N-VISION

our powerful future

The World of Engineering and Nuclear Energy

Westinghouse

Westinghouse Electric Company strives to educate students on a variety of topics that deal with energy and engineering.

This booklet is aimed to give high school students a glimpse into the careers in engineering and basic knowledge of energy and its history. We hope you find this educational booklet beneficial.

Best of luck in your educational journey!

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Preparing to Become an Engineer

Before we can discuss preparing to become an engineer, we first need to understand what engineering is. The Merriam-Webster Dictionary defines engineering as:

en•gi•neer•ing
2a: the application of science and mathematics by which the properties of matter and the sources of energy in nature are made useful to people
2b: the design and manufacture of complex products

As we can see, a person who studies and practices engineering (an engineer) typically enjoys doing math and science. Most often they are creative, forward thinkers who enjoy finding solutions and answers to problems. Let's see if a career in engineering might be the right path for you. Try asking yourself these simple questions (there is no right or wrong answer):

1. Do you always wonder how things work?
2. Do you enjoy your math and/or science classes?
3. Do you like playing with Legos®, K'NEX™ or any other type of building toys?
4. Do you like watching the Discovery or Science Channel?
5. Do you look at things you can buy today and see ways that they could be better?

If you answered yes to any of these questions, you may have the qualities suitable for a career in engineering. Let's look at how you can prepare during high school for a future as an engineer. Since there are more degrees and careers in engineering than we could ever fully cover in this pamphlet, we will also provide you with several references and resources for you to research if you'd like to learn more.

In order to become an engineer, you're going to have to go to college. If you want to be able to go to the college or university of your choosing, you'll have to show that you'll make a valuable addition to their campus. So how are you going to do that? Take a look at the recommendations below:

George's Tips for High School Success

Show those colleges/universities you would be a valuable addition to their institution.

• *Make Math and Science Count*

If you're applying to schools for engineering, they're going to pay particularly close attention to your math and science grades as well as the number of classes and advanced classes you've taken in those areas.

• *Study, Study, Study…*

It doesn't have to be your life, and it shouldn't be, but developing a good understanding of how you learn best will be crucial when you start your higher education. In this case, good habits do start young.

• *Get Involved and Stay Involved*

Consider joining some clubs, sports or any extracurricular activity. Employers are looking for well-educated people who are also involved and can communicate with their peers. Colleges and universities have recognized this and are encouraging students to branch out from their fields of study and get involved on the campus. Yes, good grades are a very important step to your engineering career, but knowing how to interact with people socially is extremely valuable.

• *Have Quality Recommendation Letters*

Develop good student-teacher relations with your math and science teachers. Glowing letters from them when applying to a school for engineering will be helpful.

• *Visit the Campus*

Be sure to visit the campus of the college or university you are interested in, as well as others, to compare. A college or university may look great in print, but you may get there and realize the place isn't a good fit for you and your ambitions. Don't just take the standard tour, ask to meet with the dean or the professors of the engineering school.

• *Reach Outside Your Comfort Zone*

You have goals for your future, right? Try identifying the qualities you may need to have to reach those goals. Do any of those qualities make you uncomfortable (e.g., speaking in public)? If so, try to find ways to defeat those shortcomings and make them your strengths. A person who is willing to go after a challenge will stand out to employers.

Straight Talk … with Two Westinghouse Engineers

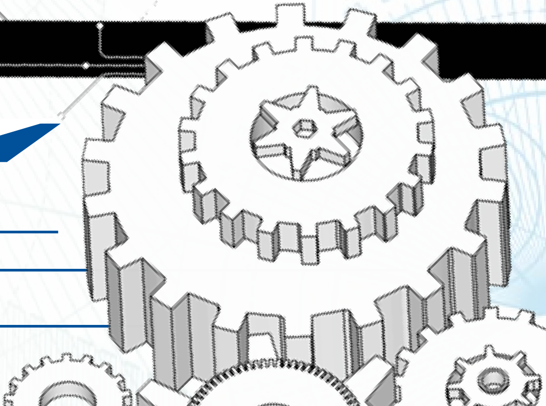
Wonder what it’s like to be an engineer? Well, we interviewed two Westinghouse engineers for you to learn more about their schooling, what their daily routine is and if they like being an engineer.

Read on for more!

KELLY ...

Name:...Kelly Semanco
Job Title:...Proposal Engineer
Type of Engineer:.........................Mechanical Engineer
Years at Westinghouse:............ Five
Education:......................................Bachelor of Science in Mechanical Engineering from Penn State University
Masters of Business Administration (MBA) in progress at Katz School of Business

Salary:..$70,000 - $100,000



What was/is your career path?

I began my career at Westinghouse as a mechanical engineer. I worked on the small bore instrumentation piece of the Steam Generator Replacement (SGR) project for Comanche Peak. After completing the engineering stage, I went to the site for four months as a resident engineer. I had the opportunity to go into the plant and work with the people installing what I designed.

After completing this project, I did the same type of work for San Onofre Nuclear Generating Station (SONGS) units two and three, but I had more of a lead role because I had the opportunity to be involved in the project from the start. After the engineering phase was complete, I became the operations lead for Plant Engineering US. In this role, I worked with the director to track the groups' metrics and current projects and was involved in strategic planning. I then returned to the SONGS SGR project to be a resident engineer at the site during the outage.

Upon returning to Pittsburgh, I became a proposal engineer for the group. Currently, I work with our internal and external customers to determine if our group can fulfill their needs by interfacing with personnel in many groups at Westinghouse. In addition to my main responsibilities, I am the current secretary for Women In Nuclear and the treasurer for North American Young Generation in Nuclear. These additional experiences help me network within the company and give me the chance to advocate nuclear power in the community. All of these roles have helped me proceed along the business leader path.

What did you do in high school to prepare for an engineering career and to prepare for college?

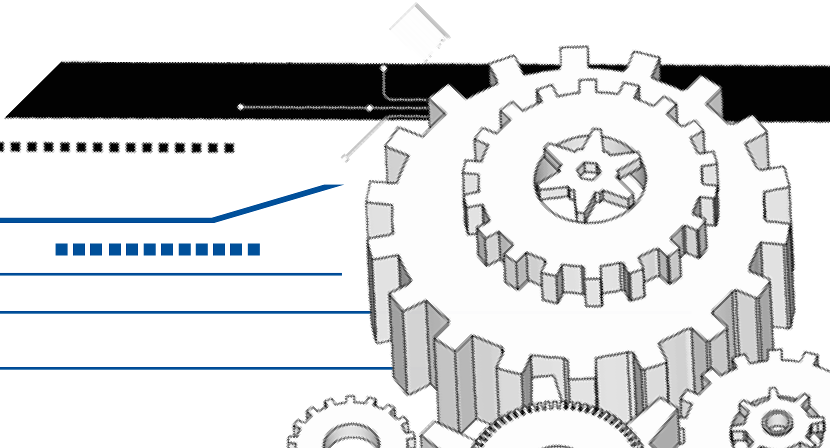
In high school, I took many advance placement courses in the math and science areas because I excelled in these areas.

What college courses did you take? And why?

My college courses mainly consisted of required courses for my engineering major and for my bioengineering minor. Examples included: chemistry, fluid dynamics, thermodynamics, computer programming, economics, English, speech communications, material science and many advanced biology-related courses to coincide with my minor. I chose to enter mechanical engineering because it is one of the broadest disciplines and engineers in this field are using in the forefront of technology development and applications. I was unsure what specific career field I would be entering, but I knew that I would have a lot of opportunity since mechanical engineers work in so many fields. After being employed at Westinghouse for several years, I realized that I was most interested in the business aspect of the company. I am now taking MBA classes.

Beyond your engineering skills, what career advice would you give?

