Joint Scientific Statement

**1. 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).** (Lana C)

Nuclear fission is the creation of energy through the splitting of nuclei. It can be described as a radioactive decay process, a process by which the nucleus of a particle is split into lighter nuclei or a nuclear reaction. The process itself of nuclear fission often creates free photons and neutrons ( in the form of gamma rays). Due to these things radioactive decay is produced this in turn releases a great deal of energy even by your everyday energetic standards of radioactive decay.

The splitting of the nuclei is what gives off the energy in the reaction known as fission. Fission itself is the main producer of nuclear energy. Within the reaction of nuclear fission, fission reactions can be moderated when this happens the fission increases. On the other hand the nuclear fission reaction can be unmoderated, if this does happens the result is the breeding of further fuel.

After the capture of a neutron, fission can take place in any of the heavy nuclei. If the energy is low (Slow or thermal) these neutrons that have been captured can only cause a fission reaction if they do so in those isotopes of uranium and plutonium that happen to contain nuclei that have an odd number of neutrons. Thermal Fission can also take place given the right conditions.

A nuclear fission reaction happens when a neutron is absorbed by Uranium-235. Uranium-235 is an isotope of Uranium that happens to make up 0.72%  of natural uranium. Uranium-235 helps the nuclear fission reaction. The uranium-235 is separated from the uranium-238 in a process. After this process is complete the Uranium-235 is used the nuclear fission process. Therefor the neutrons are absorbed and the uranium-235 serves its purpose within the reaction.

**2. Explain the meaning of E=mc2 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.** (Lana C)

E=mc2 is a measurement that is commonly used in the science world. In 1905 the great Albert Einstein’s published a scientific paper introducing E=mc2 to the world of science. E=mc2, E=energy, m= the mass, and c is the speed of light in a vacuum, this number is squared resulting in a very large number. E=mc2 has a great deal to do with nuclear power and its science.  E=mc2 in a nuclear reaction measures the amount of energy created when the reaction takes place. By using this formula  to calculate the energy you are able to find an accurate measurement of energy.

Knowing this, this equation can be used to calculate and explain the process of nuclear power.

Mass being converted to energy is the energy released by nuclear fuel. That nuclear fuel goes through a series of reactions that convert the mass of the substance into energy. When the reaction occurs the neutron are absorbed into the uranium. This Uranium makes up the mass as the mass is burned it creates energy, the mass turning into an energy that can be harnessed and used. The reaction in the end requires the concept of E=mc2 to be successful in its reaction, in this case nuclear power.

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**3. How are radioactive materials for nuclear power plants mined, milled and enriched?** (Ashton C)

The mining of the uranium ore is mined a couple of different ways. One of the ways is just excavating it from the ground, this is split into two different methods where there is underground mining and then there is pit mining. The underground mining it for the deep deposits and the pit mining is for when the uranium is close to the surface. An increasing portion of the world is starting to move into ISL (In Situ Leaching) mining. Milling is usually close by the mine, Milling produces a uranium oxide concentrate which is shipped from the mill. It is sometimes referred to as 'yellowcake' and generally contains more than 80% uranium. The original ore may contain as little as 0.1% uranium, or even less. The ore is crushed and ground to a fine slurry which is leached in sulfuric acid (or sometimes a strong alkaline solution) to allow the separation of uranium from the waste rock. The uranium oxide product of a uranium mill is not directly usable as a fuel for a nuclear reactor and additional processing is required. Only 0.7% of natural uranium is capable of undergoing fission, the process by which energy is produced in a nuclear reactor. The form, or isotope, of uranium which is capable is the uranium-235 (U-235) isotope. The remainder is uranium-238 (U-238). For most kinds of reactor, the concentration of the capable uranium-235 isotope needs to be increased typically to between 3.5% and 5% U-235.

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

After ISL mining is completed, the quality of the remaining groundwater must be restored to a baseline standard determined before the start of the operation, so that any prior use can be resumed. Contaminated water drawn from the aquifer is either evaporated or treated before reinjection.The usual radiation safeguards are applied at an ISL mining operation, despite the fact that most of the ore radioactivity remains well underground and there is hence minimal increase in radon release and no ore dust. Employees are monitored for alpha radiation contamination and personal dosimeters are worn to measure exposure to gamma radiation. Routine monitoring of air, dust and surface contamination are undertaken.

