe, and think. Your overall's body efficiency is about 15 percent efficient at converting food into useful work. The rest of the energy is transformed into heat.

Sources of Energy

We use many different sources to meet our energy needs every day. They may be classified as either renewable or nonrenewable.

In the United States, most of our energy comes from nonrenewable energy sources. Coal, petroleum, natural gas, propane, and uranium are nonrenewable energy sources. They are used to make electricity, heat our homes, move our cars, and manufacture all kinds of products. These sources are called nonrenewable because their supplies are limited. Petroleum, for example, was formed millions of years ago from the remains of ancient sea plants and animals. We can't make more crude oil in a short time.

Renewable energy sources include solar, geothermal, hydropower, and wind. They are called renewable because they are replenished in a short time. Day after day, the sun shines, the wind blows, and the rivers flow. We use renewable energy sources mainly to make electricity.

U.S. Energy Consumption by Source 2008

PETROLEUM	37.0%	nonrenewable	transportation, manufacturing	BIOMASS	3.9%	renewable	heating, electricity, transportation
COAL	22.6%	nonrenewable	electricity, manufacturing	HYDROPOWER	2.5%	renewable	electricity
NATURAL GAS	23.5%	nonrenewable	heating, manufacturing, electricity	GEOTHERMAL	0.4%	renewable	heating, electricity
URANIUM (U^{235})	8.5%	nonrenewable	electricity	WIND	0.5%	renewable	electricity
PROPANE	1.0%	nonrenewable	manufacturing, heating	SOLAR	0.1%	renewable	light, heating, electricity

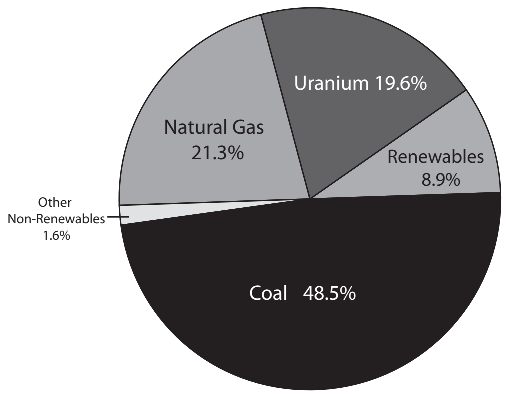
ELECTRICITY

Electricity is a secondary source of energy. That means we must use a primary energy source to produce electricity.

Electricity is sometimes called an energy carrier because it is an efficient and safe way to move energy from one place to another, and it can be used for many tasks. As societies become more technologically advanced, they consume more electricity. In the U.S. today, more than 40 percent of the energy consumed is in the form of electricity.

What exactly is the mysterious force we call electricity? It is electrons in motion. What are electrons? They are tiny particles found in atoms. Everything in the universe is made of atoms or particles derived from atoms—every star, every tree, and every animal. The human body is made of atoms. Air and water are, too. Atoms are the building blocks of the universe. Atoms are so small that millions of them would fit on the head of a pin.

2008 U.S. ELECTRICITY PRODUCTION



Source: Energy Information Administration

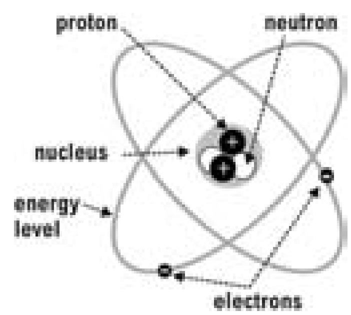
Atomic Structure

Atoms are composed of three particles: protons, neutrons and electrons. Protons and neutrons occupy a small space at the center of an atom called the nucleus which contains most of the mass of the atom. The electrons surround the nucleus in areas of probability, sometimes called energy levels. Protons and neutrons are about equal in mass. The mass of a single proton is 1.67×10^{-24} gram. This may seem small but the mass of an electron is 9.1×10^{-28}g or 1/1836 that of the proton. If the nucleus were the size of a tennis ball, the atom, with its associated electrons, would be the size of the Empire State Building. This means that atoms are mostly empty space.

Electrons are held in place by an electrical force. The positively charged protons in the nucleus and negatively charged electrons are attracted to each other by electrical forces. Within the nucleus much stronger forces hold the protons and neutrons together. A neutral atom has equal numbers of protons and electrons. The neutrons carry no charge and their number can vary. Neutrons help hold the nucleus together.

Electrons are located in areas of probability sometimes called energy levels. The energy level closest to the nucleus can hold up to two electrons. The next energy level can hold up to eight. Although additional energy levels can hold more than eight electrons, most elements are chemically stable when their outer energy level holds eight.

The electrons in the energy levels closest to the nucleus have a strong force of attraction to the protons. Sometimes, the electrons in the outermost energy level—the valence energy level—do not. In this case, these electrons (the valence electrons) easily leave their energy levels. Other times, there is a strong attraction between valence electrons and the protons. Often, extra electrons from outside the atom are attracted and enter a valence energy level. If an atom loses electrons it becomes a positively charged ion or cation. If the atom gains electrons, it becomes a negatively charged ion or anion.



Elements

The number of protons or atomic number of an atom determines the identity of an element. For example, all atoms of hydrogen have an atomic number of one and all atoms of carbon have an atomic number of six. This means that all hydrogen atoms contain one proton and that all carbon atoms contain six protons. The atomic mass of an atom is the combined mass of its protons, neutrons, and electrons.

Isotopes

Although atoms of the same element will always have the same number of protons, they can have different numbers of neutrons. Atoms of the same element with different numbers of neutrons are called isotopes. For example, there are three common isotopes of carbon. All of them have six protons. However, one isotope of carbon has six neutrons, one has seven neutrons, and the third has eight neutrons. Isotopes are identified by their atomic masses. Thus, the isotopes of carbon are known as carbon-12, carbon-13, and carbon-14.

Radioactive Isotopes

While many isotopes of the elements are stable, some isotopes are unstable and their nuclei emit particles or energy to become more stable. Isotopes of elements which are unstable and give off energy are labeled radioactive because they are radiating energy. When particles are given off, isotopes of new elements are usually made. The most common particles given off are alpha (a helium atom minus two electrons (He+2) and beta (an energetic electron). Release of high energy gamma radiation is also a common method of achieving stability but the type of isotope remains the same. Unstable isotopes may give off an alpha or beta particle, but never both together. However, gamma radiation may be given off along with either alpha or beta emissions.

The following are two examples of unstable isotopes that change identities when they release particles:

Beta emission $_{6}C^{14} \rightarrow {}_{-1}\beta^{0} + {}_{7}N^{14}$

Alpha emission $_{92}U^{238} \rightarrow {}_{2}He^{4} + {}_{90}Th^{234}$

In the first example, a neutron in the nucleus of carbon-14 releases a beta particle ($_{-1}\beta^0$) and changes into a proton. Since the new isotope now has seven protons instead of six, nitrogen 14 was formed.

In the second example, uranium-238 releases an alpha particle. The alpha particle is made of two protons and two neutrons. That means the new isotope contains 90 protons and 144 neutrons (giving a total of 234 nucleons), and thorium-234 is formed.

The process of nuclei becoming more stable is called radioactive decay. The time required for one half of the original radioactive isotope to decay into another isotope is known as its half-life. Some substances have half lives measured in milliseconds while others take billions of years. Uranium-238 has a half life of 4.6 billion years. Short half-lives result in high activities since a large number of particles or amounts of energy are emitted in relatively short time periods.

What is Radiation?

Energy that travels in the form of waves or high speed particles is called radiation. The sun produces radiant energy - light energy that travels in waves. Thermal energy, electrical energy, wireless technologies, radar, microwaves, medical treatments including x-rays and radiation therapy are all examples of radiation. Radiation is classified into two categories, electromagnetic (radio, microwave, infrared, visible light, ultraviolet light, gamma rays, and x-rays) and nuclear (alpha and beta particles).

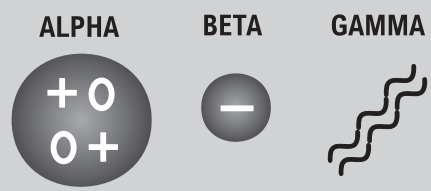
Alpha and beta particles, and gamma rays can be emitted from different elements. We say that these elements are radioactive. An element is stable when there is close to a 1:1 ratio of protons and neutrons. If an element has too few or too many neutrons the element is unstable and some are radioactive. Many elements with fewer than 84 protons have radioactive isotopes, however all elements with 84 or more protons are radioactive.

A Radioactive World

There are many natural sources of radiation which have been present since the earth was formed. In the last century, we have added to this natural background radiation with some artificial sources. It may surprise you to know that for an average person, 80-90 percent of all exposure to radiation comes from naturally occurring sources.

There are three major sources of naturally occurring radiation. They are cosmic radiation, terrestrial radiation, and internal radiation. Cosmic radiation is the radiation that penetrates the earth's atmosphere and comes from the sun and outer space. Terrestrial radiation is the radiation found in the earth, rocks, building materials, and water. The human body naturally contains some radiation. This is called internal radiation.

We are constantly using radioactive materials in our daily lives. These include medical radiation sources such as medical and dental x-rays, TV's, older luminous watches, some smoke detectors, left-over radiation from the testing of nuclear weapons, and a variety of industrial uses. Eighty-two percent of the



average human exposure to radiation is from the natural sources of radiation, and most of that is from radon gas, a gas commonly found in the earth. Almost all of the remaining 18 percent of exposure is from medical procedures with less than one percent from nuclear power plants and left-over nuclear fallout.

Radon

Radon is a colorless and odorless radioactive gas found throughout the United States. It is formed by the natural radioactive decay of uranium atoms in the soil, rocks, and water. Since radon is a gas, it can get into the air of the buildings where we live, work, and play. According to the Environmental Protection Agency (EPA), radon causes thousands of deaths from lung cancer each year. Behind smoking, exposure to radon gas is the second leading cause of lung cancer in the U.S.

Most radon enters buildings from the soil. Radon enters buildings through cracks in solid floors, construction joints, cracks in walls, gaps in suspended floors, gaps around service pipes, and cavities inside walls. Some radon can also enter a home through the water supply. Both new and older homes are susceptible to radon gas build-up. Since most exposure to radon occurs at home, it is important to measure the level of radon in your home, and limit radon exposure where necessary.

The EPA recommends that all homes be tested for radon. Simple test kits are available at most home improvement stores, are inexpensive, and are easy to use. Qualified testers can also be used and are a good choice to perform tests when buying or selling a home.

ELECTRICITY AND MAGNETISM

Electrical Energy

The positive and negative charges within atoms and matter usually arrange themselves so that there is a neutral balance. However, sometimes there can be a buildup of charges so that there are more negative than positive charges, or more positive charges than negative charges. This imbalance creates a net electric charge. Unlike electric current where electrons are moving, these electrons don't move until there is another object for them to move to. This is called static electricity. When the charges become too unbalanced there is a discharge of electrical energy between positively and negatively charged areas. This is what causes lightning to jump from cloud to cloud, or between a cloud and the ground.

Have you ever electrified your hair by rubbing a balloon on it? If so you created an imbalance between the number of protons and electrons in your hair and in the balloon which creates an electrical charge. Your hair now has too many of the same kind of charge, and your strands of hair repel and move away from each other.