I would advise new engineers to sit down with their managers and discuss their interests. There are so many opportunities at Westinghouse and each job is a little different. Your manager can help direct you on a path to success. In addition, be open and willing to accept new assignments outside of your comfort zone. I have learned the most in the opportunities that were unexpected. You grow professionally by challenging yourself. Finally, get involved in organizations where you have the opportunity to network outside your group. It is so easy to get caught up with the projects, but a lot can be learned from all the other groups at Westinghouse.



What is the future of the type of engineering you majored or currently work in at Westinghouse?

The future of mechanical engineering is extremely bright here at Westinghouse. Because the profession enables you to perform functions in a range of areas, mechanical engineers can become a part of many groups within Westinghouse. Having a background with a balance in engineering applications and theory with an emphasis on design will allow you to complete work on either existing plants or new plant design.

What factors can affect a typical engineer's salary?

A typical engineer's salary can be affected by many things: if you had any prior experience before coming to Westinghouse, if you completed assignments while at Westinghouse, if you accepted any project management roles, if you are in a leadership position, if you are willing to travel, if you take an international assignment, if you have a higher education degree applicable to your job, if you excelled at your previous assignment, if you take a special assignment and many other factors.

KOREY …

Name:	Korey Hosack
Job Title:	Project Controls Engineer
Type of Engineer:	I am a Nuclear Engineer by education, although I now "engineer" various business aspects for our ***AP1000***® reactor design.
Years at Westinghouse:	Over one year
Education:	Bachelor of Science in Nuclear Engineering with a Minor in Applied Math from the University of New Mexico, 2009. Working on an MBA and Masters of Science in Industrial Engineering
Salary:	$60,000 - $90,000

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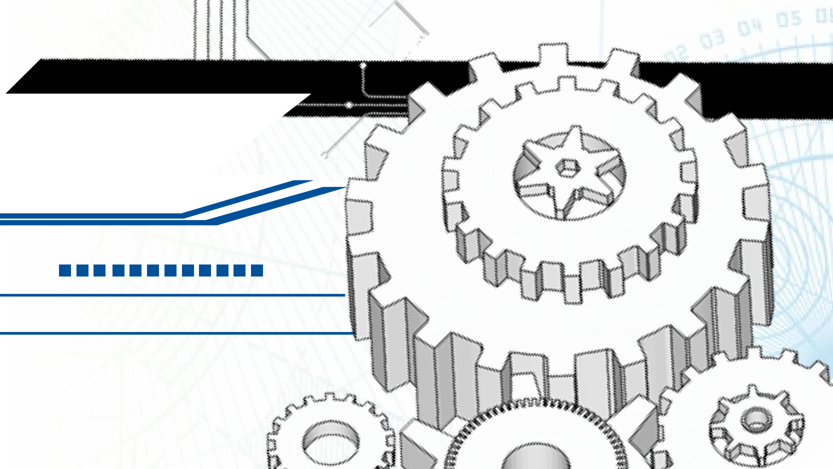


What was/is your career path?

Despite a technical education that focused on nuclear fuels and core design, I’ve found myself becoming more and more interested in business strategy, operations and logistics. Although I stay up to date with the technical material, I am on a more business-oriented career path than has been conventional for others with my degree.

What did you do in high school to prepare for an engineering career and to prepare for college?

To prepare myself for an engineering degree, I took as many advanced placement math and science courses in high school as I could. Although I knew that I wanted to be an engineer, I didn’t know exactly which discipline I would be pursuing. A strong background in math and science, however, is important to all of the engineering fields. I therefore tried to expose myself to as many areas of science as I could.

What college courses did you take? And why?

As previously mentioned, any engineering degree is going to be heavy on the math and science classes (calculus, differential equations and general physics and chemistry). You’ll have some time to decide which discipline you ultimately want to pursue while you satisfy these general course requirements, but the sooner you decide the better. When I really got deep into my program, however, I found myself taking classes like radiation protection and shielding, advanced numerical analysis and transport phenomena. These were much more specific to my degree.

Beyond your engineering skills, what career advice would you give?

Beyond coursework and technical know-how, it is extremely beneficial to be involved in the professional organizations related to your engineering discipline. In fact, become an officer of the student section, if you can. This will give you important leadership experience and insight into the various career paths your degree can take. This will also help expose you to others in your area of interest, some of whom may have internship or employment opportunities available when you graduate. Finally, this involvement outside of class shows graduate schools and potential employers that you are self-motivated and truly care about the work you are doing. This could really give you an advantage over other interviewees.

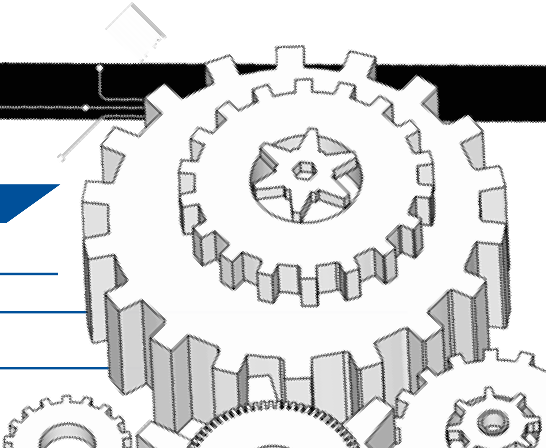
Finally, although numbers are generally the engineer's tools, don't neglect the power of words and the ability to write. Being an effective writer and communicator can help in any job, engineering included.

What is the future of the type of engineering you majored or currently work in at Westinghouse?

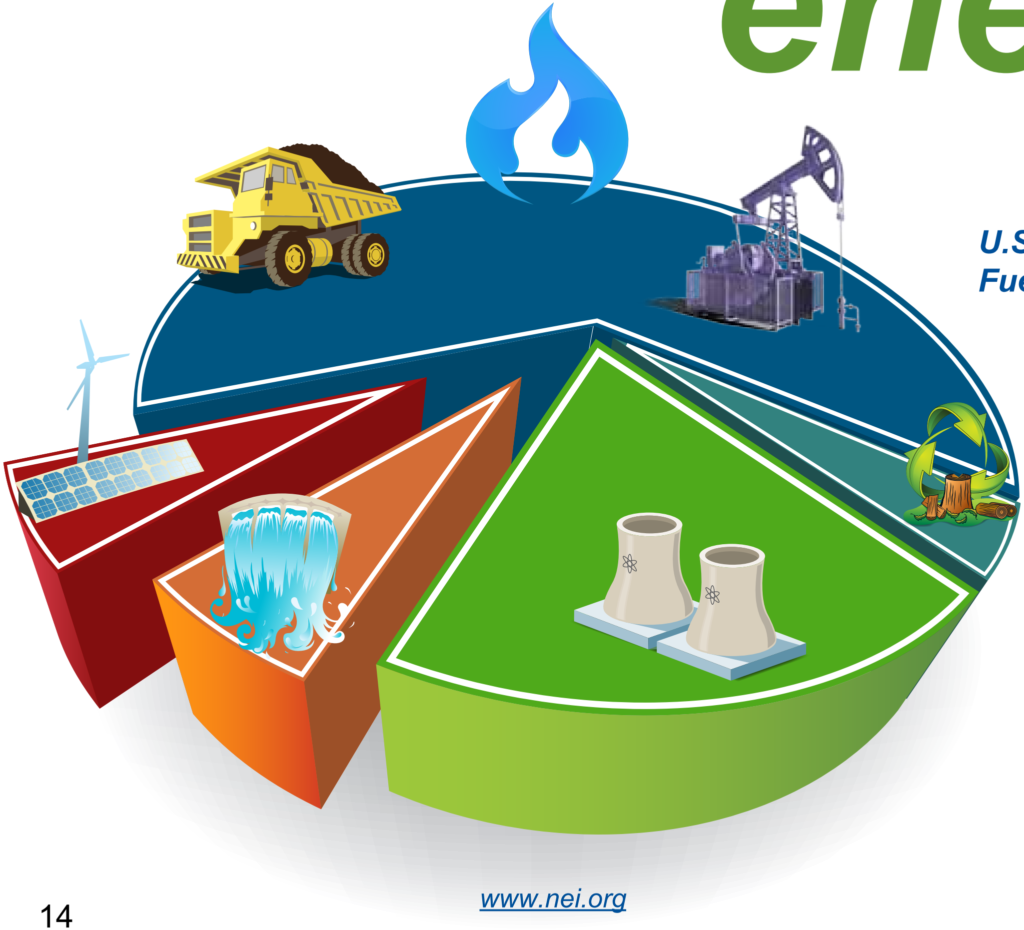
With the resurgence of the nuclear industry, there are plenty of opportunities for nuclear engineers. There are two nuclear engineers retiring for every graduate produced; this is a very positive job outlook for nuclear engineering students. In fact, this is partly what motivated me to pursue a degree in nuclear engineering: I saw the need and knew I could fill it. As for the different fields nuclear engineers go into, there is obviously a lot of opportunity in the commercial power sector (like Westinghouse, for example).

