Exploring Nuclear Energy

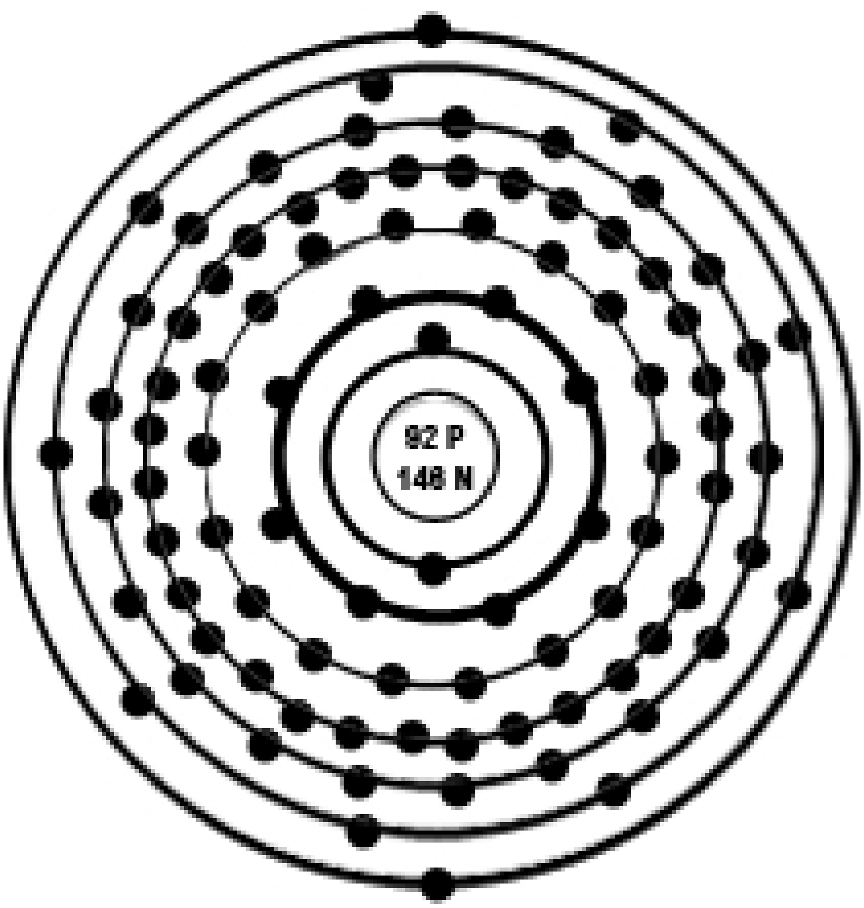
Student Guide

U 235

ENERGY SOURCES

GRADE LEVEL
Secondary

SUBJECT AREAS
Science
Social Studies
Language Arts



NEED

2009-2010

Putting Energy into Education

NEED Project PO Box 10101 Manassas, VA 20108 1-800-875-5029 www.NEED.org

Energy Introduction

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 molecular bonds. 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. 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.

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 (soloar) 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 efficient. For example, a typical car converts only about 15% of the energy in gasoline used 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 body is less than five percent efficient at converting food into useful work. The rest of the energy is lost as 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 biomass, geothermal energy, hydropower, solar energy, and wind energy. 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.

Electricity

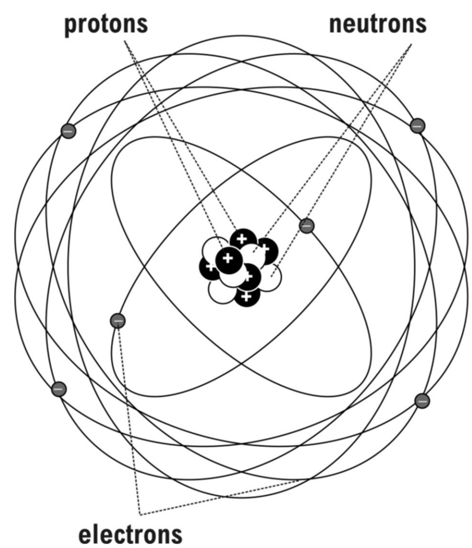
Electricity is a secondary source of energy. That means we must use a primary energy source to produce electricity. Electricity is sometimes called an energy carrier because it is an efficient and safe way to move energy from one place to another, and it can be used for many tasks.

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 simply moving electrons. What exactly 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.

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 clouds whose shapes depend upon the type of atom present. 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.



If you could see an atom, it might look a little like a ball surrounded by large clouds (or shells) containing electrons. 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 act as a glue to hold the nucleus together.

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 know as carbon -12, carbon-13, and carbon -14 respectively.

Radioactive Isotopes

While many isotopes of the elements are stable, some isotopes are unstable and their nuclei give off particles of energy to become more stable. 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 with 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 elements 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 milli-seconds 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 relative short time periods.

Electrons

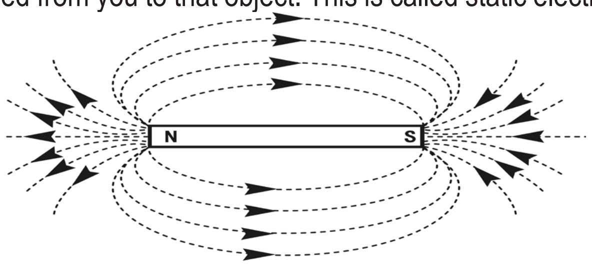
Electrons are located in areas of probability sometimes called energy levels. The energy level closest to the nucleus can hold up to two electrons. The next energy level can hold up to eight. Although additional energy levels can hold more than eight electrons, most elements are stable when their outer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

Electricity and Magnetism

Electrical Energy

Electrical energy has been moving in the world forever. Lightning is a type of electrical energy. It is electrons moving from one cloud to another or jumping from a cloud to the ground. Have you ever felt a shock when you touched an object after walking across a carpet? A stream of electrons jumped from you to that object. This is called static electricity.



BAR MAGNET

Have you ever electrified your hair by rubbing a balloon on it? If so, you rubbed some electrons off your hair and put them on the balloon. Because the hair lost electrons, it becomes positively charged. Since the same charges repel, the strands of hair move away from each other. When objects cling to each other by static electricity (like what happens sometimes when clothes are dried in a clothes dryer), they have opposite charges. Opposite charges attract each other making the clothes cling.