* **Where is uranium mined and approximately how much is available in the US?  In the World?**

In 2012 there was about 68,864 tonnes of U3O8 mined in the whole world and only 1596 tonnes of that came from the US.

* **How much of our energy needs can uranium provide?**

Typically, some 44 million kilowatt-hours of electricity are produced from one tonne of natural uranium. The production of this amount of electrical power from fossil fuels would require the burning of over 20,000 tonnes of black coal or 8.5 million cubic metres of gas.

**4. Describe the design of a light water nuclear power plant** (Gordon G)

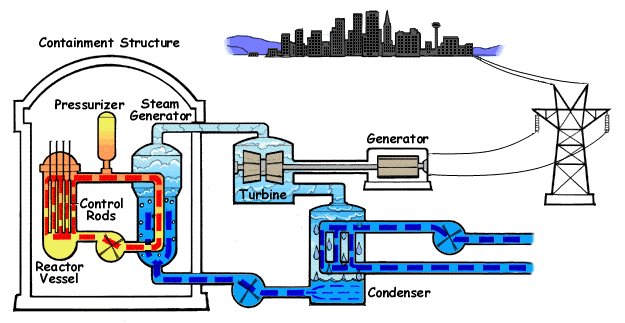


Figure : Design of pressurized water reactor

Pressurized water nuclear power plants consist of many parts. The most conspicuous of these are the cooling towers, but in reality, they are a very small part of the energy production process. The nuclear reaction actually takes place in a much smaller building; the containment structure. This is a small building with a domed roof that has very thick concrete walls to contain radiation (left side of figure 1). Inside the containment structure is the reactor, which is where the nuclear reaction takes place. The reactor is surrounded by water, which fills the containment structure. This water stays inside of the containment structure and is called the primary coolant (shown in red). Also in the containment structure is a pressurizer (see figure 1), which pressurizes the primary coolant to keep it in liquid form. Inside the reactor, there are several fuel rods, which are filled with fuel. The fuel is refined uranium oxide, U3O8, in small pellets with a ceramic coating. Refined uranium is a mixture that has a greater ratio of U-235 to U-238 than is naturally occurring. In between fuel rods are control rods that can be raised or lowered in order to speed or slow the nuclear reaction that is caused by the fission of the fuel. These are one of the active safety features of the plant, meaning they require a human operator in order to function. The control rods allow the reaction to create the right amount of heat without creating so much that the reactor overheats and melts down (labeled in figure 1). The reaction heats the primary coolant, which is just outside the reactor.

Also inside the containment structure is a second pipe, which holds the secondary coolant. The hot primary coolant heats the secondary coolant in a heat exchanger (shown in blue, figure 1). This fulfills dual purposes: cooling the primary coolant and heating the secondary coolant, which continues through the pipes as steam. It then spins a turbine, which in turn spins a generator, creating electricity (Figure 1), most of which goes on to the grid. Some of the energy is recycled to keep the plant running. After running through the turbine, the steam is run through a condenser and condensed back in to water using a second heat exchanger, this time with the tertiary coolant. The tertiary coolant is then run out through the cooling towers to condense and be recycled (Bottom right, in blue). Inside the cooling towers, the hot tertiary coolant is pumped in near the top. It then cascades down the sides of the tower, which effectively cools it. At the base of the tower it is run back in to pipes. The coolant is so hot when it comes out that massive clouds of steam usually come out of the cooling towers. Because some of the water is evaporating in to the steam cloud, new water must be added to the tertiary coolant. The primary and secondary coolants, however, are continually recycled and don’t need to be replenished regularly. In a pressurized water reactor, there are three levels of cooling because there is so much heat produced by the reaction. In a system with fewer coolants, it would be harder to effectively dispose of all waste heat and protect the reactor from meltdown.

Newer reactors include multiple safety features other than the ones mentioned above. Some of these are passive, meaning that they can function without human intervention. For example, one reactor has an additional cooling system that is activated when the primary coolant reaches a certain temperature. Another example is a gravity activated tank of cold water that drains in to the reactor if the primary coolant evaporates. Most all plants have back up pumps that will function off of auxiliary power in the event of an outage so that the coolant continues to be cycled through the core to prevent meltdown. These safety features make nuclear meltdowns much less probable, but in extremely adverse conditions, like the ones at Fukushima following the earthquake, it is still possible for the system to overheat.

