Electrical TECHNOLOGY

Electrical Tech Note — 224

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Electrical Power Generation

The known methods of producing electricity are briefly discussed in this *Tech Note*, some of which only have applications as sensors in various types of control processes and instrumentation. The bulk of electrical power in the United States is produced using mechanical generation which operates on the principle of electromagnetic induction. Thousands of horsepower are required to operate a commercial generator, and high pressure steam is a common method of providing that power. Large generating facilities use a steam turbine as the prime mover for the generator. Using the conversion factor 0.746 kW per horsepower, the steam turbine is developing in excess of 134,000 horsepower to produce 100 mega-watts of electrical power. A steam boiler electric power plant that operates with coal is illustrated in *Figure 224.1.* Steam can be produced from the heat of a nuclear reactor, from solar energy, and from hot rock deep in the earth. Components of commercial power production facilities are discussed in this *Tech Note* along with present and future sources of electrical energy. Also discussed is the impact these commercial power production facilities have on the environment.

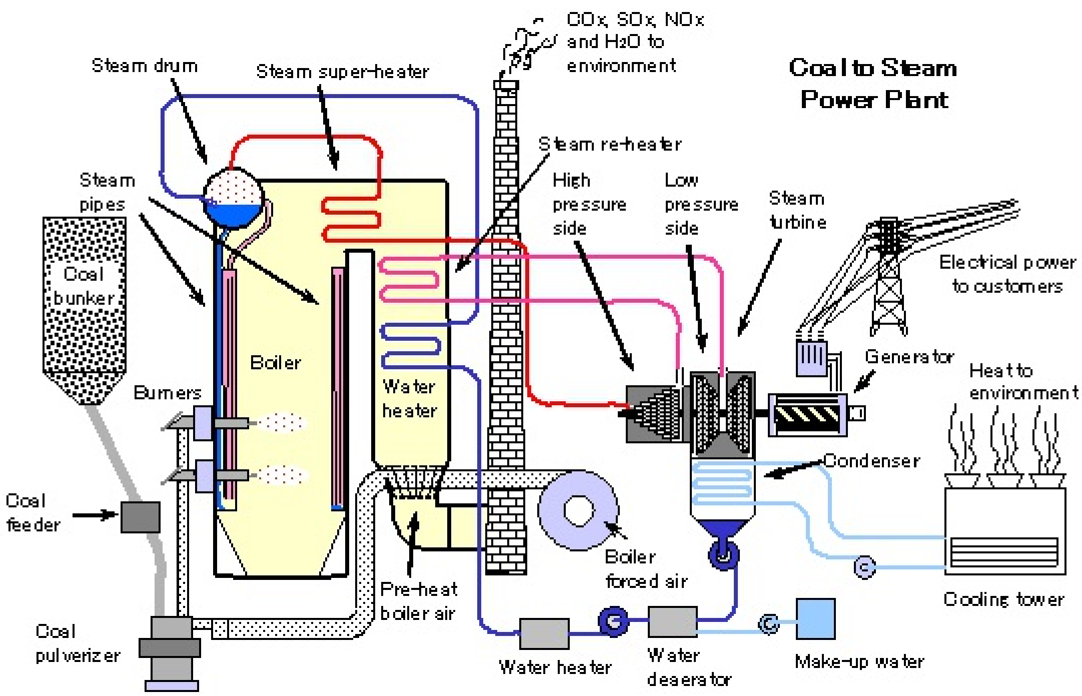

Figure 224.1 *A typical power plant fires a boiler with coal, fuel oil, or natural gas to produce steam that drives the generator. A separate water circulating system is required to condense the steam leaving the turbine. Emissions from a power plant are continuously monitored to protect the environment.*

Combustion of a hydrocarbon fuel is the principle source of energy to make electricity. Combustion involves the chemical combination of carbon, hydrogen, and oxygen that produces carbon dioxide (CO_2) and water (H_2O). The present world economy has a huge demand for heat and power that seems to be producing carbon dioxide at a rate faster than plant life can reconvert back into oxygen and elemental carbon. This *Tech Note* is intended to discuss methods of producing electricity along with present and potential sources of energy to produce electricity commercially. It is important to understand these concepts in order to make prudent decisions about energy sources in the future.

Methods of Producing Electricity: Electrical power as direct current (dc) can be produced by a number of methods, some of which are practical for producing power for general applications, and some have limited use. Common methods of producing electricity are piezoelectric, thermoelectric, photovoltaic, chemical activity, magnetohydrodynamics, and electromagnetic induction. The fuel cell will be discussed and it is actually a form of chemical activity.

A ***piezoelectric* crystal** that is placed under pressure will develop a voltage across the crystal when pressure is changing. When vinyl records were popular, this was the method of reading the music off the vinyl record. Piezoelectric crystals are used in load cells to measure pressure and acceleration. The electric power produced is direct current and it is too little to be practical as a power source.

The ***thermoelectric (PV)*** process involves two different metals joined to form a circuit. The key part is the junction between the two metals. There will be two junctions in the circuit. If these junctions are at different temperatures, a voltage will be produced between the two junctions and a direct current will flow as illustrated in *Figure 224.2.* It was discovered that the voltage produced was proportional to the temperature difference over a limited range of temperatures for specific metals. A thermocouple uses two dissimilar metals with one junction at a point where a temperature measurement is desired and the other junction acts as a reference point. It is possible to build a thermoelectric device that will produce a limited amount of direct current. It was also discovered that direct current could be passed through a thermocouple and a temperature difference develops between the two thermocouple junctions. Small precision refrigerators can be constructed using the thermoelectric process.

