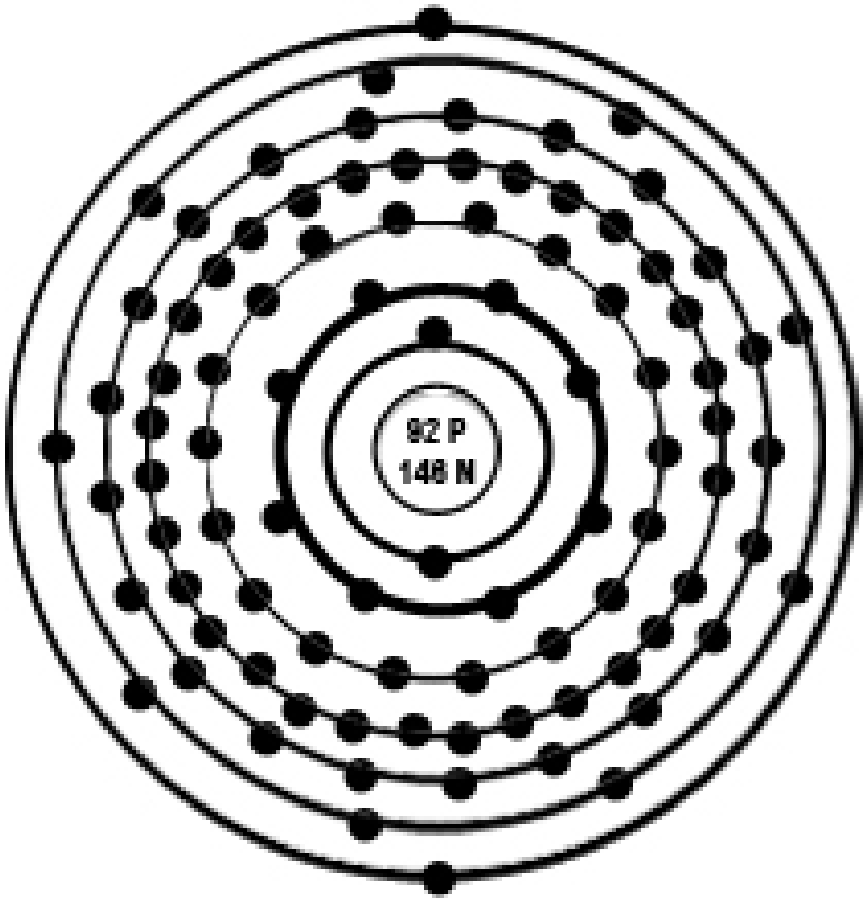
Energy From Uranium

Student Guide

GRADE LEVEL
Intermediate

SUBJECT AREAS
Science
Social Studies
Language Arts



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Putting Energy into Education

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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 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 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

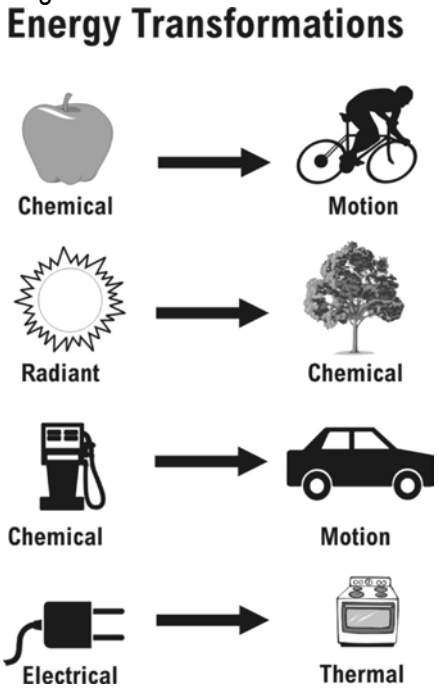
Kinetic energy is energy in motion; it is the motion of electromagnetic and radio waves, electrons, atoms, molecules, substances, and objects. Forms of kinetic energy include:

- 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 (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.

Typical coal-fired, natural gas, biomass, and nuclear power

plants convert about 30 to 35 percent of the heat they produce 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% of the 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 around fifteen 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 are usually classified into two groups—renewable and 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.

U.S. Energy Consumption by Source 2006

PETROLEUM 38.8% nonrenewable transportation, manufacturing		BIOMASS 3.3% renewable heating, electricity, transportation	
COAL 22.6% nonrenewable electricity, manufacturing		HYDROPOWER 2.9% renewable electricity	
NATURAL GAS 21.6% nonrenewable heating, manufacturing, electricity		GEOTHERMAL 0.35% renewable heating, electricity	
U^{235} URANIUM 8.2% nonrenewable electricity		WIND 0.25% renewable electricity	
PROPANE 1.9% nonrenewable manufacturing, heating		SOLAR 0.1% renewable light, heating, electricity	

Electricity

The energy sources discussed so far are known as primary sources. Electricity is known as a secondary energy source because it must be produced by the energy from a primary source. For example the heat from burning coal, a primary energy source, produces steam which turns turbines to generate 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 we use more technology, the demand for electricity grows. In the U.S. today, more than 40 percent of the energy we consume is in the form of electricity.

A Mysterious Force

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 made of smaller particles. The center of an atom is called the nucleus. It is made of particles called protons which carry a positive (+) charge, and neutrons which carry no charge, that are approximately the same size. Nuclear energy is contained within the nucleus and is holding the protons and neutrons together.

