Joint Scientific Statement on Nuclear Power

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Describe operating processes of a light water nuclear power plant. Your description should include:

How much energy does a typical power plant produce? How many homes can this serve?
How often fuel rods and control rods need to be replaced and how this process is conducted?
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What are the half-lives of the radionuclides found in radioactive waste?
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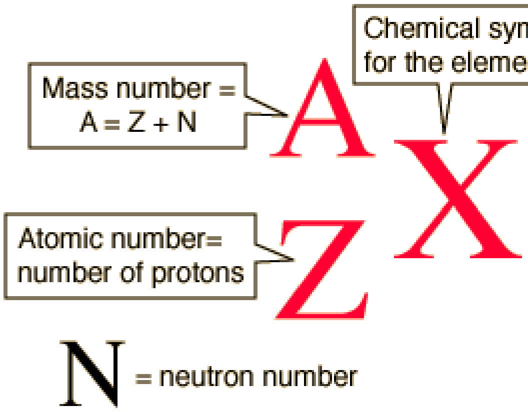
How does nuclear fission work? You should describe the process in general and then describe the exact mechanism of one fission process (i.e. U-235 or Pu-239).

Fission is the opposite of fusion. Fusion requires a great amount of energy and fuses nuclei together. Nuclear fission is a type of radioactive decay. The fission process deals with matter and energy, two forms of the same thing. A nuclei that may be considered 'fissle' is generally made of heavy atoms, and these nuclei are hit or "struck" by neutrons. This initiates the fission process, which may be defined as the process of splitting an atomic nucleus apart into multiple fission fragments. The fragments, which are the products of the reaction, usually are in the form of smaller atomic nuclei and neutrons, but have less mass than that of the reactant nuclei. This is also because a larger nuclei is more unstable and requires more energy to keep from decaying. Predictions of the decay rate of nuclides can be determined using a system called half-life.

Because of this, large amounts of what is called binding energy-essentially the glue that holds a nuclei together- are released.

This energy is typically released in electromagnetic gamma rays and produces light and heat. Fission happens by overcoming the strong force of bonds between particles through an impact. Fission can be a domino effect wherein the particles of nuclei that decayed in the first process are also fissle, and from there it becomes a chain reaction wherein even more energy is released.

For example, the fission process can be modeled using a Uranium 235 atom. First you must find the combined mass of both the parent (reactant) nuclide and the neutron before the reaction occurs. In this reaction the values in atomic mass units, or amu, are 1.009 and 235.04. Added together they equal 236.05 amu. Remember that once the neutron strikes, it becomes U-236.05 because the mass number, the value of protons and neutrons added together (the top left number in isotopic notation) [see figure 1] goes up because the neutron adds mass to the molecule. This increases the molecule's instability and triggers the process of fission.



Isotopic Notation (Hyper Physics)

Once the reaction is completed, you simply repeat that step for the nuclides and neutrons after the fission process. Make sure you find the collective mass, and not just the mass of one fragment. In this case, the decay products are Barium (140.91 amu) and Krypton (91.93 amu). The sum of these is 232.84 amu. You also must account for the three neutrons produced, so you add to the previous mass 3*1.008664916 amu. You now have 235.87 amu.

You now subtract 236.05 from 235.87 to find the change of mass, or Δm. This is -.18. Notice how the final mass is less than the initial mass; this is how much mass was expelled. To turn it into energy, however, you apply Einstein's equatLightly-contaminated items like tools and power plant operation suits make up the majority of wastesion as a conversion factor, E=mc2. In this equation E is energy in Joules, m is mass, and c is the speed of light. Because the speed of light is a large value (299,792,458 m/s) you can see that this formula produces a large amount of energy. When we apply it to our example reaction,

E=Δm(3*10^8)^2
E=0.186033(3*10^8)^2
E=1.673*10^16 J

This proves that one mole of a U-235 fission process, 1.673*10^16 J of energy is released as gamma rays.

Explain the meaning of $E=mc_2$ and the relevance of this relationship to nuclear power. Include a sample calculation that is relevant to a nuclear fission power plant. Make sure your explanation addresses the idea of conservation of mass and energy.

The equation $E=mc_2$ is an equation that predicts the theoretical reaction of converting mass into energy. However, not all mass can be converted into energy; thus the equation remains theoretical only. The literal meaning of $E=mc_2$ is energy equals mass time the speed of light squared. This equation shows that mass has a large amount of potential energy because energy is equal to mass of an object multiplied by the speed of light squared. In a nuclear power plant, Uranium-235 atoms are split apart forming two new atoms, Thorium 231 and Helium. The new atoms that are formed are more stable than the original atom. The atoms falling down into a more stable energy level release energy that was mass or binding energy. $E=mc_2$ is the equation that shows how much energy is produced when a portion of an atom's mass or binding energy is turned into energy.

Example Calculation:

$$^{235}_{92}U \rightarrow ^{231}_{90}Th + ^{4}_{2}He$$

$$E=m(3.321*10^{-27})kg)*c(299792458m/s)^{2}$$

$$E=2.988*10^{-10}J$$

This equation follows the laws of conservation of energy and mass because when weighing a mass of an atom, binding energy is part of the mass. Binding energy is the energy that is released when Uranium 235 decays and is the energy that holds the subatomic particles in the nucleus together. The relevance of the equation $E=mc_2$ to a nuclear power plant and nuclear reactor is that with little amount of mass one can create large amounts of energy.