Magnets

In most objects the molecules that make up the substance have atoms with electrons that spin in random directions. They are scattered evenly throughout the object. Magnets are different – in magnetic materials, most of the atoms' electrons spin in the same direction. Magnets are made of molecules have north- and south-seeking poles. Each molecule is really a tiny magnet. The molecules in a magnet are arranged so that most of the north-seeking poles point in one direction and most of the south-seeking poles point in the other. This gives rise to magnetic forces that can act in opposite directions (with the spin or opposite the spin).

Electromagnetism

A magnetic field can produce electricity. In fact, magnetism and electricity are really two inseparable aspects of one phenomenon called electromagnetism. Every time there is a change in a magnetic field, an electric field is produced. Every time there is a change in an electric field, a magnetic field is produced. We can use this relationship to produce electricity. Some metals, such as copper, have electrons that are loosely held. They can be pushed from their valence levels by the application of a magnetic field. If a coil of copper wire is moved in a magnetic field, or if magnets are moved around a coil of copper wire, an electric current is generated in the wire.

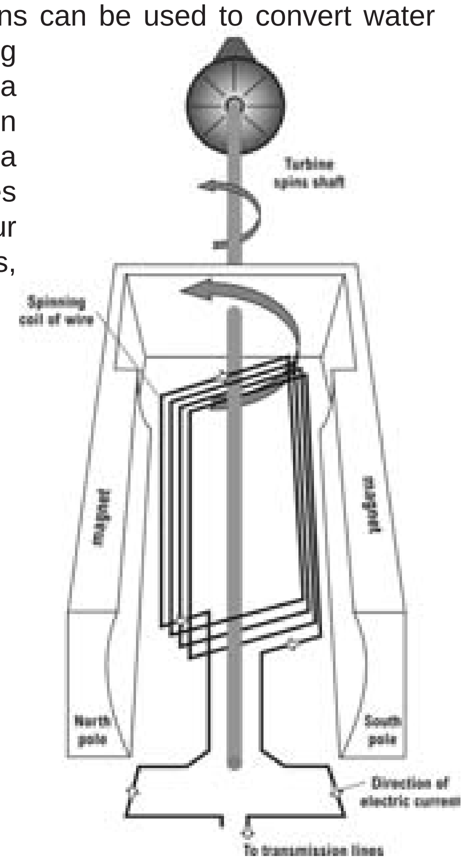
Electric current can also be used to produce magnets. Around every current-carrying wire is a magnetic field, created by the uniform motion of electrons in the wire.

Generating Electricity

When it comes to the commercial production of electricity, it is all about turbines and generators. A turbine is a device that converts the flow of a fluid such as air, steam, or water, into mechanical energy to power a generator. A generator is a device that converts mechanical energy into electrical energy.

Power plants use large turbines and generators to produce the electricity that we use in our homes and businesses. Power plants use many fuels to spin turbines. They use heat from coal, oil, biomass, natural gas, or uranium to produce high-pressure steam, which spins the turbines.

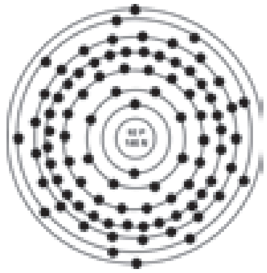
Nuclear energy is released from the nucleus of an atom when the nuclear structure (number of protons and neutrons in a nucleus) is changed. This change produces the energy for nuclear power and is called fission. Fission occurs when at atom's nucleus splits into smaller nuclei. In addition to producing thermal energy, fission produces kinetic and radiant energy. Just like burning coal and natural gas, thermal energy from nuclear reactions can be used to convert water to steam for turning the blades of a turbine. The motion of the turbine turns a generator and makes electricity to power our homes, businesses, and schools.



TURBINE GENERATOR

NUCLEAR ENERGY

Uranium



Uranium occurs in small concentrations in rocks, soil, and bodies of water. Uranium is 500 times more common than gold (Au) and about as plentiful as tin (Sn). Estimates vary, but most believe that there is enough uranium to last hundreds, if not thousands, of years.

Uranium is the heaviest of all naturally occurring elements. Uranium is an element that has three isotopes: uranium 238 with 92 protons and 146 neutrons, uranium 235 with 92 protons and 143 neutrons, and uranium 234 with 92 protons and 142 neutrons. Natural uranium consists of 99.28 percent U-238, 0.71 percent U-235, and 0.0054 percent U-234. This is important because it is U-235 nuclei which split, or fission, to produce heat in a nuclear reactor.

History

Nuclear reactions have occurred in the earth's crust since the beginning of time. However, man's working knowledge of nuclear energy occupies a very small portion of earth's history. This knowledge was started by a chain of events beginning in 1895 with the experiments of German physicist William Roentgen. He was working with gas discharge tubes and discovered that the tubes caused certain materials to glow in the dark. Shadows of the bones of his fingers were recorded on cardboard treated with barium. He named the energy given off by these gas discharge tubes x-rays.

In 1896, Henri Becquerel, a French scientist, accidentally discovered that a uranium compound left in the dark near a photographic plate produced an image on the plate. A student of Becquerel's, Marie Curie, and her husband Pierre, a professor of physics, continued to investigate these emissions from uranium and named them radioactivity. Two years later, the Curies announced that they had discovered two radioactive elements in the ore pitchblende, polonium (named for Marie Curie's native country of Poland) and radium.

Scientific work related to radioactivity continued throughout the early to middle twentieth century. In England, Ernest Rutherford identified two different types of radiation given off by uranium atoms, alpha rays and beta rays (streams of alpha and beta particles). Rutherford's experiments with radiation showed that a radioactive element changes into a different element when it gives off alpha or beta particles. This change in an element is called transmutation. Other significant events included the discovery of the electron by J. J. Thompson and Rutherford's observation that almost all of the mass and all of the positive charge of an atom were contained in its tiny nucleus. The general structure of an atom containing protons and neutrons in the nucleus and electrons outside the nucleus was completed in 1932 with the discovery of the neutron by James Chadwick.

In 1905, Albert Einstein theorized that mass and energy are interchangeable. According to his theory, when the mass of a substance increases, its energy content decreases; when the mass of a substance decreases, its energy content increases. The relationship between the mass and energy of matter is calculated by the equation $E=mc^2$. It took over thirty years for scientists to prove Einstein's theory correct, but this led to the understanding that energy could be released from radioactive materials.

In 1938 two German chemists, Otto Hahn and Fritz Strassmann, found that when uranium was bombarded with neutrons, the element barium (a much lighter element) was produced. An Austrian physicist, Lise Meitner, and her nephew, Otto Frisch, first explained nuclear fission, a process in which the nucleus splits into two nuclei of approximately equal masses. Using Einstein's equation, they calculated that this fission released a tremendous amount of energy. Immediately, the world's scientific community recognized the importance of the discovery. With the coming of World War II, the race was on to see which nation could unleash the power of the atom and create the most powerful weapon ever imagined.

Lise Meitner was head of physics at the Keiser Wilhelm Institute in Germany and worked closely with radiochemist, Otto Hahn. When Nazis came to power in 1933 many Jewish scientists left. Meitner, who was Jewish by birth, stayed to continue her work at the Institute. In 1938 she was forced to move to Sweden for her safety.

Meitner and Hahn continued corresponding about their research. Hahn wrote to Meitner perplexed that bombarding a uranium nucleus produced barium. Meitner discussed Hahn's findings with her nephew Otto Frisch. They interpreted Hahn and Strassmann's results as nuclear fission, explaining that a large amount of energy is released when the nucleus splits.

Meitner was offered a position working on the Manhattan Project, but refused to be a part in the making of a bomb. In 1944, without acknowledgement of Meitner's work, Hahn was awarded the Nobel Prize for Chemistry for the discovery of nuclear fission.

The first controlled nuclear fission occurred in 1941 at the University of Chicago under the guidance of Leo Szilard and Enrico Fermi. Graphite blocks (a “pile” of graphite) were stacked on the floor of the Stagg Field squash court. Natural uranium was inserted among the graphite blocks. Using natural uranium, the scientists were able to produce the first controlled nuclear chain reaction. A chain reaction requires the correct amount of nuclear fuel (critical mass) to sustain the reaction, neutrons of the proper speed (energy), and a way to control the number of neutrons available for fission. The basic parts of a nuclear power reactor will be described later. The first large scale reactors were built in 1944 at Hanford, Washington, to produce plutonium for nuclear weapons.

On July 16, 1945, all of the theory about nuclear energy became reality. The first release of nuclear energy from an atom bomb occurred with the Trinity Test in south central New Mexico. The explosion was dramatic and demonstrated the release of huge amounts of energy stored in uranium. Enough nuclear fuel for two more atomic bombs was available. The bombs were immediately shipped to the Pacific for use against Japan. Many scientists and U.S. politicians hoped the bombs would end World War II without requiring an invasion of the islands of Japan.

On August 6, 1945, the B-29 Enola Gay took off from its airbase on the small pacific island Tinian. The bomber carried and dropped a uranium atomic bomb that exploded 1900 feet above the city of Hiroshima, Japan. Hiroshima was a city of 300,000 civilians and an important military center for Japan. The effects of the bomb were devastating. People and animals closest to the explosion died instantly, and nearly every structure within one mile of ground zero was destroyed. Fires started and consumed the city; those who survived the initial blast were injured or later died from effects of the radiation. In the end, about half of the city’s population was dead or injured.

Japan was asked to surrender immediately after the Hiroshima explosion, but it did not do so. So, on August 9, 1945 a plutonium atomic bomb was dropped on the industrial city of Nagasaki with results similar to those of Hiroshima. On August 10, some in the Japanese government started the process of surrender. On August 14th Japan’s surrender was officially declared, and was accepted by the United States and allies on August 15, 1945. The tremendous energy inside the tiny nucleus of the atom helped end the worst war in history.

The USS Enterprise is just one of the many Navy vessels powered by nuclear energy.

Although at the end of World War II, nuclear energy was seen as very destructive, scientists started work to harness and use nuclear energy for peaceful purposes. The first use of nuclear power to generate electricity occurred in December 1951 at a reactor in Idaho. In 1954, a nuclear reactor in Obninsk, Russia, was the first connected to an electricity grid. The Nautilus, the world’s first submarine powered by a nuclear reactor, was placed into service by the U.S. Navy in 1954. In 1957, the first commercial nuclear reactor to produce electricity went on-line at Shippingport, Pennsylvania. Other nuclear plants of different designs soon followed.

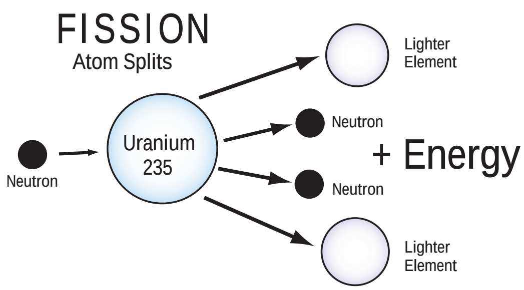
In 1946 the Atomic Energy Commission (AEC) was the first agency assigned the task of regulating nuclear activity. In 1974 the AEC was replaced by the Nuclear Regulatory Commission (NRC) which was established by Congress as part of the Energy Reorganization Act. The NRC’s primary responsibility is to protect public health and safety. To accomplish this the NRC has oversight of reactor and materials safety, waste management, license renewal of existing reactors, materials licensing, and the evaluation of new nuclear power plant applications.