What factors can affect a typical engineer's salary?

Right out of college, you probably won't have much room for salary negotiation. However, you can certainly increase the chances of a higher base pay by bolstering your resume with experience, awards and memberships. Look online at typical up-to-date salaries for various engineering fields; this will give you an idea of how much to expect.



Where do we get ... energy?



U.S. Electricity Generation Fuel Shares

Fossil Fuels:	69.6%
Nuclear:	19.6%
Hydro:	6.1%
Solar/Wind:	2.3%
Geothermal, Wood/Waste, Other Gases:	2.1%

www.nei.org

Before we speak about the nuclear core itself, we need some background on the basics of a nuclear power plant's nuclear steam supply system (NSSS). This is what separates a nuclear plant from other thermal power plants, such as coal or oil plants. This is the system that provides the heat to make steam needed to drive the turbine generator.

The reactor vessel houses the core, lower internals, upper internals, core barrel, **control rod** drive mechanisms (CRDMs), **control rods** and **neutron** flux sensors at the very high pressures necessary to keep the water from boiling at high temperatures. The lower internals mostly serve to direct the flow of the coolant water evenly into the reactor core and support the weight of the fuel. The upper internals stabilize the top of the fuel and stabilize/house the **control rods** and **neutron** flux sensors. The CRDMs raise and lower the **control rods** by using magnetically activated claws. This allows for the electromagnets to be outside the pressure boundary and the **control rods** inside the pressure boundary. Therefore, there is no need for complicated seals or to place the electromagnets inside the vessel. The **neutron** flux sensors monitor the nuclear reactions within the fuel. Lastly, the core barrel helps do three things. First, it holds the fuel in the reactor vessel. Second, it reflects **neutrons** back into the core allowing for more even fuel burnup and less **neutron** leakage. Through doing this, it also helps preserve the vessel from **neutron** embrittlement, which slowly makes the metal of the reactor vessel brittle by bombarding it with **neutrons**.

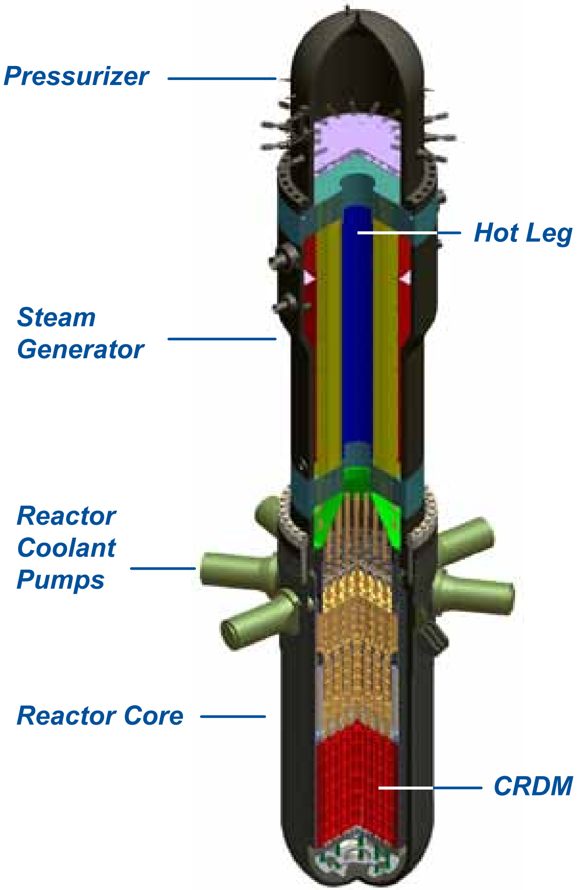
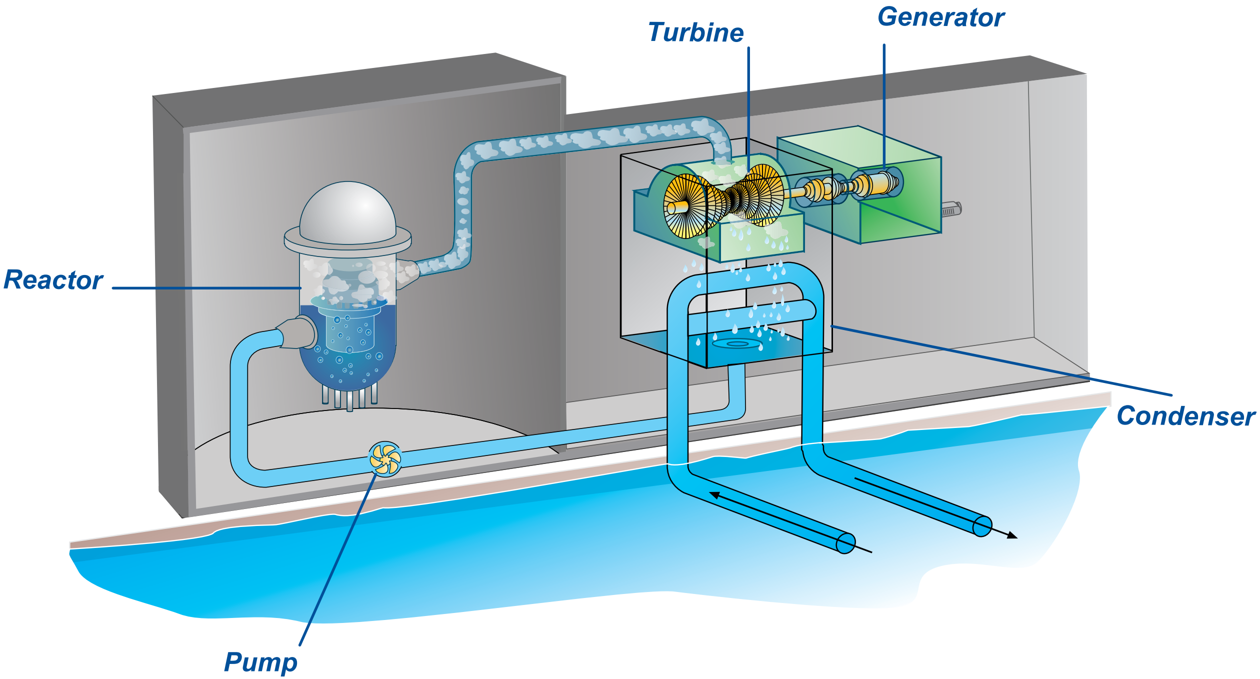


Illustration of the Westinghouse small modular reactor - an advanced reactor design

Once water leaves the vessel, it enters the hot leg. This pipe is very large (around three feet in diameter) and very thick. It carries the hot water at around 615-626 °F to the steam generators. The most common plants have four hot legs and four steam generators, although some have had as few as one steam generator. Each steam generator is a large heat exchanger with thousands of feet of tubing. In the majority of pressurized water reactors (PWRs), the primary water enters the bottom of the steam generator, then goes through a tube sheet that divides it into the many tubes. It goes through an upside down, U-shaped loop and then is recombined with the water from the other tubes on the opposite side of the tube sheet. From here, the water enters the cold loop piping into the reactor coolant pump at around 557 °F.