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—they are made of molecules that 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.

In magnetic materials, most of the atoms' electrons spin in the same direction. This gives rise to magnetic forces that can act in opposite directions (with the spin or opposite the spin). On a magnet we label these directions as the North pole (N) or South pole (S).

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 shells 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.

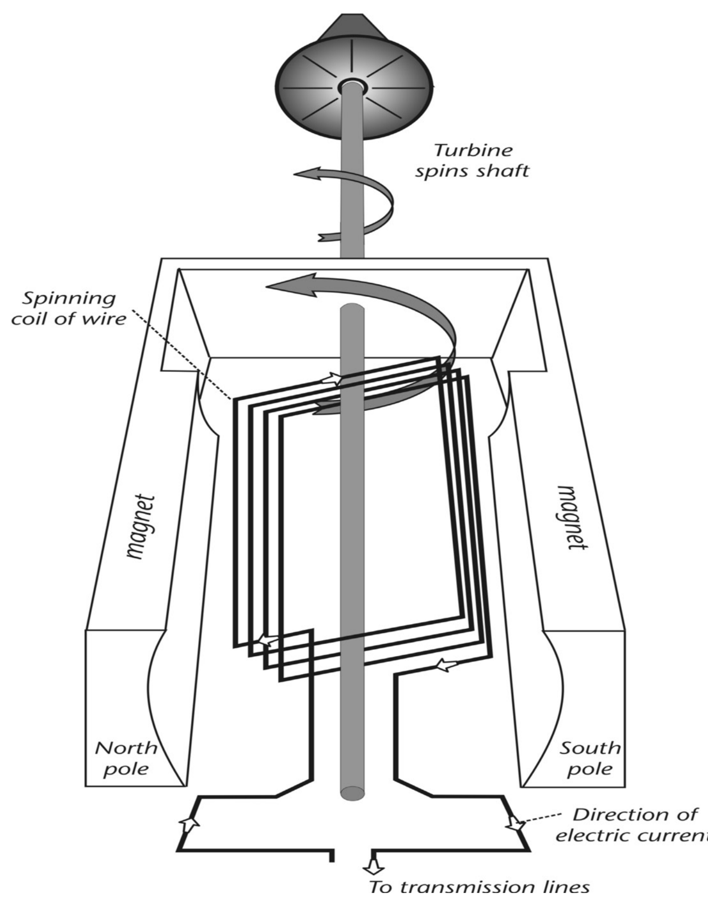
Electric current can also be used to produce magnets. Around every current-carrying wire is a magnetic field, created by the uniform motion of electrons in the wire.

Producing Electricity

When it comes to the commercial production of electricity, it is simply about spinning a turbine. 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 huge turbine generators to produce the electricity that we use in our homes and businesses. The 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.

TURBINE GENERATOR



Nuclear Energy

Nuclear energy is the energy 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 uranium atoms split to form smaller atoms. 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 heat water and create steam to turn the blades of a turbine. The motion of the turbine turns a generator and makes electricity to power our homes, businesses, and schools.

Uranium

Uranium is the heaviest of all naturally occurring elements. Uranium has two isotopes, uranium-238 with 92 protons and 146 neutrons and uranium-235 with 92 protons and 143 neutrons. Natural uranium consists of 99.28% U-238, 0.71% U-235, and 0.0054% U-234. This is important because only U-235 will undergo fission under normal conditions in a nuclear reactor. Uranium occurs in small amounts in rocks, soil, and bodies of water. Found in rocks, soil and bodies of water, uranium is 500 times more common than gold (Au) and about as plentiful as tin (Sn) but occurs in relatively small concentrations. Estimates vary, but most believe that there is enough uranium to last for hundreds if not thousands of years based on projections of demand for uranium to fuel nuclear reactors.

History

Nuclear reactions have occurred in the earth's crust since the beginning of time. However, working knowledge of nuclear energy occupies a very small portion of earth's history. This knowledge was initiated by a chain of events beginning in 1895 with the experiments of German physicist William Roentgen. He had covered a gas discharge tube with a black cloth to exclude light from external sources. As the electrical discharge passed through the tube, he noticed that a piece of cardboard coated with a barium compound several meters from the tube began to glow (fluoresce) in the totally darkened room. When he held his hand between the covered tube and the coated cardboard, the shadows of his finger bones appeared on the cardboard. The emissions from the tube, named X-rays, also exposed photographic plates. Roentgen spent several weeks verifying his work before communicating his discovery of X-rays to the scientific community.

In 1896, Henri Becquerel, a French scientist, who studied fluorescent and phosphorescent substances, investigated the possibility that these substances might emit X-rays. He accidentally discovered a uranium compound left in the dark with a photographic plate produced an image on the plate. Marie Curie, a student of Becquerel's and her husband Pierre, a professor of physics, continued to investigate the emissions from uranium compounds and coined the term radioactivity to describe them. Two years later, the Curies announced that they had isolated two radioactive elements from pitchblende, polonium (named for Marie Curie's native country of Poland) and radium. Scientific work related to radioactivity continued throughout the early to mid-twentieth century.

In England, Ernest Rutherford identified two different types of radiation emitted by uranium atoms, alpha rays and beta rays (streams of alpha and beta particles). His experiments showed that the emission of alpha or beta particle by a radioactive element resulted in the transformation (transmutation) of the element into a different element. 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 structure of an atom (a small, positive nucleus containing protons and neutrons with electrons located outside the nucleus) was completed in 1932 with the discovery of the neutron by Rutherford's colleague, James Chadwick.

Marie Curie was awarded two Nobel Prizes for her work, one in physics (1903) and one in chemistry (1911). The New York Times described Marie's accomplishments, "Few persons contributed more to the general walfare of mankind and to the advancement of science than the modest, self-effacing woman whome the world knew as Madame Cuire."

Want to Know More?

For more information on Marie Curie, the US Nuclear Navy, and Nuclear medicine, go online to www.need.org/nuclear.

Albert Einstein, in 1905, theorized that mass and energy are equivalent. 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 and generation of energy 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 Meitiner, and her nephew, physicist Otto Frisch, explained the chemists' results as nuclear fission, a process in which the nucleus splits into two nuclei of approximately equal masses. Using Einstein's equation, they calculated that the 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 by man.