Protons and neutrons are very small, but electrons are much smaller. Electrons carry a negative (-) charge and move around the nucleus in areas of probability, or levels; these areas are different distances from the nucleus. If the nucleus were the size of a tennis ball, the atom would be the size of the Empire State Building. Atoms are mostly empty space.

If you could see an atom, it might look a little like a tiny center of a ball surrounded by giant invisible clouds (or shells). Electrons are found in these "clouds." Since protons have a positive charge and electrons have a negative charge they create an electrical charge and are attracted to each other. This electrical force holds the electrons in their energy level. 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, there are never more than eight electrons in the outer energy level of an atom at any one time.

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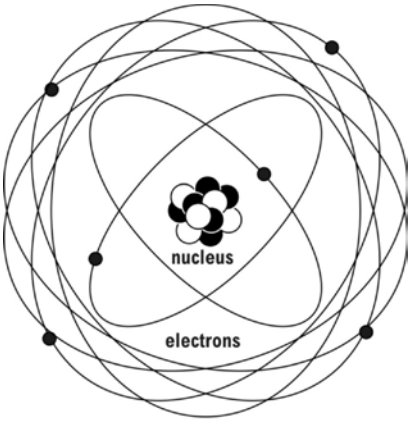


Atom of Carbon

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. Sometimes when the arrangement of electrons is changed, energy is gained or transformed. This energy from electrons is called chemical energy.

When an atom is neutral, it has an equal number of protons and electrons. The neutrons carry no charge and their number can vary. Neutrons help hold the nucleus together.

Elements

A substance whose atoms all have the same number of protons is called an element. The number of protons is given by an element's atomic number, which identifies elements. 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 size of an atom is measured by its atomic mass, based on its number of protons, neutrons, and electrons.

Atoms of the same element will always have the same number of protons. However, atoms of the same element can have a different number of neutrons. Atoms of a particular 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 type of carbon has six neutrons, one has seven neutrons, and the third has eight neutrons. Isotopes are identified by their approximate atomic masses given by the number of protons and neutrons added together. The carbon isotope that contains six protons and six neutrons is called carbon-12, the carbon isotope that contains six protons and seven neutrons is called carbon-13, and the carbon isotope that contains six protons and eight neutrons is called carbon-14.

Atoms are most stable when they have close to a 1:1 ratio of protons to neutrons. Elements with fewer than 83 protons all have a stable form as shown on the periodic table. But as with Carbon, many elements have isotopes that alter the ratio of protons and neutrons. This makes the atom unstable. Atoms will work to become stable and to do this they give off energy and often small particles. Giving off particles causes the identity of the isotopes to change. These isotopes that give off energy and often change identity are radioactive, and are commonly referred to as radioisotopes.

Electricity and Magnetism

Electrons have been moving in the world forever creating electrical energy. 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.

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).

Radiation Exposure

Did you know that we live in 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 somewhat to this natural background radiation with some artificial sources. It may surprise you to know that for an average person, 80-90% of all exposure to radiation comes from the naturally occurring sources.

There are three major sources of **naturally occurring** radiation 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. 82% 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% exposure is from medical diagnosis with less than 1% from nuclear power plants and left-over nuclear fallout.

Radon

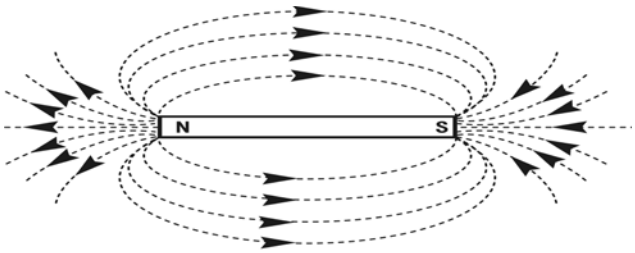
Radon is a colorless and odorless radioactive gas found throughout the United States. It is formed by the natural radioactive decay of uranium atoms in the soil, rocks, and water. . Since uranium is found in many places and radon is a gas, it can get into the air of the buildings where we live, work,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

Most radon enters buildings from the soil. Radon enters building 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.

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.



BAR MAGNET

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's all 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 converts mechanical energy into electrical energy using electromagnetism.

An electric generator is actually an electric motor that runs backward. Work is done to cause the wire to move. When the wire moves through the external magnetic field, electrons in the wire are pulled and move through the wire. These electrons can be directed out of the generator becoming electricity.

Although electric motors and generators may seem complicated, the principle of electromagnetism is simple.