Reactor coolant pumps are massive centrifugal pumps that circulate 100,000 gallons of coolant each minute. These pumps are electrically powered and are around 7,000-9,500 horsepower. They must generate enough head, or pressure increase, to overcome the resistance losses the water encounters going through the reactor vessel, loop piping and steam generators. These resistances total several times the pressure in the average car tire. To give you an idea of the amount of water these pumps move, an Olympic-sized swimming pool is around 650,000 gallons. This means that the pumps on a four-loop nuclear plant could fill one of these pools in a little over a minute and a half.

Last, but not least, in the primary side is the pressurizer. This device acts to keep the pressure in the primary system at 2,235 psi. It does this by using heaters and sprayers in a large vessel. The vessel contains about half water and half steam above this water. By using heaters to boil the water, it can increase the amount of steam in the vessel, and therefore the pressure. If pressure gets too high, sprayers can spray cool water through the steam, condensing some of it. This reduces the pressure.

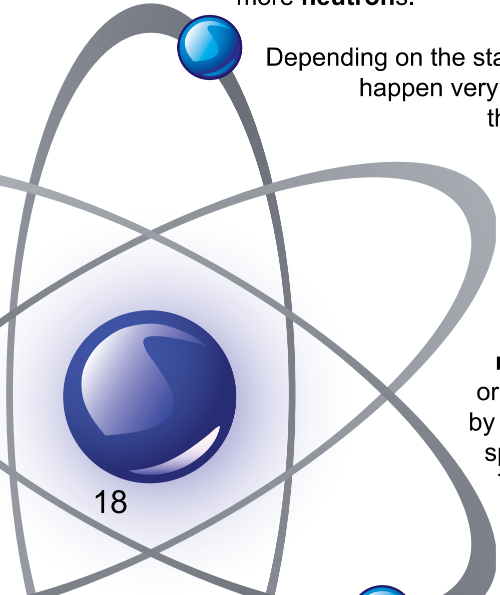
When the water is going through the U-shaped tube, it transfers its energy into water on the other side of the tube. This water is non-**radioactive** and turns to steam. This steam is sent through a series of **dryers** that separate any entrained water droplets from it, preventing damage to the turbines. From here, the steam can go to the turbines to make electricity. An entire book could be written on the turbine, or balance-of-plant side, of a nuclear power plant. While this book touches on some of the important interactions of the nuclear and turbine sides of the plant, it will not cover the specifics of these. If you would like more information on turbines and generators, a large amount of information is available online or in your local library.

Let's start with the basics – an atom…

An atom is made of three basic components: **neutron**s, **proton**s and **electron**s. The number of **proton**s in an atom determines the material, or element, of which the atom is made. In a chemically stable atom, the number of **electron**s will be the same as the number of **proton**s.

However, in nuclear reactions, we are not really concerned with the **electron**s. Our main concern is the number of **neutron**s. Unlike the **proton** and **electron**, which are electrically charged, the **neutron**, much like its "neutr" prefix would suggest, is electrically neutral. In non-**radioactive** materials, the number of **neutron**s will tend to equal the number of **proton**s. As one begins to get further down the periodic table, materials start to have increasing numbers of **neutron**s versus **proton**s.

In addition, the formation of natural **isotope**s also becomes more common. An **isotope** is a material that has a different number of **neutron**s than the most common version of that material. In this light, Uranium 235 is an **isotope** of Uranium 238. It has three less **neutron**s than Uranium 238. The ratio of **neutron**s to **proton**s in a nucleus has large implications on the stability of those atoms. When one hears of **radioactive decay**, this is a process where an unstable nucleus tries to become more stable. One of the ways in which it accomplishes this is to kick off one or more **neutron**s.



Depending on the starting material (and thus its original ratio of **neutron**s to **proton**s), this decay can happen very quickly or over millions of years. In the case of fissile materials like Uranium 235, they can be made to absorb a **neutron** to become a different and extremely unstable **isotope**. When Uranium 235 absorbs a **neutron**, it briefly (as in billionths of a second) becomes Uranium 236. Uranium 236 is so unstable that it breaks into two halves, as well as kicking out two or three **neutron**s and a considerable amount of energy.

If we were to measure the weight of a Uranium 236 atom before it **fission**s and then measure the **product**s of that **fission** (the two halves and the two or three **neutron**s), we would find that the sum of the **product**s would have less mass than the original atom. That difference in weight has been converted to pure energy as described by Einstein's equation $E=mc^2$. That is to say that energy equals the mass lost times the speed of light squared. We all know the speed of light is a very large number. That is, 300,000,000 meters per second squared is 30,000,000,000,000,000.

When you take that massive number times even a small amount of mass, the energy is very large. In fact, a single fuel **pellet** the size of one's finger tip has the same amount of energy as 1,780 pounds of coal, 17,000 cubic feet of natural gas or 149 gallons of oil. It would take16 supertankers to carry enough oil to replace the energy in one reactor core.

The water used in a reactor serves not only as a coolant, but also allows the reactor to function. The act of splitting an atom is not caused by the **neutron** "shooting it in half" as many would assume. The **neutron** must be absorbed by the atom so that it may cause it to become unstable and then **fission**.

Imagine you were to receive an opportunity to go to practice with your favorite National Football League (NFL) team. Now imagine that you are standing 10 yards from your favorite NFL quarterback and he throws the ball at you with everything he has. It is likely that you would drop the ball almost all of the time. The ball is simply coming far too fast to stop easily. Now let's pretend that a linebacker gets between you and the quarterback and tips the ball up into the air. The ball is now floating slowly in front of you. Your chance of catching that football just increased remarkably.

This is very similar to what water does for a nuclear reactor. Water consists of two elements - two parts hydrogen and one part oxygen. The most common **isotope** of hydrogen is made of one **proton** and one **electron**. A **proton**'s mass is almost exactly the same as a **neutron** and **electron**s have nearly no mass. As can be seen, a hydrogen atom weighs almost exactly the same as the **neutron**. This makes it particularly good at slowing the **neutron**. When the two hit each other, it's much like hitting a cue ball into another pool ball at a 45° angle. Both end up having roughly half the energy of the cue ball.

The **neutron**s eventually go through enough of these collisions to fall into a range of energies that are powerful enough to allow them to be absorbed, but not so powerful as to bounce. This process is called **moderation**. These **neutron**s are called **"thermal" neutrons** and without the water present, they cannot be produced. For this reason, if a reactor loses coolant, the nuclear reaction actually stops. So why is it so bad when reactors lose water?

All **radioactive** materials decay. The **product**s of uranium **fission** are still very large atoms and are very **radioactive**. These **product**s decay and give off heat. In fact, at normal operation, 7.5 percent of the core's energy, or roughly 342,000 horsepower (HP) worth of heat, comes from this decay.

The decay heat in a core falls off very quickly. Within a few seconds, it is already down below six percent. It eventually evens out to around one percent after a couple days. However, one percent of core power is still nearly 46,000 HP worth of heat. To put that in perspective, the two, three-story tall engines and one steam turbine powering the Titanic produced about 48,000 HP. That 46,000 HP worth of heat in a core small enough to fit in most dining rooms is enough to melt nearly any material without proper cooling. As will be discussed later, fuel melting violates one of a nuclear plant's **containment layers** and is a serious problem.