Describe the design of a light water nuclear power plant. You description must include the following elements: reactor, containment structure, primary coolant, secondary coolant, fuel, fuel rods, control rods, turbine, heat exchanger, condenser, generator, cooling towers, active safety features, passive safety features and may include a comparison between boiling water reactors and pressurized water reactors.

Describe operating processes of a light water nuclear power plant. Your description should include:
How much energy does a typical power plant produce? How many homes

can this serve?
How often fuel rods and control rods need to be replaced and how this process is conducted?
How do power plant operators control the rate of power generation and how easy is it to change power supply to meet demand?
What do power plant designers and operators do to ensure safety?
What is the lifespan of a typical light water reactor nuclear power plant?

In 2011, each nuclear power plant produced an average of 12.2 billion kilowatt-hours (kWh) with the average home using about 11,280 kWh annually (U.S. EIA). In the United States, there was a combined total of 64 nuclear power plants which had a total of 104 nuclear reactors running. Altogether, these plants produced over 790 billion kWh which, to put the number into perspective, was about 19% of our nation's produced energy (U.S. EIA) that year and yielded enough energy to serve over 70,035,400 homes that year.

Of those 64 nuclear power plants, those most commonly found in the United States are light water power plants (Light Water Reactors). There are three flavors of nuclear reactor: The pressurized water reactor, the boiling water reactor, and the supercritical water reactor. Of these three, the most often utilized is the pressurized water reactor due to the improved safety it has over the boiling water reactor (Pressurized Water Reactors). The design of this type of reactor is most easily summarized as a series of closed and interlocked circuits, different from the boiling water reactor because the water that passes over the reactor core moved through these circuits rather than directly to the energy turbines of the plant (Types of Nuclear Reactors). This means that, in the event of overheating in the reactor, the boiling water that is a part of the boiling water reactor won't evaporate and spread radioactive water over a large area of land. To describe it, one must start with the housing for the nuclear reactor, nuclear auxiliaries, safeguard systems and diesel generators. Adjacent to these systems are energy turbines located in order to convert the energy released by the reaction into electricity.

To understand each of these pieces, one must first start by looking at the nuclear reactor. This reactor is where the energy generation process begins. The core of the reactor contains a bundle of nuclear fuel assemblies which appear similar to long, hollow rods. Inside these rods are hundreds of small metal tubes which hold very small pellets of enriched uranium 235 (U-235), eight of which contain enough potential energy to supply electricity to the average household for nearly a year (Nuclear Power: How it works). In between the nuclear fuel assemblies are rods known as control rods, which may be raised and lowered at will in order to control the speed at which the nuclear reaction takes place. In the event of an emergency the control rods will drop automatically in order to stop the fission reactions taking place, ending them within two seconds (PWR video). This all comprises the core of the nuclear reactor.

The core is contained within a tank filled with water. This water is known as the primary coolant, and is a critical part of the design structure as the coolant prevents the core from overheating and causing a nuclear meltdown (PWR video). The water surrounding the reactor also acts as a moderator, preventing stray neutrons from leaving the reactor core. The primary coolant is run by the primary circuit, a closed circuit of pressurized water kept at a controlled temperature which pumps water into the reactor at 293° C and out of the reactor at 327° C after it has been heated by the fuel assembly rods. The heated water is pumped into a steam generator which then moves it into a second circuit, exchanging heat through around 6000 inverted horseshoe shaped tubes. Once that heat has been exchanged, the water is moved back down through the tube and is sent off for another cycle (PWR video).

The heated water creates large amounts of steam which are then transferred to the energy turbines mentioned previously. Pressure from the steam runs the energy turbines in order to create electricity. Once the steam has passed through the turbines, it passes into a condenser which condenses the steam into water that will again pass through the steam generator.

This second circuit is cooled through the use of a third circuit, which may consist of river or sea water, or may be cooled through the use of cooling towers. The steam condenser pumps this water in order to cool the steam which has been passed through the energy turbines. This is what causes the steam to condense back into water. Then, the water is run through the circuit again in another cycle.

The reactor must be heavily sealed in order to contain the radiation it gives off. To block the neutrons shot off from the reaction as radiation, concrete containment buildings are built in order to maximize safety in the event of an accident. This is the outermost piece of a three-layered radiation prevention system. The first layer is present in the tubes which hold the fuel rod assemblies as well as the control rods, and the second layer is present as the primary coolant. With three layers of protection, most diffused radiation can be blocked, making the entire process far safer than it would be without that protection.

The fuel rods used to supply this power must be replaced periodically in order to achieve maximum energy gain. This takes place every 12 to 18 months, but only about 1/3 of the rods in an assembly are changed at a time (Light Water Reactors). This is because fuel depletion is not a uniform process, and changing fuel rods before their time would decrease efficiency of the plant in generating electricity (Light Water Reactors). When it is time for the rods to be changed, those which have lost efficiency are removed from the fuel rod assembly. However, the particles that those rods emit are still dangerous and as they continue reacting, they continue to generate massive amounts of heat.. Therefore, they are stored in pools that are 40 feet deep called spent fuel pools (Spent Fuel Pools), the water in which is regularly cycled through a cooling system to prevent water evaporation. The evaporation of too hot water may potentially spread dangerous radioactive substances through the air, which is especially dangerous when no backup cooling systems are in place as was the case with the Fukushima Daiichi power plant (Spent Fuel Pools).