As of 2010, 104 nuclear reactors are operating in the United States, and 435 nuclear reactors are generating power throughout the world. Despite the success of peaceful uses of nuclear power some people remain hesitant about increasing usage of nuclear energy because of its potential to be used in non-peaceful ways.

Generating Electricity with Nuclear Energy

Fission

Energy used to generate electricity in a nuclear power plant is released from the nucleus by a process known as fission, the breaking apart of a nucleus. In a uranium fission reaction, a neutron from outside the atom hits the nucleus of the U-235 atom, is momentarily captured by the nucleus, and then breaks the nucleus into two smaller fragments, of nearly equal masses creating two lighter elements. As a nucleus undergoes fission it also ejects two or more neutrons which are then able to collide with additional U-235 nuclei.



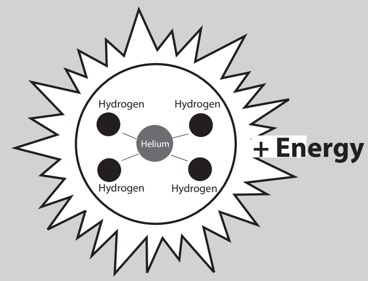
If this reaction occurs under conditions favorable for the rapid release of energy, we can see two neutrons bombard and fission two additional U-235 nuclei, then four neutrons bombard and fission four, eight bombard and fission eight, and so on. This forms what is called an explosive chain reaction where the energy released rapidly doubles from one round of fissions to another. This is the type of reaction needed for a nuclear weapon. Inside a reactor, a much more controlled chain reaction takes place where one fission leads to one additional fission and so on. Thus, reactors cannot produce an explosive chain reaction and act like a nuclear bomb.

When the mass of the fission products and neutrons produced by the fission are added and compared to the original mass of the U-235 nucleus and the initial neutron, we find a small difference in mass; the mass of the original U-235 and neutron is greater than the mass of the fission products and neutrons produced. One of the fundamental laws of nature is the Law of Conservation of mass and energy. This law states that mass cannot be created or destroyed, but can change forms. During these changes, some of the mass is often converted into energy. The amount of energy formed can be predicted using Einstein's equation, $E=mc^2$. At first glance it looks like mass was lost during this reaction. However, the difference in mass is equal to the energy released from the U-235 during the nuclear reaction.

Fusion

In **nuclear fission** an atomic nucleus splits creating two lighter elements and energy is released. **Nuclear fusion** also releases energy, but in this process light atoms combine to form a heavier nuclei.

The sun is a big ball of gases, mostly hydrogen and helium atoms. The sun's extremely high pressure and temperature cause hydrogen atoms to come apart and their nuclei to fuse. Four hydrogen nuclei fuse to become one helium atom. The helium atom that is created contains less mass than the four hydrogen atoms that fused. The "lost" mass is emitted as radiant energy.



Nuclear Fuel Cycle

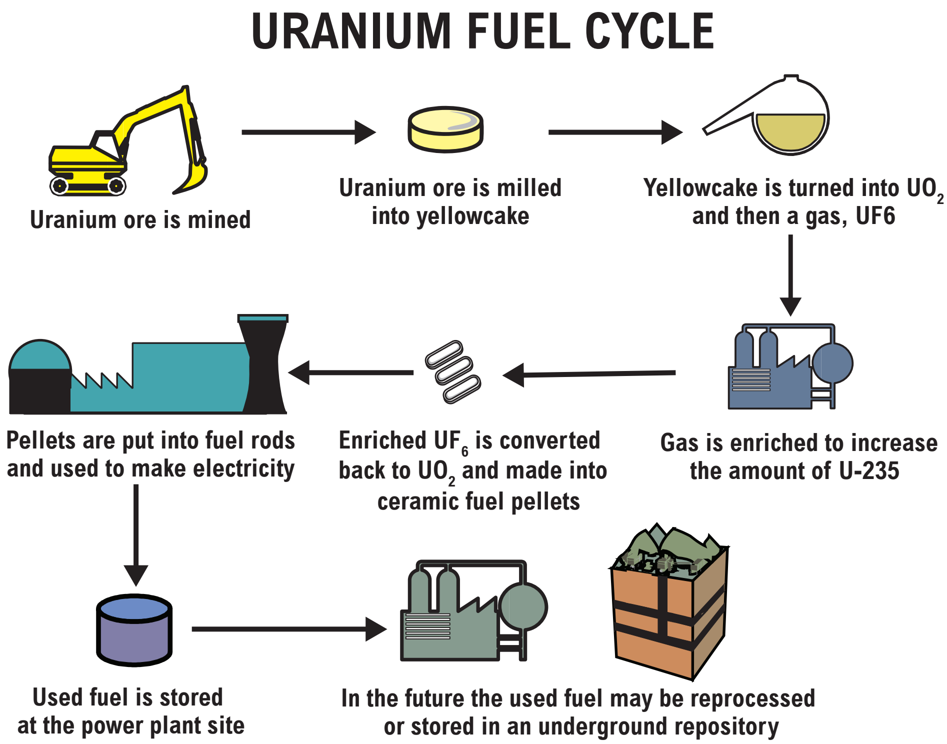
The fuel cycle is made up of a series of processes that manufacture reactor fuel, burn the fuel in a reactor to generate electricity, and manage the used reactor fuel. These processes are grouped into three components, the front end, which includes all activities prior to placement of the fuel in the reactor, the service period, when the fuel is converted into energy in the reactor, and the back end, which covers all activities dealing with used fuel from the reactor. If the used fuel is sent to storage, the cycle is referred to as open. If it is reprocessed to recover useful components, it is known as closed. The United States employs an open fuel cycle, while France, Russia, China, and Japan reprocess their used fuel.

FRONT END

Mining and Milling

There are three different methods used to mine uranium ore. If the ore lies close to the earth's surface, it is removed by open pit mining. Ore that is deep in the ground is removed by deep mining methods. The third way to retrieve uranium is by "in situ" methods, where chemicals are pumped into the ground dissolving the ore. The chemical-ore mixture is then pumped to the surface. Whichever method is used, the ore is moved to a mill for processing.

At the mill, the ore is crushed and treated with an acid



solution that separates the uranium from the rock and other waste materials. If in situ mining is used, the uranium is already dissolved in solution. The solution is then separated from its surrounding rock and waste materials. The solution undergoes further chemical treatments to separate the uranium. Uranium is collected and dried as uranium oxide (U_3O_8) concentrate. The concentrate is a bright yellow powder and is called yellowcake. The yellowcake is then packaged in steel drums and transported to conversion plants.

Refining and Conversion

During this step, the solid yellowcake is first refined into uranium dioxide (UO_2). Next, it is converted into a gas, uranium hexafluoride (UF_6). Below 60°C (140°F) UF_6 is a solid compound. When temperatures near 60°C, UF_6 turns into a gas allowing impurities to be removed. The gas is then turned back into a solid so it can be shipped to the enrichment plant.

Enrichment

The solid received at the enrichment plant is mostly U-238 with small amounts of U-235 mixed in. Since only the U-235 undergoes fission in a reactor, its concentration must be increased. UF_6 is converted back into a gas where it goes through gas diffusion or centrifugation for enrichment. The enrichment process separates the lighter U-235 from the U-238. This increases the concentration of U-235 from 0.7 percent to the three to five percent required for reactor fuel. The enriched fuel is reconverted into enriched uranium dioxide (UO_2) in the form of a black powder.

Fuel Manufacturing

During fuel manufacturing, the UO_2 is pressed into small cylindrical shapes, and baked at very high temperature (1600-1700 degrees Celsius). This baking turns the UO_2 into ceramic pellets that are about the size of a pencil eraser, called fuel pellets. Approximately 300 pellets are then placed into fuel rods and sealed. Fuel rods are bundled into fuel assemblies of 179-264 rods. When the reactor is brought on-line the U-235 nuclei undergo fission, producing the heat necessary to make steam and generate electricity.

One uranium fuel pellet provides as much energy as:

- **149 gallons of oil**
- **1,780 pounds of coal**
- **17,000 cubic feet of natural gas.**

Source: NEI
Photo Source: NRC Photo File

Reasons for Refining, Conversion, and Enrichment

Only the U-235 nucleus has a high likelihood to undergo fission under normal conditions in a reactor. The likelihood of fission depends mainly on four factors: the concentration of fissionable U-235, the number of neutrons in the reactor, the speed of those neutrons, and the concentration of materials such as U-238 that absorb neutrons without usually resulting in fission.

Think of the materials in the reactor core as competing for neutrons. If too few U-235 atoms absorb neutrons or too many U-238 atoms absorb neutrons, the chain reaction stops and energy production grinds to a halt. Slower neutrons generally are more likely to be absorbed by U-235 and cause fission. These slow neutrons are often called “thermal” neutrons because their kinetic energy is typical of the kinetic energy of atoms moving at room or thermal temperatures.

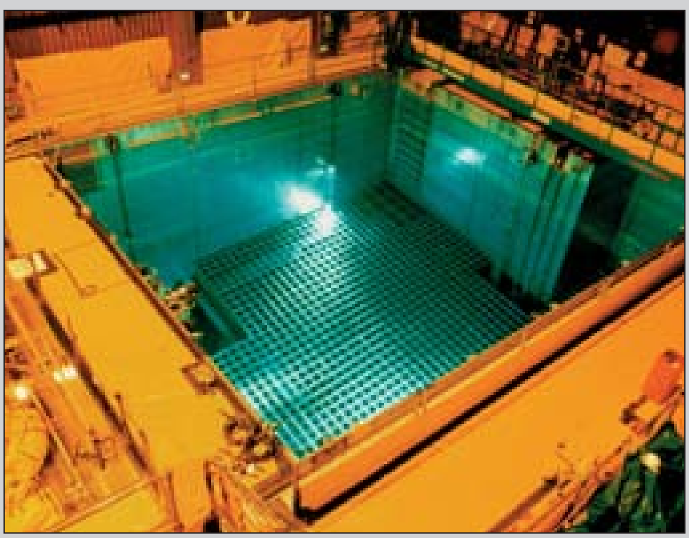
A thermal reactor uses materials to slow down or “moderate” the speeds of neutrons. A typical moderator is water. But ordinary water, also called “light water” can absorb neutrons and rob U-235 of the neutrons needed for sustaining the chain reaction. To compensate for this neutron absorption by water and by U-238, the concentration of U-235 must be increased to between three percent and five percent for use as fuel in a thermal light water reactor. All U.S. commercial reactors require enriched uranium. Another type of thermal reactor that uses heavy water does not require uranium enrichment because the heavy water, which consists of a heavier isotope of hydrogen, has a much lesser likelihood of absorbing neutrons. Thus, natural uranium fuel can be used in a thermal heavy water reactor. Canada and India, for example, use many of these reactors.