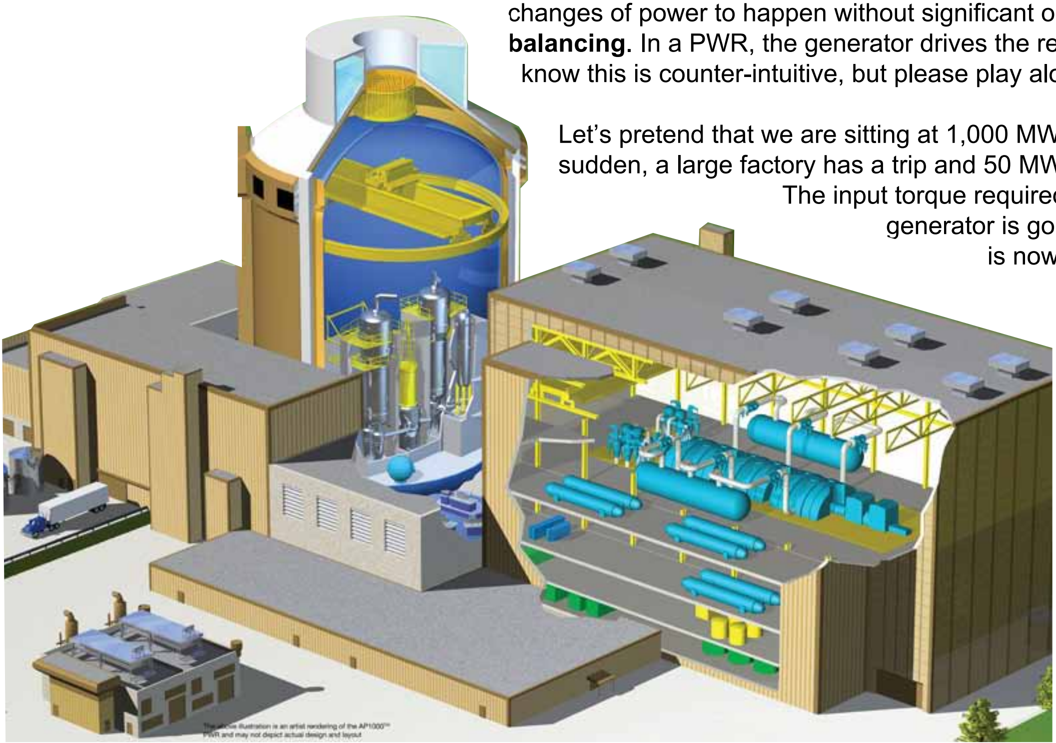
To control the reaction, several different techniques are used. The first method is known as a **control rod**. This is a rod that absorbs **neutron**s. It can be inserted to various depths into the core. When all rods are in their full down position, there are not enough **neutron**s to have a reaction, and therefore the core is at zero power. As rods begin to be pulled out, the reactor becomes **supercritical**. This means that each atom that splits triggers more than one new **fission** reaction. This trend continues until the amount of **neutron**s being produced and absorbed is equal. At this point, the reactor is **critical**.

The time in which it takes to equalize is extremely fast; far faster than the time it takes to move the rods. As you can imagine, if **control rod**s are partially inserted, the fuel at the bottom will react more than the fuel at the top, as the **fuel rods** won't affect the bottom of the core as much. This is not desirable because uneven power means uneven fuel burnup. It's very similar to burning a campfire with a log placed too far to the outside. The one end burns to ash while the other end stays wood. The way we counteract this in PWRs is to introduce **boron** into the cooling water. This **boron** absorbs **neutron**s, allowing us to control the reaction. **Control rod**s can still be used for fast changes, but typically a nuclear reactor is run at constant power, so the **boron** control mechanism works well. As the fuel becomes less reactive through the fuel cycle, **boron** concentration is lowered to allow for a greater **neutron** density in the core.

Boiling water reactors (BWRs) also have **control rod**s, however, they insert from the bottom. This is done for two reasons. The first reason is that there are a series of **dryers** at the top of the core. These remove any water droplets from the steam, before they can damage the turbine. The second reason is, that by inserting from the bottom of the reactor, the changes in **neutron** absorption are better known. At the top of the core, there is a mixture of water and steam. This mixture doesn't moderate the **neutron**s in the same way as pure water, so depending on the height of boiling a **control rod**'s effect could be different. This height of boiling is the control mechanism BWRs use in place of **boron** injection to change core power. As was mentioned, steam is a poor **moderator**. By changing the concentration of water around the fuel, the population of **thermal neutron**s can be changed.

Nuclear plants typically run at full power to maximize their cheap energy production, but occasionally things happen beyond the operators' control. PWRs have one other control mechanism that differentiates them from BWRs and it is helpful in these situations. This control mechanism is mostly passive and allows small changes of power to happen without significant operator input. This is known as **load balancing.** In a PWR, the generator drives the reactor, not the other way around. We know this is counter-intuitive, but please play along.

Let's pretend that we are sitting at 1,000 MW of power and all is well. All of a sudden, a large factory has a trip and 50 MW worth of electrical load is lost. The input torque required from the turbines to turn the generator is going to be lower, as the electrical load is now lower. The turbine control system will automatically close the steam inlet valves slightly, raising the pressure and lowering the flow of steam behind those valves. Because of this, the heat exchanger, or steam generator, will not be able to transfer as much heat from the **reactor cooling system (RCS)** into the water/steam that goes to the turbines. The reactor coolant water leaving the steam generator is now



The above illustration is an artist rendering of the AP1000™ PWR and may not depict actual design and layout hotter than it would normally be, having transferred less energy. This means it’s hotter when it enters the reactor core as well.

We know that any substance, including water, will become less dense as it is heated. Because the water is now less dense, it is unable to moderate as many **neutrons**, lowering the population of **thermal neutrons.** This lowers the number of **fissions** and, therefore, the core power. As this core power is lowered, so is heat, and therefore the entire system equalizes itself.

The reactor coolant temperature is easily monitored and its expected value well known. This allows for a simple, automatic change in rod height, and therefore **neutron** population, to take place. This is done to bring down the coolant temperature from its elevated level. If this is not done, the core will settle at the higher temperature, which suits the **moderation** needed to make less power. If the operators know they are going to be changing power, they can change **boron** concentration ahead of time to avoid having to use the **control rods**. This **natural feedback** from the generators makes PWRs very predictable to control and require little operator input, minimizing **human error**. BWRs do not have this effect and require more complicated mechanisms to control output.

Nuclear reactors are unique in the fact that they contain all of their fuel for 18-24 months inside of them. Nuclear reactors cannot have a **fission** reaction during a loss-of-coolant accident, but still contain large amounts of decay heat with which to contend. Due to these unique concerns, nuclear power plants have layer upon layer of safety systems. U.S. PWR power plants have a minimum of three different emergency cooling strategies, all of which have at least one backup system. Many times, these backup systems accomplish the same task, yet use different equipment, different paths, different wiring routes and different locations within the plant. This assures that a failure mode in the equipment cannot be shared and that if damage to the plant incapacitates wiring or equipment for one system, the other system is unaffected. This system of redundant, yet different, systems is known as **defense-in-depth**.

What about safety?

The Basics

All of these systems are engineered in conjunction with three different containments, which we do not desire to breach. The first containment is the **fuel rod** itself. Each **fuel rod** is made of a zirconium alloy and contains fuel **pellets** roughly the size of a fingertip. They are sealed and contain gas inside. The goal of the safety systems is that these rods are never breached, even if the coolant system has a breach. Multiple pumps within the **emergency core cooling system (ECCS)** exist to keep the **fuel rods** cool in the event of a breach. In Westinghouse plants, **fuel rods** are designed to withstand 2,200º F. As one can imagine, melting is a serious problem and can block the cooling water nozzles from below as well as preventing the overhead **control rod**s from inserting. The best defense against this is to not have a failure of the **RCS** in the first place.