A boiling water reactor functions very similarly except that it has only two coolants, the primary and secondary, and no pressurizer. This type of reactor allows the primary coolant to evaporate in to steam. It is then run through a turbine to spin a generator. Finally, it runs through a condenser with the secondary coolant and then run back in to the reactor. The secondary coolant runs through the cooling towers and is condensed.

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**5. Describe operating processes of a light water nuclear power plant** (Gordon G)

The primary fuel for nuclear power plants is Uranium 235, which can easily be converted in to Uranium 236, an unstable isotope. This isotope then goes through fission, emitting another neutron. This neutron causes another atom to be converted to U-236, which releases more neutrons, and so on. This creates a chain reaction. Uranium 235 is relatively uncommon and is separated from the more common uranium 238 during the refining process. Once refined, the uranium 235 is manufactured as small pellets. These pellets are less than an inch long. They are put together in bundles of 179-264, called fuel rods. These fuel rods are placed inside the reactor. Each reactor has about 200 of these rods. They need to be replaced about every three years. To replace the fuel rods, the reactor is shut down and the used rods are removed and new rods are inserted in to the reactor. This is a delicate process because the used rods are radioactive and therefore dangerous. They are removed from the reactor and placed in storage pools full of cold water. The water serves a double purpose: first, it cools the spent fuel, which is still extremely hot. Second, it provides a barrier to some of the radiation emitted.

The average nuclear reactor produced about 11.85 billion kilowatt hours in 2012. There are 65 operable power plants in the US for a total of around 769,000,000,000 kilowatt hours, which accounted for 19% of the nation’s energy. The average US household uses about 10,837 kilowatt hours per year, so nuclear power plants produce enough energy for about 70,960,598 homes per year. The amount of energy being produced can be easily controlled using the control rods. These rods absorb the neutrons being emitted by the decaying uranium atoms and can be raised or lowered to change the rate of the reaction. The rate of reaction can be changed, but there is so much residual heat even when the reaction is slowed, it’s very hard to change the heat output and energy output of the plant to meet energy demand. As such, nuclear power is a better base-load power, meaning that it is always running and does not turn on and off based on power demand.

Designers do their best to make reactors safe by including multiple backup systems that will keep the reactor from melting down even if the primary electricity goes out. Operators also have a role in making sure that everything is working properly and shutting down as soon as something seems like it’s not functioning properly. They also have the responsibility of managing the control rods so that the fission chain reaction doesn’t get out of control. The standard operating life for a nuclear power plant is about 40 years. The US power plant fleet is nearing the end of its operable life because the vast majority of nuclear power plants were built before 1977. However, industry experts say that because almost every part of a nuclear reactor can be replaced as they age, most power plants can continue to operate long after their usual operable lifespan. By some estimates, the lifespan of a nuclear power plant could be increased by 50 years or more by replacing various components of the reactor and plant (Voosen, Nov 20, 2009).

According to the U.S. Energy Information Administration, the average efficiency of a nuclear power plant is about 32.6%. This is calculated using the kilowatt hour production of the power plant and its heat output.

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**6. What safety risks accompany the use of nuclear power?** (Marley W-G)

By using nuclear power, there are several risks that we must consider. The most apparent risk we embody when working with nuclear power is the radiation from the rods used in the production of the energy. When these rods have been used, they are then disposed of, but they still are radioactive and present a level of risk. In their storage, they leave traces of radiation and these containment systems may be in contact with a fault line or fracture in earth’s surface as well as being vulnerable to a natural disaster. Yucca Mountain, a proposed disposal location, was directly on a fault line. This disposal location was built, but never used due to the excessive cost that would continue to rise if waste was disposed of at Yucca Mountain (Beyond) Currently, dry cask storage is used for nuclear waste but there is no permanent location for waste. These facilities steel and can be sealed by welding or bolting the lid closed. All of the casks are enclosed in an extra layer of concrete or steel which creates a radiation shield. While these are fairly secure, if heavily damaged they may still pose risk of radiation exposure. Another risk we run when working with nuclear power is the risk of a meltdown in the power plant. When the reactor runs out of primary coolant or there is an unaccounted for hitch in the system, the core with the uranium rods may become too hot to be contained. If this is the case, the core of the reactor may melt through the containment building and release the primary coolant, water, which had come in contact with radioactive material as well as releasing radioactivity into the surrounding areas. If the control rods are not monitored and moved accordingly, there may be too much energy in the core and it could lead to a melt-down. These risks are very minimal due to heavily monitored systems.