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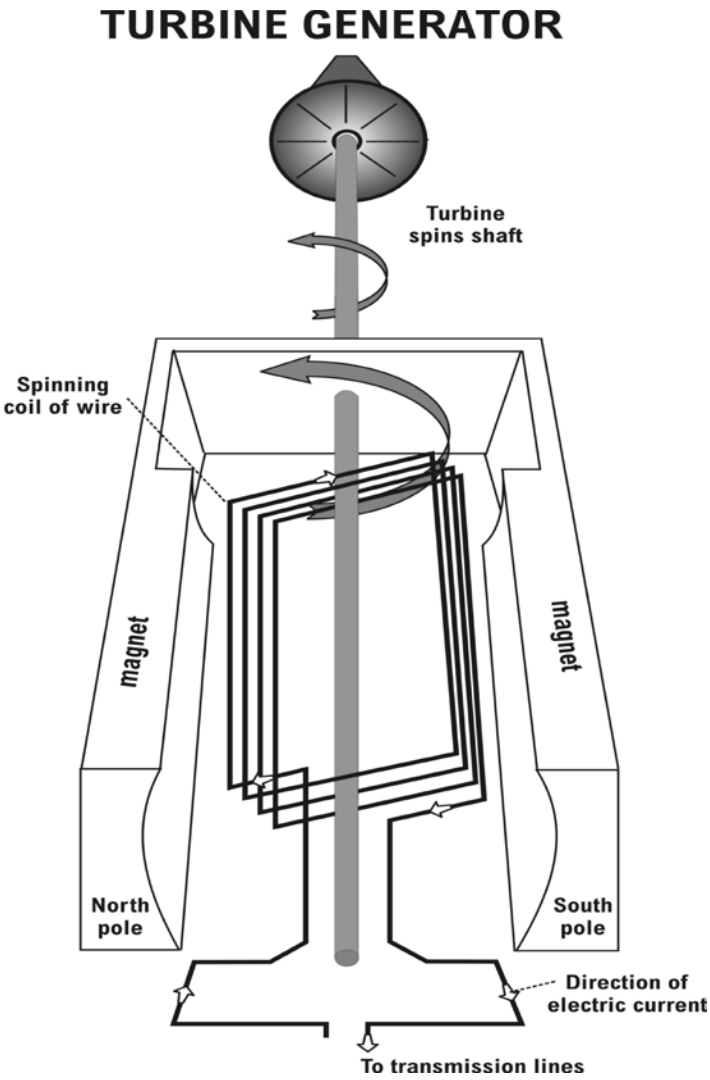
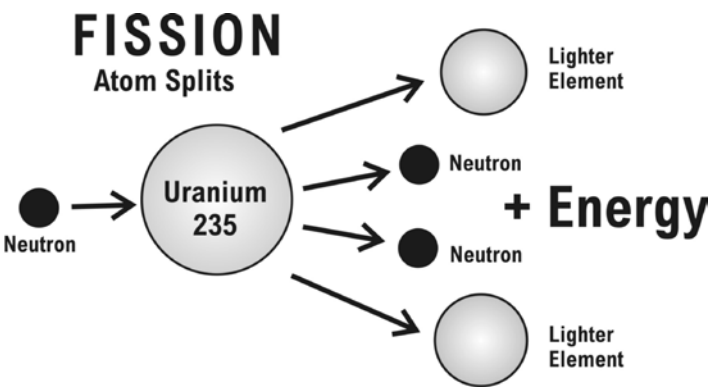


When electricity moves through a wire, a magnetic field is created around the wire. In an electric motor, the motor's wire is placed between external magnets. When electricity is sent through the wire, the magnetic field created around the wire interacts with the magnetic field of the external magnets. This interaction causes the wire to move. If the wire is designed so it is free to turn, the wire will spin and you have an electric motor.

Power plants use huge turbine generators to generate the electricity that we use in our homes and businesses. Different types of power plants use different fuels to change water into steam. Power plants can burn coal, oil, biomass, or natural gas to heat water into high-pressure steam, which is used to spin the turbines. Splitting uranium atoms in a nuclear power plant can also produce the thermal energy needed to generate steam.

Once the electricity is produced, it is moved to our homes and businesses. It moves through large electrical lines. Electricity moves most efficiently under high voltage. When the electricity leaves the power plant, its voltage must be drastically increased. When it reaches our homes and businesses, the voltage must be reduced so it will not burn up or damage things that use the electricity. The voltage of electricity is easily increased or decreased by a transformer. Transformers are commonly seen in our neighborhoods. Electrical substations are a series of transformers used to increase or decrease voltage. If you have an overhead electrical line that goes into your house, you will see a transformer on the pole where the overhead line leaves the larger power line. Usually, these overhead transformers are grey cylinders. They reduce the voltage on your electricity so that it can safely enter your house.

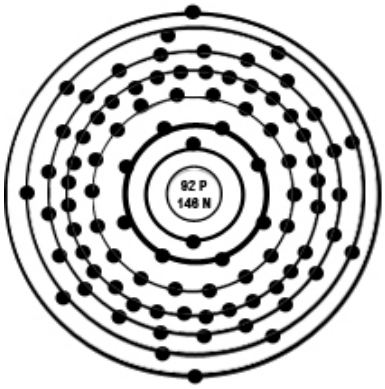
Generating Electricity with Nuclear Energy



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. Neutrons colliding with the nuclei of uranium and plutonium atoms can split these atoms into smaller atoms under certain conditions. This atom splitting is known as nuclear fission.

When nuclei undergo fission energy is released in the form of thermal, kinetic, and radiant energy. This thermal energy can be harnessed and put to work. 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 that we use to power our homes, businesses, and schools. A nuclear power plant uses the heat from controlled fission of uranium atoms to produce steam to turn the turbine.

Uranium



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 and uranium, 235 with 92 protons and 143 neutrons, and U-234 with 92 protons and 142 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 concentrations in rocks, soil, and bodies of water. When analyzing the total amount of uranium found 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 us hundreds if not thousands of years if estimates of how much we need are accurate.