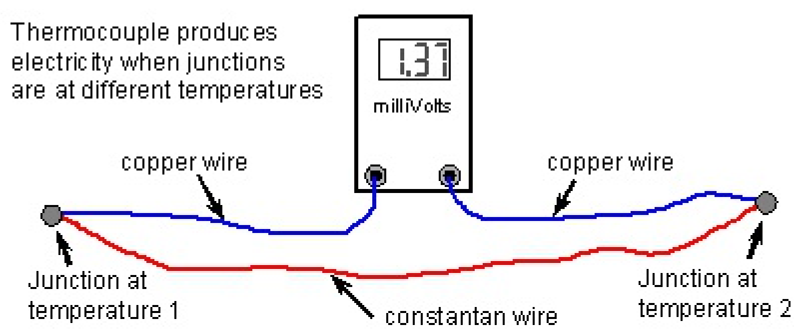

Figure 224.2 *A thermocouple consists of two different metals joined such that two junctions are created. When the two junctions are at different temperatures, a voltage will be produced. Usually thermocouples are used to measure temperature, but sometimes they are used to produce electrical power.*

A ***photovoltaic*** cell is constructed of two thin semiconductor crystals. The top layer is an n-type semiconductor and the bottom layer is a p-type semiconductor. When light penetrates these semiconducting materials, they absorb much of the energy of the photons of light which dislodges electrons from their positions within the atomic crystal structure. (See *Figure 224.3*) Electrons from the p-type semiconductor cross a boundary and enter the n-type semiconductor, and an electrical charge builds up between the two semiconductors. When the sun is shining on the photovoltaic cell, it can sustain approximately _0.5 volts_ to supply direct current to a load. A photovoltaic cell of about 100 cm^2 (3.94 in^2) will have a maximum output of about 1.55 watts at about 0.5 volts. Output voltage, current, and power delivered to a load will vary depending upon the intensity of sunlight entering the cell. Here are approximate values that can be expected from a photovoltaic cell supplying maximum output to a load. *Typical output of direct current per cell is 0.5 volts.* In a photovoltaic module many cells are connected in series to achieve the module output voltage desired. Typical output current from a photovoltaic cell is about *0.2 amperes per square inch*. This is about 3.1 amperes for a 100 cm^2 photovoltaic cell. Expected operating *power output is about 0.1 watts per in^2.* For a 100 cm^2 photovoltaic cell this is about 1.55 watts. Power from solar panels typically is converted to alternating current by a device called an **inverter**. The inverter connects to the ac power system of a building and provides power for use in the building with excess power supplied to the utility power system.

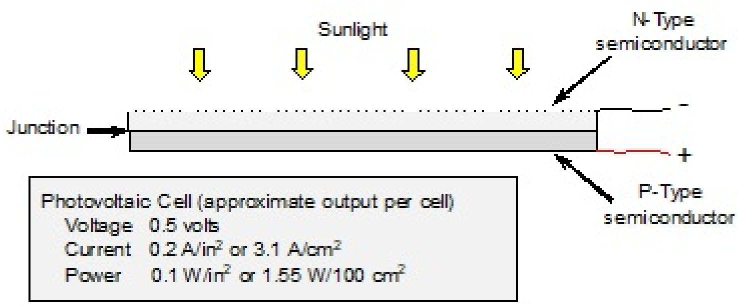

Figure 224.3 *Each photovoltaic cell has an typical output of 0.5 volts of direct current and many cells are connected in series to achieve the desired output voltage of a PV module.*

Chemical batteries of all types are available. Many types are single-use and throw-away, and many are re-chargeable. They are frequently used as back-up power for industrial and commercial applications. Since they are direct current sources, an inverter is required if they are to be used to power alternating current equipment. Storage batteries are often a part of alternate power sources such as a wind powered generator, or a solar photovoltaic array. Storage batteries are often heavy which is a major disadvantage for their use for mobile equipment and vehicles.

A ***fuel cell*** *is an electrochemical device that converts* ***hydrogen*** *and* ***oxygen*** *into* ***electricity****, water, and heat.* It is like a battery except rather than requiring periodic recharging, it runs continuously as long as it gets a supply of hydrogen gas and oxygen. The hydrogen must be stored in a pressurized tank, but the oxygen is taken from th air. Fuel cells are presently available for powering homes and other loads. Unlike a storage battery, fuel cells can be slow to respond to a sudden increase in load. A fuel cell consists of two chambers into which is pumped hydrogen and into the other is pumped oxygen usually using air. The proton of the hydrogen atom passes through a membrane from the hydrogen chamber to the oxygen chamber where it combines with the oxygen to form water. The electrons left behind must pass through an external electrical circuit to get from the hydrogen chamber to the oxygen chamber. Platinum is required in the membrane as a catalyst which adds to the cost of fuel cells. Fuel cells run quite hot so they produce heat and water in the form of steam in addition to electricity. Any type of hydrocarbon fuel can be used but a device called a reformer is required to free the hydrogen to become a gas. In the reforming process carbon combines with oxygen to form carbon dioxide. Research continues on fuel cells as a mobile vehicle power source.

Magnetohydrodynamics is an interesting approach to power production, but thus far abrasion of the combustion venturi tube is too excessive to be practical. Air is heated to the point of ionization and this plasma is passed through a venturi tube at high velocity. The tube is surrounded with coils of wire into which is induced an electrical current.

Using the principle of ***electromagnetic induction***, a wire exposed to a magnetic flux such that the magnetic flux is moving perpendicular to the cross-section of the wire will induce a voltage into the wire that produces electrical current flow. An electrical generator has coils of wire built into the outer steel frame, called a *stator,* with an electromagnet spinning inside to create the moving magnetic flux similar to the illustration of *Figure 224.4.* Some type of prime mover is required to spin the electromagnet. The spinning magnet called the armature is energized with direct current to produce the required magnetic flux density required to produce the required output from the stator winding. The output of a mechanical generator is alternating current power. Typical prime movers are engines, hydroelectric water power, wind turbines, turbine engines, and steam turbines. Typical fuels for steam turbines are any type of hydrocarbon such as coal, oil, and natural gas. A natural source of heat, if available, is ***geothermal*** *heat where hot rock below the surface of the earth converts liquid water to steam to power a generator*. In some locations computer controlled mirrors aim solar energy at a boiler to make steam. Nuclear energy can also be used as a heat source to produce steam to power the turbine. Inside a generator a magnetic flux cuts across coils of wire, and a voltage is induced into the wires. *The magnetic field inside commercial generators spins at 3600 revolutions per minute (rpm) to produce 60 Hz power*.