The **RCS** normally sees 2,235 psi of pressure. However, it is designed to withstand up to 2,485 psi. In the event of an accident leading to overpressurization, the pressurizer has automatically activated **power-operated relief valves (PORVs)** to bring the pressure down in a controlled fashion to maintain the **RCS** integrity. These valves lead to **spargers** in a tank of water called the **pressurizer relief tank**. A **sparger** is a nozzle that directs steam into tank of water to condense so that it does not reach the atmosphere. If these valves fail to open or cannot control the reactor pressure, there are multiple, redundant **popoff valves** that are one-time open valves. These valves are purely mechanical and require zero external input. These systems ensure that the coolant system never exceeds the design pressure.

In a worst-case scenario where both a **fuel rod** and the coolant system breach, releasing **radioactive** material into containment, the second goal is that the **radioactive** materials inside cannot reach the public. If the **RCS** were to breach, some of the water inside would **flash** to steam. The containment itself is designed to withstand up to 65 psi. This is roughly twice the pressure that is inside the average passenger car tire. The large volume of the Containment Building allows the steam to expand to a much lower pressure than it had when it was in the pipe.

A **containment spray** system acts much like the sprayers in the pressurizer to condense the steam in the Containment Building. This ensures that the 65 psi limit is not exceeded. This condensation also allows the water to return into drains in the floor called **sumps**. These **sumps** are part of the **ECCS** and lead to the various pumps that are cooling the core.

Terrorist Attacks and Plane Impacts

Nuclear plants are also hardened against attack of all types. The containment vessel is four-foot thick concrete, reinforced with two-inch thick steel **rebar**. In addition, the inside of containment is lined with one-half to one-inch thick steel. This containment can withstand the impact of a large passenger jet as well as small missiles. Security is very strict, with multiple levels of protection to keep attackers from reaching **critical** areas of the plant. Lastly, there are numerous fully automatic, nondefeatable safety systems that would prevent an attacker from putting the plant into an accident scenario.

Nuclear energy: Past, present and future

While nuclear energy production has long proven itself to be very safe, especially when compared to other forms of energy production, three historical accidents in nuclear power plants come to mind for many when considering nuclear power: Three Mile Island, Chernobyl and Fukushima Daiichi.

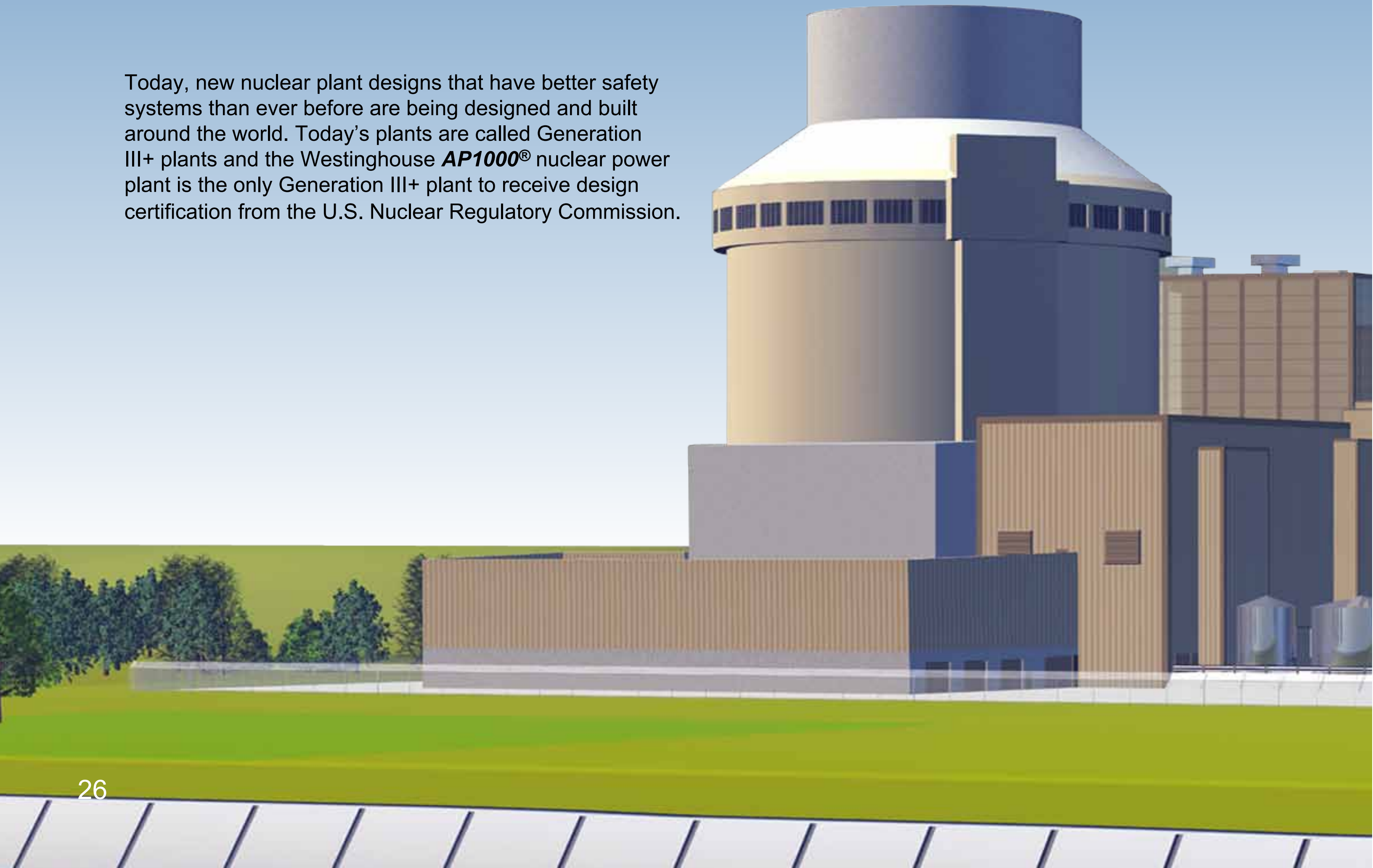
At Three Mile Island, near Harrisburg, Pa., the 1979 accident was what is commonly referred to as a meltdown. This is when the fuel assembly (containing the **fuel rods**) melts. This can happen if the temperature inside of the reactor core becomes hot enough to melt the zirconium cladding of the rods and thus release uranium into the coolant water. At Three Mile Island, this occurred when one of the **PORVs** on the pressurizer stuck open, but the control panel did not indicate this to operators. Due to conflicting signals, poorly laid-out instrumentation, insufficient training and the inability to prioritize alarms, operators turned off emergency cooling to the core. This uncovered part of the core and about half the fuel in the core melted before the water could be switched back on. However, the worst prospect feared - an uncontrolled release of radiation to the environment - did not occur. Despite the conditions that presented themselves, the release to the public was extremely minimal. The melted fuel and radiation were contained - trapped inside of the steel reactor vessel inside of the containment. This was the worst accident of any nuclear reactor in the U.S. and led to massive changes to existing plants' design, regulations and personnel training.