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 and record shadows of the bones of his fingers on cardboard treated coated 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. Marie Curie, a student of Becquerel's 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 mid 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

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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 Meitiner, 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 by man.

Lise Meitner

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 about 230 miles south of Los Alamos, NM. The explosion was dramatic and demonstrated the huge amounts of energy released 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 Enola Gay, B-29 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 either injured or later died from effects of the radiation. In the end roughly 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 known to man.

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. As of 2009, 104 nuclear reactors are operating in the United States, and over 400 nuclear reactors are generating power throughout the world. Despite the successful of peaceful nuclear uses some people remain hesitant about furthering usage of the nuclear energy because of its potential to be used in non-peaceful ways.

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 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 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 uranium-containing solution undergoes further chemical treatments to separate the uranium from its solution. Uranium is collected and dried as uranium oxide concentrate. The concentrate is a bright yellow powder and is often called yellowcake. The yellowcake is then packaged in steel drums and transported to a refinery.

Refining and Conversion

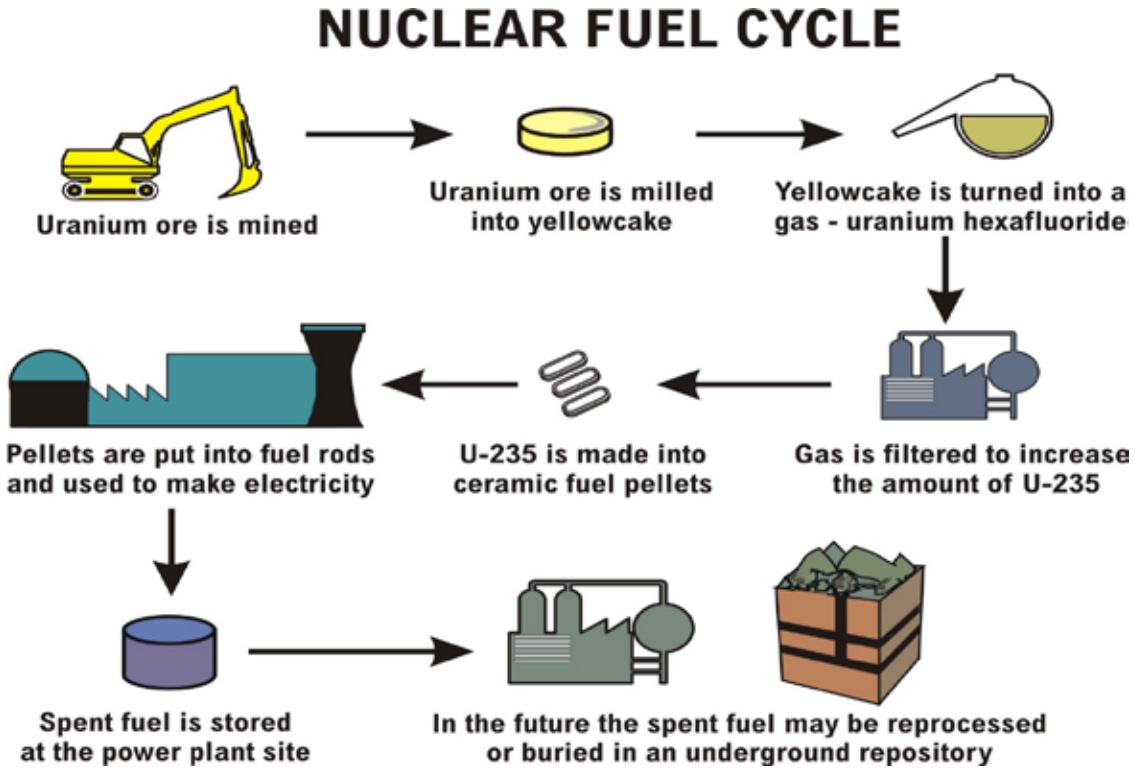
During this step, the solid yellowcake is turned into a gas, and impurities are removed. The gas is then turned back into a solid so it can be shipped to the processing site.

Enrichment

The solid received at the processing site 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. The enrichment process separates the lighter U-235 from the U-238. This increases the amount of U-235 present until there is enough in the fuel to power a nuclear reactor. The enriched fuel is converted into uranium dioxide in the form of fuel pellets.

Fuel Manufacturing

During fuel manufacturing, the enriched uranium dioxide, 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. The pellets are then placed into fuel rods and sealed. When the reactor is brought on-line the fuel pellets are ready to undergo fission and create the heat necessary to make steam and generate electricity.



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Nuclear Power Plants

The center of a nuclear power plant is the nuclear reactor. Inside the reactor is where fission takes place. The purpose of the reactor is to create favorable conditions allowing for a controlled chain reaction. If fission is not monitored carefully then an uncontrolled chain reaction could result in a nuclear explosion. Safety is the top priority at nuclear power plants.

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.

