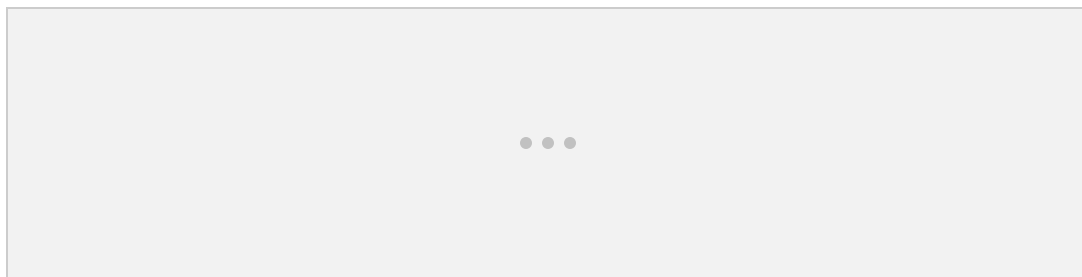


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1. How does nuclear fission work? You should describe the process in general and then describe the exact mechanism of one fission process (i.e. U-235 or Pu-239).

Nuclear fission occurs when an atom splits in two. When this occurs, energy is released, as well as radioactive particles. This occurs spontaneously, but also can be induced in elements like Uranium. This happens by firing a free neutron at the atom. The parent nuclei is hit by the neutron. The parent nuclei then fires out a few neutrons and at least two daughter nuclei. This process releases a substantial amount of energy. One fission process occurs in nuclear power plants. In the core of the nuclear reactor, an element such as U-235, undergoes decay. The decay of U-235 releases energy in the form of heat and turns water into steam, which powers a turbine generator. This method of generating power is very clean, but has potential radioactive hazards. One possible way that the U-235 can decay is seen in the following equation:



In this equation the U-235 is the parent nuclei. When hit with a free neutron, it produces two daughter nuclei: Kr and Ba. It also releases three neutrons.

How Nuclear Power Works

Marshall Brain and Robert Lamb

<http://science.howstuffworks.com/nuclear-power1.htm>

Image:

Nuclear Fission

http://antonine-education.co.uk/Pages/Physics_GCSE/Unit_2/Add_14_Fission/add_14.htm^[SS1]

2. 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 meaning of $E=mc^2$ is Energy = mass times the speed of light squared. It is a way to measure the amount of energy in an object. This is very important to nuclear power. This equation is a way to determine how much energy you can get from elements like Uranium when it is placed inside of the reactor of a nuclear power plant. For example, if you had one kg of uranium in the reactor and wanted to see the amount of energy it has, you would use this equation. You would start by setting up the equation. $E=1\text{kg}(3\times 10^8\text{ms}^{-1})^2$. You would end up finding that 1 kg of that uranium holds 90,000,000,000,000,000 joules of energy. Conservation of mass says that one element cannot undergo a reaction and change in mass. However, when looking at radioactive decay, energy can be viewed as mass. Any energy produced would make up for the amount of mass lost during decay. Because of these laws, we are able to determine about how much energy will be produced during the decay process.

$E=mc^2$: Solving the Equation

(No listed author)

<http://www.emc2-explained.info/Emc2/Equation.htm#.U1E2M1VdX1c>

3. How are radioactive materials for nuclear power plants mined, milled, and enriched?

- a. How much of our energy needs can uranium provide?
- b. What are environmental and safety issues associated with the mining and refining of nuclear fuel?

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

The process making uranium fuel pellets starts with exploration. Geologists determine as best they can where deposits of uranium may be. The uranium is then mined using either open pit mining or traditional underground methods similar to that of other metal extraction. In the US, in-situ leach mining processes are used in addition to the other methods. In this technology, uranium is leached from the in-place ore through an array of regularly spaced wells and is then recovered from the leach solution at a surface plant.

Once the uranium has been mined, it is sent to a mill. Milling happens when the mined uranium ore is ground up to a uniform particles size and then treated to extract the uranium via chemical leaching. The product of milling, often called yellowcake, is a dry powdery substance that is sold on the uranium market as U_3O_8 .

The milled uranium is then converted into uranium hexafluoride (UF_6). Uranium hexafluoride is the form that is most commonly used by uranium enrichment facilities. Once the uranium has been converted, it goes through the enrichment process.

The correct concentration of uranium-235 does not occur in nature, so the uranium hexafluoride must be enriched to a certain concentration for the customer. The most common concentration is about 3.5% uranium-235. To enrich the uranium, one or more methods of isotope separation are used. Two of the most common methods are gaseous diffusion and gas centrifuge.

Gaseous diffusion works by forcing uranium hexafluoride (UF_6) in its gaseous form through a

permeable membrane, which slightly separates the uranium-238 and uranium-235. Gas centrifuge works by using centrifugal force to accelerate the molecules and then separates the molecules of different mass as they travel different distances.