The reaction process is carefully controlled by the placement of the control rods within the assemblies. Depending on the position of the control rods, the reaction will move at faster or slower rate which must be decided by carefully juggling safety with energy demands. If there were no rods in place, the reaction would become uncontrolled, possibly leading to a nuclear meltdown as the reactor reaches critical temperatures (World Nuclear Association).

The various security systems a power plant employs to block neutrons diffused during the nuclear reaction process have been mentioned above: The control rods, the coolant systems, the various circuits (in pressurized water reactors), the concrete containment buildings which block particles from leaving the plant, the placement of spent rods in pools and the subsequent cooling of those pools to keep radiation from escaping as the reactions carry on. These systems must be maintained carefully so they may be employed throughout the life of the power plant, which may last anywhere from 30 to 60 years depending on the plant (World Nuclear Association).

What is nuclear waste? Describe in general and then characterize the nuclear waste of a standard light water reactor.
What radionuclides are typically in radioactive waste and in what concentrations?
What are the half-lives of the radionuclides found in radioactive waste?
What are the types of decay the radionuclides in radioactive waste undergo? You may describe the entire decay chain or only the most relevant decay processes.
How much radioactive waste is produced by a typical light water reactor?

Nuclear waste is considered to be a high level waste according to the U.S. Nuclear Regulatory Commission (NRC). The NRC, on it’s page of high level waste, states that high level waste from nuclear reactors has two forms: the first form is spent fuel, which is used reactor fuel; the other is the bi-products of processing the spent fuel. The NRC states, “Spent nuclear fuel is used fuel from a reactor that is no longer efficient in creating electricity, because its fission process has slowed. However, it is still thermally hot, highly radioactive, and potentially harmful.” In this high level waste, 95% radionuclides are Uranium 235 according to the NRC and The World Nuclear Association. The elements in High Level Waste (HLW) are Uranium 235, Plutonium 239, Cesium 137 and Strontium 90 according to the NRC. The half life of Uranium 235 is 703,800,000 years. Plutonium 239’s half life is 24,100 years. Cesium 137’s half life is 30 years. Strontium 90 has a half life of 29 years. When Uranium 235 decays, it will eventually turn into lead 209. Plutonium 239 decays into Lead 207. Cesium 137 decays into lead 209. Strontium 90 decays into lead 206. The greatest threat to humans of these elements is Strontium 90 because, according to the NRC, Strontium 90 is the one that releases the most amount of beta particles. According to the Energy Information Commission, there are 104 active nuclear reactors in the U.S.A. According to the NRC, 7800 fuel assemblies are taken out of nuclear reactors every year. It takes about 3-4 years for a whole fuel assembly to be replaced. In one PWR reactor there are 150-250 fuel assemblies; in each fuel assembly there are 196 to 289 fuel rods according to wikipedia’s page on nuclear fuel. The NRC says that in a PWR reactor there can be 10 million uranium pellets which is about 195,312.5 sqft of uranium if each pellet is 3/8 of an inch by 5/8 of an inch. One pellet weighs on average 20g, according to wikipedia's page on nuclear waste. On average there are 41,237 pellets in one fuel rod and on average there are 243 fuel rods in one assembly. All toll, 1,563,212,196kg, or 3,446,292,970 pounds, of nuclear waste is produced every year in the U.S.A.

What are environmental and safety considerations for the storage of nuclear waste?

One type of emission from nuclear power plants is Greenhouse Gas Emissions. These emissions, such as CO_2, have negative effects on our atmosphere and are thought to be the partial cause of global warming. Greenhouse gas emissions from nuclear plants are significantly lower than that of energy alternatives like fossil fuels(Kleiner). This makes nuclear power appealing because it has little carbon emissions, or emissions that will contribute to climate change. However, the entire lifecycle of the plant must be considered when making such claims. Carbon emissions can be produced through construction, operation, decommissioning, mining and fuel preparation. Additionally, storing waste releases commissions that expand nuclear power plants’ carbon footprint. However, considering these factors, nuclear plants still rank among other ‘green’ energy technologies like solar and wind.

The emissions from nuclear plants have had a generally low effect on local air quality as compared to other forms of energy. Air pollution from coal-powered plants alone is estimated to kill 13,000 people annually while “Nuclear power plants do not emit carbon dioxide, sulfur dioxide, or nitrogen oxides. However, fossil fuel emissions are associated with the uranium mining and uranium enrichment process as well as the transport of the uranium fuel to the nuclear plant.” (Zelman, EPA)

What are emissions from nuclear power plants?
How have the emissions from nuclear power plants affected local air quality as compared to other forms of energy production?

Nuclear waste is extremely dangerous due to its radioactivity. The waste varies in form and danger, and there are different concerns and ways to deal with each. . Low-risk level waste as such is considered by most corporations safe to bury in underground because it is predicted to neutralize in a relatively short amount of time (a few hundred years)(Thinkquest). The biggest concern about this method of storage is to prevent leakage of the substance into the earth, where it could have negative effects on life and would contaminate groundwater.

Items considered intermediate-level threat wastes include materials to build the reactor but did not directly come in contact with the nuclear substance and used filters. Additionally, reactor emissions that are slightly more dangerous are also treated as intermediate-level. Scientists usually solidify these emissions and again store them underground to wait until they are safe.