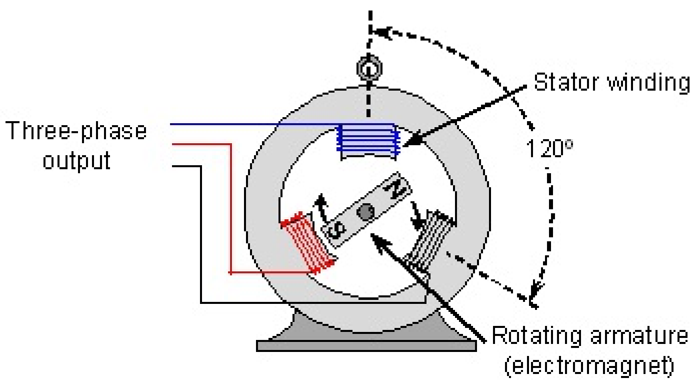

Figure 224.4 *Most electrical energy is produced as alternating current by means of electromagnetic induction where a magnetic field spins inside a steel frame containing these windings to produce 3-phase power. The windings are usually connected in a wye configuration.*

Steam Driven Power Plant: It takes thousands of horsepower to operate a commercial power plant generator. The most effective prime mover that can develop thousands of horsepower in a relatively small space is a high pressure steam turbine as illustrated in *Figure 224.1.* Most any significant heat source can be used to produce the steam. In the United States typical methods of producing steam for electrical power production is to use a large boiler that burns either coal, or natural gas. A nuclear reactor can also be used as a heat source to produce steam. Steam typically enters the turbine at up to 1800 psi and 1000^{o} F and leaves at atomospheric pressure (14.7 psi, 101.3 kpa). The steam leaving the turbine is cooled in a device called a *condenser* which returns the steam to liquid water, dropping the pressure suddenly to atmospheric pressure or below. Condensing the steam as it leaves the turbine produces a huge quantity of heat that is removed from the power plant by an installation known as the *cooling tower*.

A *boiler* at a coal fired electrical power plant is nothing more than a rectangular box 30 ft to 50 ft square and about 100 ft tall. The walls of the boiler are lined with several layers of vertical water pipes. Liquid water is supplied at the bottom of these vertical pipes and it turns to steam before it reaches the top of the pipes. Burners or flame injectors near the bottom of the boiler mix powdered coal, fuel oil, or natural gas with preheated air to inject a flame into the boiler. The mixture of fuel and air is controlled to minimize the release of undesirable products of combustion into the atmosphere. Typically there are many flame injectors (burners) in a boiler. The water in the pipes boils and rises to the top of the boiler where it is collected in a large chamber sometimes called the steam drum. The hot gas leaving the boiler still has energy available and the steam from the steam drum is passed through pipes in the boiler exhaust to superheat the steam to about 1000° F before going to the steam turbine. Water used in a steam boiler must be pure water that is free from minerals and air. The water leaving the turbine is condensed to create the maximum pressure drop across the turbine, then re-circulated back to the boiler for another cycle. Some steam is lost, so demineralized make-up water is constantly being added. Air at these high temperatures will corrode the steam pipes, so dissolved air is also removed from the water before it returns to the boiler. The returning water passes through pipes in the boiler exhaust to pick up energy that might otherwise be wasted out the stack.

Coal, fuel oil, and natural gas in it's purest form combine with oxygen (burned) to produce heat and the release of water (H_2O) and carbon dioxide (CO_2). Humans and animals also consume oxygen and release water and carbon dioxide. The boiler in a power plant is carefully controlled to maximize the efficiency of combustion, but 100% combustion efficiency is virtually impossible to achieve. The result of incomplete combustion is the release of oxides of nitrogen (NO_X) and oxides of carbon (CO_X). *Oxides of nitrogen (NO_X), which can be a contributor to* ***smog**,* as well as oxides of carbon (CO_X), such as carbon monoxide (CO), must be minimized. *Mixed in with the coal are minerals that do not burn thus producing small particles in the exhaust called* ***fly ash**.* These small particles of fly ash are fairly easy to remove from the boiler exhaust, and the amount that gets into the atmosphere is extremely small.

Boiler fuels, especially coal, are hard to find that do not contain traces of the mineral sulfur. When combined with oxygen at high temperatures, oxides of sulfur are produced (SO_X). If released into the atmosphere these *oxides of sulfur combine with water in the atmosphere to form acids. This is the origin of the term* ***acid rain**.* Some sulfur in the atmosphere is needed by plants, but uncontrolled, coal fired power plants can produce excessive sulfur emissions. Oxides of sulfur can be removed from boiler exhaust, but the process is difficult and expensive. Many electric power plants control sulfur emissions by using only coal that has a low sulfur content.

There are small quantities of other minerals contained in hydrocarbon fuels especially coal. One of these mineral in coal deposits of concern is a small quantity of ***mercury***. Even though the quantity of mercury in power plant stack emissions is extremely small, this mercury is successfully removed at some power plants to prevent it from being released into the environment. Regulations on power plant emissions varies from state to state in the U.S., but in general *limits are placed on the release of oxides of nitrogen (NO_X), oxides of sulfur (SO_X), and some oxides of carbon (CO_X)*. Natural gas generally has a low sulfur content, and natural gas combustion is a more efficient fuel than coal as a power plant energy source. High efficiency generally means less carbon released into the atmosphere.