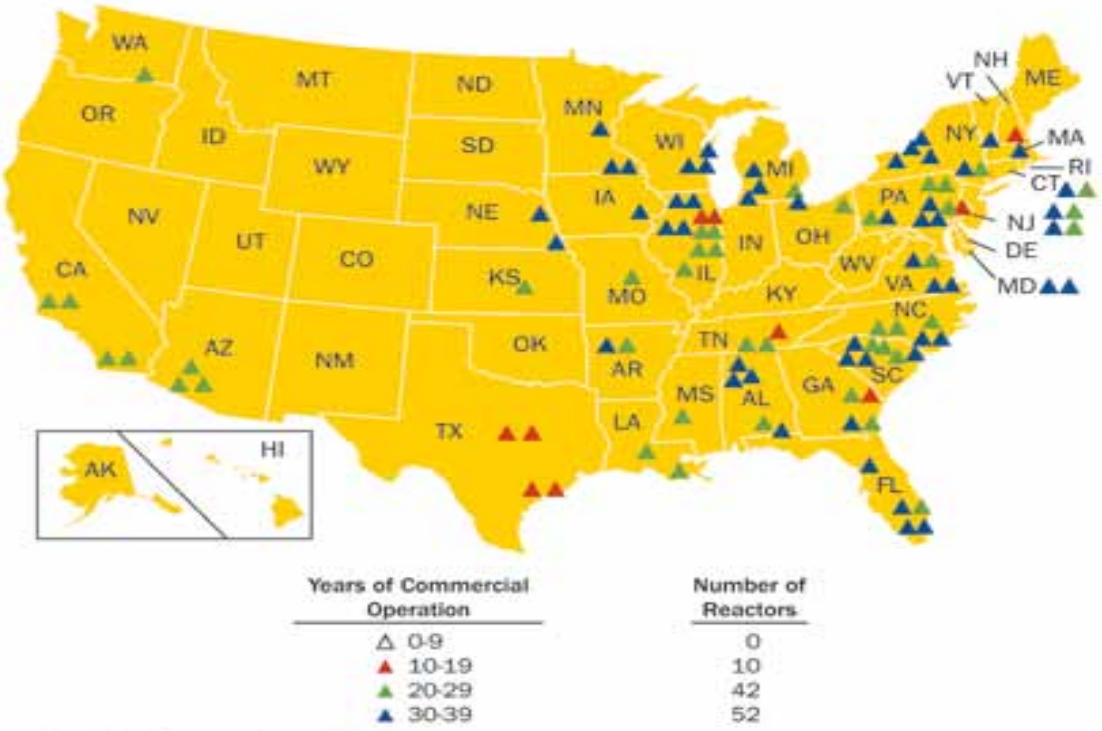
Fuel and Fuel Rods: These rods are filled with the UO2 pellets that have already been enriched (nuclear fuel). The UO2 fuel is a ceramic that contains only solids which limits the volume of radioactive gases that can escape into the atmosphere from the fuel itself. The fuel rods isolate the fuel from 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 purified 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.

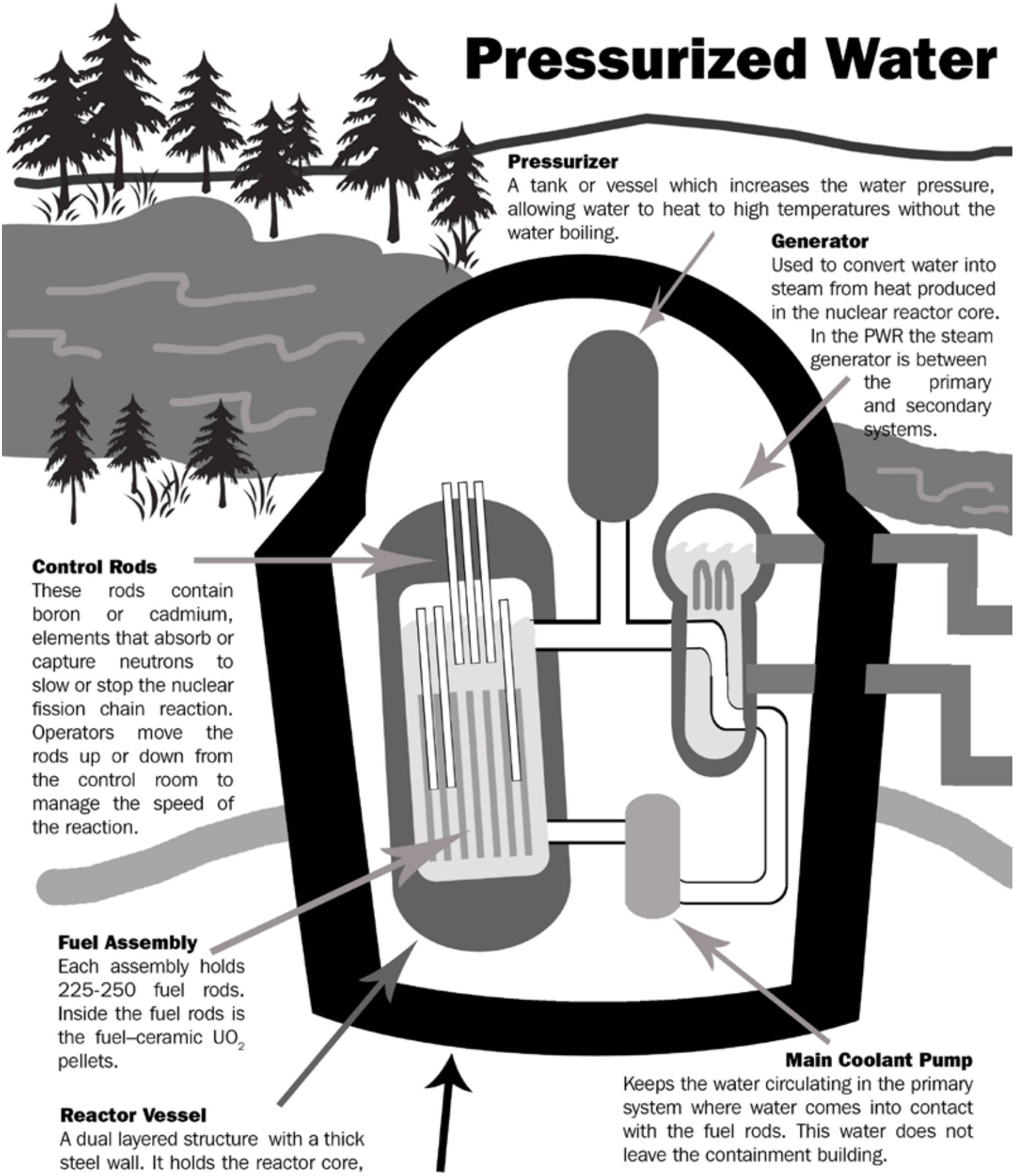
Heat Exchange System: A nuclear plant's thermal energy must be used to make steam and generate electricity. The heat is used to make steam which carries energy from the reactor vessel to the turbines. After the steam turns the turbines, it must be condensed back into water and returned to the reactor 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 direct contact with fuel rods in the reactor core, is converted into steam which turns the turbines which make electricity. A secondary system isolates the fuel rods from the steam used to turn the turbine by using a heat exchanger.. The operations of heat exchange systems are described below.