* **How much radiation is the surrounding environment subjected to from a properly function nuclear power plant?**

Through the sun, the soil and manmade technology, we are exposed to radiation in our everyday settings. Radiation is commonly measured in millirems, or one thousand rems, which measures the amount of ionizing radiation in the human tissue. The average American is exposed to 620 millirems per year. This is all from our own devices and natural sources. A properly functioning nuclear power plant minimally affects our exposure to radiation, or it doesn’t change it at all. There are several safety requirements that nuclear power plants must oblige to, one of them being the amount of radiation emitted. The accepted amount of mrems that the public can be exposed to by the manufacturing of radioactive material is 100 mrems. Currently, the nuclear power plants are only releasing 0.02%, or 1.24 mrems, of our natural exposure. This is such a low value, it is clear that the surrounding environment of a nuclear power plant is not effected daily by the radiation. Nuclear power plants currently do not dramatically change the level of radiation we are exposed to. At the Darlington plant in Canada, the security requires that all entrants must pass through a metal detector, x-ray machine, bone scan and scan machine that checks for explosive materials. The extensive scanning workers are subjected to before entering the plant may cause more radiation than the power plant causes to the natural environment. To ensure little radiation is released, resident inspectors work for each power plant and the Nuclear Regulatory Commission performs regular inspections of power plants to check safety procedures and functionality of equipment. Through these inspections, the limited level of radiation from a nuclear power plant is kept to a minimum and the environment around the plants remains a safe place to live or visit. In fact, we may be at higher risk for radiation from our everyday gadgets like TV’s, microwaves and cellphones, than we are from nuclear power plants.

* **What risk for nuclear meltdown exists in light water reactors in the United States?**

In the United States, there are 104 nuclear reactors. Some of these nuclear power plants have had emergency shut downs in the past, indicating the possibility of a more unexpected shut downs in the future. According to the Natural Resources Defense Council, “A future severe nuclear accident at a U.S. nuclear power plant is a real possibility” (Natural) In May of 2011, five of the nuclear reactors were shut down due to emergencies. Severe weather such as hurricanes, tsunamis and tornadoes can affect the nuclear power plants. Along with natural disasters, these plants are also at risk through a few other instabilities including the type of reactor, either boiling water reactor or a pressurized water reactor; the age of the reactor; power level of the reactor. Researchers have found that the boiling water reactors are less able to prevent the release of radiation in the event of a natural disaster. Most nuclear power plants have a life span of 40 years. However, the Nuclear Regulatory Commission has declared that several nuclear power plants can operate for 60 years. As the plant gets older, so do the components, potentially making for a weaker, less secure plant. Lastly, the power production of a plant determines the level of wear and tear. In some cases, the reactors have been pushed past their limit to produce more energy than they are designed for, weakening all back-up systems. The United States has organizations that aim to monitor and ensure all nuclear power plants are practicing the safest methods of energy production. Additionally, all power plants are closely monitored and improved emergency systems have been developed to increase safety. Through all of these safety procedures, there is still the slim chance that a natural disaster could occur and that unpredictable accident may lead to a meltdown or other damage to the plant.

* **What safety features are being built into future light water reactors?**

As ever, humans are innovating and creating. Going into the future, there are many plans for improving safety and environmental impact of these nuclear reactors. There are a couple different plans, all detailing different aspects of future improvements. One plan is looking into advanced pumps, heating and cooling systems and turbines. With advanced pieces, the efficiency will be improved. Safety in this new plan will be monitored through “man-machine” interface and other features. Another plan that is being implemented in the United States mandates that the reactor be built with “32 per cent fewer valves, 35 per cent fewer pumps, and 45 per cent less pipe than a traditional PWR” (Nuclear) This will lower the cost of building the reactor and elevate the efficiency and reliability of the plant. Less valves, pumps and pipes means there will be less area for error because there will be less little detail pieces that could break and throw off the whole system. Additionally, this plan is considering less man initiated safety back-up, meaning that if there is an emergency, the plant will not rely on human intervention. The emergency cooling systems will not run on diesel and the containments will be cooled through a natural process instead of a forced cooling. A third design is focusing on stabilizing the core of the nuclear reactor so that remains intact and untouched in the case of an emergency. In nuclear power plants, the control rods are also part of an emergency backup system. The control rods are lowered to control the rate of the nuclear reaction because they absorb neutrons. In the case of an emergency or power outage, the control rods, elevated by electromagnetic machinery, will drop to prevent the nuclear reaction from producing too quickly without control. All plants work with the “defense in depth” system, which basically allows for multiple layers of backup systems.