The main by-product of uranium enrichment is depleted uranium. Depleted uranium is uranium that has a lower uranium-235 content than is found in nature. This material is dense and can be used in many things such as armor, kinetic energy penetration, and, ironically, radiation shielding.

When open-pit mining is used, rocks that may contain radioactive materials is exposed and crushed up, releasing radioactive elements into the air, which animals or workers can then breathe. Tailings and other radioactive wastes can be washed into bedrock if they are not properly contained.

When underground mining is used, toxic chemicals can be released into the air or water. If enough of something gets into a water supply, then the water becomes a contaminant and can infect the surrounding area. As is a concern with any underground mining, the possibility of cave-ins is a big danger to the workers as well as the surrounding ecosystem.

If in-situ leach mining is used, many of the environmental and safety concerns of the other two methods are evaded. However, the strong acids used to dissolve the ore body commonly dissolve metals in the host rock as well. The fluids remaining after the leaching process commonly contain elevated concentrations of metals and radioactive isotopes, posing a significant risk to nearby water sources. Additionally, the low pH of ISL mining wastewater can result in acidification of the surrounding environment.

Known Recoverable Resources of Uranium 2011		
	Tonnes U	Percentage of world
Australia	1,661,000	31%
Kazakhstan	629,000	12%
Russia	487,200	9%
Canada	468,700	9%
Niger	421,000	8%
South Africa	279,100	5%
Brazil	276,700	5%
Namibia	261,000	5%
USA	207,400	4%
China	166,100	3%
Ukraine	119,600	2%

Uzbekistan	96,200	2%
Mongolia	55,700	1%
Jordan	33,800	1%
other	164,000	3%
World total	5,327,200	

The table above shows how much each country has in terms of recoverable uranium. It also shows what percentage each country has compared to the world. It is interesting to note that Australia is the only country that has a significant percentage of the uranium. The United States of America is low on the list with only 4% of the total amount of recoverable uranium. In 2012, the average nuclear power plant in the United States generated about 11.8 billion kilowatt-hours (kWh). There were 65 nuclear power plants with 104 operating nuclear reactors that generated a total of 769 billion kilowatt-hours (kWh), or 19% of the nation's electricity. Thirty-six of those plants have two or more reactors. The Palo Verde plant in Arizona has three reactors with the largest combined generating capacity of about 3,937 megawatts. Fort Calhoun in Nebraska had the smallest capacity with a single reactor at 502 megawatts.

Energy Conversion: Typical Heat Values of Various Fuels	
Firewood (dry)	16 MJ/kg
Brown coal (lignite)	10 MJ/kg
Black coal (low quality)	13-23 MJ/kg
Black coal (hard)	24-30 MJ/kg
Natural Gas	38 MJ/m ³
Crude Oil	45-46 MJ/kg
Uranium - in typical reactor	500,000 MJ/kg (of natural U)

Figure 1:

<http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Introduction/Energy-for-the-World---Why-Uranium-/>

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4. Describe the design of a light water nuclear power plant.

Radiation is an incredible phenomenon, and can create an abundance of power for many people around the world. Creating this power can be very complicated.

The fuel used in Nuclear Reactors is usually Uranium Oxide (UO_2) pellets. These pellets make up fuel rods. The Uranium in these fuel rods decays and shoots radiation onto the other fuel rods, causing them to decay as well. It is a chain reaction that generates extreme amounts of heat. This heat must be controlled, so control rods are placed between the fuel rods. The control rods must be made of neutron-absorbing material, so they stop the radiation when it hits them. Cadmium, hafnium or boron is usually used as the control rod material. The control rods can be raised or lowered, allowing more or less of the fuel rods to react. The control rods can even shut down the reaction completely, if necessary.

In pressurized water reactors, inside the core, water acts as the primary coolant. A pressurizer pressurizes the water so it will not create steam inside the core. The water runs around the fuel rods as they heat it. It is pumped through the core and runs into a radiator-like system. In this system, the primary coolant runs through a secondary coolant. The secondary coolant is also water, but is not as pressurized, as it must be allowed to generate steam. As the steam generates it turns a turbine, which powers a generator. The steam then flows through a condenser, which is another coolant. The steam condenses into water which runs back to the primary coolant to be used again. The water for the condenser can be used from nearby water sources, such as streams, rivers, or oceans.

5. Describe operating processes of a light water nuclear power plant.

a. What is the fuel for light water nuclear reactors and what form does this fuel take?

Light water nuclear reactors produce heat through nuclear fission and then use the created heat to generate energy, by converting water into steam which then turns a turbine. The reactors are fueled by radioactive rods that can be 5 to 9 inches square and up to 12 feet long. Radioactive pellets, made up of low-enriched uranium dioxide, fill the fuel rods. Some companies combine the low-enriched uranium dioxide with plutonium oxide. The fuel rods are then placed in the reactor's core with upwards of 270 fuel rods in the core at the same time. The group of fuel rods is referred to as the fuel assembly.