The largest and most threatening issue is that of high-grade wastes. According to the World Nuclear Association, high level wastes make just 3% of the total volume of waste but are 90% of the threat (World Nuclear Association, *What Are Nuclear Wastes?*). This category is almost exclusively composed of used fuel rods from nuclear power plants. The fuel spends about three years generating heat for electricity, but after that, scientists are at somewhat of a loss about what to do with these substances. They solidify them as they do intermediate, but if the casings they are held in were to break, there would be devastating results.

They have considered shooting them into space, but this would not be cost-effective and would have further consequences if the substances began to rotate around earth. Fourteen countries including the USA attempted depositing their wastes at the bottom of the ocean before it was deemed to be universally prohibited in a 1993 agreement for obvious safety and environmental concerns.

Some experimentation has been researched in Britain and France to see if high-threat wastes can be treated to decrease the time they remain radioactive, which can be hundreds of thousands of years. However, the processes they have tried are not realistic because they just make the waste more dangerous for a lesser amount of time. Scientists believe that their best option is to bury the substances deep underground. They are concerned about burying them beneath unstable plates in the ground that may break or shift to open, releasing the toxicity of the fuel remains to future generations, because the toxicity of this level of radiation lasts for hundreds of thousands of years (Wikipedia). Transporting the waste to a permanent storage facility is also an issue.

Describe the science involved in global climate change and how it relates to emissions from nuclear power plants and fossil fuel power plants.
What is the greenhouse effect?
What are greenhouse gases and what about their structure makes them greenhouse gases?
How do the emissions from energy production by nuclear power plants compare to that of coal and of natural gas?
How is the combustion of fossil fuels related to global climate change?

Simply put, greenhouse gases are gases that trap heat in the atmosphere.These gases allow direct sunlight (relative shortwave energy) to reach the earth without interruption (NCDC). As the shortwave energy heats the surface of the earth, it is then reradiated to the atmosphere. When it is reradiated, the energy contains more infrared than the original radiation, and the total amount of radiation existing in the atmosphere contains longer wavelength ranges than before. Greenhouse gases do not let the longer wavelength radiation to pass through the atmosphere as easily as the shortwave radiation (CMU). This means less heat can escape back into space because it is absorbed by greenhouse gases, and is encapsulated in the lower atmosphere. Carbon dioxide, methane, water vapor and nitrous oxide are all greenhouse gases that naturally occur in the atmosphere. (NCDC) They are considered greenhouse gases because of the amount of infrared energy (heat) the gas can absorb. This extends from the end of the visible spectrum to about 700 nm, which is the beginning of the microwave spectrum. Greenhouse gases absorb energy in this range (ANL). Due to the industrial revolution and a growing population's dependence on fossil fuels, more synthetic and natural gases have been concentrating the atmosphere. Greenhouse gases like carbon dioxide occur naturally and are vital to human survival, as they trap heat in the atmosphere to keep the earth warm. The Earth traps heat in the atmosphere using greenhouse gases, which maintain a warm atmosphere, and a warm surface of Earth (Iowa State). Despite all of this being a natural process, activities like mining and burning coal, humans have interfered with the carbon cycle. In this, carbon undergoes a state change from a solid state to a gaseous state, increasing atmospheric concentrations (NCDC). As atmospheric concentrations of greenhouse gases increase, the temperature of the atmosphere increases, warming the earth's surface (NCDC).

The warming of the Earth's surface is commonly referred to as global warming or global climate change. The emissions of different energy sources are examined in an effort to emit the least amount of greenhouse gases to reduce global warming. Emissions are measured in megawatt-hours. One megawatt-hour (MWh), is the equivalent of 1,000 kilowatts of electricity used continually for one hour. To put that in perspective, one megawatt is enough electrical energy to power 1,370 average Western homes each month. (CEC) When coal is burned, carbon dioxide, sulfur dioxide, nitrogen oxides, and mercury compounds are emitted. On average, the emission rates from coal-fired generation in the United States are 2,249lbs/MWh of carbon dioxide, 13lbs/MWh of sulfur dioxide, and 6 lbs/MWh of nitrogen oxides. Coal burning can also emit methane, which is trapped inside the coal (EPA). The burning of natural gas produces nitrogen oxides and carbon dioxide. When not burned completely, or when leaks occur during transportation, methane can also be emitted into the air. Compared to coal, natural gas emits 1135lbs/MWh of carbon dioxide, 0.1lbs/MWh of sulfur dioxide, and 1.7lbs/MWh of nitrogen oxides (EPA). In comparison, Nuclear power plants emit no carbon dioxide, sulfur dioxide or nitrogen oxides. Despite this, fossil fuel emissions are associated with uranium mining and enrichment in addition to the transport of the uranium fuel to the nuclear plant (EPA).

Different greenhouse gases have different atmospheric lives which determine their environmental impact. Carbon dioxide has an atmospheric life of 50-200 years, meaning it has a warming effect for a span of up to 200 years (Iowa State). Methane has an atmospheric life of only 12 years but poses a greater environmental risk than carbon dioxide because it has 21 times the warming effect of carbon dioxide (Iowa State). This is considered the Greenhouse Warming Potential, which is measured along with atmospheric life to determine the impact of a greenhouse gas. (Iowa State) Nonetheless, these gases have a strong and long term impact on the global climate.

How are radioactive materials for nuclear power plants mined and refined?

What are environmental and safety issues associated with the mining and refining of nuclear fuel?