* **What are potential risks to nuclear power plants from events like natural disasters and terrorist attacks?**

In Fukushima, the nuclear power plant experienced a natural disaster. The plant was prepared for the effects of an earthquake through the seismically secure building. Additionally, the plant was intentionally built above the predicted height of tsunamis in the region. When the earthquake hit, the operating power plants automatically shut down and the back-up generators kicked in. The buildings were not heavily damaged by the earthquake, but the back-up generators were flooded by the unexpectedly large tsunami, causing damage to the plants and radioactive waste to leak into the ocean. The system implemented in the Fukushima power plant was clearly functioning with emergency shutoffs as well as safety procedures. Natural effects may damage other power plants near shores or on fault lines by disrupting the foundation of these buildings, leading to potential hazards. Many of the plants are built to withstand these natural disasters and seismic activities. Though we are able to build to accommodate natural disasters, the earth and its activities are constantly unpredictable which may inadvertently effect and damage the power plants. However, these storage facilities and plants are highly protected against terrorist attacks. To create a nuclear meltdown, the coolant has to be drained in order to cause overheating and melting in the reactor. In order to create overheating in the core, also leading to a melt-down, the control rods have to be raised so there is no limiting of fission in the core of the reactor. Both of these require access to the inside of the power plant. All power plants are highly guarded and to get from section to section within the power plant, you have to go through security checks. In the Darlington power plant in Canada, to get access to the inside of the plant, they scan your bone structure, an impossible body part to replicate. These power plants are so well guarded and protected they are not highly susceptible to terrorist attacks. The one area where there might be an attack is in the area where the waste is stored. These facilities are not guarded as well and might be vulnerable to attack.

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

A heavy water reactor uses a different type of water than a light water reactor. Heavy water is found in all water sources, including lakes, rivers and the ocean. This water is about 10%heavier than light water because it contains deuterium. In hydrogen, there are two stable isotopes; deuterium and protium. Deuterium and protium differ in the way of their isotopic structure. A nucleus of deuterium, commonly referred to as a deuteron, has one proton and one neutron. The other isotope, protium, has no neutrons in the nucleus. In a reactor, the heavy water “slows down neutrons so they are more likely to hit and split the uranium atoms” (Jenetopulos) A light water reactor uses regular water without deuterium in it. However, when using light water reactors, other products can be easily created to make nuclear weapons, which could be considered a liability. Another significant difference between the heavy water and light water reactors is the type of uranium that is used in each one. In a heavy water reactor, natural uranium can be used. Natural uranium is 0.7% U-235 and 99.3% U-238, which is not fissionable. The uranium that is used in light water reactors is U-235, which requires extensive enriching and separating from the U-238. Heavy water reactors do not require the uranium to be enriched like the light water reactors do, meaning that uranium can be used directly from the mining process in a heavy water reactor. Natural uranium is less expensive and can be used to produce the same amount of energy as enriched uranium, making heavy water reactors a potentially beneficial system. While the natural uranium used is less expensive, the heavy water necessary is hundreds of dollars per kilogram. Additionally, when using natural uranium, the fuel rods need to be replaced more often which translate to spent fuel in the process of moving and disposing of the rods. In the United States, we use light water reactors as opposed to Canada which uses heavy water reactors.