"Fuel Fabrication." *NRC*:. N.p., n.d. Web. 24 Apr. 2014.

<<http://www.nrc.gov/materials/fuel-cycle-fac/fuel-fab.html#mixed>>.

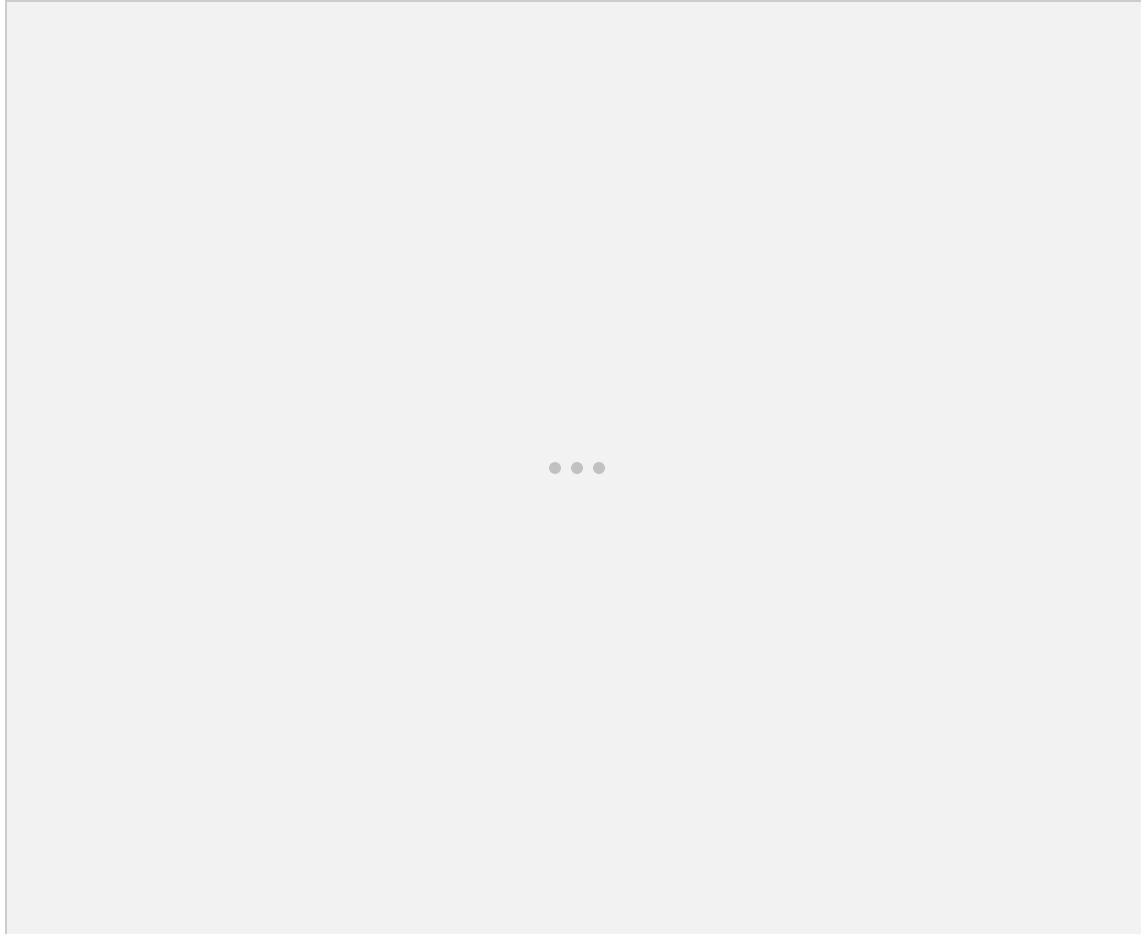
a. **How much energy does a typical power plant produce? How many homes can this serve?**

In 2012, an average nuclear power plant, which contains at least one nuclear reactor, was able to generate 11.8 billion kilowatt-hours, which is approximately the amount of energy it would take to light 1,970,000,000 sixty watt light bulbs for 100 hours. This amount of electricity would also provide energy to approximately 1 million American homes for an entire year.

"U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." *How Much Electricity Does a Typical Nuclear Power Plant Generate?* N.p., n.d. Web. 23 Apr. 2014. <<http://www.eia.gov/tools/faqs/faq.cfm?id=104&t=3>>.

b. How often fuel rods and control rods need to be replaced and how this process is conducted?