The steam turbine shaft is connected directly to the generator shaft which in the United States turns at 60 revolutions per second (3600 rpm) to produce 60 cycles per second electricity (60 Hz). The purpose of the steam turbine is to power te generator which usually requires 100's of thousands of horsepower. *The generator consists of three windings, spaced 120° apart, in the outer stationary portion of the generator called the stator*. An electromagnet called an armature spins inside at 3600 rpm, illustrated in *Figure 224.4*. This spinning magnetic flux induces current flow into the stator windings. The more power that is demanded by customers, the harder it is to turn the generator shaft. This requires larger quantities of steam, thus requiring higher rates of consuming boiler fuel such as coal or natural gas. Direct current is supplied to the rotating armature winding to provide a strong enough magnetic flux to supply the customer power demand. A commercial power plant generator typically produces 3-phase power with a voltage between output wires of from 15,000 volts to 18,000 volts. Transformers outside the power plant change the voltage from the level produced by the generator to the transmission line level required for delivery to distant locations. In order to transport electrical power long distances efficiently, *transmission line voltages are generally several hundred-*

thousand volts to minimize current and losses due to voltage drop. These bulk power transmission lines usually consist of aluminum wires suspended on tall steel towers.

How coal is delivered to a power plant depends upon it's location. For inland locations coal is delivered with unit trains consisting of about 100 cars each holding about 100 tons of coal per car. For power plants located next to a large lake, river, or ocean, coal can be delivered by ship or barge. Enough coal to operate the power plant for several weeks is usually stored in huge outside coal piles. Coal is delivered from storage to the power plant with belt conveyers and deposited into *coal bunkers*. Coal feeds by gravity into a metering device called *feeders* which controls the rate at which coal is supplied to the boiler. This coal is supplied to a *crusher* that breaks chunks down into a fine powder where it is mixed with preheated air and transported to *flame injectors* (burners) located in the lower portion of the boiler. *The power plant footprint can be reduced as well as elimination of power consuming coal precessing and transporting equipment for power plants fueled with natural gas. A power plant built specifically for natural gas operates more efficiently than one using coal as the energy source and requires a smaller building site.*

In order to extract as much power as possible from the steam, the maximum possible pressure drop is achieved between the input and output of the turbine by condensing the steam back into liquid water after it leaves the turbine. Located directly below the turbine is a device called the *condenser*. Cool water from outside the power plant is pumped over pipes containing steam from the turbine. That cool water takes the remaining heat from the steam causing it to condense thus resulting in a pressure drop. The cooling water, now hot, is pumped outside the power plant to an installation called a *cooling tower*. Inside the cooling tower the hot water from the condenser is released at the top where it drips down a series of baffle plates similar to a water falls where air is pumped through it using giant fans. Some of the water evaporates resulting in cooling. On most days a cloud of harmless steam can be seen rising into the atmosphere above the cooling tower. The remaining cooling water is then pumped back into the power plant where it once again passes through the condenser. Since some of the cooling water evaporates into the atmosphere, water is constantly being added to make up the difference. The source of this make-up water is usually a nearby lake or river.

Greenhouse Effect: Combustion of a hydrocarbon fuel such as coal, oil, natural gas, gasoline, and ethanol, releases energy in the form of heat along with the products of combustion which are water (H_2O) and carbon dioxide (CO_2). Carbon dioxide is considered a greenhouse gas, but it is a product of combustion that cannot be avoided. A greenhouse is an enclosure (building) that has transparent walls and roof. Solar radiation in the visible light spectrum passes through this transparent material and is absorbed by plants and other objects and surfaces inside. As plants, objects, and surfaces within the greenhouse enclosure absorb solar radiation they become warm and sometimes even hot. Objects that are warm or hot radiate heat directly to cooler surfaces in a manner similar to light from the sun. Light travels through space as a wave. Light waves are at an extremely high frequency with each color having a slightly different frequency. Heat from a warm or hot surface is also a wave of the same type, but at a frequency lower than that of light. The surfaces of the greenhouse that are transparent to visible light are opaque to infrared radiation. The solar radiation enters the greenhouse where it is trapped and cannot radiate back out. The result of this trapped energy is a build-up of heat that causes the temperature to rise inside the greenhouse. Similar to the transparent surfaces of a greenhouse, *the* ***greenhouse effect*** *is where excess oxides of carbon (CO_X) released into Earth's atmosphere allows visible solar radiation to reach the surface, but prevents excess heat from radiating back out into space*. The result over time is a small rise in the average annual temperature of the earth atmosphere which is referred to as *global warming*. There is a debate as to wether global warming is really occurring, but most scientists are convinced that it is real and to some extent caused by excessive release of carbon dioxide into the atmosphere. Since much of the commercial electrical power production burns a fuel, carbon dioxide is released into the atmosphere in large quantities. Producing electrical power by a means that does not burn a fuel, such as nuclear, wind, solar, geothermal, or hydroelectric, is believed necessary to slow or stop the process of global warming. However, there are environmental issues with these alternative sources of energy.

Nuclear Power Plants: Some power plants use a nuclear reactor as the heat source to make steam rather than using a fuel fired boiler. Since there is no combustion of a fuel, oxides of carbon are not released into the atmosphere. Nuclear power plants are a way of generating electricity without contributing to global warming. By a process called ***fission,*** an isotope of uranium known as U-235 is split to form smaller atoms, and releasing large quantities of energy as heat. *This heat is then used to make steam to operate a turbine powered generator*. Such a nuclear power plant is shown in *Figure 224.5.* An advantage of such a system is that there are no products of combustion released into the atmosphere. There is, however, the slight chance of an accidental release of radioactive materials. Another concern is where to store the highly radioactive spent fuel.