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



Source: U.S. Nuclear Regulatory Commission

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.

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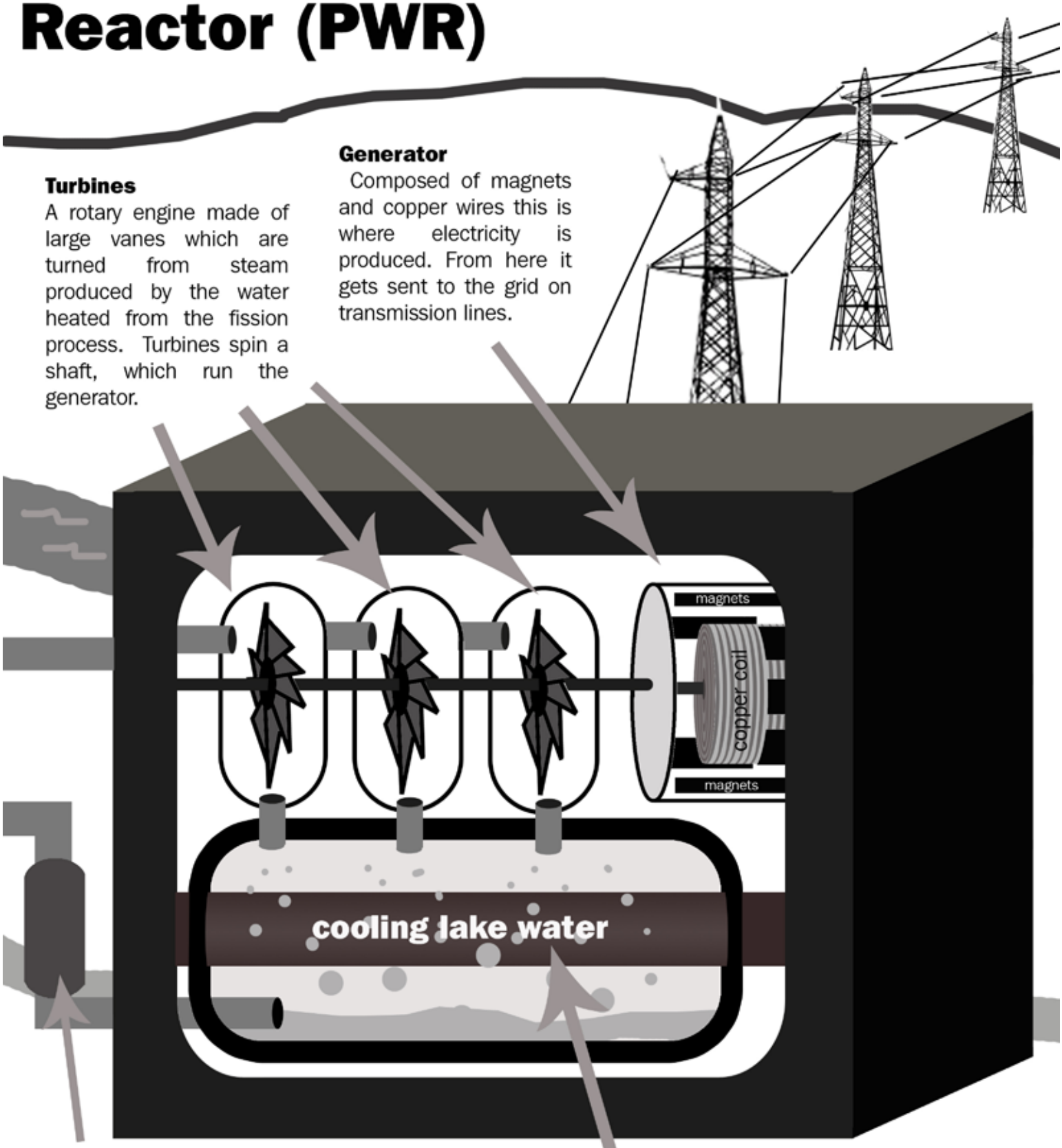
Reactor (PWR)