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**7. What is nuclear waste?  Describe in general and then characterize the nuclear waste of a standard light water reactor.** (Cole H)

Radioactive wastes are wastes that contain radioactive material. Radioactive wastes are usually by-products of **nuclear** power generation and other applications of **nuclear** fission. Uranium in a typical light water reactor 500,000 MJ/kg of natural energy, "Uranium Recovery." *NRC:*. N.p., n.d. Web. 29 Apr. 2014. In the long-term however, appropriate disposal arrangements are required for HLW, due to its prolonged radioactivity. Disposal solutions are currently being developed for HLW that are safe, environmentally sound and publicly acceptable. The solution that is widely accepted as feasible is deep geological disposal, and repository projects are well advanced in some countries, such as Finland, Sweden and the USA. In fact, in the USA a deep geological waste repository (the Waste Isolation Pilot Plant) "DoE Concludes WIPP Release Was Preventable." *Radioactive Waste Management*. N.p., n.d. Web. 27 Apr. 2014. (long-lived ILW contaminated with military materials such as plutonium), although Nevada is showing classic Nimbya  resistance to the proposed Yucca Mountain repository. These countries have demonstrated that political and public acceptance issues at a community and national level can be met. The nuclear industry therefore has clearly defined waste disposal methods for all waste produced and is making progress in many countries to achieve public acceptance of the approved programs. It is important that other governments in nuclear energy-producing countries now follow the lead set by these countries on the issue of long-term disposal of high-level radioactive waste.

* **What radionuclides are typically in radioactive waste and in what concentrations?**

Radioactive (or nuclear) waste is a byproduct from nuclear reactors, fuel processing plants, and institutions such as hospitals and research facilities. It also results from the decommissioning of nuclear reactors and other nuclear facilities that are permanently shut down. The Nuclear Regulatory Commission separates wastes into two broad classifications: (high-level or low-level waste. High-level radioactive waste results primarily from the fuel used by reactors to produce electricity. Low-level radioactive waste results from reactor operations and from medical, academic, industrial, and other commercial uses.) (got from)"Uranium Recovery." *NRC:*. N.p., n.d. Web. 29 Apr. 2014.

* **What are the half-lives of the radionuclides found in radioactive waste?**

High-level radioactive waste is uranium fuel that has been used in a nuclear power reactor and is “spent” or is no longer efficient in generating power to the reactor to produce electricity. Spent fuel is thermally hot as well as being highly radioactive, requiring remote handling and shielding. The basic fuel of a nuclear power reactor contains uranium 235, which is in ceramic pellets inside of metal rods. Before these fuel rods are used, they are only slightly radioactive and may be handled without special shielding. During the nuclear reaction, the fuel “fissions,” (got from) "Decay & Half Life." *IEM Integrated Environmental Management Inc Decay Half Life Comments*. N.p., n.d. Web. 29 Apr. 2014. Which means that an atom of uranium is split, releasing two or three neutrons and a small amount of heat. The released neutrons then strike other atoms, causing them to split, and a chain reaction is formed, which releases large amounts of heat. This heat is used to generate electricity at nuclear power plants. These are described in more detail below.

|  |  |  |
| --- | --- | --- |
| Radionuclide | % Yield | Half life |
| Cs-137 | 6.91% | half life million years | |
| Sr-90 | 4.51% | half life 30 years | |
| Cs-137 | 6.34% | half life 30 years 3.0x106 | |
| Pd-107 | 1.25% | half life 24,000 years | |
| I-129 | 0.84% | half life 15.7 million years | |
| TC-99 | 6.14% | half life 211,000 | |
| Zr-93 | 5.46% | half life 1.53 million years | |
| Sm-151 | 0.53% | half life 90 years | |
| Sr-90 | 4.51% | half life 30 years | |
| U-235 |  | half life 30 years | |

* **How much radioactive waste is produced by a typical light water reactor?**

The light water reactor is a type of thermal-neutron reactor that uses normal water, as opposed to heavy water, as both its coolant and furthermore a solid form of fissile elements is used as fuel. Thermal-neutron reactors are the most common type of reactor, and light water reactors are the most common type of thermal-neutron reactor. In the OECD countries, some 300 million tones of toxic wastes are produced each year, but conditioned radioactive wastes amount to only 81,000 m3 per year (reative from) "DoE Concludes WIPP Release Was Preventable." *Radioactive Waste Management*.” N.p., n.d. Web. 27 Apr. 2014. A typical 1000 MWe light water reactor will generate (directly and indirectly) 200-350 m3 low- and intermediate-level waste per year.