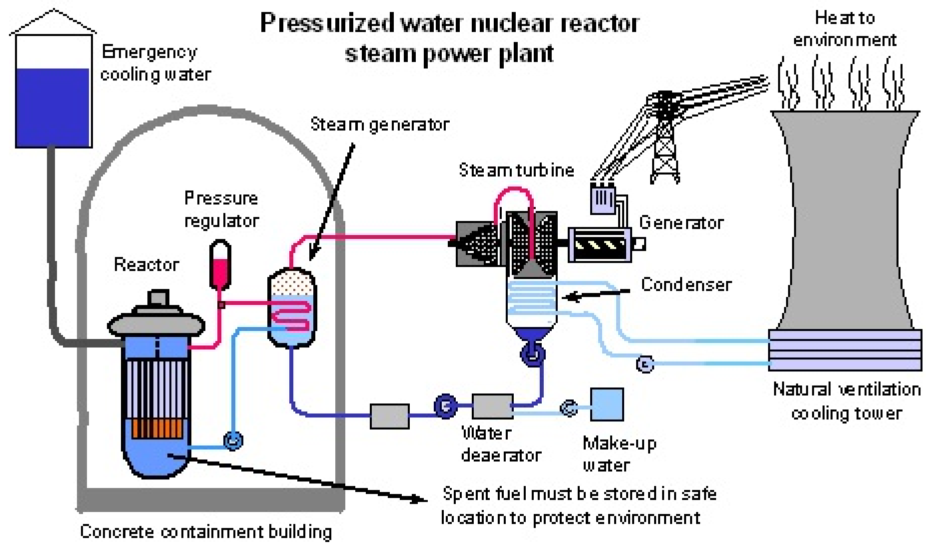

Figure 224.5 *In a pressurized water reactor, the heat from the reactor coolant generates steam in the containment building to power the turbine. With this type of reactor, radioactive material does not leave the containment building until the spent fuel is removed from the reactor.*

Nuclear Terminology: *Atoms* are made up of a nucleus consisting of particles called protons and neutrons, and electrons moving in spherical shells about the nucleus. The protons and neutrons cling together and form the nucleus of the atom. The protons have a positive charge, and electrons have a negative charge. Neutrons have no charge. The electrical charge of an atom is zero because there is an equal number of protons and electrons. A material consisting all of the same atom is called an *element*. There are only 92 elements that occur naturally. Other elements with higher atomic numbers than uranium are produced artificially. Some such as neptunium and plutonium do occur naturally in very small quantities in some mineral deposits. *Atomic number* is the number of protons in the nucleus. Each different element has a different atomic number. There should be an equal number of electrons circulating in spherical shells about the nucleus. This is illustrated in *Figure 224.6* which depicts an atom of helium.

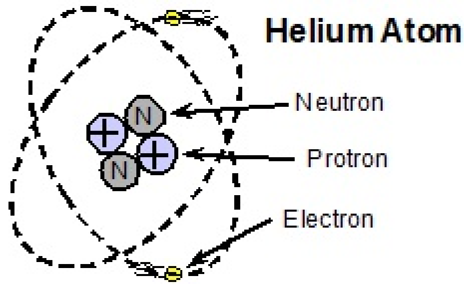

Figure 224.6 *An atom of helium has an atomic number of two and an atomic mass of four. It has two electrons, two protons, and two neutrons.*

Atomic mass of an atom is approximately the number of protons and neutrons in the nucleus of the atom. An electron has an electrical charge as strong as that of a proton, but it's mass in only a small fraction of that of the proton. All of the electrons forming an atom only make up a small fraction of the total mass of the atom. *Figure 224.6* depicts an atom of helium with two electrons, two protons, and two neutrons. There are four particles in the nucleus, therefore, the atomic mass of helium is approximately four atomic units.

An ***isotope*** is a different form of the *same element with the same atomic number, but a different atomic mass*. For example, uranium exists in nature generally with an atomic mass of 238 atomic units. It has 92 protons and electrons, therefore, it has 146 neutrons. An important isotope of uranium has an atomic mass of 235. This isotope of uranium only has 143 neutrons.

While a typical hydrogen atom consists only of one proton in the nucleus, it has an isotope with a nucleus consisting of one proton and one neutron. The isotope is called ***deuterium*** illustrated in *Figure 224.7.* One out of every 6500 atoms of hydrogen in sea water is a deuterium isotope of hydrogen. Water, normally H_2O, can be formed using the deuterium isotope of hydrogen rather than normal hydrogen. The result is deuterium oxide or *heavy water*. Heavy water is an important ingredient for the operation of some nuclear reactors. Another important isotope of hydrogen has one proton and two neutrons in it's nucleus. This isotope has three times the mass of normal hydrogen and is called ***tritium.*** Deuterium and tritium are likely to be the fuel that powers nuclear power plants of the future.

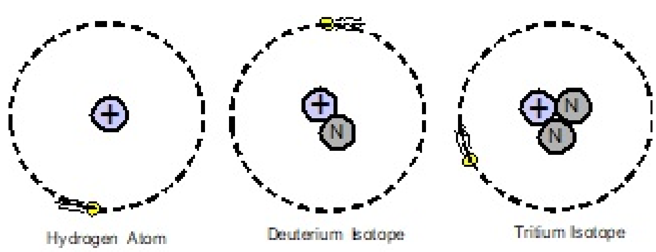

Figure 224.7 *An atom of hydrogen has an electron and a proton. An isotope is the same atom with a different atomic mass resulting form a different number of neutrons in the nucleus.*

An ***ion*** is an atom that has more electrons than protons or fewer electrons than protons. *The ion will have an electrical charge*. If a hydrogen atom loses it's electron, it will have a charge of plus one. When table salt (sodium chloride) is dissolved in water it separates into sodium ions with a plus one charge and chloride ions with a minus one charge.

Nuclear ***fission*** *is the process of splitting the nucleus of an atom*. The strongest force in the universe is the force that holds the particles of the nucleus of an atom together. In the process of splitting an atomic nucleus, some of this force is released as energy. A ***fissile*** isotope of an atom is one that can be split by fission. There are only a few isotopes that can be split. The common fissile isotopes are uranium U_{235}, uranium U_{233}, thorium Th_{232}, and plutonium

Pl_{239}.

A ***fertile*** material is one that is not fissile, but can be converted to a fissile material by absorbing a neutron and undergoing a series of radioactive decays. Uranium found in deposits around the world consists mainly of the isotope uranium U_{238}. Uranium U_{238} is not *fissile*, but it is *fertile* because it can be converted to a fissile material (plutonium Pl_{239}). If a neutron hits the nucleus of uranium U_{238} at the right speed, the uranium nucleus will absorb the neutron to become the isotope uranium U_{239}. Several other changes will occur and the uranium ends up as the isotope plutonium Pl_{239} which is fissile.