At the Chernobyl nuclear power plant, located on the Belarus-Ukraine border, an accident occurred in 1986 during a test. The aim of this test, oddly enough, was to verify safety in a loss of offsite power accident. The goal was to see if the turbines had enough momentum to drive the generators long enough for the emergency diesel generators to start up and reach full power. Due to a buildup of **neutron**-absorbing poisons in the **fuel rod**, when the operators brought the reactor down to the level at which the test was to be run, it continued to shut down even after **control rods** had stopped being inserted. The reactor power continued to plummet until it was almost at zero power. Rather than let the poisons decay away, the operators started pulling **control rods**, despite many safety alarms, eventually getting to a stable, but relatively low power value. Even with all of the allowable rods out of the core, the reactor would not produce any more power. Given the time pressure to complete the test, as well as pressure to get back to power production, the decision was made to violate procedures and extract rods beyond what was allowed. This brought power up to the starting point for the test. The test was started and offsite power was cut. As the turbine generators coasted down to a stop, the pumping power of the cooling pumps decreased and steam voids formed around the fuel. In an RBMK (Reactor Bolshoi Moschnosti Kanalynyi) reactor, graphite was used to moderate **neutrons**. Water was merely used as a coolant and actually served as one of the controls, absorbing some **neutrons**. In the case of Chernobyl, the forming of steam voids meant that less **neutrons** were absorbed, causing greater power, causing more steam and absorbing even less **neutrons** in a never-ending cycle. This feedback loop, coupled with almost all of the **control rods** being out (against procedures), resulted in a very large power spike. Operators hit the button to insert all **control rods** only to reveal a second design flaw. The **control rod** ends had been made of graphite (the **moderator**), to assist in startup reactivity. The insertion of the **control rods** displaced the **neutron**-absorbing coolant with more **moderator**, serving to add even more reactivity, spiking power to an exceptionally high level. Some estimates have placed the final core power around 30,000 MWt. This blew the top of the reactor vessel off along with some of the core itself. Potentially, the biggest design flaw of the plant was that there was no Containment Building around the nuclear reactor vessel. Therefore, the explosion resulted in a large release of radiation into the environment, resulting in numerous deaths, thousands of citizens displaced and a large area around the plant to be uninhabitable. This type of design has never been used in the U.S. and never could be licensed, but still serves to remind the industry about the importance of redundant safety features, stable core design and adherence to procedures.

On March 11, 2011, a devastating 9.0 magnitude earthquake and tsunami hit northeastern Japan. The tsunami not only swept away everything in its path, including houses, cars and farm buildings, it also devastated the reactors at Japan’s Fukushima Daiichi site. As more is learned about the Japanese events, lessons learned will be applied to the existing fleet of plants. The U.S. nuclear energy industry, for example, has already started an assessment of the events in Japan and is taking steps to ensure that U.S. reactors can respond to extreme events that may challenge safe operation of the facilities. It is also important to realize that the existing fleet of operating nuclear plants are already highly safe, and that no industry takes safety more seriously than the commercial nuclear energy industry.

Next generation (today’s new) nuclear power plants

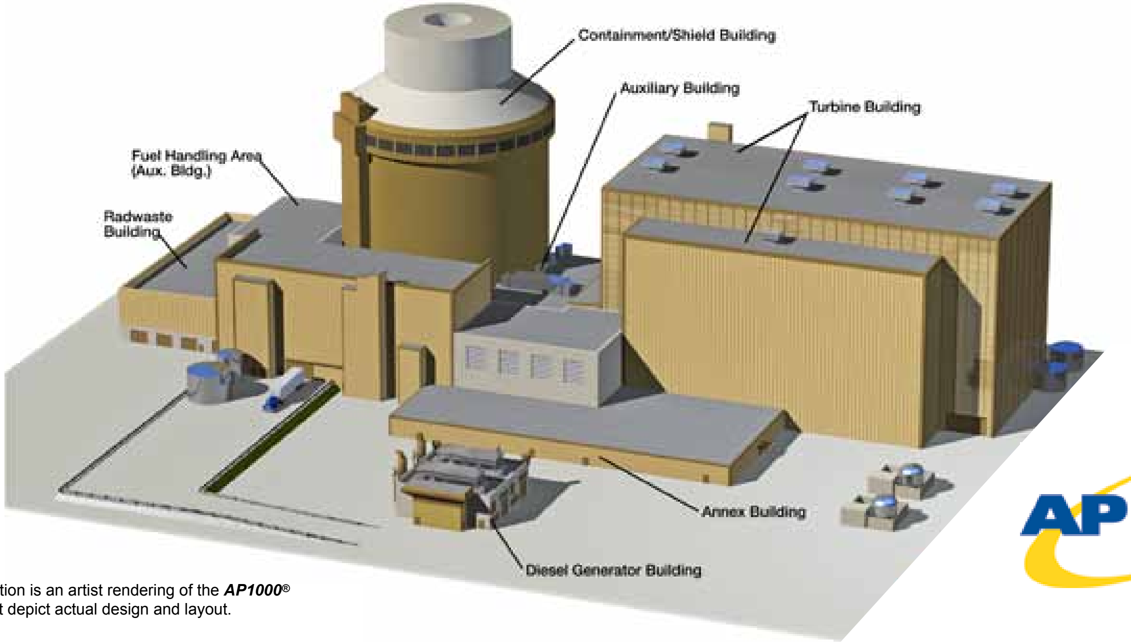
Today, new nuclear plant designs that have better safety systems than ever before are being designed and built around the world. Today’s plants are called Generation III+ plants and the Westinghouse ***AP1000®*** nuclear power plant is the only Generation III+ plant to receive design certification from the U.S. Nuclear Regulatory Commission.



Westinghouse AP1000® (tomorrow's) nuclear power plant

The ***AP1000®*** plant uses advanced passive and active safety systems. The systems are called passive because they use natural forces to work, without the need for human action. These passive safety systems will work even when there is no ac power available. Active safety systems are used in cases where operator action is required.

Additionally, the ***AP1000®*** plant is designed to mitigate a severe accident, such as core meltdown. If such an unlikely event were ever to occur at an ***AP1000®*** plant, an operator could flood the reactor cavity space immediately surrounding the reactor vessel with water and submerge the reactor vessel. The cooling would be sufficient to prevent molten core debris from melting the steel vessel wall and spilling into the containment vessel.



The above illustration is an artist rendering of the ***AP1000®***
PWR and may not depict actual design and layout.

GLOSSARY

Boron
Containment Layers
Containment Spray
Control Rod
Critical
Defense-in-Depth
Dryers (Steam Dryers)
Electron
Emergency Core Cooling System
Fission
Flash (Flash Boil)
Fuel Rods/Pellets
Human Error
Isotope
Load Balancing
Moderation/Moderator
Natural Feedback
Neutron
Popoff Valves
Power-Operated Relief Valves
Pressurizer Relief Tank
Product
Proton
Radioactive
Radioactive Decay
Reactor Cooling System
Rebar
Spargers
Sumps
Supercriticality
Thermal Neutrons

Boron:

A metalloid element with atomic number five and periodic symbol B. **Boron** is an effective **neutron** absorber and is used in nuclear power production to help maintain an even fuel burn inside the reactor.

Containment Layers:

Various redundant layers of air/gas tight, radiation shielded and physically robust barriers that separate a nuclear reactor from the biosphere. These layers prevent any radiation or substance that might have been exposed to radiation from escaping the nuclear power plant and contaminating the surrounding environment.

Containment Spray:

A redundant safety system similar to the **spargers** in the core, built to condense any steam in the Containment Building.

Control Rod:

A tube in a **control rod** cluster that controls nuclear reactions in a power plant by absorbing **neutron**s. As part of the **control rod** cluster, **control rod**s are used to follow load changes, to provide reactor trip capability and to furnish control for slight deviations in reactivity due to temperature. In the event of a reactor trip, the **control rod**s fall into the core by gravity.

Critical:

The condition at which a nuclear reactor is just capable of sustaining a chain reaction.

Defense-in-Depth:

An approach to designing and operating nuclear facilities that prevents and mitigates accidents that release radiation or hazardous materials. The key is creating multiple independent and redundant layers of defense to compensate for potential human and mechanical failures so that no single layer, no matter how robust, is exclusively relied upon. **Defense-in-depth** includes the use of access controls, physical barriers, redundant and diverse key safety functions and emergency response measures.

Dryers (Steam Dryers):

A component of a BWR nuclear plant design. The steam **dryer** removes excess moisture from the steam before it passes to the turbine. The steam that remains is of a higher quality to produce more power with minimal degradation impact to the turbine blades.

Electron:

An **electron** is an elementary particle, and it is the carrier of the negative electrostatic charge. It can be thought of as a building block, along with the **proton**s and **neutron**s that comprise an atomic nucleus, of an atom.