After 18-36 months the used fuel rods are removed and replaced. When removed from the reactor, the fuel still is emitting radiation and heat. To shield the radiation and absorb the heat, the fuel is immediately placed in storage ponds which are located near the reactor. The used fuel will sit in the ponds from anywhere between several months and several years. If the fuel is in the pond for longer than five years it is transferred to a naturally-ventilated dry storage on site. The used fuel can then be reprocessed to recover the usable portions or the fuel can be placed in long term storage without reprocessing. The US currently doesn't reprocess its previously used fuel. To reprocess the fuel, it is placed in an acid that breaks down the uranium and plutonium. From here the used fuel can be converted into fuel that can undergo fission to create energy in the reactors. The figure below shows the process that the fuel goes through in order to create energy. Starting with mining, the uranium is extracted from the tailings, converted, enriched, fabricated, put in the reactor and stored. The stored fuel can either be reprocessed or disposed of.



"The Nuclear Fuel Cycle." *Nuclear Fuel Cycle Overview*. N.p., n.d. Web. 24 Apr. 2014.
<<http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Introduction/Nuclear-Fuel-Cycle-Overview/>>.

c. How do power plant operators control the rate of power generation and how easy is it to change power supply to meet demand?

Control rods, which are located between each of the fuel rods, allow the operators to control the rate of the nuclear reaction. The reaction occurring in light water reactors is known as fission, which is a process where one unstable atom will decay and split into smaller pieces. The control rods are made from a material that absorbs neutrons so by lowering the rods the reaction slows and less heat is created. By raising the rods the reaction increases and more heat is created. The operators can move these rods up and down easily and are able to change the height at any moment to determine how much heat is created by the uranium.

Brain, Marshall, and Robert Lamb. "How Nuclear Power Works." *HowStuffWorks*.
HowStuffWorks.com, 09 Oct. 2000. Web. 23 Apr. 2014.
<<http://science.howstuffworks.com/nuclear-power2.htm>>.

d. **What do power plant designers and operators do to ensure safety?**

To ensure safety, power plants have been designed so that most operations can be controlled remotely from behind protective barriers. The work that isn't controlled remotely is closely monitored to ensure the health and safety of workers. Workers are only allowed to work in radioactive areas for limited amounts of time and the areas that they work in are monitored to ensure that radioactivity doesn't exceed a dangerous amount. Various layers of protection exist between the radioactive substances and the operators. Fuel pellets are contained in a zirconium alloy tube which is confined inside a steel pressure vessel with walls up to 30 cm thick. All of this is further contained by a concrete structure with walls at least one meter thick. To ensure that these barriers are performing correctly they are monitored continually. The fuel pellet encasement is monitored by finding the amount of radioactivity in the cooling water. The cooling system is monitored by the leak rate of water and the containment structure is monitored by the leak rate of air that is at about five times the atmospheric pressure. Control rods are also used to monitor how much heat is created in the reactor. The operators can ensure the reactor doesn't over heat by lowering the rods whenever the reactor gets too hot. Nuclear reactors also have various types of emergency core cooling systems. These will shut down and cool the reactor when the existing cooling system fails. Many nuclear power plants have sensors that will automatically shut down the reactor when an earthquake occurs.

"Safety of Nuclear Power Reactors." *Safety of Nuclear Reactors*. N.p., n.d. Web. 22 Apr. 2014. <<http://www.world-nuclear.org/info/Safety-and-Security/Safety-of-Plants/Safety-of-Nuclear-Power-Reactors/>>.

e. **What is the lifespan of a typical light water reactor nuclear power plant? What is the current status (age & condition) of the US nuclear power plant fleet?**

The lifespan of a typical light water reactor was 30-40 years but because of new technology, the lifespan has increase to 40-60 years. The US has 100 reactors, 65 of which are pressurized water reactors and 35 of which are boiling water reactors, in 31 different states owned by 30 different companies. In 2012 nuclear reactors produced 800 TWh (terawatt-hours), which was 19% of the United States' gross electricity. The average age of nuclear power plants in the United States is 33 years old. The oldest nuclear reactor is Oyster Creek in New Jersey and it began its operations in 1969. The majority of nuclear power plants began construction before 1974.

"Nuclear Power Reactors." *Nuclear Reactors*. N.p., n.d. Web. 24 Apr. 2014. <<http://www.world-nuclear.org/info/nuclear-fuel-cycle/power-reactors/nuclear-power-reactors/>>.

"Fuel Cycle Roundup #24." *Nuclear Power in the USA*. N.p., n.d. Web. 23 Apr. 2014. <<http://www.world-nuclear.org/info/Country-Profiles/Countries-T-Z/USA--Nuclear-Power/>>.

"Oyster Creek Nuclear Generating Station." *Wikipedia*. Wikimedia Foundation, 23 Apr. 2014. Web. 25 Apr. 2014.

<http://en.wikipedia.org/wiki/Oyster_Creek_Nuclear_Generating_Station>.

f. **What is the typical efficiency of a light water nuclear reactor?**

Depending on the different types of light water nuclear reactors, efficiencies can vary between 35% and 45%.