The primary fuel source of a nuclear reactor is uranium. Uranium is a radioactive substance that emits alpha particles as a process of radioactive decay. The isotope U-238 is the most common isotope of uranium in the world, which is why it is most commonly mined. Additionally the isotopes U-234 and U-235 exist though are not common as an abundant resource and therefore are not used abundantly in energy production. The isotope U-235 is however used in an enrichment process that will be spoken of later. Uranium is most commonly found in granite, a material that makes up roughly 60 percent of the earths crust, and it is about as abundant as tin or 500 times more abundant than gold. (The Nuclear Fuel Cycle) Though uranium is not as common as many ores its required quantity’s for energy production are relatively low due to an incredibly high energy output during a reaction. This energy output can be calculated using an equation discussed previously known as $E=MC_2$.

Two processes are most commonly used in uranium mining, excavation and situ techniques. Excavation mining is generally utilized when deposits are close to the surface, usually within a range of 120 meters; below this range underground mines are used. The mines with a closer range are referred to as open pit mines because they are exposed to the elements. These open pit mines can be seen as less efficient than underground mines because of the amount of material needed to be removed to expose the uranium. Open pit mines require there to be more material removed because large holes in the surface are needed with sloped side walls to prevent collapse, the construction of these holes requires the removal of much material. While underground mines are slightly more efficient than open pit mines situ techniques have one the favor of efficiency in today’s world and are most commonly used in mining. Situ leach mining is the process of circulating acidic liquids, such as sulfuric acid, through abundant deposits of uranium to dissolve the uranium oxide and bring the material to the surface. Often time’s acidic or alkaline solutions are used to keep the uranium in solution before extraction. (The Nuclear Fuel Cycle)

Once the uranium is extracted from the earth it must be refined to be used in power plants. The purpose of a mill is to concentrate the extracted ore. Often times the ore extracted contains less than .1% uranium, however the end product after milling can contain 80% uranium. This end product, commonly known as “yellow cake”, is achieved by crushing the ore into fine powder and leaching it using sulfuric acid, this allows for the uranium to separate from the waste rock. The uranium is then precipitated as uranium oxide, heated, and finally packaged in 200-litre drums. (The Nuclear Fuel Cycle)

Before the uranium can be utilized in a power plant an enrichment process must take place to increase the percentage of the isotope U-235, an isotope capable of undergoing fission. This percentage must be increased because only . 7% of natural uranium from a mill can undergo fission. Most power plants require between a 3.5 and 5% U-235 content in order to undergo fission. The process of enriching the uranium begins by turning the uranium oxide into a gaseous form with a low temperature known as a hexafluoride. There are then two methods to decreasing the amount of U-238, using centrifuges and the gaseous diffusion technique. To begin the enrichment process using centrifuges, the uranium hexafluoride is injected into a centrifuge, these centrifuges then rotate rapidly until the heavier U-238 is pressed up against the sides of the centrifuge walls. It is then syphoned off to reach the appropriate ratio of U-238 to U-235. The gaseous diffusion technique works by pushing the gaseous hexafluoride through semi permeable membranes to decrease the abundance of the heavier U-238. (Gaseous diffusion) After either of these processes take place the enriched uranium is baked at approximately 1400° C to become small ceramic like pellets. These pellets are then loaded into metal tubes to form fuel rods that can then be used in power plants to undergo fission. (The Nuclear Fuel Cycle)

The following issues pertain to excavating processes; though many of these issues have become irrelevant due to a shift in mining process it is important to discuss historical issues to understand why new methods have adopted. As stated previously large holes must be dug to excavate uranium, and due to sloped walls an additional amount of matter must be removed to prevent collapse. The ramifications of digging these holes range from destroying habitats to increasing the risk of airborne radiation exposure. Another significant risk of excavation methods is the matter that is removed during mining. Many people claim that all of our radiation impacts are as a direct result of uranium, however many of the impacts are as a result of the matter that has been in contact with the uranium. During the mining and milling process large quantities of matter surrounding the uranium is removed and often times left out in the open. This matter is often times contaminated and is often responsible for many radiation related issues. (The Nuclear Fuel Cycle) A final common issue with past excavation methods and new methods alike, is lung cancer, during World War 2 a group of Navajo people began opting for mining jobs, little did they know that radon was collecting in the mines and interring their lungs as radon daughters. Slowly these miners began developing cases of lung cancer. (Doug, Brugge, Benally Timothy, and Yazzie-Lewis Esther)

The current mining techniques known as Situ mining have been designed to remove many of the negative impacts of former excavation mining. However with this new technique come new issues. One of the impacts of situ techniques is the leaching agent contaminating surrounding groundwater, and rendering that areas groundwater unusable. The other hovering issue with situ mining is the wastewater that is collected in evaporating ponds; this water can often have high levels of radon that can then be released into the environment. Although radon is released it tends to disperse so quickly into the air that it becomes virtually harmless, the greater issue is the wastewater that can get into groundwater. (Impacts of Uranium In-Situ Leaching)

What safety risks accompany the use of nuclear power?
How much radiation is the surrounding environment subjected to from a properly function nuclear power plant?
What risk for nuclear meltdown exists in light water reactors in the United States?
What safety features are being built into future light water reactors?

Radiation is a form of energy emitted by matter, This energy can be a particle moving at high speeds or simply electromagnetic radiation (light). Matter is made up of atoms. Within these atoms, the nucleus holds protons (carrying a positive charge), neutrons, (carrying a negative electrical charge) in the outer shell. These forces within the atom try to create a stable, strong balance through getting rid of excess atomic energy, also called radioactivity. When radioactivity is released, unstable nuclei can emit an amount of energy. This spontaneous emission is referred to as radiation (NRC).