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. These scientists' goal was a controlled nuclear chain reaction. This required the correct amount of nuclear fuel (critical mass) to sustain the nuclear reaction, neutrons of the proper speed (energy), and a means of controlling the number of fissions (a stable chain reaction). 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.

Civilian nuclear power developed at a slower pace with the first use of nuclear power to generate electricity occurring 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. As of early 2009, 104 commercial nuclear reactors are operating in the United States and produces about 20% of this country's electricity. Over 400 commercial reactors are generating power throughout the world and meet about 16% of the world's electricity needs.

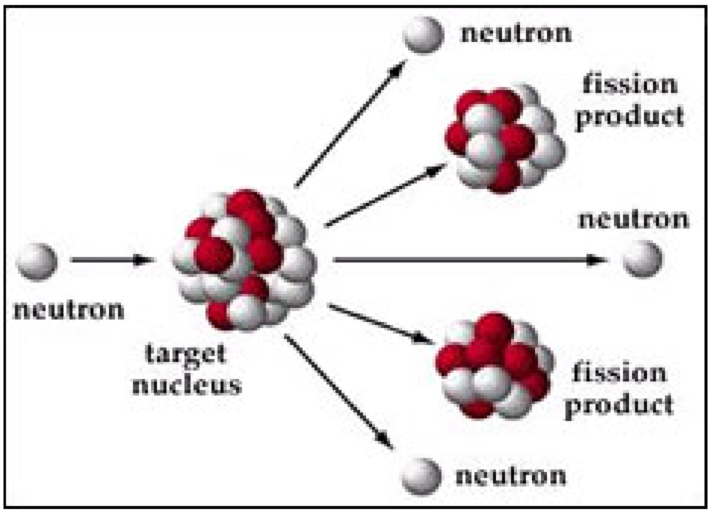
Nuclear energy is used for more than providing electricity and powering naval vessels. Medicine has also benefitted from using nuclear energy. Nuclear medicine is a branch of medical imaging that uses small amounts of radioactive material to diagnose or treat a vareity of diseases including many types of cancer, heart disease and certain other abnormalities within the body. Nuclear medicine includes the use of x-rays and radionuclide imaging.

The United States Navy powers attack submarines, ballistic missile submarines, and aircraft carriers such as the USS Enterprise with nuclear power. The Enterprise's first refuleing occurred after three years of service. During that time the carrier traveled 207,000 miles, a distance equal to more than eight times around the world.

Generating Electricity With Nuclear Power

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 atom, and then breaks the atom into two smaller fragments of nearly equal masses. As an atom 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 to power a nuclear bomb.



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.

Currently, nuclear reactors produce electricity through the process called thermal fission, and are called thermal reactors. In thermal fission of U-235, the speed of neutrons produced by fission must be decreased (moderated) in order for them to maintain the chain reaction. Of the uranium isotopes, only U-235 can release energy through thermal fission. U-238 can undergo fission, but only using fast neutrons. In fast fission, high-speed neutrons are used to create a chain reaction. Nuclear reactors which generate electricity by fast fission are called fast neutron reactors.

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.

If a chain reaction occurs in an uncontrolled fashion, the energy from the U-235 will be released in microseconds as a nuclear explosion. This is why it is very important to control rate of energy released in a nuclear reactor – which is the heart of a nuclear power plant.

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.

Formed from the natural radioactive decay of uranium atoms in the soil, rocks and water, radon is a colorless and odorless radioactive gas found throughout the United States. Radon can enter the buildings where we live, work and play through the air, soil, and sometimes the water supply. The Environmental Protection Agency recommends that all homes be tested for radon.

Want to Know More?
For more information on radon, go online to www.need.org/nuclear and www.epa.gov.

Nuclear Fuel Cycle

Fission does not occur on its own. In order to harness the energy that is released during fission uranium has to be mined, milled, refined, converted, enriched, (for fueling most commercial reactors), and finally the fuel has to be manufactured. After the fuel has been used it then can be reprocessed to make new fuel or safely stored as spent fuel which is highly radioactive. Reprocessing the spent fuel also generates radioactive waste that requires safe storage. This whole process is known as the nuclear fuel cycle. The first four steps are referred to as the "front end" and the last two steps are referred to as the "back 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 or by in situ methods, where the ore is dissolved in certain solutions and 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 uranium-containing solution undergoes further chemical treatments to separate the uranium from its solution. Uranium is collected and dried as uranium oxide concentrate, U_3O_8. The concentrate is often called yellowcake, a bright yellow powder. The yellowcake is then packaged in steel drums and transported to a refinery.

Refining and Conversion

The U_3O_8 is further purified, and then converted into powdered uranium dioxide, UO_2. Natural uranium is composed of three isotopes, 99.28% U-238, 0.71% U-235, and 0.0054% U-234. Since only the U-235 can undergo fission under normal conditions in a reactor, its concentration must be increased to between 2.8% to 5.6% for use as thermal reactor fuel. The process that does this is called enrichment. Before uranium can be enriched U-235 and U-238 need to be physically separated since they are chemically identical. The enrichment processes require that the uranium be in the form of a gas. Therefore the solid uranium yellowcake, (uranium oxides), must first be converted to gaseous uranium hexafluoride, UF_6.