"U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." *What Is the Efficiency of Different Types of Power Plants?* N.p., n.d. Web. 25 Apr. 2014.

<<http://www.eia.gov/tools/faqs/faq.cfm?id=107&t=3>>.

"The Efficiency of Power Plants of Different Types." *Brighthub Engineering*. N.p., n.d. Web. 25 Apr. 2014.

<<http://www.brighthubengineering.com/power-plants/72369-compare-the-efficiency-of-different-power-plants/>>.

6. What safety risks accompany the use of nuclear power?

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

Living within 50 miles of an active nuclear power plant exposes residents in that vicinity to 0.01 millirem per year. The average dose that a US citizen receives annually is 300 millirems. Although no amount of radiation is safe, nuclear power plants do not pose a threat to the surrounding environment.

<http://www.nrc.gov/about-nrc/radiation/related-info/faq.html#9>

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

The risk for a nuclear meltdown in the US is very very small. For instance, the risk of a nuclear meltdown in Europe in 1985 was calculated to be around 0.1%. Not only has nuclear technology greatly advanced since then but the US also has higher safety standards than most countries.

<http://www.ipnw-students.org/chernobyl/meltdown.pdf>

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

The two main safety features in most modern light water reactors are. Control rods made that limit the rate of fission by absorbing the neutrons created by the reaction, therefore limiting the chain reaction that will occur. A passive safety measure is in the event of a nuclear meltdown the water in the reactor core boils and forms pockets of steam. The steam slows [SS2] down the fast neutrons causing a significant decrease in power.

<http://www.world-nuclear.org/info/Safety-and-Security/Safety-of-Plants/Safety-of-Nuclear-Power-Reactors/>

http://en.wikipedia.org/wiki/Passive_nuclear_safety

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

Nuclear power plants are very safe from terrorist attacks such as if a plane were high jacked and crashed into the plant. The uranium used in the plants is not enriched enough to cause a nuclear bomb like explosion. The main goal of a terrorist attack would be to breach the containment domes and release radiation, contaminating a large area. The containment domes have walls three to six feet thick reinforced with steel bars and a half inch steel liner. A test was carried out in which a plane was flown at around 500 miles an hour into a mock wall. The plane was destroyed while the wall stayed sound. Nuclear power plants are built to be able to withstand pretty much all earthquakes. In seismically active areas such as Japan there are detectors that will shut the plant down if certain seismic activity is detected.

<http://www.nytimes.com/2002/01/21/opinion/nuclear-reactors-as-terrorist-targets.html>

<http://www.world-nuclear.org/info/Safety-and-Security/Safety-of-Plants/Nuclear-Power-Plants-and-Earthquakes/>

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

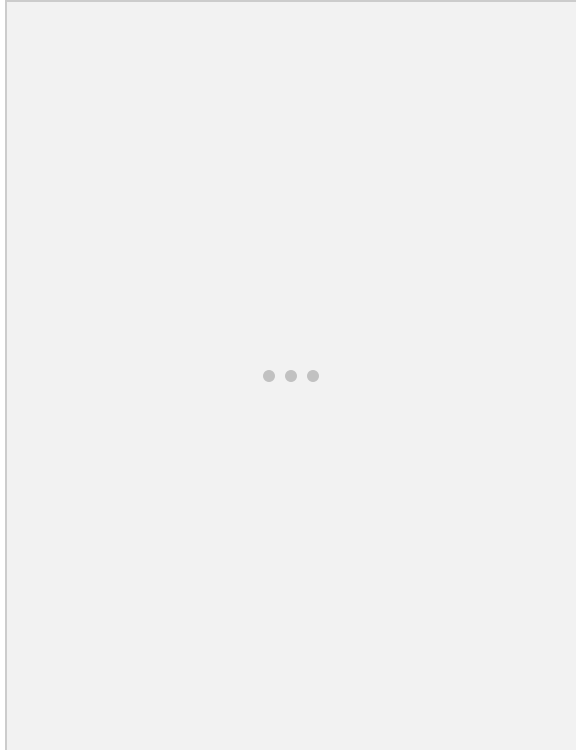
d. What radionuclides are typically in radioactive waste and in what concentrations

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

f. What are the types of decay the radionuclides in radioactive waste undergo?

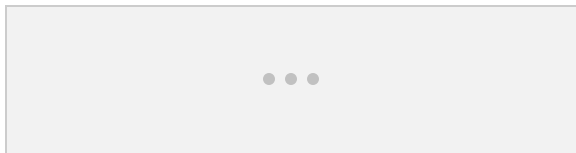
What are their decay energies? You may describe the entire decay chain or only the most relevant decay processes.

g. How much radioactive waste does a typical light water reactor produce?