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**8. What are emissions from nuclear power plants?** (Allee M)

Nuclear power plants emit several types of radioactive waste, but create minimal carbon dioxide emissions and no emissions of the substances regulated by the clean water act. The clean air act limits emissions of nitrogen oxides, sulfur dioxide, airborne particles and mercury, nuclear power plants do not create any of these pollutants which can create smog, dust, acid rain (“Clean”). However fuel burning energy production does release these pollutants into the air. An average coal-fired power plant releases an average of 7,000 tons of sulfur dioxide, 3,300 tons of nitrogen oxide, 500 tons of airborne particles and 170 tons of mercury per year (“Environmental”). Additionally, a coal fired power plants emit approximately 3.5 million tons of carbon dioxide per year, while a nuclear power plant produces approximately 30 times less than that amount (“Environmental”; “Life-Cycle”).

Nuclear power plants do not emit any of these air pollutants but they do create contaminated waste. This waste is classified in one of several ways very short lived waste, very low level radioactive waste, low level waste, intermediate level waste, high level waste and disused sealed sources (“Overview”). This waste must be stored in secure locations until they have emitted all of their radiation and can be classified as normal waste, in some cases this can take billions of years, so high level waste must be in-earthed and left. Storage of nuclear waste produces its own environmental and health considerations. Nuclear power plants can also emit small leaching quantities of radioactive gases and liquids (“Radiation”).

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**9. What are environmental and safety considerations for the storage of nuclear waste?** (Allee M)

All nuclear waste must be stored securely as to prohibit its radiation from contaminating people, earth and air. Very short lived waste such as contaminated suits and other supplies can be stored on surface until radioactive decay is complete. Very low level waste must be stored in surface trenches. Low level waste is put into near surface engineered facilities; 97% of waste produced by nuclear power plants is classified as low level waste (“Radioactive”). This waste poses little concerns as concentration of radioactive materials is fairly low and in ground storage has become routine and can be transported and stored safely. Intermediate level radioactive waste is stored in deep geological subsurface facilities. High level waste (HLW) is currently stored in interim storage facilities until more secure storage can be created or until waste can be transported there (“Overview”). Currently the nuclear power industry creates 12,000 tons of HLW per year compared to over 300,000 tons of ash and sludge created by each coal fired power plant per year (“Radioactive”; “Environmental”). While HLW creation is relatively low in comparison to that of other energy industries, a long term, sustainable, solution that is accepted and used world wide for HLW storage is still being developed both nationally and internationally in Finland and Sweden (“Radioactive”).

A HLW storage facility (Waste Isolation Pilot Plan (WIPP)) exists near Carlsbad, New Mexico where radioactive waste and contaminated items are disposed into underground rooms carved into of salt formations over 2,000 feet below the surface (US). In-earthing radioactive materials does poses several health and environmental risks. Disposal facility accidents are one problem, these include misuse or malfunctions of operational equipment. At WIPP, this past February a salt excavation truck caught fire (“What”). While fire pose little risk to spreading radioactive waste, smoke inhalation in the underground spaces pose significant risk to workers. Workers in underground storage facilities face similar treats as miners. Because these facilities are underground risk of collapse, smoke inhalation (in the case of fire), gas inhalation and being in a sealed space with radioactive materials pose risk to workers. While all radioactive waste is sealed and surrounding them poses little risk, in the case of a leak, workers are then trapped underground, exposed to radiation. On February 14, 2014, another accident occurred at the WIPP, the spill caused radioactive particles to become airborne, both underground, threatening workers, and leaked through sealing valves, spreading radioactive dust into the environment and human habitat (“What”).

While radioactive storage is classified by varying levels and disposed of accordingly, the environment, safety and health can be compromised in case of accidents. In addition to these risks, safe HLW disposal is still being researched and new solutions and flaws are still being explored globally. Therefor, HLW disposal is still experimental and its safety can not be guaranteed.

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**10. Describe the science involved in global climate change and how it relates to emissions from nuclear power plants and fossil fuel power plants.** (Ande L)

* **What is the greenhouse effect and how is it related to global climate change?**

About 50% of the sun’s energy is absorbed in earth’s surface, and since it is warm it radiates thermal radiation. The greenhouse effect is the absorption of thermal radiation from the earth’s surface. And that thermal radiation has much larger wavelengths than solar UV rays emitted from the sun. Once the various gasses within the atmosphere absorb the thermal radiation from the earth’s surface some of the energy is bounced back and warms the overall temperature of the planet. Of the green house gases water vapor is about 36-70%, carbon dioxide 9-26%, methane 4-9% and ozone 3-7%. The problem that is occurring is the fact that the amount of CO2 being produced mostly by fossil fuels, as never been this high. And when you pump more green house gasses into the atmosphere it will cause the over all temperature to increase globally. And this is how the greenhouse effect relates to the huge issue of climate change.