Enrichment

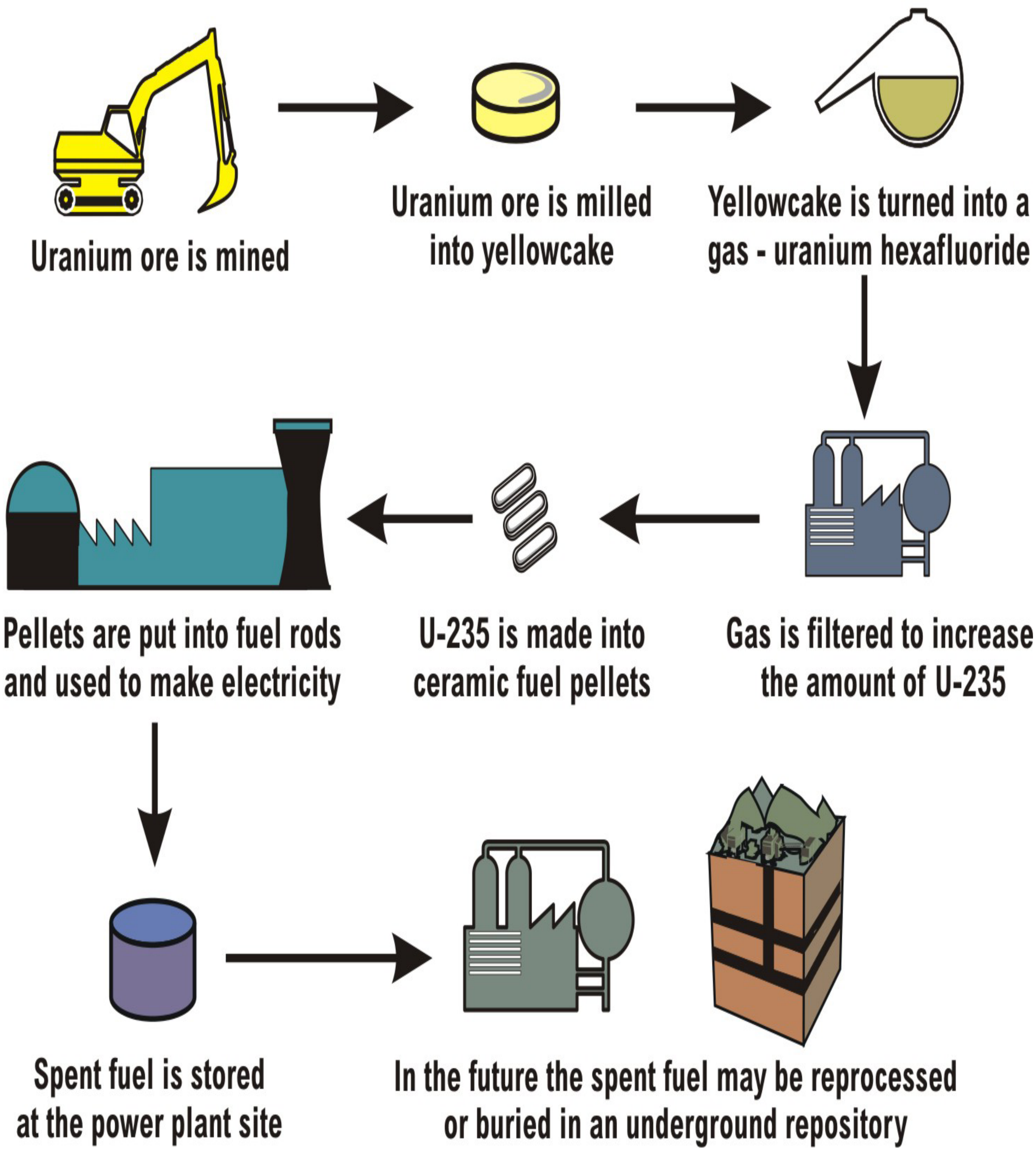
Once uranium has been converted to a gas it is ready to be enriched. Enrichment involves the separation of the lighter 235-UF_6 atoms from slightly heavier 238-UF_6 atoms. There are two commercial methods for uranium enrichment, gaseous diffusion and centrifuge enrichment. In gaseous diffusion, UF_6 gas moves through a series of porous barriers or sieves. The lighter U235-F_6 moves faster than the heavier U238-F_6. Thus, as the gas passes through a large number of barriers, the concentration of U-235 gradually increases to that required for reactor fuel.

In centrifuge enrichment, the gaseous UF_6 is placed in a centrifuge, a large container that spins at high speeds. During the spinning, the heavier U-238 moves to the outer part of the centrifuge, separating itself from the U-235. Normally, one centrifuge cycle is not enough to reach the required 3-5% concentration of U-235. Therefore, the gaseous UF_6 is passed through a series of centrifuges, called cascades. Centrifuge enrichment uses much less energy than gaseous diffusion, and is therefore a more economical method of enrichment.

Reasons for Refining, Conversion, and Enrichment

Only the U-235 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 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 speeds neutrons generally are more likely to be absorbed by U-235 and cause fission. These slow-speed 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 3% and 5% 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 is made of a heavier isotope of hydrogen,