Back End

Open and Closed Cycles

After the ceramic pellets are used to generate electricity there are two possibilities of how to complete the nuclear fuel cycle. In the United States we have an “Open Cycle.” After being used once the fuel is placed into storage pools containing water at the reactor site. Plans for future long term storage of used fuel at a national repository in Nevada are currently on hold.

Some countries, including France, use a “Closed Cycle” where used nuclear fuel is reprocessed. The nuclear materials are separated and reusable materials are recycled into new fuel pellets. (See page 18 for more information on the open and closed cycles.)



The United States uses an Open Cycle. After fuel has been used it is stored in a used fuel pool (left picture) at the nuclear power plant. The Nuclear Waste Policy Act of 1982 specifies that used nuclear fuel will be stored “underground in a deep geologic repository.” A final repository is not yet available and nuclear power plants currently store used fuel on site. Originally used fuel assemblies were kept in used fuel pools. As fuel pools became full, a dry cask storage system (right picture) was developed.

Fuel assemblies cool in a storage pool for at least one year. Then, they may be sealed inside a container called a cask. The casks are steel cylinders welded or bolted closed, surrounded by additional steel or concrete. Casks may be stored vertically or horizontally depending on the storage design at each particular site.

Dry cask storage sites are called Independent Spent Fuel Storage Installations (ISFSI). Each site must be licensed by the NRC. At the end of 2009, 33 states had at least one independent spent fuel storage installation.

Photos: NRC Photo File

Nuclear Power Plants

The center of a nuclear power plant is the nuclear reactor. The purpose of the reactor is to release energy at a controlled rate. This allows the thermal energy produced during fission to produce the steam that turns a turbine and generates electricity.

There are two common types of thermal reactors: a boiling-water reactor (BWR) and a pressurized water reactor (PWR). They both have many of the same parts and safety features.

Containment Building: This is a thick-walled concrete and steel building designed to prevent leakage of radioactive gases, steam, and water entering the environment should a leak occur.

Reactor Vessel: This holds the nuclear reactor and is dual-layered with a thick steel wall so radioactive gases and liquids are still held in the vessel should a crack occur in one of the layers.

Fuel and Fuel Rods: These rods are filled with the UO_2 pellets that have already been enriched (nuclear fuel). The UO_2 fuel is a ceramic that contains only solids which limits the volume of radioactive gases that can escape into the atmosphere from the fuel itself. The fuel rods isolate the fuel from the water in the reactor vessel. They are bundled into a fuel assembly, a square lattice of 225-250 fuel rods held in a metal alloy canister.

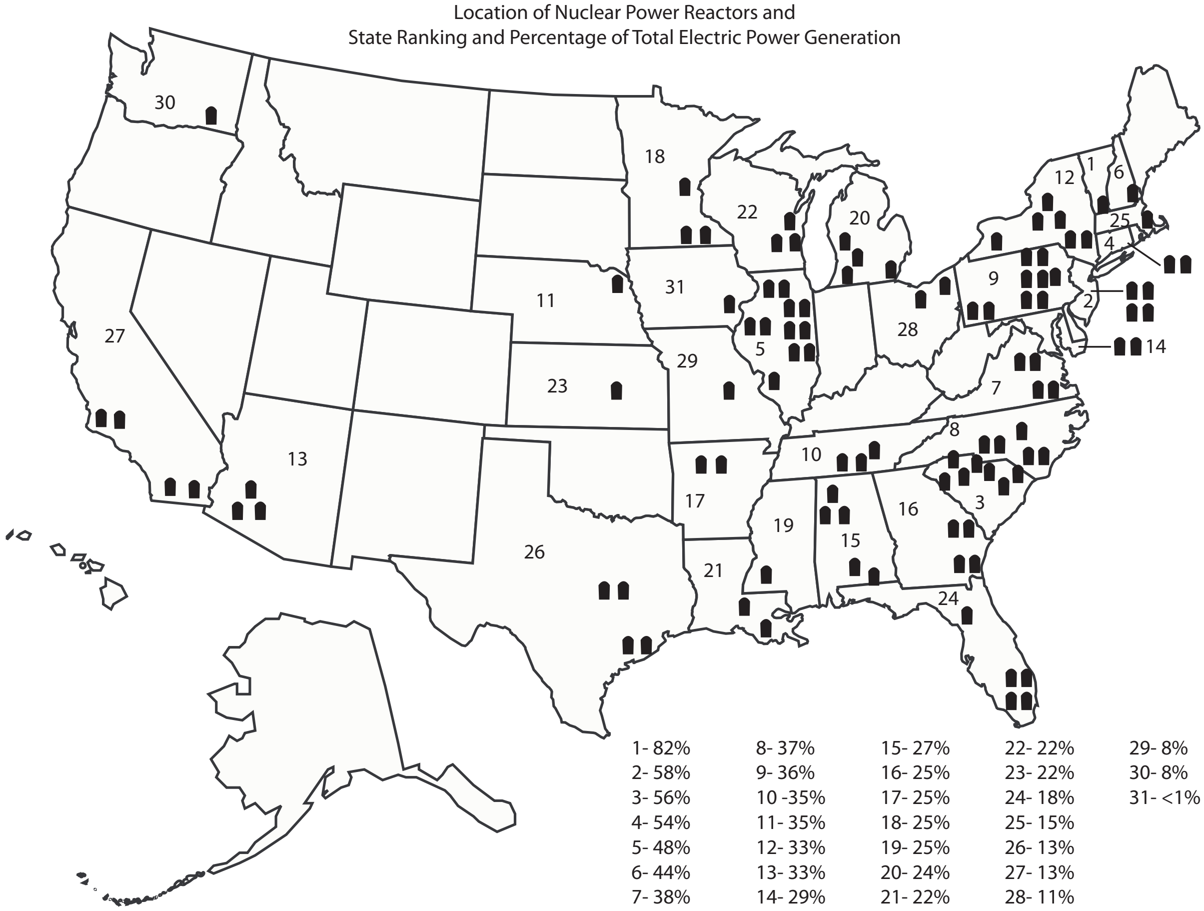
Control Rods: Control rods usually contain boron or cadmium, elements that absorb or capture neutrons to slow or stop the nuclear fission chain reaction. The control rods move up and down among the fuel rods increasing or decreasing the number of neutrons exposed to the fuel in order to control the chain reaction.

Moderator: A substance that slows down neutrons so that a chain reaction can be maintained. The moderator is usually natural water, or heavy water (deuterium oxide). Graphite, a form of carbon, can also be used as a moderator. Unlike graphite in school pencil “leads,” nuclear-grade graphite is almost pure carbon. The United Kingdom and Russia each have some graphite reactors.

Heat Exchange System: A nuclear plant’s thermal energy must be used to make steam and generate electricity. The heat is used to make steam which carries energy from the reactor vessel to the turbines. After the steam turns the turbines, it must be condensed back into water and returned to the reactor vessel. This is done by the heat exchange systems.

Nuclear Energy Production

Location of Nuclear Power Reactors and
State Ranking and Percentage of Total Electric Power Generation



Source: NRC and EIA

How a Nuclear Reactor Works

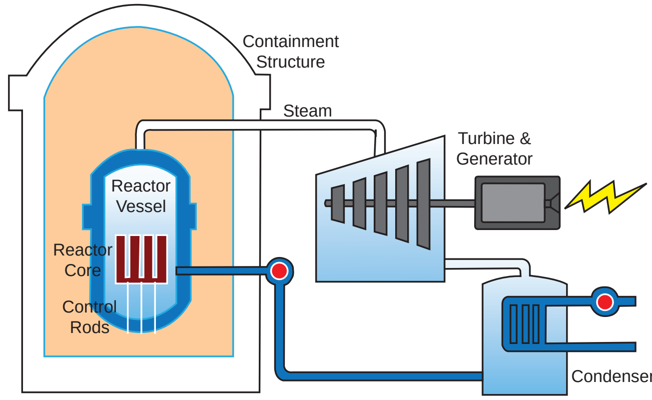
A boiling water reactor (BWR) operates with only one heat exchange system, the primary system. In the primary system of a BWR, water surrounds the reactor core and comes into contact with the fuel rods.

As the water is heated by the nuclear energy, it changes to steam. The steam then flows out of the reactor to the electrical generator. The steam is used to turn the turbines that spin the shaft, which turns the wires and magnets making electricity. At the generator, there is an external system that uses water from the environment (river, ocean, lake, etc.) to condense the steam in the primary system back into water. The cooled water in the primary system is then pumped back into the reactor vessel where the cycle is repeated. Impurities in the water in the primary system can absorb radiation from the reactor and may become radioactive. Water in the external system does not come into contact with the reactor vessel or with the water in the primary system. Thus, it is not radioactive and once cooled can be returned to the environment after use.

The pressurized water reactor (PWR) is the most popular commercial reactor type worldwide. Unlike a BWR, a PWR contains both primary and secondary heat exchange systems. Heated water from the reactor core, or the primary system, is sent to a steam generator or heat exchanger. The heated water is placed under high pressure to prevent it from boiling. Heat is transferred from the reactor water to a separate water/steam system, the secondary system. This means that water from the reactor core does not come into contact with the water and steam in the steam chamber. The steam in the secondary system then flows into the turbine where it turns the generator and generates electricity. This steam is then condensed by water from an external system before it returns to the heat exchanger in the containment building where it is heated and the cycle repeated.

Both types of reactors use an external source of cooling water is required to transfer waste heat to the environment. Generally, there are two methods for accomplishing this transfer of heat. If the reactor is located on a large body of water, the hot coolant water can be pumped from the plant into the body of water. The hot water is replaced by cool water from the outside water supply. However, as this heat is released, the temperature of the body of water increases. This temperature increase is closely monitored to make sure the increase does not exceed accepted limits. This system is similar to those of many fossil fueled generating plants that also transfer heat from the power plant into an external body of water.

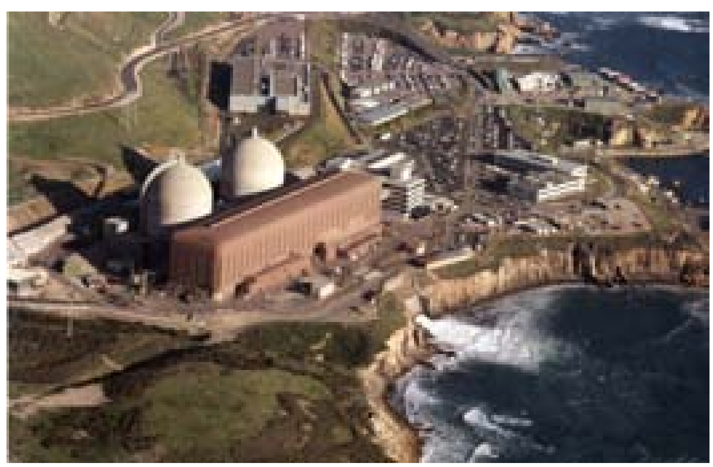
Boiling Water Reactor



The second method involves releasing heat from the external cooling system into the atmosphere. This is usually accomplished using a cooling tower where air flows past the warm water in the coolant water. The air cools the water which condenses at the bottom of the tower and is pumped back to the plant to be reheated. Cooling towers are designed to maximize the draft of air they create. Usually the cooling towers are concave shaped and are the most visible feature of many nuclear plants and other power plants. They do not release radiation into the atmosphere.