* **What are greenhouse gases and what about their structure makes them greenhouse gases?**

The green house gases are water vapor, carbon dioxide, methane, and the ozone layer in the atmosphere. What makes a greenhouse gas is its ability to absorb certain wavelengths that is emitted from the earth’s surface. Short wave radiation passes through the atmosphere then is absorbed into the earth’s surface. Then long wave radiation is reemitted and absorbed by green house gases. The greenhouse gases absorb the long wave radiation, if they have three or more atoms. While O2 and N2 are what make up most of the atmosphere, they are not big enough for the long wave radiation to be absorbed. But CO2 and H2O have enough atoms, which the long wave radiation can be absorbed.

* **How has the amount of greenhouse gases in the atmosphere changed over time?**

Since we have adopted the use of fossil fuels, the amount of CO2 that is being emitted into the atmosphere has greatly increased. From prehistoric air bubbles found in ice core sample from sites all around the world showed the amount of CO2 varied at different levels, but it never has gone above 300 parts per million. Over the last 100 years the amount of CO2 found in the atmosphere sky rocked due to the industrial revolution and was more than 400 parts per million in 2012. And everyday that number is growing causing more heat from the earth’s surface to be absorbed and increase the temperature of the earth.

* **What are some predictions of global climate change?**

By 2100 the expected over all temperature is expected to rise by 5 degrees due to the increased CO2 emissions in the atmosphere. Because of the increased temperature the icecaps will melt and cause the sea level to rise. The expected amount the sea is supposed to raise is around 20 cm to 60 cm, which will displace millions of people living near the sea level. The countries that will be most affected will be low-lying countries like Bangladesh costing billions of dollars.

Another factor of global climate change is ocean acidification. Ocean acidification is the decrease of pH is the oceans through the absorption of CO2 in the atmosphere. The ocean absorbs about a quarter of the amount of CO2 emitted into the atmosphere every year. When the CO2 levels in crease so does the acidity of the oceans. When CO2 is absorbed into water carbonic acid is formed. Carbonic acid is proven to prohibit shell growth and cause some reproductive disorders in some fish. Shell-forming animals including corals, oysters, shrimp, lobster, many planktonic organisms, and even some fish species could be gravely affected. If we don’t control and eventually eliminate fossil fuel emissions, organisms will have to adapt or it will potentially cause them to perish.

* **How do the emissions from energy production by nuclear power plants compare to that of coal and of natural gas?**

Nuclear power plants do not emit carbon dioxide into the atmosphere but do require massive amounts of water for production. However problems with nuclear power plants are the fact they cannot be turned off very easily, as for oil and gas power plants they can be turned off fairly quickly. But emissions from nuclear power plants do not do a huge impact on the environment as a whole.

Coal plants are the primary source of CO2 emissions and are the primary cause of global warming. When coal is burned, carbon dioxide, sulfur dioxide, nitrogen oxides, and mercury compounds are released. The average emissions of the US are 2,249 lbs/MWh of carbon dioxide. As for oil and gas compared to coal it produces half as much CO2, and a third amount of nitrogen oxide (local air pollutant). The average emissions of the US are 1672 lbs/MWh of carbon dioxide for oil, and 1135 lbs/MWh of carbon dioxide for natural gas.

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**11. What are the best estimates for the purely financial cost of nuclear power generated electricity?** (Ashton C)

* **What are the levelized costs per kWh?**

The LOCE (Levelized Cost Of Electricity) system total is 96.1 MWh for an advanced nuclear plant.

* **What are fuel costs annually or per kWh? Construction costs for a new plant? Operating and maintenance costs?**

The average fuel cost at a nuclear power plant in 2012 was 0.75 cents / kWh. Construction for a new plant average over a couple billion dollars for everything that is needed for the process of the build. The average non-fuel O&M (Operations and Maintenance) cost for a nuclear power plant in 2012 was 1.65 cents / kWh.

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**12. Optional Science Considerations:**

* How do the closed waste cycle and open waste cycle fuel options compare?
* 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?
* **What are heavy water reactors and how do they differ from light water reactors?**
  + See final bullet point, question number six
* 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?