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

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

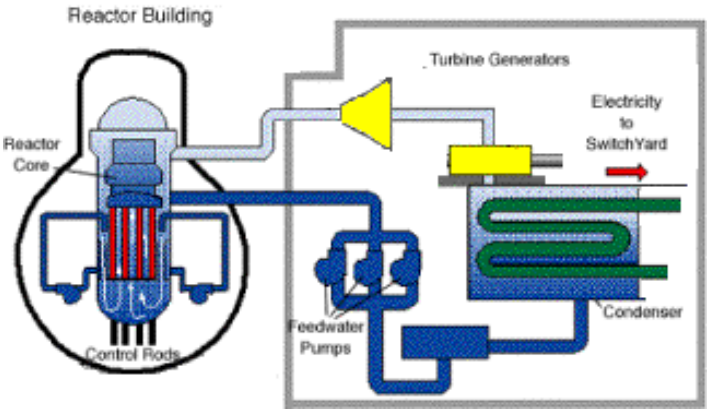
How a Nuclear Reactor Works

In a BWR the water flows through a single, primary, loop from the reactor core to the turbine. In this system, water in the reactor core and comes into contact with the fuel rods. As the water is heated by the nuclear fission, it changes to steam.

The steam then flows out of the reactor to the turbines. The steam turns the turbines of the generator to produce 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 loop back into water.

Water in the primary loop 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 water in the primary system. Thus, it is not radioactive and can be returned to the environment after use.

Boiling Water Reactor System



The PWR (see the diagram on pages 12-13) is the most popular commercial reactor type worldwide. Unlike a BWR, a PWR has both a primary and secondary heat exchange loop. Heated water from around the reactor, the primary loop, 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 secondary loop containing a water/steam mixture. The water from the reactor does not mix with 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 outside environment in the external loop before it returns to the containment building and steam chamber where it is heated and the cycle repeated.

In either system, 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. 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

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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.

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.

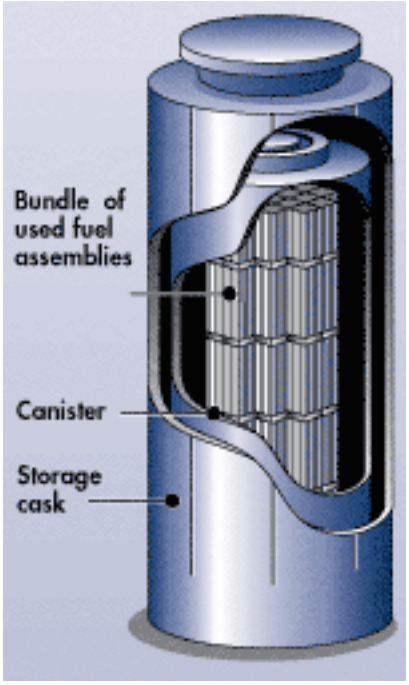
In 1986 at Chernobyl, a much more serious accident occured. While conducting tests of reactor behavior at low power settings plant operators turned off all of the automatic plant safety features. During the test the reactor became very unstable and there was a massive heat surge. Operators were unable 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.

Used Fuel Options

Radioactive Waste Handling and Storage Open Cycle



After cooling off in a used fuel pool, fuel assemblies are moved to interim storage in dry casks at the nuclear power plant sites. According to the Nuclear Energy Institute, if all of the United States' used fuel were lined up side to side and end to end in dry casks, it would take the space of one football field that was less than 10 yards deep.

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 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.

Some components of the used fuel will remain radioactive for thousands of years. Therefore, the challenge of long-term storage of the waste must be solved. In 1987, the U.S. Congress chose Yucca Mountain in southwest Nevada as the most likely site for long-range nuclear waste disposal. It is considered a stable area where radioactive waste can be buried deeply underground and security can be maintained.

However, plans for its use are not finalized, and 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 an additional 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. 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.

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 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 high-level radioactive waste can be stored in liquid form and solidified in glass for permanent storage. If a person's individual used fuel were solidified in glass for disposal, it would be about the size of a golf ball. While reprocessing recovers uranium and plutonium for use as additional nuclear fuel and reduces the mass of waste to be managed, it also produces waste which is both radioactive and chemically toxic.

Concerns About Nuclear Energy Proliferation Risks of Nuclear Power Programs

Beginning with the use of the first nuclear weapons on Japan, the spread of nuclear weapons (proliferation) has been a global concern. To combat this concern the "Atoms for Peace" agency formally known as the International Atomic Energy Agency was formed in 1959. The IAEA works closely with the United Nations but is a separate organization. Its job is to inspect and verify that nuclear materials in countries around the world are used for peaceful purposes, help countries upgrade nuclear safety and security, and help countries develop peaceful uses for nuclear science and technology.