NUCLEAR FUEL CYCLE

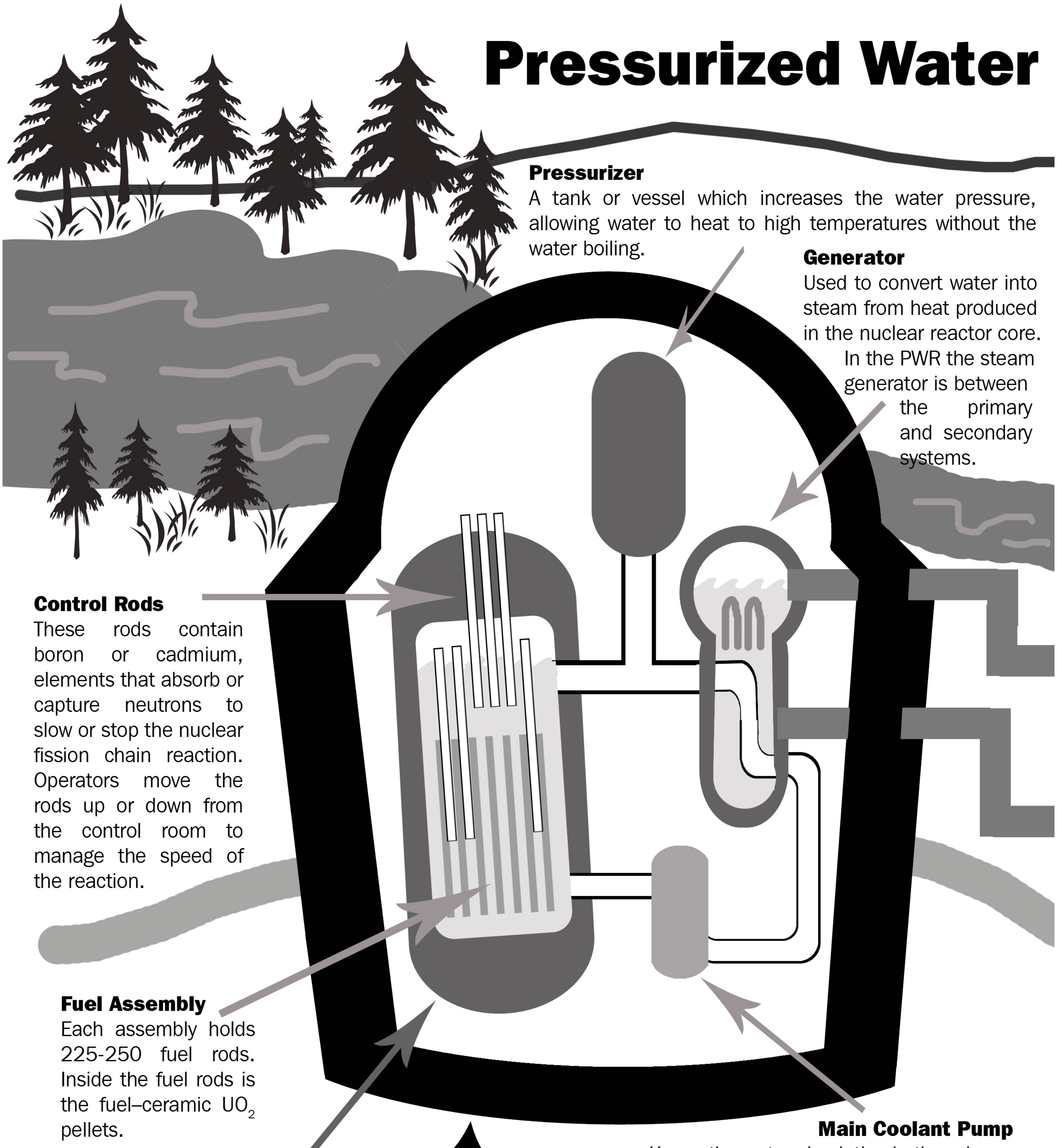


has a much lesser likelihood of absorbing neutrons. Thus, natural uranium fuel can be used in a thermal heavy water reactor. Canada and India, for example, use many of these reactors.

Fuel Manufacturing

During fuel manufacturing, the enriched uranium dioxide, 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, called fuel pellets. The pellets are then placed into fuel rods and sealed. The rods are then grouped into fuel assemblies for placement into the reactor's core. When the reactor is brought on-line the U-235 in the fuel pellets undergoes fission and creates the heat necessary to make the steam to generate electricity.

Pressurized Water



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

Generator
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.

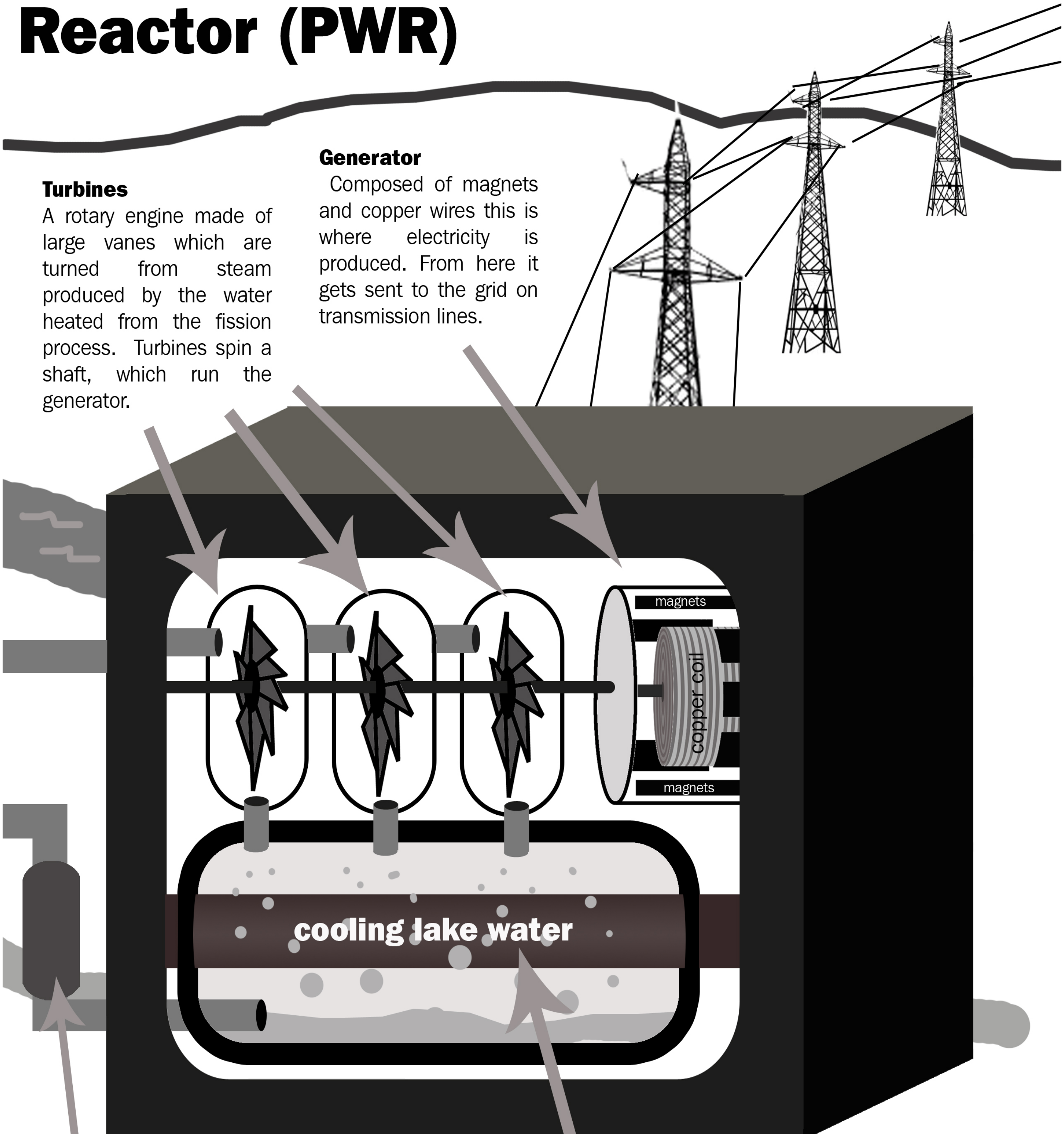
Fuel Assembly
Each assembly holds 225-250 fuel rods. Inside the fuel rods is the fuel–ceramic UO_2 pellets.