Additional Safeguards

Generally, there are two classes of newer nuclear reactor designs, evolutionary and passive. Evolutionary reactors are those that have the same basic design as pre-1990s reactors but with improved safety systems. The safety systems are larger with more cooling capacity, more dependable with increased



Operated by Pacific Gas & Electric, the Diablo Canyon Nuclear Power Plant is located in San Luis Obispo County, CA. Two pressurized water reactors provide electricity for nearly three million northern and central California homes.

Diablo Canyon uses water from the Pacific Ocean to cool water cycling through the power plant.

Photo Source: NRC Photo File

back-up systems, controlled by the latest technology that monitors and controls the safety systems, and are easier to maintain and up-grade.

Passive reactors are designed so that safety systems operate automatically, powered by gravity or natural convection. These systems are designed to minimize operator error. Passive safety systems contain no moving parts, or if valves are needed, the valves are air or battery-operated. In either case, no electricity is needed for valve operations, and thus a loss of electricity does not affect the valves.

New safety designs place large amounts of emergency coolant (water) inside the containment shell above the reactor vessel. In the case of an accident, coolant above the reactor vessel is released and floods the reactor core with water. Earlier designs placed the emergency cooling system outside the containment. In these designs, pumps and back-up electricity sources are needed to move emergency coolant into the reactor. In later-design reactors, emergency coolant and air circulates by natural convection to remove built-up heat by natural convection. Again, pumps and fans are not needed and back-up electrical systems are not required.

No matter what type of safety systems are in place, it is still necessary for strict Nuclear Regulatory Commission (NRC) procedures to be followed and inspections carried out as required. For example, inspection and reporting failures at the Davis Besse nuclear plant near Toledo, Ohio, came to light in 2002. Corrosion of the reactor lid by boric acid caused the lid to weaken and drastically increased the chances of a nuclear accident. Engineers may have made false reports to the NRC, and the NRC did not follow up in timely fashion. This illustrates the importance of enforcing safety regulations and procedures in order for nuclear plants to have a place in the U.S. energy portfolio.

Used Fuel Options

Radioactive Waste Handling and Storage: Open Cycle
A typical thermal reactor fuel assembly remains in the reactor for three years. Reactors are typically shut down for one month out of every 18 months for refueling and maintenance. Approximately one-third of the used fuel is removed and replaced with fresh fuel assemblies. The level of radioactivity of used fuel is initially extremely high due to the short half-lives of the products of U-235 fission and the radioactive transuranium elements (elements with atomic numbers

Nuclear Accidents:

Three Mile Island and Chernobyl

Two events that have influenced people's perception of nuclear energy are the accidents at Three Mile Island in Pennsylvania and Chernobyl in the Ukraine (former Soviet Union).

In 1979 there was an accident at the Three Mile Island (TMI) reactor. In the morning, feed-water pumps that moved coolant into the reactor stopped running. As designed, the turbine and reactor automatically shut down, but an automatic valve that should have closed after relieving pressure inside of the reactor stayed open. This caused coolant to flow out of the reactor and the reactor overheated, and the nuclear fuel started to melt. By evening, the reactor core was stabilized. Over the next few days there were additional dilemmas including the release of some radiation into the atmosphere which led to a voluntary evacuation of pregnant women and pre-school aged children who lived within a five mile radius of the plant.

The accident at TMI has been the most serious in U.S. commercial nuclear power plant history, however there were no serious injuries and only small amounts of radiation were measured off-site.

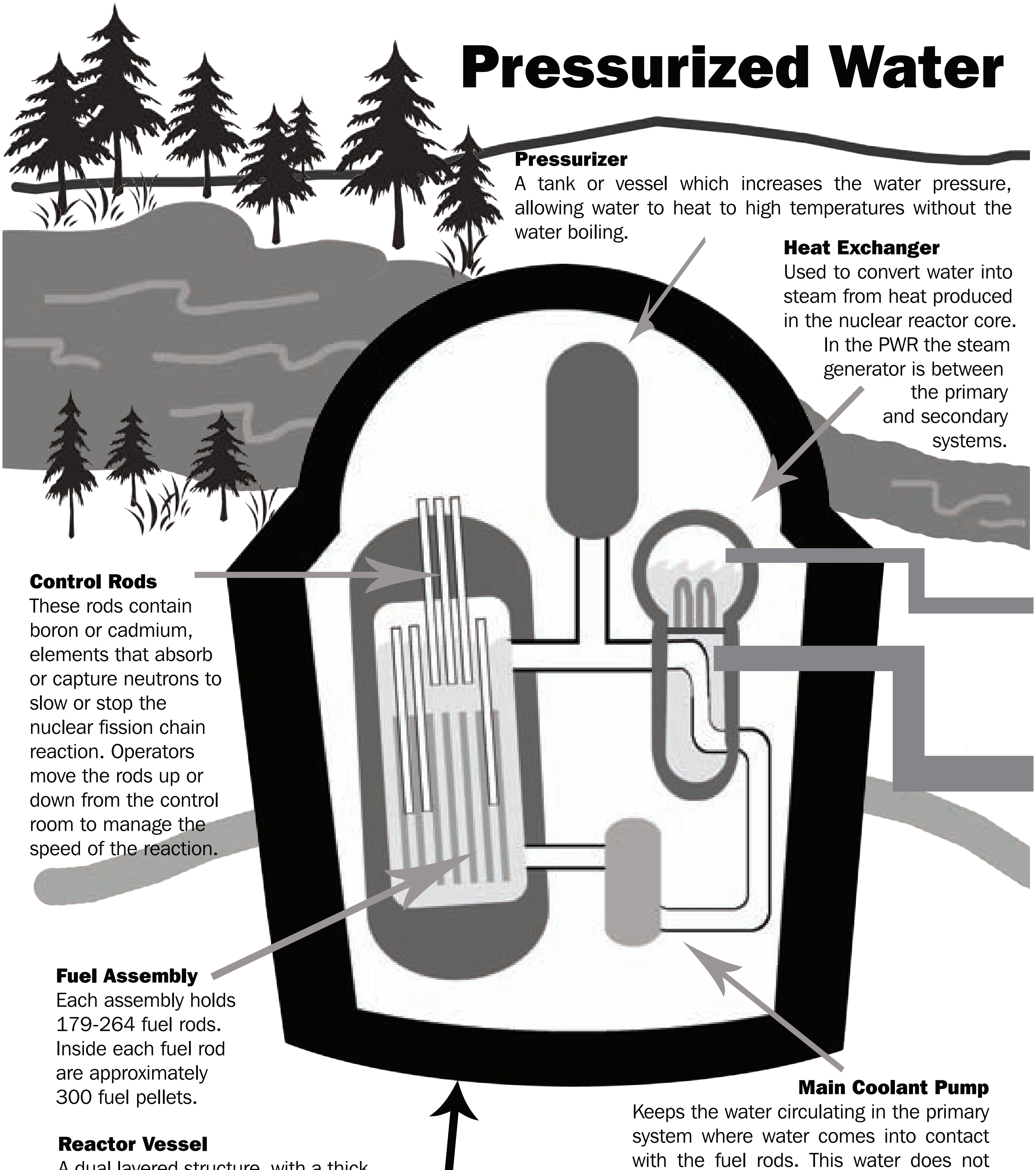
In the Ukraine, they rely heavily on nuclear power to generate electricity. In 1986 at the Chernobyl Power Complex there were four reactors operating with two more reactors under construction. On April 26, 1986 while conducting tests of Unit 4's reactor behavior at low power settings, plant operators turned off all of the automatic plant safety features. During the test the reactor became very unstable and there was a massive heat surge. Operators were unable to stop the surge and two steam explosions occurred. Fission products and burning radioactive fuel were thrown into the atmosphere. When air entered the reactor the graphite moderator burst into flames and the entire unit became engulfed in fire. Two workers died in the initial explosion and by July, 28 additional plant personnel and firefighters had also died. Between May 2-4 about 160,000 persons living close by the reactor were evacuated. During the next several years an additional 210,000 people were resettled from areas within an approximate 20 mile radius of the plant. Soon after the accident Unit 4 was encased in a cement structure allowing the other reactors nearby to continue operating.

Today about 1,000 people have unofficially returned to live within the contaminated zone. A new "Safe Confinement Structure" is being built to more securely contain the radioactive materials that remain in Unit 4. The new structure will encompass Unit 4 and the existing concrete shelter. Scheduled to be completed in 2011 the structure will be 344' high, 656' long, and 843' wide.

Much was learned by nuclear engineers and operators from both accidents. Although the reactor of Unit 2 at TMI was destroyed, most radioactivity was contained as designed. No deaths or injuries occurred. Lessons from TMI have been incorporated into both evolutionary and passive nuclear plant designs.

While some Chernobyl-style reactors are still operating in Eastern Europe, they have been drastically improved. Training for nuclear plant operators in Eastern Europe has also been significantly improved with an emphasis on safety.

Pressurized Water



Pressurizer
A tank or vessel which increases the water pressure, allowing water to heat to high temperatures without the water boiling.

Heat Exchanger
Used to convert water into steam from heat produced in the nuclear reactor core. In the PWR the steam generator is between the primary and secondary systems.

Control Rods
These rods contain boron or cadmium, elements that absorb or capture neutrons to slow or stop the nuclear fission chain reaction. Operators move the rods up or down from the control room to manage the speed of the reaction.

Fuel Assembly
Each assembly holds 179-264 fuel rods. Inside each fuel rod are approximately 300 fuel pellets.

Main Coolant Pump
Keeps the water circulating in the primary system where water comes into contact with the fuel rods. This water does not leave the containment building.