Further prevention of the use of nuclear materials for military purposes was accomplished by the United States and the Soviet Union. In 1968, acting through the United Nations, these two countries wrote the Non-Proliferation Treaty (NPT). At this time 189 countries have signed the treaty designed to prevent the spread of nuclear materials for military uses. The only three that have not agreed to the treaty are Israel, Pakistan, and India. North Korea originally signed the treaty, but later

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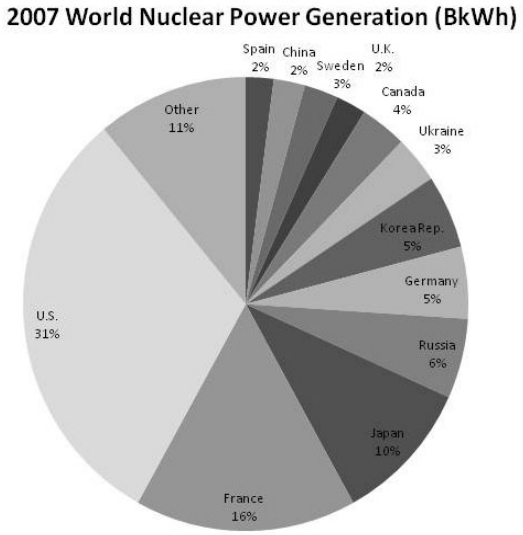
withdrew. Article IV of the NPT, declares that a state has the "right" to peaceful nuclear technologies as long as the state maintains safeguards on its peaceful nuclear program and does not manufacture nuclear explosives. Some non-nuclear-weapon countries such as Argentina, Brazil, and Japan, have pursued enrichment or reprocessing or both, and have maintained safeguards on these programs. Today, 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 Association (IAEA) and the UN Security Council have ruled that Iran is not in compliance with its safeguards commitments. If Iran proceeds with its nuclear program it creates risks for countries that Iran opposes.

A country desiring a large nuclear power program may still want to enrich and reprocess fuel so that it can operate nuclear plants. Generally, if a country has fewer than eight nuclear plants, it is not economically sound for that country to make its own nuclear fuel. In this case, a group of countries could become partners to make fuel. This means that nuclear-fuel-making activities would take place in each of the partnership countries. Each of the partner countries would have access to the nuclear facilities of the other countries. This should mean that the proliferation risk is reduced because more than one country would be involved in those activities, and each country would keep watch over its partners.

Whether partner countries watch over each other or agencies like the U.N. use outside inspectors to watch over some countries, openness and accountability are the keys to preventing proliferation of nuclear materials.



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

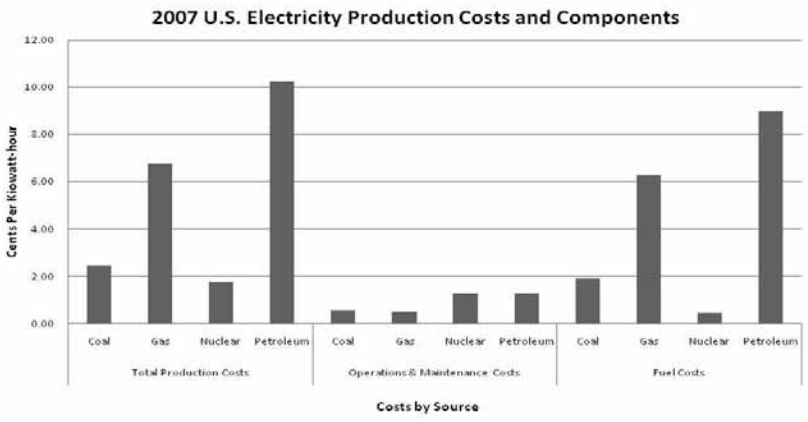
Is it economical to build nuclear reactors to generate electricity? Some groups that support building nuclear generating plants say that in the future, nuclear generators will be economical to develop and maintain. Some groups opposed to building nuclear generating plants say the plants are dangerous,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

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. Although the costs of uranium used for fuel is much lower than those of coal or natural gas extra expenses associated with the added construction materials and safety features of a nuclear plant causes the price of electricity generated by a nuclear plant to be higher than the cost of electricity generated by fossil fuel plants.

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 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 means that designs pre-approved by the NRC are used by power companies. 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 limit regulatory delays after the plant is completed.

Despite new licensing procedures there has still been reluctance by investors to put forth monies to build 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 the construction and operation of nuclear plants. 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.



At the end of 2008, construction and operating licenses for 27 new plants have been submitted with three more soon expected. If construction proceeds on schedule, the first of these plants will go on-line in 2016.

Another issue that affects the economics of all types 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

Nuclear power plants currently generate about 20% of the electricity consumed in the United States. As the demand for electricity grows in the coming years it will be necessary to build more nuclear power plants in order to keep nuclear energy meeting 20% of our needs. As the country moves forward in planning how to meet its energy needs, people need to weigh the costs and benefits of each energy source.

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.

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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 in the event of an accident

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 deposit such as petroleum, coal, or natural gas, derived from prehistoric fossils and used for fuel.

fuel cycle - The series of steps involved in supplying fuel for nuclear power reactors. It includes include 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 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.

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.

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 overheat and 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.

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, 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.

non-renewable 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 in nuclear medicine.

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.

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

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 – 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 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 that has an unlimited supply.

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

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

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

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 - The process of changing one isotope into another through a nuclear reaction.

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.

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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