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.

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.

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 in the event of an emergency.

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 it gets sent to the grid on transmission lines.

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 radioactive materials.

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.

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 into the atmosphere should a leak occur inside.

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.

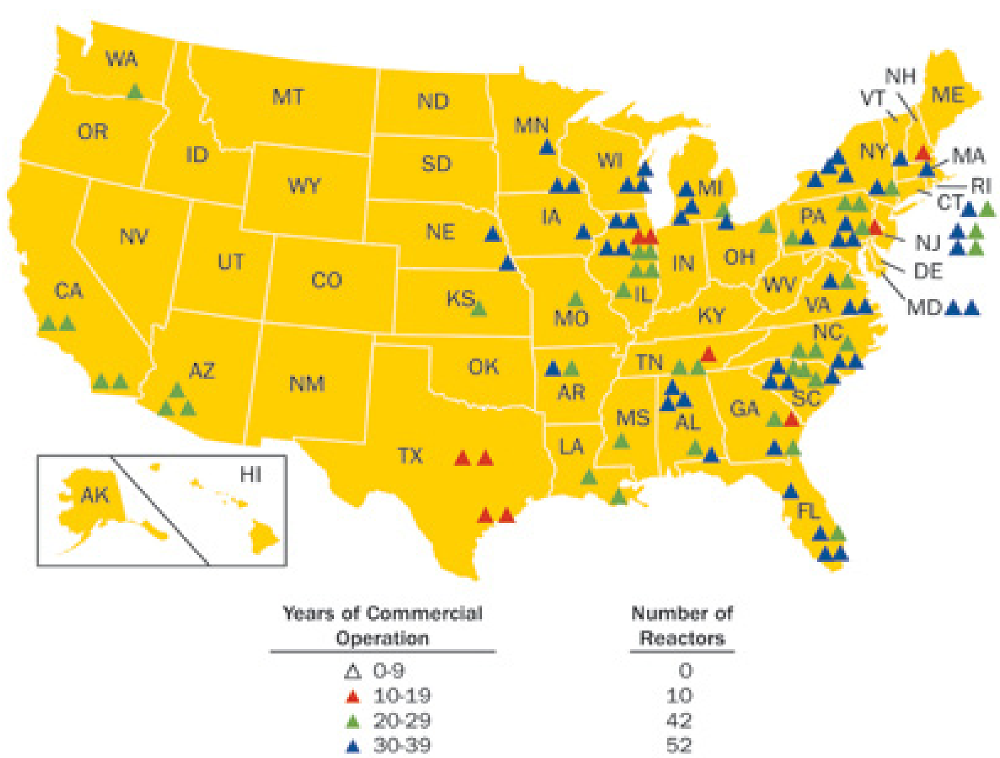
Fuel and Fuel Rods: These rods are filled with the UO_2 pellets that have already been enriched (nuclear fuel). The UO_2 fuel is a ceramic that contains only solids which limits the volume of radioactive gases that can escape into the atmosphere from the fuel itself. The fuel rods isolate the fuel from 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.

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. There are two types of heat exchange systems, the primary and secondary. In a primary system, the water comes into contact with fuel rods. This allows the impurities in the water to become radioactive. The water in the secondary system is isolated from the fuel rods and does not contain radioactive impurities. The operations of heat exchange systems are described below.

U.S. Commercial Nuclear Power Reactors—Years of Operation



Source: U.S. Nuclear Regulatory Commission

How a Nuclear Reactor Works

A 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 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, 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. Here 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 creates electricity. This steam is then condensed by water from the external system before it returns to the heat exchanger in the containment building where it is heated and the cycle repeated.

In either system the transfer of heat has to be dealt with, 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.

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 evaporates some of the water which leaves the cooling towers as vapor. This evaporation cools the remaining water, which is returned to the plant to cool the steam in the heat exchanger. 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. While they look large in pictures of nuclear power plants, they are removed from the actual reactor building and do not release radiation into the atmosphere. In fact, many fossil fuel plants are also equipped with cooling towers that serve the same function as they do in nuclear plants.

Additional Safeguards in a Nuclear Power Plant

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 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 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.

Routine inspections at nuclear power plants are important for ensuring everyone's safety.

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.

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 the 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 operating history, however there were no serious injuries and only small amounts of radiation were released off-site.

In 1986 at Chernobyl, a much more serious accident occured. While conducting tests of 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 occured. 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 a part of the fire. About 160,000 persons living close by the reactor were evacuated within a week of the accident and have not returned to the area. During the next several years an addtional 210,000 people were resettled from areas within an approximate 20 mile radius of the plant.

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 occured. 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.

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. PWR and BWR 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 spent 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 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.

However, some concerns about movement of ground water into the storage site have recently surfaced. Nevada political leaders also believe that it is unfair to make their state receive all nuclear waste from commercial reactors. Another option could be to open a different repository in another state or federal territory. More than 20 years after its selection, it is not certain that Yucca Mountain will be used as a long term nuclear waste repository. If it does become a repository, it is estimated that the first shipments of waste will not arrive until 2017 at the earliest. No nation currently has a permanent repository for the storage of radioactive waste from used fuel.

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 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.

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

Want to Know More?

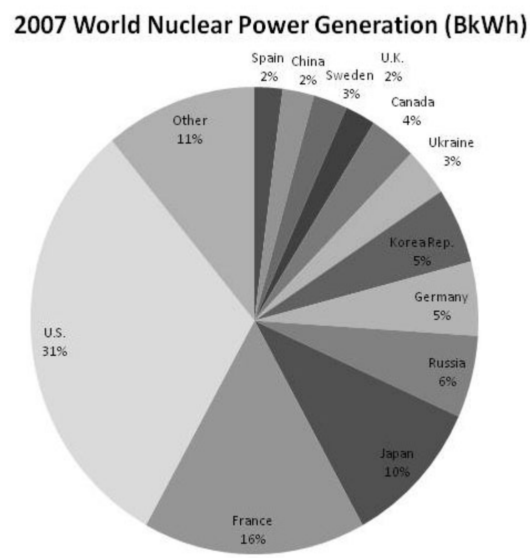
For more information on nuclear proliferation and controlling risks, go online to www.need.org/nuclear.