Radiation is found in many everyday forms like humans and microwaves, and can be emitted in the form of heat or light. Radiation is emitted by the sun and the stars, and is therefore present in the environment. Radiation is dangerous to humans in excess quantities, because it can lead to genetic mutations and cells that incorrectly repair themselves, leading to biophysical change (NRC). The distance that radiation travels depends on the type of radiation emitted, and the particle or electromagnetic radiation’s ability to penetrate other materials. Alpha particles can be stopped by paper, beta particles by skin, x-ray and gamma by a cement barrier, while neutrons are far more difficult to block (NRC). The risk to humans is dependent upon the particle being radiated, and the distance the human is from the particle when it is emitted. According to the NRC, "a person who spends a full year at the boundary of a nuclear power plant site would receive an additional radiation exposure of less than 1 percent of the radiation that everyone receives from natural background sources." This is about 300 millirems, and has not been shown to harm any humans (NRC). Properly functioning power plants produce small amounts of radioactive gasses and liquids, and small amounts of direct radiation. People who live within fifty miles of a nuclear power plant receive an average radiation dose of about 0.01 millirem per year. In comparison, the average person in the United States is exposed to about 300 millirems per year from natural background sources of radiation (NRC).

The nuclear reactor core is the part of a nuclear reactor that holds the nuclear fuel components where the nuclear reactions take place. Nuclear meltdown occurs when the loss of coolant or coolant flow to the nuclear core creates extreme heat in the core and it melts (UCSC). In 1986, at Chernobyl, the nuclear core of Reactor 4 melted during a plant-output test. This test was conducted without certain safety features, and according to UCSC, “This positive feedback effect produced a surge of power in Chernobyl's Reactor 4, from 7 percent to hundreds of times its rated thermal output.” This energy surge produced an explosion in the reactor core, and caused fires in the plant and highly radioactive material outside of the plant (UCSC). Today Chernobyl is uninhabitable due to the high levels of radiation. In addition, Chernobyl induced thousands of deaths, people with health problems, and contaminated a large food supply (UCSC). In 1979, at the Three Mile Island plant, a light water reactor design of the type that currently generates eighty-five percent of the world's nuclear generated electricity, had a meltdown. About half of the fuel had a meltdown, but the public was protected from radiation by the containment meant for such accidents (UCSC). Today, 107 nuclear power plants in the United States have full power licenses and generate approximately 18% of the nation's electricity (Taylor). Chernobyl's infamous nuclear meltdown, and meltdowns like those at Three Mile Island pose large questions about the risks of nuclear meltdown in light water reactors in the United States.

In order to prevent nuclear meltdowns from happening, and having devastating effects if they do, safer technology is being developed. In one case, through using passive design characteristics to ensure core stability, the reaction rate instantaneously decreases as the temperature of the coolant, fuel, or the power of the reactor increases. This all occurs without the help of external control devices. Passive features in the plant cooling process make sure that the core is constantly cool. Features such as natural circulation, gravity, gas expansion and built in heat sinks are being implemented. While this is all occurring internally, the public is protected through containment and confinement systems that prevent radioactive material from escaping the plant were an accident to occur. On a less technical level, meltdowns are being prevented by investing more in the humans that operate the plants. Improved technology has made nuclear plants safer because workers can now operate more simply and with a larger scope of plant conditions.

Some examples are graphic displays, diagnostic aids and expert systems are being developed for control rooms. In the bigger picture, the licensing process for nuclear plants is becoming less ambiguous, which in turn leads to safer operations and safer technical features (Taylor).

What are potential risks to nuclear power plants from terrorist attacks?

There have always been risks to having nuclear power plants, most commonly people think of the risks for the workers and the environment around the plant. However most people do not think about the risks of an attack on a power plant. According to (Wells, Jane), reactor walls are built to withstand a suicide crash from an F-4 jet, however past terrorist attacks have been jumbo jets not small military craft. With reasonable concern it should be noted that a successful attack on a nuclear power plant would be catastrophic, with the possibility of a second Chernobyl like event. To defend any structure from an attack like that on the twin towers is unfortunately a close to hopeless defense. According to (Wells, Jane), there have been no tests that have been able to show whether a jumbo jet would actually penetrate a power plants four foot thick walls. However it is important to note that even if a power plants wall could hold up against one impact there is a small chance that it would hold up to a sustained attack. Instead of trying to fortify a structure the focus has been placed on fortifying security. According to (Wells, Jane), after nine eleven occurred nearly 370 million dollars was expended on the nuclear industry’s budget for security measures. Much of this extended budget has been devoted to hiring and training about 2000-armed guards for the 60 existing power plants.

According to (Wells, Jane), there have also been simulation done to prevent cyber terrorist attacks. After these tests on multiple power plants the conclusion was drawn that the systems can be compromised through cyber terrorism. During these tests the hackers were able to interrupt the power allowing for a shutdown but not a leak. Additional research is currently being done to investigate how to prevent these cyber attacks.

Another arising issue to be aware of is the enrichment processes, spoken of earlier in this paper. For uranium to be used in a nuclear reactor it must have a U-235 percent concentration of between 3.5 and 5% to undergo fission. According to (Allison, Garham), a nuclear warhead must contain an optimal U-235 percent concentration of 90 to be used in a nuclear weapon, anything below 20% concentration would theoretically not go off. This information is good because it reassures us that the percent concentration of U-235 used in reactors is well below the threshold, making any possibility of turning a nuclear reactor into a weapon a far off fantasy. However at the same time this enriched uranium if found in the wrong hands could feasibly be re-enriched to increase the level of concentration of U-235 to become weapon capable. Due to this issue the concealment of this enriched uranium is a high priority in security against a foreign attack.