Nuclear waste is the material that is left over after a radioactive substance has gone through radioactive decay and is no longer being used but still has radioactive material in it. For example, a light water reactor uses uranium-235 as a fuel and when the fuel has been hit with a neutron and decays releasing energy and neutrons, it turns into thorium-231. Thorium is still radioactive and can still undergo radioactive decay, so it is considered a nuclear waste. The fission of uranium in a nuclear power plants creates many elements. The most common products of nuclear fission in a nuclear reactor are uranium-238, uranium-235, and polonium-239/240. There are other elements that are created in fission but they are uncommon and make up a small percentage of nuclear waste.

About 96% of the mass is the remaining uranium: most of the original ^{238}U and a little ^{235}U . Usually ^{235}U would be less than 0.83% of the mass along with 0.4% ^{236}U .



About 1% of the mass is ^{239}Pu and ^{240}Pu resulting from conversion of ^{238}U , which may be considered either as a useful byproduct, or as dangerous and inconvenient waste.

Traces of the minor actinides are present in spent reactor fuel. These are actinides other than uranium and plutonium and include neptunium, americium and curium.

The half-life of plutonium-240 is about 6,563 years. A plutonium-240 particle emits alpha decay when a neutron hits a plutonium-239 particle. The half-life of uranium-238 is almost 4.5 billion years. The decay energy of plutonium-240 is 5.255 MeV (MeV stands for "Million Electronvolts"). When a uranium-238 atom decays, it emits an alpha particle and becomes thorium-234. The decay energy of uranium-238 is 4.267 MeV.

Uranium-235, on the other hand, has a half-life of 703.8 million years. When it decays, it emits alpha particles and becomes a thorium-231 atom. Its decay energy is 4.679 MeV.

When talking about nuclear waste, there are three classifications of that waste: low-level, intermediate-level, and high-level. Low-level waste includes things like suits, rags, or other things that do not fit into another category of waste that have been irradiated by radioactive materials. Intermediate-level waste are items that have been exposed to more radiation than low-level waste, but are still not at the level of high-level waste.

Intermediate-level waste includes things such as resins or chemical sludge. High-level waste is the actual radioactive fuel that does not get used in the fission process.

Worldwide, nuclear reactor facilities only produce about 200,000 square meters of low and intermediate-level waste and about 10,000 square meters of high-level waste each year. A typical light-water reactor only makes about 200-350 square meters of low and intermediate-level waste each year. Only about 20 square meters of this waste is used fuel. If the fuel is reprocessed, it is possible to only produce 3 square meters of vitric waste (glass) (WNA).

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

Nuclear waste is often talked about as being unsafe and as one of the largest issues facing the environment. The truth of the matter isn't that simple; in some cases, yes, it is an extreme toxin to the environment, but radioactivity comes from much more than just nuclear fission reactors. Fission reactors do cause upwards of 95% of all radioactivity produced, but the amount of waste that the reactors produce is under 1% of all waste produced.

Nuclear power is the only large-scale energy-producing technology which takes full responsibility for all of its wastes and fully costs this into the product. Although they take all waste into consideration, the amount of radioactive wastes produced by nuclear reactors is very small relative to wastes produced by using fossil fuels for electricity generation. The waste produced isn't particularly hazardous nor is it hard to manage relative to other toxic industrial waste. The internal consensus for the disposal of high level radioactive wastes is geological disposal, which has been technically proven.

There are four main types of radioactive waste: exempt and very low level waste, low-level waste, intermediate-level waste, and high-level waste.

Very low level waste is produced from demolished materials that were once part of a nuclear power plants. These radioactive materials aren't considered harmful to the surrounding environment or to the people and is therefore disposed of along with domestic refuse. One current nuclear energy advocate, France, is developing facilities to store very low level waste and is also developing specifically designed very low level waste disposal facilities.

The next level of wastes, low-level wastes, is generally produced from hospitals and industry as well as the nuclear fuel cycle. Low-level waste is typically contained in paper, rags, tools, clothing, and filters. All of these contain a small amount of mostly short-lived radioactivity. During handling and transport these do not require any type of shielding and are suitable for shallow burial. Before being buried these wastes are incinerated or compacted. Although low-level waste comprises 90% of all of the radioactive waste, it only contains 1% of the entire radioactivity in all of the radioactive waste produced.