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 needed 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.



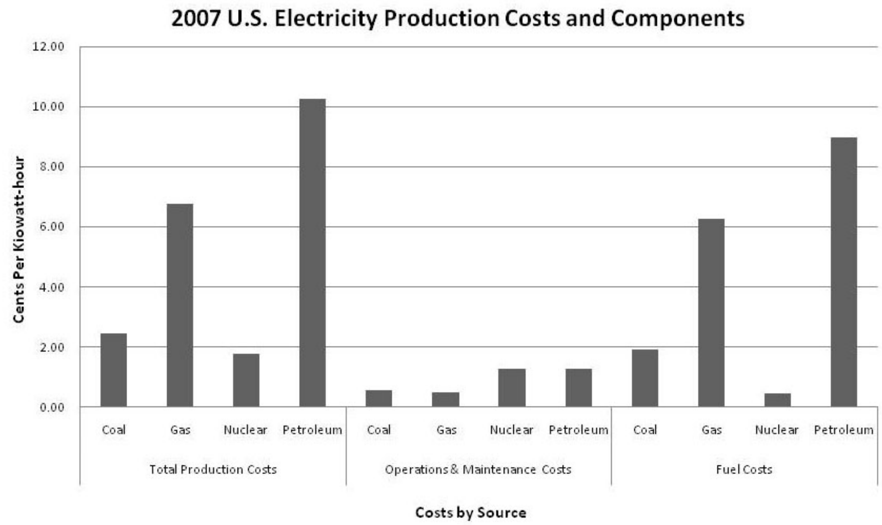
Countries combined for “Other” are (in order from greatest to least nuclear power generation): Belgium, Taiwan, India, Czech Republic, Switzerland, Finland, Bulgaria, Hungary, South Africa, Brazil, Slovakia, Romania, Mexico, Lithuania, Argentina Slovenia, Netherlands, Pakistan, and Armenia.

Economics of Nuclear Energy

Is it economical to build nuclear reactors to generate electricity? Some groups that support building nuclear generating plants say that in the future, nuclear generators will be economical to develop and maintain. Some groups opposed to building nuclear generating plants say the plants are dangerous, and that the money spent in building nuclear generating plants can be better spent on new technology like wind and solar.

Electricity generated by a nuclear plant currently costs more than that generated by fossil fuel plants. Although the costs of uranium used for fuel is much lower than those of coal or natural gas, a nuclear plant has extra expenses that fossil fuel plants do not have. Nuclear plants require heavier construction using additional concrete and steel. The reactors are expensive to manufacture and must meet rigid standards. Back-up safety systems add to the cost of a nuclear plant. It takes longer to build a nuclear plant than it does a fossil fuel plant, and that adds additional costs to the construction and financing of the plant. Nuclear plant operators also have expenses involved with handling radioactive wastes. No central waste repository is currently available and waste must be stored on site. Furthermore, it is doubtful that the Yucca Mountain site will be available until at least 2017. The uncertainty of how and when a central waste repository is available makes it more difficult to plan for the construction and operation of a nuclear plant.

A report prepared for the U.S. Congress by a non-partisan research group (Parker and Holt, 2007) shows that costs for the construction and operation of a nuclear plant that goes on-line in 2015 will be approximately 20% to 40% higher than those of a coal or natural gas plant that goes on-line at the same time. However, the U.S. Congress passed the Energy Policy Act of 2005 that contains economic incentives for the construction and operation of nuclear plants. These incentives include tax credits for the first eight years of nuclear plant operations for up to 6,000 Megawatts of electric power capacity, regulatory risk insurance which provides economic aid to nuclear companies if delays occur during plant regulation, and loan guarantees to assure adequate financing of new clean-air plants which include nuclear plants.



Another issue that affects the economics of all type of power plants is climate change caused by carbon emissions. A Massachusetts Institute of Technology study (Deutch and Moniz, 2003) found that the adverse consequences of greenhouse emissions justify government support of nuclear power. Furthermore, several proposals in Congress have included taxes or tariffs on carbon emissions to encourage decreased use of fossil fuels and reductions in greenhouse emissions. If such proposals are adopted, nuclear power will become more economically feasible even without financial incentives from the government. The combination of government economic incentives, less costly regulation processes, and taxing greenhouse emissions should make nuclear generated electricity competitive with that produced from fossil fuels.

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 US 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.

GLOSSARY

alpha particle - A positively charged particle that is identical to a helium nucleus. It has a mass number of 4 and a charge of +2. Alpha particles are emitted by radioactive elements.

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

beta particle - A negatively charged particle with characteristics exactly like those of an electron. It is released from a nucleus during radioactive decay. A positively charged beta particle is called a positron. Beta particles are emitted by radioactive elements.

boiling water reactor (BWR) - A reactor in which water, used as both coolant and moderator, is allowed to boil in the core. The resulting steam can be used directly to drive a turbine and electrical generator producing electricity.

cascade – A process that separates radioactive isotopes. It uses a number of similar stages which produce successfully higher concentrations of the desired isotope.

chain reaction - A reaction that keeps itself going. In a fission chain reaction, the nucleus of a radioactive isotope absorbs a neutron and undergoes fission releasing more neutrons. These neutrons create more fission reactions which in turn, create more neutrons. A fission chain reaction is self-sustaining when the number of neutrons released in a certain amount of time equals or exceeds the number of neutrons lost by absorption to its surroundings or by escape from the system.

climate change - The change in Earth's overall climate patterns since the mid-20^{th} 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 in the event of an accident

control rod - A rod, plate, or tube containing a material such as hafnium, boron, etc., used to control the power of a nuclear reactor. By absorbing neutrons, a control rod prevents the neutrons from causing further fissions.

cooling tower - A heat exchanger designed to aid in the cooling of water that was used to cool exhaust steam exiting the turbines of a power plant. Cooling towers transfer exhaust heat into the air instead of into a body of water.