Emergency Core Cooling System:

A group of reactor system components designed to remove residual heat from the reactor **fuel rods** in the event of an **RCS** failure. Pumps, valves, heat exchangers, tanks and piping are all part of the **ECCS**.

Fission:

The splitting of atoms into smaller atoms to release energy.

Flash (Flash Boil):

The process of liquid water being heated so quickly that it immediately converts to its gaseous state, steam.

Fuel Rods/Pellets:

Long, slender, zirconium metal tubes containing **pellets** of fissionable material that provide fuel for nuclear reactors. **Fuel rods** are assembled into bundles called fuel assemblies, which are loaded individually into the reactor core.

Human Error:

Human performance mistakes and oversights or a measure of the propensity for humans to make certain common mistakes under certain conditions. **Human error** must be accounted for in the design of any complex system that relies on contributions of human activities.

Isotope:

One of several nuclides having the same number of **proton**s in their nuclei, hence belonging to the same element but differing in the number of **neutron**s and therefore in mass number A, or energy content.

Load Balancing:

The use of various techniques by electrical power stations to store excess electrical power during low-demand periods for release as demand rises.

Moderation/Moderator:

A substance, usually water, that lowers the energy of the free high-energy **neutron**s generated by a **fission** reaction to the point where energy of the **neutron**s is within the range that allows them to be absorbed by the nuclei of Uranium 235 atoms.

Natural Feedback:

The ability to use the natural properties and tendencies of substances within a nuclear reactor to passively regulate the output of a nuclear power plant.

Neutron:

An uncharged particle with a mass nearly equal to the mass of a **proton**. **Neutrons** are the particles that sustain a chain reaction in a nuclear reactor.

Popoff Valves:

One-time use valves that are part of the multiple and redundant safety systems that can help control reactor pressure in the event of an emergency, which includes the failure of primary cooling systems.

Power-Operated Relief Valves:

Automatic valves that control reactor pressure in such a way as to maintain core integrity in the event of an emergency.

Pressurizer Relief Tank:

A tank containing water with a nitrogen atmosphere that condenses steam discharged by the safety or relief valves to decrease pressure in the core.

Product:

A substance resulting from a chemical reaction.

Proton:
A positively charged particle found in the nucleus of an atom.

Radioactive:
An adjective used to describe a substance that emits radiation.

Radioactive Decay:
The spontaneous emission by a nucleus of photons or particles. The spontaneous transformation of one nuclide into another by emission of particles, absorption of an orbital **electron**, or by **fission**. It also refers to gamma-ray and conversion **electron** emission that only reduces the excitation energy of the nucleus.

Reactor Cooling System:
A system that removes energy from the reactor core of a nuclear power plant and transfers it to the steam turbine.

Rebar:
A ridged steel rod or bar arranged as part of a grid to reinforce poured concrete or asphalt.

Spargers:
Specialized nozzles that are part of the **ECCS** of a Westinghouse ***AP1000***®. In the event of an emergency, these nozzles direct steam out of the core and into a tank of water to condense, at once lowering the pressure within the core and preventing any water than might have had contact with the **radioactive** fuel from reaching the atmosphere.

Sumps:
The drains within the core and Containment Buildings designed to contain the water and condensate from any steam within the Containment Building.

Supercriticality:
The condition for increasing the level of operation of a reactor. The rate of **fission neutron** production exceeds all **neutron** losses, and the overall **neutron** population increases.

Thermal Neutrons:
Slow moving, low-energy free **neutron**s necessary for a **fission** reaction.

SOURCES:*

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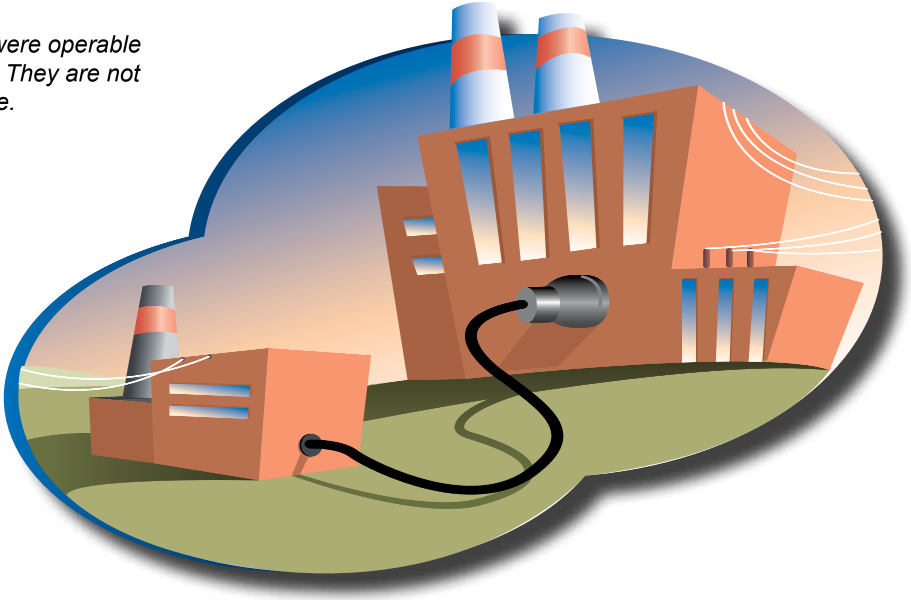
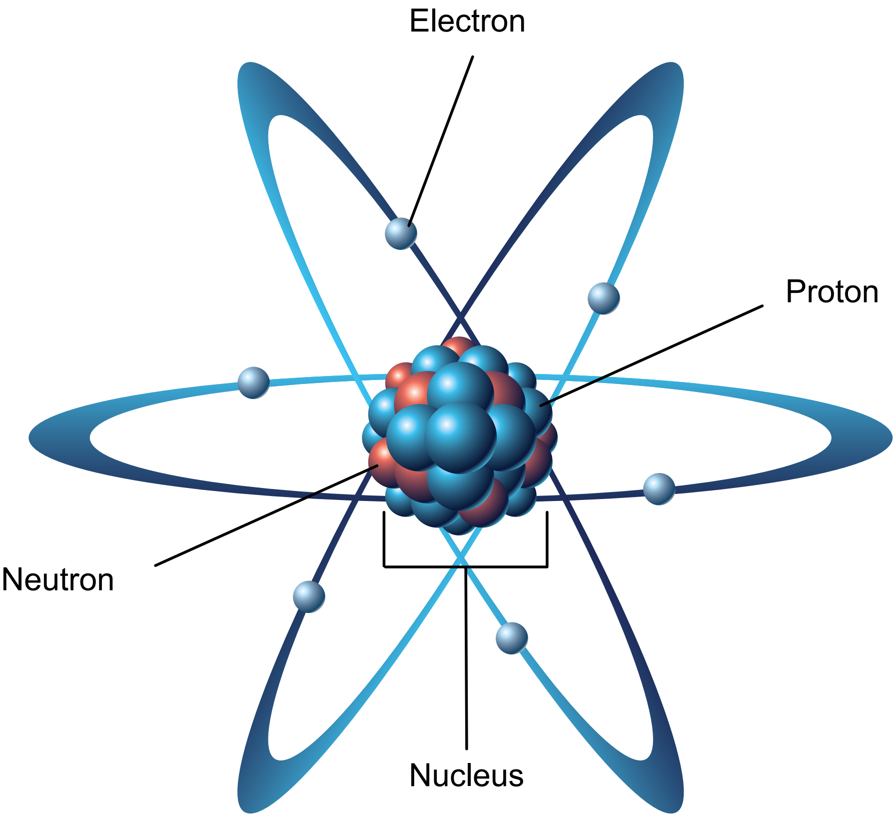
**These website addresses were operable at the time of fact gathering. They are not maintained by Westinghouse.*



The Atom



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