What are the best estimates for the purely financial cost of nuclear power generated electricity?
Per kilowatt-hour? Per Power Plant?

Per kilowatt-hour is a convenient measurement to compare beside the costs of other energy providers.
Per kilowatt-hour: Nuclear power is the lowest-cost producer of baseload electricity. ... steady for more than 10 years averaging 2.19 cents per kilowatt-hour in 2011. (Nuclear Energy Institute)
When determining if nuclear plants are cost effective you must also consider the entire lifetime of the power plant.

Per power plant: Costs of production, operation, and maintenance are complicated. Over the 40-year lifespan of a plant, billions of dollars are spent. This table (EIA) depicts the Updated (as of 2010)Estimates of a Uranium Plant Cost.

	Plant Characteristics		**Plant Costs**		
	Nominal Capacity (kilowatts)	Heat Rate (Btu/kWh)	Overnight Capital Cost (2010 $/kW)	Fixed O&M Cost (2010$/kW)	Variable O&M Cost (2010 $/MWh)
Uranium Dual Unit Nuclear	2,236,000	N/A	$5,335	$88.75	$2.04

How do the closed waste cycle and open waste cycle fuel options compare?

After a nuclear reaction has taken place there are waste by products left over. Currently there are two cycles that exist to deal with this discharged fuel, the open fuel cycle and the closed fuel cycle. The open fuel cycle takes the discharged fuel from the reactor and treats it like waste to be disposed of. While the closed fuel cycle takes the discharged fuel and reprocess it into a viable fuel source to be recycled through the reactor once more. (Chapter 4 fuel cycles) The closed cycle option has significant advantage over open cycle option, this advantage is as a result of resource utilization which from an economic standpoint is more efficient in price. Additionally the closed cycle option has a significant reduction in waste because the waste is recycled and therefore reduced after a second process, its waste also has a shorter half life due to less actinides.

While the closed cycle option has many benefits its actual implication has many negative side effects. Two of the greatest negative factors are the short term costs and the increased levels of radioactivity of the nuclear waste. In order to incorporate a closed cycle option a more intricate nuclear process must be utilized, this process uses less fuel rods but achieves a higher heat by releasing more neutrons, this increased heat raises the cost because it requires a more refined system to cool and contain the reaction, these additional safety measures according to (Beckjord, Eric S), are not cost benefit to the reduced levels of fuel needed for running the reactor. As stated previously a closed cycle option has a significant reduction of nuclear waste that additionally has a shorter half life then once used waste. However because this minimal amount of waste has a shorter half life it decays more rapidly, when a radioactive substance decays more rapidly it tends to become more dangerous because radioactive particles are being emitted more rapidly. Therefore the final concern of a closed cycle option is that though the radioactive waste will be around for a much shorter period of time it will be significantly more dangerous than waste from an open cycle option this waste will also be closer to what is necessary for nuclear bombs.

What are breeder reactors (aka fast neutron reactors)? How do answers to the above questions (particularly radioactive waste and safety) change if you are considering breeder reactors instead of light water reactors?

In addition to light and heavy water reactors there are breeder reactors. Breeder reactors, under correct circumstances, can literally breed, creating more fuel from isotopes that are not usually at a proper enrichment ratio to undergo fission. One of the more common breeding process is that of non-fissionable U-238 to fissionable plutonium-239. This process occurs when a neutron released from the fission of U-235 comes in contact with the isotope U-238, this contact then begins a process of nuclear transmutation starting with U-238 > U-239 > Np-239 > Pu-239. The end product of this decay process is plutonium-239 which is capable of undergoing fission and can be used in the reactor as a fuel. Breeder reactors are often referred to as fast neutron reactors, they have earned this name because they can often be configured to produce more fissionable fuel than is used in the reactor. This efficient renewable process is possible because U-238 is 140 times more abundant than U-235, thus creating a more cost benefit solution to a fuel source then obtaining U-235. Using an efficient process the U-238 can then undergo nuclear transmutation to become a fission capable fuel and allow the plant to be more self sustaining. (Fast Breeder Reactors)

Light water reactors bring a number of issues concerning nuclear waste and safety for both workers and surrounding communities, many of these issues were spoken of previously. Breeder reactors however bring new safety concerns that are not present in light water reactors. Breeder reactors are most predominantly cooled by sodium because the neutrons used to initiate fission in breeder reactors are traveling at a higher velocity than those used to initiate fission in light water reactors. One of the biggest concerns and reasons why breeder reactors are not used conventionally today is because the liquid sodium reacts explosively to both air and water. Controlling sodium fires and generators used to transfer heat from sodium to water has proven to be incredibly difficult. So far several breeder reactors have been successfully built, however the energy output to cost ratio made the reactor close to worthless. Additionally there have been several incidents, one of which killed an engineer and injured four other people when a relatively small amount of sodium residue exploded. On top of the risky design that may pose many safety issues, the reactors require an additional complex step to remove the depleted plutonium from the spent fuel rods, without this costly step the only benefits to breeder reactors would be non-existent. (Biello, David)

What are heavy water reactors and how do they differ from light water reactors?