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

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

electron- Held in an atom's energy levels an electron is a fundamental subatomic particle that has 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.

enriched (uranium) - Uranium in which the proportion of uranium-235 (to uranium-238) has been increased above its natural concentration so it can be used as a fuel source in a reactor.

evolutionary nuclear reactor – a nuclear reactor that has the same basic design as pre-1990's reactors but with improved safety systems .

external (cooling) system – the system holding coolant from the environment that is not radioactive.

fast fission - Fission of a heavy atom (such as uranium-238) when it absorbs a high energy (fast) neutron. Most fissionable materials need thermal (slow) neutrons in order to fission.

fast reactor – A nuclear reactor that operates by **fast fission.**

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

fossil fuel - A hydrocarbon deposit, such as petroleum, coal, or natural gas, derived from living matter of a previous geologic time and used for fuel.

fuel cycle - The series of steps involved in supplying fuel for nuclear power reactors. It can include mining, milling, isotopic enrichment, fabrication of fuel elements, use in a reactor, chemical reprocessing to recover the fissionable material remaining in the spent fuel, re-enrichment of the fuel material, refabrication into new fuel elements, and waste disposal.

fuel pellets - Consisting of uranium fuel in a ceramic form (uranium dioxide or UO_2) a fuel pellet is a small cylinder approximately 3/8-inch in diameter and 5/8-inch in length. Multiple fuel pellets used in pressurized water reactors and boiling water reactors,

fuel rods - Long, slender tubes that hold fuel for nuclear reactor use. Fuel rods are assembled into bundles called fuel elements or fuel assemblies, which are loaded individually into the reactor core.

gamma rays - High-energy, short wavelength, electromagnetic radiation emitted from the nucleus. Gamma radiation frequently accompanies alpha and beta emissions and always accompanies fission. Gamma rays are very penetrating and are best stopped or shielded by dense materials, such as lead or depleted uranium. Gamma rays are similar to x-rays.

greenhouse gases - Gaseous parts of the atmosphere, both natural and manmade, that absorb and emit thermal heat emitted by the Earth's surface, the atmosphere itself, and by clouds.

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

heavy water (D_2O) - Water containing significantly more than the natural proportions of heavy hydrogen (the hydrogen isotope deuterium, D). Heavy water is used as a moderator in some reactors because it slows down neutrons and does not easily absorb neutrons.

highly-enriched uranium (HEU) - Uranium enriched to 20 percent or greater in the isotope uranium-235 used in nuclear weapons.

ionizing - The process of adding one or more electrons to, or removing one or more electrons from, atoms or molecules, thereby creating charged particles. High temperatures, electrical discharges, or nuclear radiations can cause ionization.

light water - Ordinary water as distinguished from heavy water.

low-enriched uranium (LEU) - Uranium enriched to less than 20 percent in the isotope uranium-235.

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

meltdown – A severe nuclear reactor accident that occurs when all or part of a nuclear power plant fails. This causes the reactor core to no longer be properly controlled or cooled. The sealed nuclear fuel assemblies overheat and melt usually releasing radioactivity into the environment.

moderator - A material, such as ordinary water, heavy water, or graphite, that is used in a reactor to slow down high-velocity neutrons increasing the chances of a nuclear reaction.

neutron- a fundamental subatomic particle that has 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 throughout the world, 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). There are four recognized sovereign states that probably have nuclear weapons that have not signed the treaty: India, Israel, Pakistan, and North Korea.

nuclear energy - The energy released from a nuclear reaction (fission or fusion) or by radioactive decay.

nuclear fuel cycle – see **fuel cycle**

nuclear proliferation - A term now used to describe the spread of nuclear weapons, fissile material, and weapons-based nuclear technology and information, to nations which are not recognized as "nuclear weapon States" by the NPT. **Also see Nonproliferation Treaty (nuclear).**

Nuclear Regulatory Commission (NRC) - The U.S. Nuclear Regulatory Commission (NRC) was created as an independent agency by Congress in 1974 to enable 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 in nuclear medicine, through licensing, inspection and enforcement of its requirements.

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

passive nuclear reactor – A nuclear reactor designed so that safety systems operate automatically. The safety systems operate using water and air controlled by gravity or natural convection. Electricity, if needed, is provided by batteries.

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

pressurized water reactor - A power reactor in which heat is transferred from the core to an exchanger by high temperature water kept under high pressure in the primary system. The steam used to power the turbines is generated in a secondary circuit, and is not exposed to radiation.

primary system - A term that may be used for referring to the reactor coolant system.

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

radioactivity – A property possessed by some elements that spontaneously emit energetic particles from the disintegration of their nuclei.

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

reprocessing - Chemical treatment of used reactor fuel to separate uranium and plutonium and possibly other transuranic elements from the small quantity of fission wastes. This drastically reduces nuclear waste output.

secondary system - The steam generator tubes, steam turbine, condenser, and associated pipes, pumps, and heaters used to convert the heat energy of the reactor coolant system into mechanical energy for electrical generation. Most commonly used in reference to pressurized water reactors.

spent fuel - Nuclear reactor fuel that has been used and can no longer effectively sustain a chain reaction.

thermal fission -A chain reaction which occurs with neutrons with an average kinetic energy similar to that of their surroundings.

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

transmutation - The process of transforming one isotope into another through a nuclear reaction (such as neutron absorption in a nuclear reactor).

transuranic element - An artificially made, radioactive element that has an atomic number higher than uranium in the periodic table of elements such as neptunium, plutonium, americium, and others.

uranium dioxide (UO_2)**-** An oxide of uranium that is a black, radioactive, crystalline powder. It occurs naturally in the mineral uraninite. It has a melting point of 2800°C and is used as fuel in nuclear fuel rods in nuclear reactors.

yellowcake - Yellowcake is the product of the uranium extraction (milling) process; early production methods resulted in a bright yellow compound, hence the name *yellowcake*. The material is a mixture of uranium oxides that can vary in proportion and in color from yellow to orange to dark green (blackish) depending on temperature at which the material was dried Yellowcake is commonly referred to as U_3O_8.This fine powder is packaged in drums and sent to a conversion plant that produces uranium hexafluoride (UF_6) as the next step in the manufacture of nuclear fuel.

NEED

Putting Energy into Education