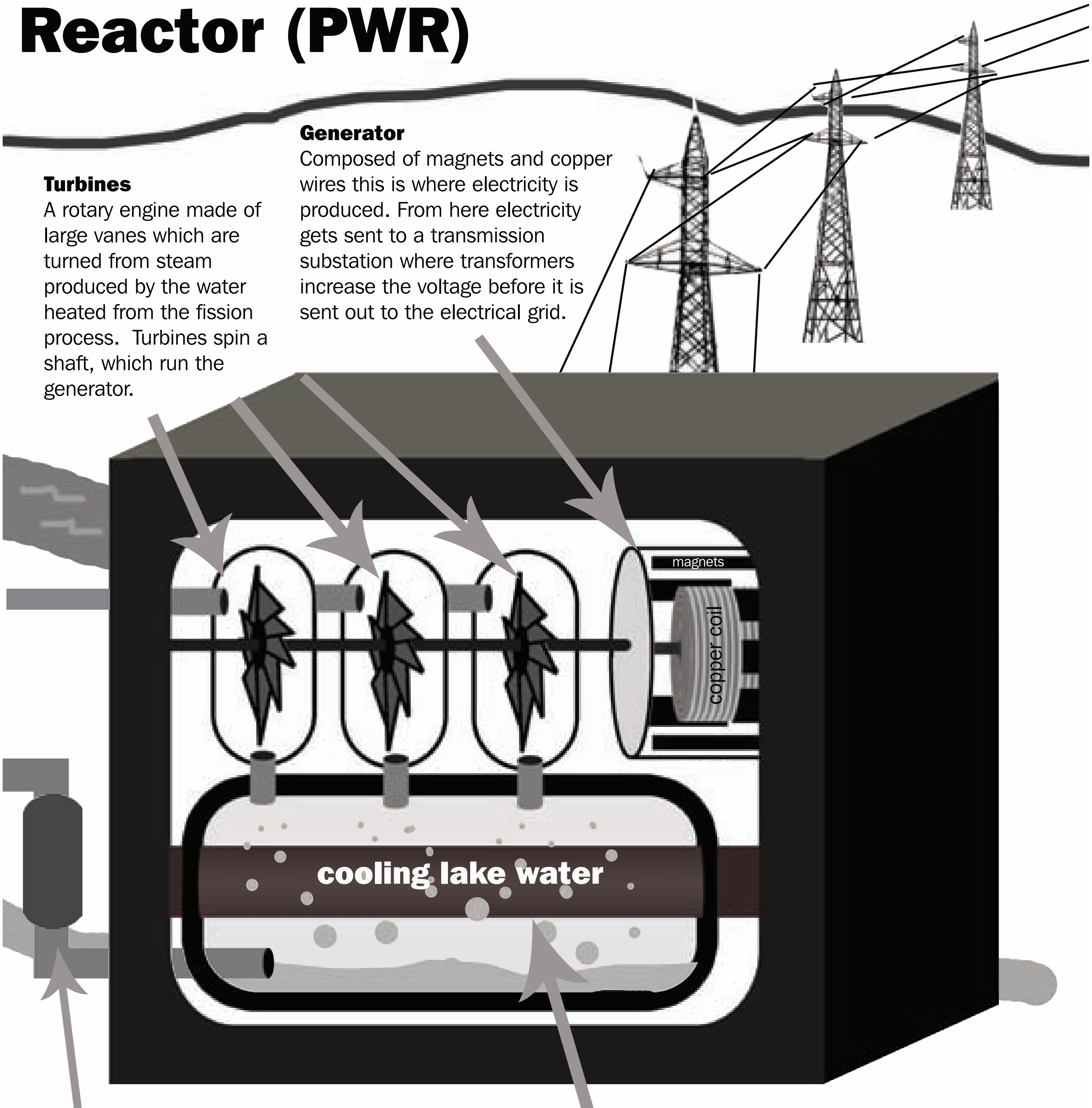
Reactor Vessel
A dual layered structure with a thick steel wall. It holds the reactor core, and the moderator/coolant. In most PWRs the coolant is light (natural) water.

Containment Building
This structure houses all of the parts of the nuclear reactor. It is a thick-walled, steel lined building designed to prevent radiation leaks.

Reactor (PWR)

Turbines
A rotary engine made of large vanes which are turned from steam produced by the water heated from the fission process. Turbines spin a shaft, which run the generator.

Generator
Composed of magnets and copper wires this is where electricity is produced. From here electricity gets sent to a transmission substation where transformers increase the voltage before it is sent out to the electrical grid.



Feedwater Pump
After the steam has been condensed back to water the pump keeps it circulating to be reheated again. This water is part of the secondary system and does not come in contact with radioactivity.

Cooling Water
In some cases nuclear power plants are built along a river or lake. After the steam has passed by the turbines, it continues traveling in pipes to an area to be condensed. Here, the steam is cooled by cold water running through the plant in a pipe. In instances where a water source is not nearby, cooling towers are used to condense the steam.

greater than 92) resulting from the absorption of neutrons by U-238. The used fuel is placed in pools of water near the reactor to allow both the radioactivity and heat to decrease. After approximately five years, the fuel can be removed from the pools and placed in secure containers known as dry casks for intermediate storage.

The storage of waste containing used fuel presents a challenge which has yet to be solved. Currently all nuclear waste in the United States is stored in water-filled pools or in dry-storage casks on site at nuclear power plants. In 1987, the U.S. Congress chose Yucca Mountain in southwest Nevada as the most likely site for long-range nuclear waste storage. It is generally considered a stable area where radioactive waste can be buried deeply underground and security can be maintained.

In 2010, the Department of Energy filed a motion to withdraw the license application for a high-level nuclear waste repository at Yucca Mountain. More than 20 years after its selection, it is not certain that Yucca Mountain will be used as a long term nuclear waste repository. A Commission on America's Nuclear Future has been formed to review current nuclear fuel management policies and make recommendations for managing the nation's used nuclear fuel and nuclear waste. No nation currently has a permanent repository for the storage of radioactive waste from used fuel.

A used fuel cask can be transported by truck.

Photo Source: NRC Photo File

Reprocessing Nuclear Waste: Closed Cycle

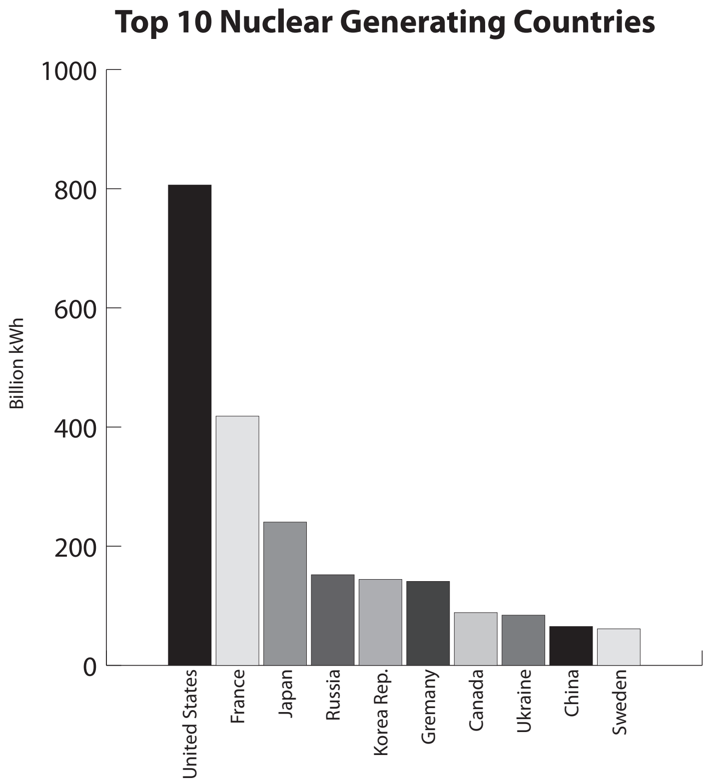
Reprocessing spent fuel uses chemical methods to separate the uranium and plutonium from the other components of the fuel from the reactor. The extracted uranium 238 is recycled once to produce additional reactor fuel. The plutonium can be mixed with enriched uranium to produce metal oxide (MOX) reactor fuel for both thermal and fast neutron reactors. The relatively small volume of remaining radioactive waste can be stored in liquid form and solidified in glass for permanent storage. While reprocessing recovers uranium and plutonium for use as additional nuclear fuel and reduces the amount of waste to be managed, it also produces waste which is both radioactive and chemically toxic.

NUCLEAR WEAPONS

Proliferation Risks of Nuclear Power Programs

Beginning with the use of the first nuclear weapons on Japan, the spread of nuclear weapons (nuclear proliferation) has been a world-wide concern. Ferguson (2007) describes four issues that have occurred within the last ten years that have caused many world leaders to become concerned that nuclear materials designed for peaceful nuclear power uses could be used for weapons. First, after September 11, 2001 there has been an increasing threat of nuclear terrorism. Second, since 2002 Iran has made substantial progress in enriching uranium and building a nuclear research reactor that could produce plutonium. Both cases could lead to the development of nuclear weapons by Iran. Third, in December 2003 it was learned that a Pakistani scientist, A. Q. Khan, was selling nuclear secrets to other countries and groups. Finally, the renewed interest in nuclear power as a way to reduce greenhouse gases has led to many countries expressing interest in starting or increasing nuclear power programs. However, there is a fear that some of these countries would use peaceful activities to hide the development of a nuclear weapons program. Furthermore, terrorist groups would not have to actually build a nuclear weapon to create a terror situation. Radioactive substances can be placed inside weapons based on ordinary explosives. Activation of such weapons could spread the radioactivity creating fears of radioactive contamination of the environments of exposed areas.

The same technologies that make fuel for nuclear reactors can also produce materials that are usable for nuclear weapons. These technologies include uranium enrichment and extracting plutonium from spent nuclear fuel. Therefore, a major concern exists where a country may say it is developing nuclear power for peaceful purposes while creating fuel that could be used in a nuclear weapon.



Source: Nuclear Energy Institute

Controlling the Proliferation Risks

While many countries have desired nuclear weapons, only eight are currently known to possess them (the United States, Russia, France, the United Kingdom, China, India, Pakistan, and North Korea). There is a strong possibility that Israel also has nuclear weapons. There are many international concerns about nuclear weapons falling into the hands of terrorists and "rogue" states. Controlling the proliferation of nuclear weapons materials and technology involves political, financial, and technical solutions.

An important international treaty related to nuclear technology is the nuclear Non-Proliferation Treaty (NPT). Article IV of the NPT, declares that a state has the "right" to peaceful nuclear technologies as long as the state maintains safeguards on its peaceful nuclear program and does not manufacture nuclear explosives. The rights of countries under the NPT are not clearly defined. This article does not specifically mention uranium enrichment and plutonium reprocessing technologies as part of a state's right to peaceful nuclear technologies. Many countries want to interpret the NPT as giving them the right to enrich uranium and extract plutonium from nuclear wastes. Thus, non-nuclear-weapon countries such as Argentina, Brazil, and Japan, for example, have pursued enrichment or reprocessing or both, and have maintained safeguards on these programs. Iran claims that it wants to be like Japan and have a peaceful nuclear program that includes enrichment and possibly reprocessing. However, the International Atomic Energy Agency (IAEA) and the UN Security Council have ruled that Iran is not in compliance with its safeguards commitments.

Discussion of how to guard access to weapons-grade nuclear materials while allowing access to needed fuel for nuclear reactors is continuing. Possible solutions to the problem include having a few countries that are closely monitored by the nuclear community supply nuclear fuel to other countries who wish to operate a few nuclear power plants. These "fuel service contracts" would include management of spent fuel to make sure it cannot be accessed so that plutonium would not be extracted for weapons programs.

A country desiring a large nuclear power program may still want to enrich and reprocess fuel so that it can operate nuclear plants. Because these countries will enrich uranium or reprocess spent nuclear fuel, the nuclear industry should work to significantly reduce proliferation risks in those activities. Currently reprocessing methods that do not isolate plutonium from fission products or other radioactive materials such as transuranics are being investigated. This would leave higher amounts of radioactive materials near the plutonium making it more dangerous to steal or store. International safeguards and inspections would need to be maintained since a country could continue to reprocess the fuel and extract more plutonium.

Although proliferation could be substantially reduced if nuclear power were phased out, nuclear power has many advantages over other forms of energy. Some countries are planning to expand their nuclear power programs, and concerns about proliferation will remain for the foreseeable future. In the end, the international community must balance the benefits of nuclear energy with its risks. Faced with the continued use of nuclear energy in the foreseeable future, the international community must be vigilant about controlling the risks of proliferation.