The third level of waste is intermediate-level. These wastes unlike the others do require a small amount of shielding during transport and handling. This is the waste produced from decommissioning old nuclear power plants. This category typically is comprised of resins, chemical sludges, and metal fuel cladding as well as contaminated materials from reactor decommissioning. For disposal small items and non-solids are often solidified in concrete or bitumen. This category makes up 7% of all waste and has 4% of all radioactive waste produced. The final level of waste, high-level waste, is the product of using nuclear power. This arises from "burning" uranium fuel in nuclear reactors. "Burning" uranium happens when uranium fuel rods react with each other. From this reaction "ash" is produced, which is what this category is mainly comprised of. This type of waste required both heavy shielding and cooling, as it is highly radioactive and extremely hot. There are two different types of high-level waste, the used fuel itself and separated waste from reprocessing used fuel. There are also two different components in high-level waste; it has both long-lived and short-lived components. Generally short-lived fission products can be separated from long-lived actinides, actinides being radioactive particles. This becomes important in management and disposal of high-level waste. High level waste makes up only 1% of all radioactive waste produced, but it contains 95% of all radioactivity from nuclear waste.

There is no perfect way to dispose of nuclear waste; our current solution that has been agreed upon by every nuclear committee is to dispose of it in the ground. The nuclear power industry is currently trying to find a way to mark the burial sites with symbols so that for the remainder of time that the earth exists, it will be marked and people will stay away. Less than 1% of all nuclear waste in the world comes from the production of nuclear power; the other 99% mostly comes from our general everyday tasks.

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"DoE concludes WIPP release was preventable." *Radioactive Waste Management*. N.p., n.d. Web. 27 Apr. 2014.

<<http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Nuclear-Wastes/Radioactive-Waste-Management/>>.

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

Nuclear power plants themselves emit no criteria emissions (the six most common air pollutants: Ozone, particulate matter, carbon monoxide, nitrogen oxides, sulfur, and lead) or greenhouse gasses. The only emission produced during energy production is water vapor. The mining of the uranium can however produce around 2000-5000 tons of CO₂ per year. Nuclear power plants do not affect the local air quality as they only emit warm water vapor which rises high into the atmosphere.

<http://www.epa.gov/air/urbanair/>

<http://www.nei.org/Issues-Policy/Protecting-the-Environment/Life-Cycle-Emissions-Analyses>

<http://ec.europa.eu/environment/integration/research/newsalert/pdf/109na4.pdf>

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

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

The greenhouse effect is, somewhat of a found/proven fact, that there are gasses that are being created and trapped in our atmosphere. As a result the earth is heating up. However, even though the greenhouse effect may be one reason responsible for climate change, it provides a cycle that helps support life. For instance, without it, there is a slight chance the earth could actually freeze. Making the environment an inhabitable planet for life.

Even though this cycle does support life, it also destroys homes for other wild animals. For example, glaciers that are home to polar bears, penguins, and other mammals are melting away so significantly that the climate change is so dramatic, that ways to help find a cleaner energy is to reduce the climate change.

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

Greenhouse gases are carbon dioxide and chlorofluorocarbons. These gases contribute to the greenhouse effect by absorbing infrared radiation.

Sources

<http://www.dnrec.delaware.gov/ClimateChange/Pages/Greenhouse%20Effect.aspx>

<http://www.acs.org/content/acs/en/climatescience/greenhousegases.html>

11. What are the best estimates for the purely financial cost of nuclear power generated electricity?

One factor that weighs heavily upon the production of energy is the total levelized cost of the system compared to the total levelized cost of another. In the case of nuclear energy the total levelized cost is \$107.30 per megawatt hour produced. This number is more than only three

other types of energy production: geothermal, conventional coal, and conventional natural gas. One major factor in the cheapest energy, natural gas, is that it is subsidized by the government, making it cheaper than any other type of energy production.

Nuclear energy does have one of the lowest costs for operation and maintenance though, coming in at only \$8.70 per megawatt hour produced. This cost factors in the cost of fuel as well as operation and maintenance. Only renewable energy and hydroelectric energy production is cheaper, with renewables costing nothing for fuels, operations, and maintenance and hydroelectric costing \$6.10 per megawatt hour produced.

On top of all of that, nuclear energy also has the highest capacity factor of all power generation at 90%. Geothermal energy is the only type of energy that is similar; it is tied with nuclear energy. All other energy sources have a lower capacity factor, making them less efficient than nuclear.

Nuclear energy is the cheapest energy to produce based on its fuel costs. Per mWh (megawatt hour) of energy produced, it costs between \$1-3/mWh. By contrast renewables have a much larger cost, coming between \$15-80/mWh produced. Of course, this number depends on country, context, and the type of technology (onshore wind < offshore wind < Solar Photovoltaic). Over half of the cost of nuclear power plant construction is directly related to the cost of licensing, approval, and other bureaucratic expenses. A recent proposal for plant construction by NuStar is expected to cost \$520 million for licensing alone. Some have suggested that a modular reactor system could be built for under a few million dollars. This might be possible, and some of the smaller experimental reactors were able to be constructed for, by modern standards, extremely low costs. At the moment the cost to make a nuclear power plant is around \$255 million. This number includes the cost of security around the plant, non-power related pieces such as roads and land clearing, and the power itself. The estimated cost for just the power plant, no security or roads, is \$220 million. The cost for a plant with licensing, security, and everything else is estimated to be around \$775 million.