Nuclear Fission Reactors: The objective in a nuclear reactor power plant is to load the reactor with fissile material and achieve a self-sustaining fission chain reaction that produces heat to create steam for a steam turbine powered electrical generator. A common nuclear reactor uses ***enriched*** *uranium U_{235}* as the fuel. Small cylindrical pellets containing the uranium isotope U_{235} are assembled in long rods and grouped together into bundles of several rods in a manner similar to *Figure 224.8.* When the reaction is started, heat is produced, and a coolant is circulated up through the spaces between the rods to carry away the heat. The atom splitting occurs when a free neutron hits a uranium U_{235} nucleus at the correct speed. If the neutron hits the nucleus at too high a speed, it will pass right through the nucleus and the Uranium U_{235} will not split.

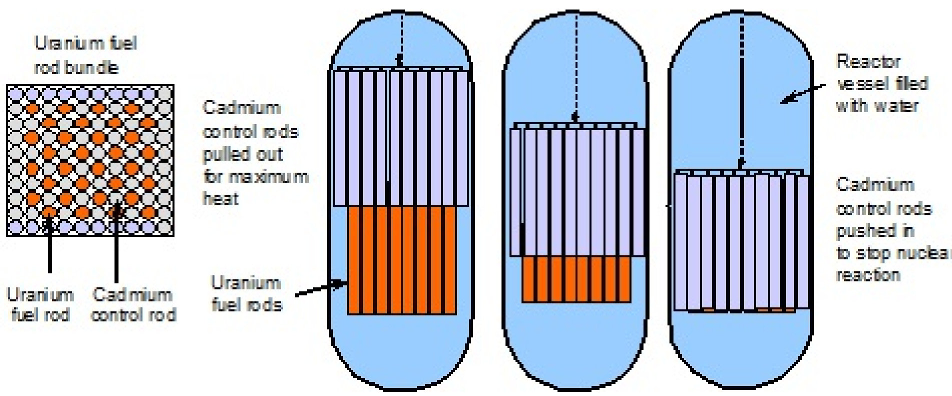

Figure 224.8 *The rate of fission in the core of a nuclear reactor is controlled by inserting control rods in among the fuel rods to absorb neutrons and slow the reaction.*

The fission (splitting) of uranium U_{235} is illustrated in *Figure 224.9.* A stray neutron impacting the nucleus of the uranium U_{235} at the right speed will be absorbed into the nucleus creating a new isotope uranium U_{236}. Uranium U_{236} is unstable, and quickly splits apart into two other isotopes of lesser atomic mass. Over 20 different isotopes can be produced depending upon how the uranium U_{236} splits apart. One or two neutrons, in addition to the original neutron, are released when uranium U_{236} splits. These neutrons are available to impact other uranium U_{235} atoms to keep the process going. The splitting of the uranium U_{235} atom results in the release of some left over neutrons plus released energy. If there is an abundant supply of uranium U_{235} available, the fission process will continue. This is called a ***chain reaction***. When the uranium U_{235} splits, some of the energy that held the nucleus together is released as heat. This heat is used to produce steam to power a turbine driven generator.

The concentration of uranium U_{235} in natural deposits of uranium ore U_{238} is only about seven tents of one percent (0.7%). Except in certain reactors, this concentration is too low to achieve a sustained chain reaction. Most nuclear reactors use ***enriched uranium*** U_{238} where about 4% of the fuel is uranium U_{235}. ***Enrichment*** *is the process of increasing the concentration (or percentage) of uranium U_{235} in the nuclear fuel.* A 4% concentration is high enough to achieve a sustained chain reaction, but too low to result in a run-a-way chain reaction. In atomic bomb fuel, the concentration of uranium U_{235} is very high, and a run-a-way chain reaction will occurs once the fission process is started.

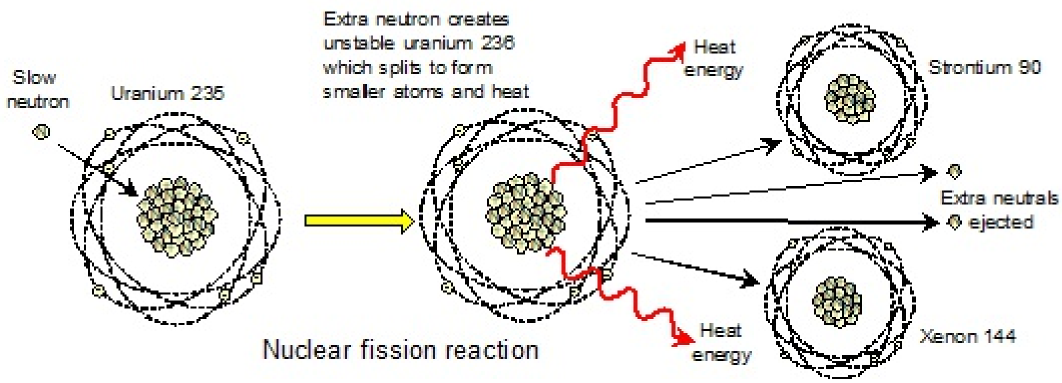

Figure 224.9 *A typical fission reaction of uranium U_{235} results in the production of strontium 90 and xenon 144, with the release on one or three neutrons and a lot of energy as heat.*

Controlling a fission reaction in a nuclear reactor is accomplished by inserting control rods into the reactor core. The nuclear fuel containing the uranium U_{235} is formed into cylindrical pellets and loaded into long rod shaped tubes, then assembled into a bundle containing many fuel rods as shown in *Figure 224.8.* The chain reaction can be controlled by putting a material into the reactor that absorbs the free neutrons. *Cadmium* is very *good at absorbing neutrons*, and long rods of cadmium are inserted among the fuel rods. By pulling out the cadmium control rods, the chain reaction is allowed to proceed. *By inserting the cadmium control rods into the reactor fuel bundle, the neutrons are absorbed and the chain reaction slows.*

Another important part of a uranium nuclear reactor is a *moderator*. A ***moderator*** is some substance that will slow the speed of neutrons. In a uranium reactor fast neutrons will pass right through the atom without causing the nucleus to split. The neutrons must be slowed down to get efficient fission to occur. ***Water is a good moderator*** *and will slow the speed of the neutrons.* Water used to cool the reactor and carry away the heat also acts as a *moderator* to slow the neutrons. Some nuclear reactors use water made from deuterium, which is called *heavy water*. This is an even better moderator. Heavy water does such a good job of slowing the neutrons it may not be necessary to enrich some uranium fuels.