ECONOMICS OF NUCLEAR ENERGY

Building new nuclear power reactors will be costly. Cost estimates for building two nuclear units at an existing nuclear power plant site range from $8 billion to $18 billion. At these costs, the construction and operation of a nuclear reactor that goes on-line in 2016 will be approximately 20-40 percent higher than those of a conventional coal or natural gas plant that goes online at the same time. When compared to alternative sources of energy and advanced technology coal and natural gas plants, the expense of building and operating a nuclear power plant becomes economically competitive.

Licensing Procedures

Prior to the 1990s, the approval and licensing for nuclear plants was expensive and time-consuming. Under the old process, the NRC issued a construction permit that allowed a power company to build a nuclear plant. Companies built expensive nuclear energy plants with no guarantee from that the government would allow them to be used. Some plants were built or almost built, but never went on-line, and power companies lost huge amounts of money. In 1989, the NRC changed the licensing procedure. Now, the plant site is approved by the NRC before any construction is started, and standard designs for nuclear plants are encouraged. This should speed up the approval and building process. Finally, all licensing hearings are held and completed before any construction occurs. This will prevent expensive delays after the plant is completed.

Under the new licensing process by the end of 2009 construction and operating licenses for 28 new units had been submitted to the NRC. If licensing procedures and construction proceeds on schedule, the first of these plants will go on-line in 2016.

Despite new licensing procedures, there has still been reluctance by investors to invest in new nuclear power plants. To make nuclear plants more affordable and to encourage companies to build, the U.S. Congress passed the Energy Policy Act of 2005 that contains economic incentives for projects, including the construction and operation of nuclear plants, that avoid, reduce, or sequester air pollutants or greenhouse gas emissions. These incentives include tax credits for the power companies building nuclear power plants, government-backed insurance to cover economic losses of power companies if operations are delayed, and loan guarantees to make sure companies can get financing for new nuclear plants.

In 2010 the first conditional loan guarantee for a nuclear power facility was issued by the Department of Energy to support the building of two nuclear reactors at the Alvin W. Vogtle Electric Generating Plant in Burke County, GA. The plant currently is operating two

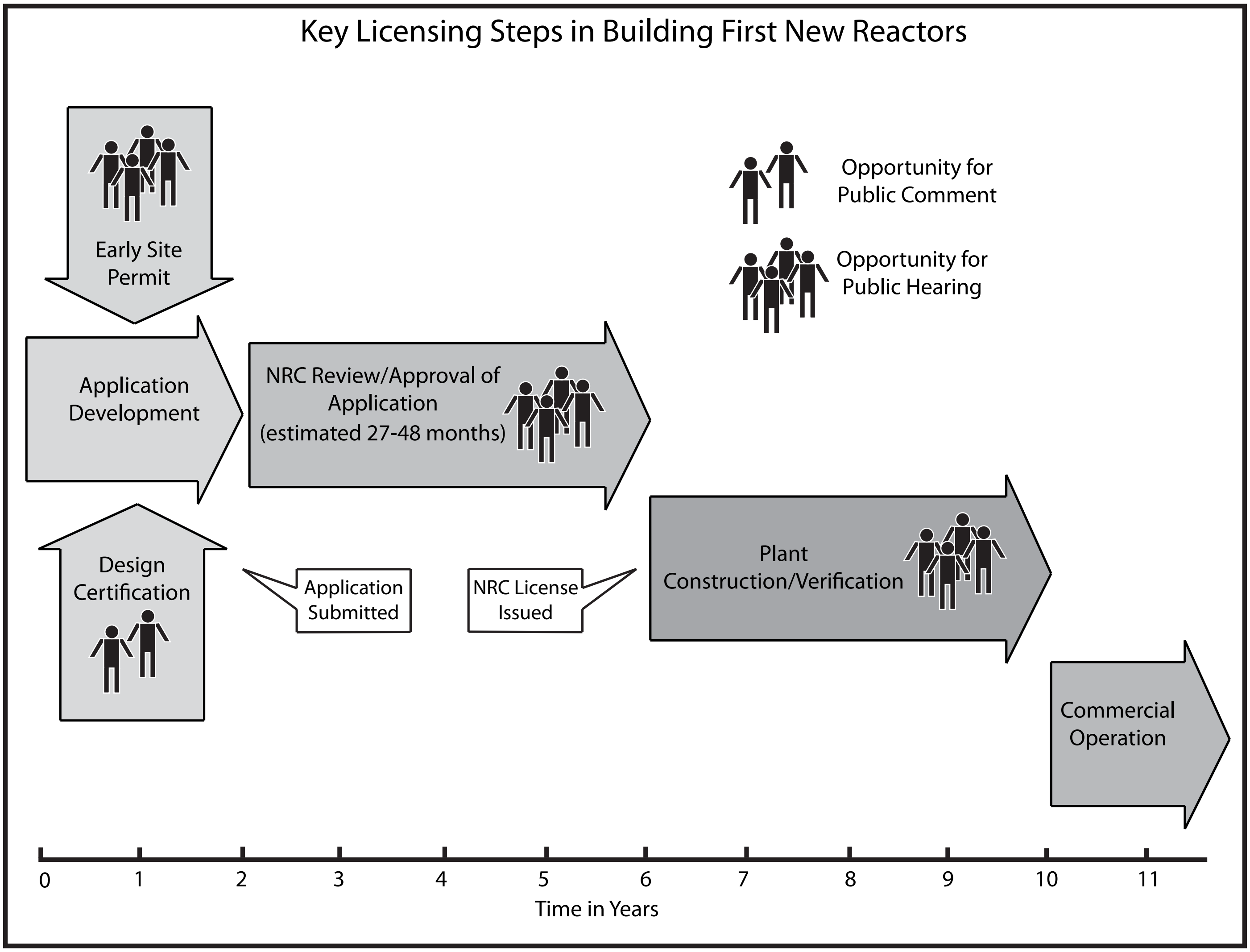
Work is already underway at the Vogtle Electric Generating Plant preparing sites for two additional nuclear reactors. When the NRC issued the Early Site Permit for Vogtle, it included a Limited Work Authorization which has allowed limited safety-related activities to begin. The first reactor is expected to go on-line in 2016.

Source: Southern Company

U.S. Average Levelized Costs ($/Megawatthour) for Plants Entering Service in 2016	
Conventional Coal	100.4
Advanced Coal with CCS	110.5
Natural Gas-fired	
Conventional Combined Cycle	83.1
Advanced CC with CCS	113.3
Advanced Nuclear	119.0
Wind	149.3
Wind – Offshore	191.1
Solar PV	396.1
Solar Thermal	256.6
Geothermal	115.7
Biomass	111.0
Hydropower	119.9

Levelized costs for new power plants include the cost of constructing the plant, construction time, non-fuel operating costs, fuel costs, the cost of financing, and the utilization of the plant. Not included in the levelized costs are any state or federal tax credits or other incentives which may play a role in the future.

Source: Annual Energy Outlook 2010



units with a combined capacity of 2,400 MW. The new reactors will add an additional 2,200 MW of capacity. The $8.33 billion loan guarantee is conditional based in part on the NRC approval of the Westinghouse AP1000 reactors chosen to be built on site.

Local Economic Impacts

Despite high capital costs to build new nuclear power plants, the local and state economies will benefit in the long run. Building a new nuclear power plant will create many jobs. During construction 1,400-1,800 jobs will need to be filled, at some construction phases the number could be as many as 2,400 jobs. After the plant begins operating, 400-700 permanent jobs will remain. These jobs pay approximately 36 percent more than the average salaries in the local area.

The average nuclear power plant generates about $430 million in local sales of goods and services. This includes the plant's own expenditures, and those of the employees working at the plant. The average nuclear power plant also pays local and state taxes which total almost $20 million every year, and federal tax payments of almost $75 million.

Climate Change

Another issue that affects the economics of all types of power plants is climate change. Carbon dioxide (CO_2) emissions are believed to be a leading factor in climate change. Generating electricity contributes to 40 percent of carbon dioxide emissions in the United States. Several proposals in Congress have included taxes or tariffs on CO_2 emissions to encourage decreased use of fossil fuels and reductions in greenhouse gas emissions. If such proposals are adopted, generating electricity from coal and natural gas will have increased costs, and nuclear power will become more economically competitive even without financial incentives from the government.

Advantages and Challenges of Nuclear Energy

Advantages of Nuclear Energy

- Nuclear power plants do not emit any greenhouse gases.
- Nuclear power plants do not give off pollutants such as soot, ash, or sulfur dioxide.
- There is a large supply of nuclear fuel available – enough for several hundred to many thousands of years, and uranium fuel costs are low relative to coal and natural gas.
- Nuclear energy can provide electricity where renewable sources are limited.
- The operating cost of a nuclear power plant is low, and will continue to be reduced as plants become more dependable and operate for longer periods of times.
- New plant designs are safer and more efficient than those of older plants.
- Increasing the number of nuclear plants in the U.S. can reduce our dependence on foreign oil if Americans buy and drive electric-powered vehicles. This requires a dramatic increase in the design and production of electric-powered vehicles by car manufacturers.

Challenges of Nuclear Energy

- Overall costs of construction and waste disposal are high.
- It takes longer to build a nuclear power plant than a coal or natural gas plant.
- Radiation released from nuclear reactions must be contained, and radioactive wastes must be safely and securely stored.
- The public has major concerns about the safety of nuclear energy.
- Transporting nuclear waste across the country worries many people.
- It is unknown how long-term storage of radioactive waste will impact the environment.
- Uranium enrichment and nuclear fuel reprocessing technologies created during enriching and reprocessing can be used in producing fissile materials for nuclear weapons.
- The nuclear industry is facing a shortage of human resources, more technicians and engineers are needed.
- There are limited material resources including plants to make reactor components, and an increased demand for raw materials including concrete and copper.

Two PWR reactors at Surry Power Station in Virginia generate 1,598 megawatts of electricity, enough electricity to power 400,000 homes. Unit 1 went on-line in 1972 and Unit 2 followed in 1973. Initially licensed for 40 years, both reactors received 20-year license extensions in 2003.

Photo Source: NRC Photo File

CAREERS IN THE NUCLEAR INDUSTRY

The following are examples of careers that require training in the use of nuclear energy or that help support nuclear industries.

Nuclear Power:
Entry-Level Engineer - Helps to develop complex plans to support plant operations. The engineer also monitors, assesses and improves the performance and reliability of plant systems and components.

Experienced Engineer - An experienced or senior engineer at a nuclear power plant plans and coordinates programs and large-scale engineering projects or several medium projects while acting as a technical specialist for a specific engineering field.

Mechanical Technician - Performs preventive, corrective and special maintenance on systems, components and structural facilities to ensure the reliability of a nuclear power plant.

Electrical Technician - Performs maintenance and repair of highly complex electrical/electronic equipment required for a nuclear plant. Responsibilities include troubleshooting, testing and inspecting the equipment in a highly skilled manner.

Instrumentation and Control Technician - Responsible for calibrating, testing, troubleshooting, reworking, modifying and inspecting nuclear plant instrumentation and control components and systems.