Lightwater reactors are used primarily by the United States, unlike heavy water reactors used in Canada, they use regular water as both a coolant and moderator because of water's high specific heat. Light water reactors require an enrichment process, mentioned previously, to maintain fission. The uranium is enriched with U-235, this specific isotope releases 2.4 fast neutrons per fission, to slow these neutrons down, or moderate them in a light water reactor the water is used. The moderator prevents the neutrons from reaching the other fuel rods to quickly and becoming uncontrollable. (Light Water Reactors)

There are two forms of light water reactors used today, pressurized water reactors (PWR) and boiling water reactors (BWR). The (PWR) reactors utilize a pressurized water flow that passes over the reactor core to be used as moderator but is cut off from the turbine and condenser, additionally this water is kept pressurized under to keep the extremely hot water from vaporizing. The primary advantages to this system is that if there is a fuel leak the radioactive contaminants would not go into the turbine or condenser, thus preventing large scale contamination. Additionally (PWR) reactors can run at higher pressures and temperatures allowing for a higher carnot efficiency, meaning a calculated heat efficient cycle that provides the greatest efficiency allowed by physics. However because of this increased efficiency comes a more complex running system, thus this system is more costly than the (BWR) reactors. (BWR) reactors have a fully connected system, the water that runs over the reactor core is boiled and steam created directly powers the turbines. Because the system is fully connected any leak that occurs will be exposed to the turbines and the remainder of the system. This process has the potential of being a significant hazard making it a rarely used process in the United States. (Light Water Reactors)

Heavy water reactors, primarily used in Canada, use heavy water as a moderator. Heavy water deuterium is more effective in slowing down the neutrons released in fission allowing un-enriched uranium to be used. (Light Water Reactors) The heavy water is more effective in slowing down the neutrons because it is literally heavier, instead of the water containing the hydrogen isotope protium which has one proton and no neutrons, the heavy water contains the hydrogen isotope deuterium which has one proton and one neutron making the water simply heavier. (Helmenstine, Anne Marie) Because of the heavy waters properties it is has a neutron moderating ratio 80 times greater than regular water, making it more efficient in nuclear processes. (Light Water Reactors)

What is nuclear fusion? How do answers to the above questions change if you are considering a nuclear fusion reactor instead of a light water reactor?

Fission reactors are the only reactors to have moved past testing stages to become commercially used throughout the world. Fission reactors are widely used because they are relatively safe and cost efficient compared to fusion reactors. Fission is a process of splitting one atom to release energy, this is done by firing a neutron into the nucleus of a U-235 atom, the atom then becomes unstable and immediately splits releasing more neutrons to start a chain reaction. The job of the nuclear reactor is to moderate how fast the neutrons are moving. By using sodium, heavy water, or light water the neutrons can be slowed down to prevent a meltdown.

Currently fusion reactors are more of an idea than a reality, fusion reactors have never really left the blueprint stage in development, though some tests have been successful there are no fusion reactors functioning well enough to produce usable energy. This is because fusion requires a significantly larger amount of energy to initiate the reaction, and a larger amount of energy is released during reaction which can achieve higher temperatures that cannot be contained. Unlike fission, fusion is smashing atoms together to release energy. As stated previously the reaction requires a higher amount of initiation energy, this is because an incredible amount of energy is required to bring two or more protons close enough that nuclear forces overcome their electrostatic repulsion. Additionally the product of nuclear fusion is a massive amount of energy, much greater than a fusion reaction. As far as we know the only naturally occurring fusion reactions that take place are in stars, such as our sun. (Nuclear Fission vs Nuclear Fusion)

Currently on the drawing table are two forms of fusion reactors, magnetic confinement reactors and inertial confinement reactors. These fusion reactors were designed with the intention of creating a solution to containing fusion temperatures that are far too high to be held in any material container. The first fusion reactor, the magnetic confinement reactor, functions by keeping the hot plasma away from the walls of the reactor. This is done by keeping the plasma moving in a circular or helical motion using a magnetic force on the charged particles. The most common magnetic confinement reactor is called a tomahawk fusion reactor. This reactor uses two magnetic fields to control the plasma. One is generated from a donut shaped external coil that creates a field on the axis of the toroid, or a perimeter inscribed at the radius of a donut shaped cylinder. The other field is generated from a heating current on the toroid which is used to heat the plasma. During tests this reactor was able to produce large quantities of power, however the breakeven level of efficiency between input and output power was not approached. The second type of fusion reactor, the inertial confinement reactor aims to fuse the nuclei fast enough so that the nuclei dont have time to move apart, this process is done primarily by utilizing lasers to achieve a high enough temperature in a quick enough amount of time to undergo fusion without the nuclei separating. (Fusion Reactors)

The primary concerns that come along with fusion reactors is the magnitude of energy that plays a role in the reaction. As mentioned previously it takes a large sum of energy to initiate fusion, this intern becomes very costly and because more energy is usually needed to initiate then is collected during reaction fusion has not yet reached a breakeven efficiency. Additionally the amount of energy that is released during reaction is substantially more than in fission, because of this increase in energy containment requires a more technical solution that is costly. Though fusion reactors contain hot plasma that cannot be contained by any material, fusion reactors are actually considered to be relatively safe from melt down. In the rare event of a magnetic field failure or other loss of control the reaction would stop and the plasma would simply disperse and rapidly cool to become virtually harmless to the reactor walls. In the event of a leak only tritium would be released, though radioactive tritium is considered to be less lethal and will quickly disperse. (Fusion Reactors)

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