Nuclear waste is a problem for nuclear reactors. The splitting of the uranium U_{235} isotope results in a variety of other isotopes with a smaller atomic number and atomic mass. In one common reaction, uranium U_{235} with an atomic number of 92, splits to form strontium 90 with an atomic number of 38, and xenon Xe_{144} with an atomic number of 54 (38 + 54 = 92). Strontium Sr_{90} in particular is highly radioactive and will pose a health problem if it is released into the environment. ***Spent fuel rods*** *from a nuclear reactor are highly radioactive and must be placed into safe long-term storage for hundreds of years* to prevent contamination of the environment. Spent nuclear fuel is often stored at nuclear power plants, and some is reprocessed to decrease it's volume and stored at one of several repositories around the country.

The nuclear reactor itself is housed inside a concrete *containment building* that will prevent radioactive material from being released into the environment should something happed to the reactor or parts of the system carrying radioactive materials. There was a reactor melt-down many years ago in what is now Ukraine that released radioactivity into the atmosphere because the reactor was not housed in a containment building.

Once put into operation, the *uranium fuel rods will last about* ***18 to 24 months*** before the U_{235} is depleted and must be replaced. The weight to energy ratio of these fuel rods compared to coal for producing heat is about 17,000 to 1. There are two basic reactor designs. One is a pressurized water reactor (PWR) where the water is kept under pressure so it will not boil similar to the radiator of a car. A nuclear power plant of the pressurized water type is illustrated in *Figure 224.5.* There is a heat exchanger (steam generator) in the containment building where the heat from the reactor coolant water is transferred to a secondary system where water is boiled to form steam to power the turbine. With this type the radioactive coolant water never leaves the containment building. The other type is a boiling water reactor (BWR) where the coolant water boils and steam rises to the top of the reactor vessel. This steam then goes to the turbine that powers the generator. An advantage of the boiling water reactor is that the reactor vessel operates at a lower pressure than a pressurized water reactor.

Fast Breeder Fission Reactors: Reactors using Uranium 235 fuel require slow neutrons for fission to take place efficiently. If the neutrons travel at high speed plutonium 239 or thorium 233 will fission and the remaining *fast neutrons* will go on to fission other plutonium atoms and then be absorbed by a surrounding blanket of non-fissile uranium 238. When the uranium 238 absorbs a neutron into the nucleus it becomes the unstable isotope uranium 239. After a series of changes the uranium 239 eventually ends up as plutonium 239. It is called a breeder reactor because it converts *fertile* uranium 238 into *fissile* plutonium 239 while producing heat to make steam to power the turbine. The world's first nuclear generated electricity was from a breeder reactor. There are no nuclear power plants of this type operating in the U.S.

Thermonuclear Fusion Reactors: With limited supplies of nuclear fissile fuels available, research continues to achieve controlled thermonuclear ***fusion*** with a positive energy output. It seems to be a relatively clean source of energy that does not end up with toxic spent fuel that must be safely stored for thousands of years. ***Deuterium** and **tritium** are fused with high temperature and high pressure to form helium* as illustrated in *Figure 224.10.*

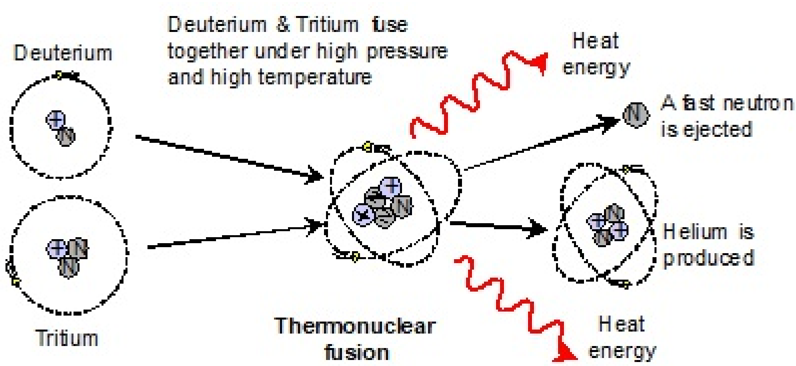

***Figure 224.10** Under high pressure and high temperature deuterium and tritium isotopes fuse to form helium and the release of heat energy.*

The *fusion* process requires a temperature of about 100 million degrees K to strip the hydrogen nuclei of its electrons to form a plasma. This is called the *critical point*. At this temperature the nuclei can collide with enough force to overcome the repulsion between the positively charged nuclei and fuse together to form helium. A nucleus of a deuterium isotope of hydrogen fuses with a nucleus of a tritium isotope to form a helium nucleus. An extra neutron is released at high speed and some of the energy that held the original nuclei together is released as heat energy to make steam to power a turbine driven generator. This is the same process that fuels the sun and stars.

The hot plasma of a thermonuclear fusion reactor must be confined within some containment vessel before a working heat source can produce steam to power a turbine. In a star or the sun the confinement is easy. Gravity holds it together in a hot sphere. On earth this won't work. There are two alternative methods being tested to confine the hot plasma. One method is *magnetic confinement* and the other is *inertial confinement*. One reactor uses a toroid shaped chamber and suspends the hot plasma inside with a strong magnetic field. With the *inertial confinement* technique a pellet containing deuterium and tritium is *imploded* using powerful lasers to create the plasma inside a vessel. This multi-national research continues with the objective of achieving a continuous process with a positive energy output. No major breakthrough has been reported in recent years.