Chemistry Technician - Measures and records plant chemistry and radioactivity levels, and operates chemical and radiochemical instrumentation and equipment.

Radiation Protection Technician - Radiation protection technicians measure and record radiation levels; in addition, they service and calibrate radiation protection instruments and equipment. They play a vital role in ensuring the safety of employees working in radiation areas, as well as the facility's compliance with radiation requirements.

Non-Licensed Operator - Supports the licensed reactor operators and senior reactor operators. Duties include opening and closing valves, electrical breakers and other devices as well as directly monitoring plant equipment performance.

Reactor Operator - A reactor operator, licensed by the U.S. Nuclear Regulatory Commission, is responsible for operating a reactor's controls in cooperation with the remainder of the shift team. The reactor operator moves control rods, starts and stops equipment, implements operations procedures, conducts surveillance tests and records data in logs.

Senior Reactor Operator - A senior reactor operation is licensed to operate a nuclear power plant in accordance with all regulations. Duties include operating the mechanical, electrical and reactor systems from the plant control room in a safe and efficient manner to ensure maximum electrical generation in compliance with regulations.

Industrial Machinery Mechanic - Repairs, maintains, and helps install mechanical systems of reactors, generators.

Skilled Trade Workers - Includes electricians who repair, maintain, and help install electrical systems that supply reactors, generators.

Electrical Line Workers - Repairs, maintains, and helps install electrical lines feeding and leaving electrical generators.

Welders - Install and repair various parts of reactors, generators, and cooling systems.

Non-Nuclear Power:
Archaeologist and Paleontologists - Use radiation to determine age and composition of fossils.

Biologist - Use radiation in experiments to develop new varieties of crops.

Biological Research Assistants - Help scientists and food engineers collect and analyze data to improve food supply.

Civil Engineer - Design, construct and/or supervise the building of roads, tunnels, bridges, facilities, water supply and sewer systems.

Gamma Facilities Operators - Use radiation to destroy microorganisms like salmonella or E. coli in food supplies.

Health Physicists - Assure safe application of radiation to humans in all areas where human radiation exposure may occur.

Medical Staff - Doctors, nurses, and other health practitioners use nuclear medicine to diagnose and treat diseases.

Nuclear Medicine Technologists - Run various tests in hospitals that use radiation.

Public Affairs - A career in public affairs often involves communicating with the public on nuclear energy and/or radiation topics. This may include writing press releases, attending public meetings, website administration, or leading tours at facilities.

Radiobiologist - A radiobiologist studies the effects of ionizing radiation on cells and organisms.

Radioecologist - An environmental scientist that studies and determines how radioactive material is transported through the environment and through ecosystems.

X-ray technicians - Administer and develop x-rays in health care setting.

Others - Persons trained in the use of radiation are needed in crime investigation, science education, policy making, and art appraisal and authentication.

GLOSSARY

alpha particle - A particle released from the nucleus of an atom made of two protons and two neutrons stuck together.

atomic mass - The number of neutrons and protons in the nucleus of an atom. Also known as the atomic weight.

atomic number - The number of protons in the nucleus of an atom.

beta particle - A negatively charged electron released from the nucleus of an atom.

Boiling Water Reactor (BWR) - A reactor in which water is used as both a coolant and a moderator. The water is allowed to boil in the core. This makes steam which is used to drive a turbine and electrical generator, and produce electricity.

chain reaction - A fission reaction that keeps itself going due to more and more neutrons being released. Depending on how fast neutrons are released, a chain reaction can be controlled or uncontrolled.

climate change - The change in Earth's overall climate patterns since the mid-20th century which includes an increase in the average measured temperature of the Earth's near-surface air and oceans.

containment building - A concrete and steel enclosure around a nuclear reactor that confines fission products that otherwise might be released to the atmosphere.

control rod - A rod, plate, or tube containing a material such as cadmium, boron, etc., used to control the power of a nuclear reactor. By absorbing neutrons, a control rod slows down or stops a chain reaction.

cooling tower - A heat exchanger used to cool water that comes from the inside of a nuclear reactor. Cooling towers transfer the exhaust heat into the air instead of into a body of water.

critical mass - The smallest mass of nuclear material that will support a chain reaction.

deuterium - An isotope of hydrogen with one proton and one neutron in the nucleus.

electron - One of three main subatomic particles (electrons, protons, and neutrons). It is the smallest of the three. It is only 1/1836 the mass of a proton and has a -1 charge. Electrons can be shared or transferred creating new chemical compounds. The moving of electrons produces electricity.

electron volt (eV) - A very small unit of energy equal to the energy gained by an electron as it passes from a point of low potential to a point one volt higher in potential.

energy - The ability to do work.

energy efficiency - The amount of useful energy in a system's output compared to its input.

enriched (uranium) - Uranium ore contains mostly U-238 and a small amount of U-235. Enriched uranium has its concentration of U-235 increased above its natural concentration.

external (cooling) system - The part of the cooling system holding that interacts with the environment and is not radioactive.

fission - The splitting of a nucleus into at least two smaller nuclei and the release of a large amount of energy. Two or three neutrons are usually released during this reaction.

fossil fuel - A hydrocarbon such as petroleum, coal, or natural gas, derived from prehistoric plants and animals and used for fuel.

fuel cycle - The series of steps involved in supplying fuel for nuclear power reactors. It includes mining, milling, enrichment, making fuel rods, use in a reactor, and waste handling and storage.

fuel pellets - A small cylinder approximately the size of a pencil eraser containing uranium fuel (uranium dioxide, UO_2) in a ceramic pellet

fuel rod - A long, slender tube that holds nuclear fuel pellets for reactor use. Fuel rods are bundled together in assemblies and placed into the reactor core.

gamma rays - Energy in the form of high-energy, short wavelength, or electromagnetic radiation released by the nucleus. Gamma rays are similar to x-rays and are best stopped or shielded by dense materials, such as lead.

greenhouse gases - The parts of the atmosphere, both natural and manmade, that trap and hold heat within the earth's atmosphere.

half-life - Time required for half the atoms contained in a sample of radioactive substance to decay naturally.

heat exchanger - A device that moves heat from one fluid (liquid or gas) to another fluid or to the environment.

heavy water (D_2O) - Water that contains a significant amount of deuterium. Heavy water is used as a moderator in some reactors because it slows down neutrons effectively.

ionizing - The process of adding or removing one or more electrons to or from atoms or molecules creating charged particles.

kinetic energy - Energy of motion.

light water - Ordinary water as distinguished from heavy water (D_20).

meltdown - A severe nuclear reactor accident that happens when a nuclear power plant system fails and causes the reactor core to no longer be properly controlled and cooled. This causes the nuclear fuel to melt, and releases radiation.

moderator - A material, such as ordinary water, heavy water, or graphite, that is used in a reactor to slow down high-velocity neutrons. This increases the chances of fission of U-235.

neutron - A fundamental subatomic particle that has nearly the same mass as the proton and no charge.

neutron number - The number of neutrons in a particular isotope.

Non-Proliferation Treaty (nuclear) - A treaty to limit the spread of nuclear weapons, opened for signature on July 1, 1968. There are currently 189 countries party to the treaty, five of which have nuclear weapons: the United States, the United Kingdom, France, Russia, and the People's Republic of China (the permanent members of the UN Security Council). Only four recognized countries have not signed the treaty: India, Israel, Pakistan, and North Korea.

nonrenewable energy - Energy that has a limited supply.

nuclear energy - The energy given off by a nuclear reaction (fission or fusion) or by radioactive decay.

nuclear fuel cycle - See **fuel cycle**

nuclear proliferation - The spread of nuclear weapons or materials that can be used to build nuclear weapons. **Also see Nonproliferation Treaty (nuclear).**

Nuclear Regulatory Commission (NRC) - An independent agency created by the United States Congress in 1974 to allow the nation to safely use radioactive materials for civilian purposes. The NRC regulates commercial nuclear power plants and other uses of nuclear materials, such as for medical purposes.

nucleon - A common name for a particle in the nucleus of an atom. Most common are protons and neutrons.

nuclide - A general term referring to all stable (279) and unstable (about 2,700) isotopes of the chemical elements.

nucleus - The center of an atom.

oxide - a compound in which oxygen is bonded to one or more electropositive atoms.

passive nuclear reactor - A nuclear reactor designed so that safety systems operate automatically.

pitchblende or uranium oxide (U_3O_8) - It is the main component of high-grade uranium ore and also contains other oxides and sulfides, including radium, thorium, and lead components.

plutonium (Pu) - Chemical element with the atomic number 94. Plutonium-239 is a fissile isotope produced in nuclear reactors from uranium-238.

positron - A particle equal in mass but opposite in charge to the electron. A positive electron.

potential energy - Energy of position; stored energy.

Pressurized Water Reactor (PWR) - A nuclear reactor in which heat is transferred from the core to an exchanger by high temperature water kept under pressure in the primary system. Steam that turns turbines is generated in a secondary circuit. Many reactors producing electric power are pressurized water reactors.

primary (heat exchange) system - A term that refers to the reactor coolant system.

proton - A fundamental particle of an atom that has the nearly same mass as a neutron and a +1 charge.

radiation (ionizing) - Energy capable of producing ions. Examples of ionizing radiation include alpha particles, beta particles, gamma rays, x-rays, neutrons, high-speed electrons, and high-speed protons. Radiation, as frequently used in the nuclear industry, does not include non-ionizing radiation, such as radio- or microwaves, or visible, infrared, or ultraviolet light.

radioactivity - A description of some elements that spontaneously give off energetic particles from their nuclei.

radionuclide - A radioactive nuclide (**see nuclide**).

radon - A naturally occurring radioactive gas found in the earth around the world.

renewable energy - Energy sources that can be replenished in a short period of time.

reactor vessel - The main steel vessel containing the reactor fuel, moderator and coolant.

reprocessing - Chemical treatment of spent reactor fuel to separate uranium and plutonium and possibly other radioactive elements from other waste products.

secondary (heat exchange) system - The part of a PWR that contains the steam used to turn turbines and generate electricity. In a PWR, the steam is not in contact with radiation.

thermal reactor - A reactor in which the fission chain reaction is sustained primarily by thermal (relatively slow) neutrons. Most current reactors are thermal reactors.

transmutation - A process involving a change in the number of protons in the nucleus, resulting in the formation of a different element. This occurs during alpha and beta emissions and certain other changes.

transuranic - Chemical elements with an atomic number greater than 92.

uranium (U) - Chemical element with the atomic number 92. Uranium has three natural isotopes, U-234, U-235, and U-238. U-235 is the fissioned in a nuclear reactor.

uranium dioxide (UO_2) - An oxide of uranium that is a black, radioactive, crystalline powder. It is used as fuel in nuclear fuel rods in nuclear reactors.

uranium hexafluoride (UF_6) - A white solid obtained by chemical treatment of U_3O_8 and which forms a vapor at temperatures above 56 degrees Centigrade. UF_6 is the form of uranium required for the enrichment process.

used fuel - Nuclear reactor fuel that has been used until it can no longer sustain a nuclear reaction.

yellowcake - Yellowcake is a bright yellow compound obtained from uranium ore that contains uranium oxides which will be used to make nuclear fuel.

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