A nuclear power plant at the moment is one of the most expensive things in energy production. Because the building of the plant and operating of the plant is not subsidized by the government, the cost for everything must come from an independent company. The operating costs once the plant is produced are less than most other types of energy production, making nuclear power a viable source of energy for the future.

Works Cited

"Depleted Cranium » Blog Archive » What does it cost to build a nuclear plant? What could it cost?." *Depleted Cranium RSS*. N.p., n.d. Web. 27 Apr. 2014.
<<http://depletedcranium.com/hope-this-works/>>.

"The Economics of Nuclear Power." *Nuclear Power Economics*. N.p., n.d. Web. 27 Apr. 2014.
<<http://www.world-nuclear.org/info/Economic-Aspects/Economics-of-Nuclear-Power/>>.

12.

b. 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?

Breeder Reactors (Fast Neutron Reactors) are much different from Light Water Reactors. A light water reactor uses a moderator to slow down the radiation between fuel rods to maintain maximum efficiency. Breeder reactors, however, use moderators that slow the neutrons much less, letting them maintain their speed. Natural Uranium must be concentrated so it contains a relatively higher ratio of U235 isotopes to U238 isotopes. This Uranium fuel contains 3-8% U235. U235 fissions readily, unlike U238. Most of the fissioning happens to the U235. U238 can be useful, as it turns into Pu239 when it absorbs fast neutrons. This Pu239 decays into U235. Pu239 fissions as reactors operate, but as they fission, they reduce the amount of fuel left in the reactor. Fast neutrons are absorbed by U238 easily, and do not easily cause fission in Pu239, which makes them good for creating high amounts of U235. These reactors can generate 30% more fuel than used in the reaction. The plutonium created in these reactions can be used in nuclear weapons, which has become a concern. Another concern is that the waste can cause high radiation exposure when it is being reprocessed.

Sources

"How Do Fast Breeder Reactors Differ from Regular Nuclear Power Plants?" *Scientific American Global RSS*. N.p., 17 July 2006. Web. 28 Apr. 2014.

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

Heavy water nuclear reactors use heavy water (D₂O) rather than light water (H₂O) as a moderator. It slows neutrons even more than regular water, as it is 10% heavier. Heavy water reactors can use Uranium that has not been enriched as fuel. It can be used right from the mine.

Sources

"Light Water Reactors." *Light Water Nuclear Reactors*. HyperPhysics, n.d. Web. 29 Apr. 2014. <<http://hyperphysics.phy-astr.gsu.edu/hbase/nucene/ligwat.html>>.

- d. 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?

Nuclear fusion is when two atomic nuclides collide at a high speed to form one new type of an atom. Fusion creates three to four more times the energy as fission does, although it is still in the experimental phases, as scientists are attempting to find the best way to collide the two particles together in the most efficient way. Fusion reactors also produce less radioactive waste which deteriorates in a short to medium timescale rather than the long timescale of fission reactor waste. One major safety risk is the possible release of tritium which is radioactive and hard to contain. If it did leak, it could make our water and air slightly radioactive.

"Convoy Tests 'Iter Itinerary'" *Nuclear Fusion : WNA*. N.p., n.d. Web. 25 Apr. 2014.

<<http://www.world-nuclear.org/info/current-and-future-generation/nuclear-fusion-power/>>.

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

The closed waste cycle is a way to recycle radioactive waste. Most reactors use U-235, and view the more common U-238 useless when it comes to generating power. When a

generator uses up its supply to U-238, it needs to be restocked, even though there are substantial amounts of U-238 inside of it. [SS3] The most common way to use the closed cycle waste is to filter the P-239 out of the U-235 and then reuse the U-235. Another way to utilize the closed waste cycle involves taking the U-238 and adding a neutron to it, turning it into P-239. This is a very usable element, as it acts very similar to U-235. As this process continues, the final waste is harmless after a couple hundred years, instead of the hundreds of thousands of years it takes for the waste to become safe when it is in an open waste cycle. The open waste cycle is much cheaper than the closed waste cycle, but not as efficient. Once the U-235 is used up, the waste is removed and stored until it is no longer radioactive. However, the waste from the open cycle system takes much longer to become harmless than the waste from the closed cycle.[SS4]

“Recycling Nuclear Waste and Breeder Reactors”

Nick Touran

<http://www.whatisnuclear.com/articles/recycling.html>

[SS1] Make sure you are following a standard citation format like MLA

[SS2] The steam wouldn't slow the neutrons down, which surprisingly means they would be going too fast to hit and join another atom.

Anything else? Containment structure, back up cooling pumps etc.

[SS3]?

[SS4] Which does the US employ? Does the cost question take into account the cost to safely store radioactive waste?