Utilities Must be Able to Meet Peak Demands for Power: Electric utilities provide power to customers in specific geographic areas. Some utilities only distribute electric power to customers and purchase bulk power from other utilities that have generating capacity. Electric utilities have transmission lines that connect to other utilities. For example, utilities in the Eastern U.S. and Canada are interconnected to form what is known as the ***Eastern power grid***. This permits utilities to purchase excess electrical power from each other in order to maintain a reliable supply of power to their customers.

The demand for electricity throughout the day varies with peak demand usually occurring on hot summer afternoons and minimum demand in the early morning when people get up to go to work. If electrical power is generated, it must be consumed. Direct current can be stored in batteries for later use, but alternating current cannot be stored as electricity. Utilities also buy and sell power to each other to help meet peak demands. A few utilities located next to large bodies of water have constructed artificial lakes which they fill with water during off-peak times of the day. During times of peak demand the water in the artificial lake is run through a hydroelectric turbine powered generator to produce electricity. Such a water storage generating facility is shown in *Figure 224.11.* These pump/storage facilities can be started quickly to supply power to the grid in times of peak demand for power.

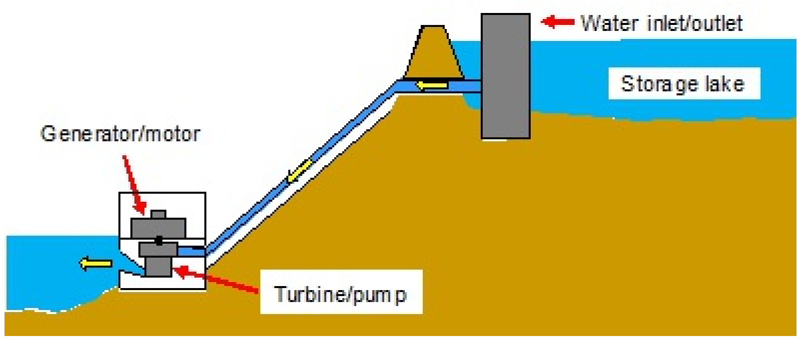

Figure 224.11 *Excess alternating current can be stored as potential energy by pumping water from a large body of water into an elevated lake. Then when power is needed to meet a peak demand, the water can be released in a manner of minutes to supply the demand.*

Renewable Energy: A renewable energy source that can be used for the generation of electrical power is a source of energy that is abundantly available in nature or a resource that can be consumed in a sustainable manner. Wind, solar energy, and water are naturally available energy sources. Waste bio-degradable materials are other potential sources of renewable energy that can be used to generate electrical power.

Much of the renewable electric power is produced as direct current and must be converted to 60 Hz alternating current for most applications. There are some applications where direct current can be supplied directly to a load such as electric resistance heaters, dc motors, electronic equipment, and dc lighting sources. *A device called an **inverter** is needed to convert direct current to 60 Hz alternating current.* A device called a **utility interactive inverter** is needed to connect a customer with a direct current source to supply 60 Hz alternating current to the electric utility grid.

Net Metering: Electric utilities that offer net metering provides an opportunity for customers to own some type of electric power generating on their personal property and tie it into their own ac power system to offset the amount of power they would have to purchase from the utility. Net metering allows the customer to deliver excess power to the utility grid for use by other utility customers in *exchange for a credit* on the monthly energy bill. Net metering allows a customer to install a photovoltaic (solar panel) system that inter-connects to the utility system with a device called an ***interactive dc to ac power inverter***.

Conclusions: Small generating stations powered with engines can be started and connected to the electrical grid in a matter of minutes to meet peak demands for electricity. The bulk of electrical power around the world is produced with steam turbine powered generators. These generating plants that produce steam by means of burning fuel in a boiler can be throttled up and down to meet changing demand, but they cannot simply be turned off when the need for electricity is low. Starting with a cold boiler it can take hours to get a steam powered generating plant to a point where it can supply electricity to the grid. Until recent years and the availability of large wind turbine powered generators and photovoltaic systems, central station power has been the most efficient, economical, and environmentally friendly means of providing electrical power to consumers. Stack emissions from fuel fired generating plants is regulated to minimize impact on the environment, however, an unavoidable product of combustion is carbon dioxide which in excessive amounts can contribute to global warming. Converting automobiles to electrical power allows utilities to take advantage of means of generating electricity by ways that do not require combustion of a fuel. Such means are wind, solar, geothermal, hydroelectric, and nuclear power.

There is a concern around the world that carbon dioxide produced by burning fuels to generate electricity, heat buildings, and power automobiles is becoming excessive and will accumulate in the atmosphere to cause global warming. It is feared that global warming is causing accelerated melting of polar ice which will eventually raise sea levels resulting in widespread flooding in costal areas.

Present day nuclear reactors split uranium 235 by a process called fission to produce heat to make steam for a turbine powered generator. Fuel is not burned at a nuclear power plant, therefore, carbon dioxide is not produced. One fear is that an accident at a nuclear power plant could release radioactive materials into the environment. Another issue is where to safely store the highly radioactive spent nuclear fuel. Like other sources of power, the world supply of uranium ore is limited and eventually will be depleted. Scientists are looking far into the future for an abundant energy source that will have a limited impact upon the environment. They think they have found it with **thermonuclear fusion**, the process that powers the sun, but there are enormous difficulties at making the process work here on earth.

Thermonuclear fusion is a process where two isotopes of hydrogen, deuterium and tritium, are compressed at high temperature to make harmless helium. A large amount of energy in the form of heat is released which can be used to produce steam. Shielding must be provided to protect workers from flying nuclear particles, but the process does not produce radioactive waste like fission reactors. The fuel for such a reactor is an abundant supply here on earth. When such a power plant might be able to supply electricity to the grid is only a guess at this point.