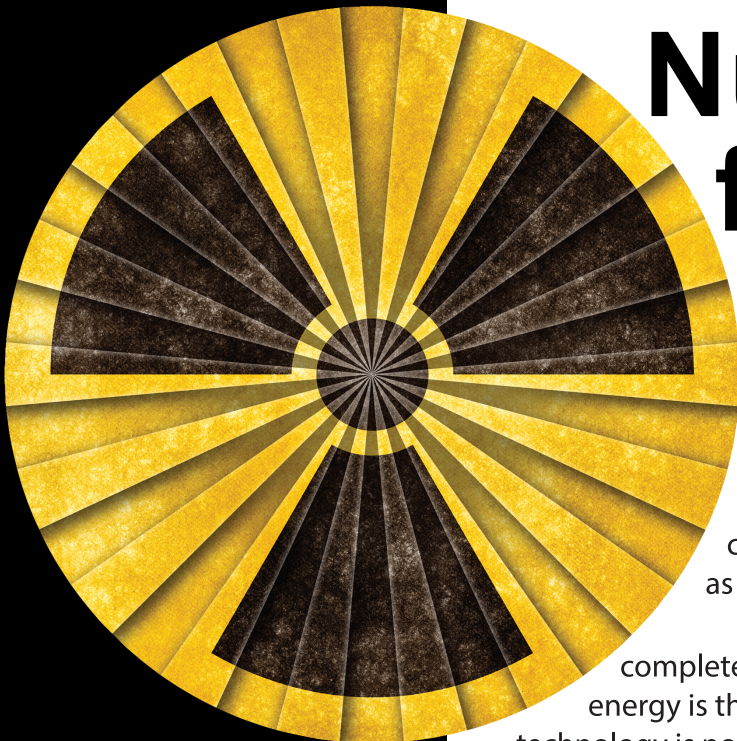

Science
The Future of
Clean Power



Nuclear Power for the Future

The demand for clean energy sources is growing each year, along with global energy consumption. The vast majority of the population is aware that fossil fuels pollute the environment, are in limited supply, and are expensive. Environmental engineering is a growing field that seeks to meet the world's energy demand and clean up the planet with renewable energy sources such as wind, solar, and hydroelectric. The problem with using completely renewable energy is that human technology is not advanced enough to supply a constant and reliable source of power. Nuclear power is a an extremely potent energy source that releases a fraction of the pollution from other non-renewable energy sources, and is substantially more potent. The big problem with nuclear power is that a majority of the public is terrified by the thought of living near a plant. Nuclear power is very dangerous, but is also heavily regulated, and when operated under strict procedures, it is very safe. Education if the key to eliminating the public's fear about nuclear power, and allowing it to be used more for energy.

Radiation is a phenomena that occurs when an unstable atom undergoes fission into one or more daughter nuclei, releasing energy and energy other small particles. There are three main types of nuclear radiation, alpha, beta, and gamma radiation, each are slightly different in their prostheses but have similar effects. The small particles released (an alpha particle, electron or positron, or gamma ray bundles) during fission are responsible for the effects of radiation. The small particles have massive amounts of energy as they break apart the strong bonds of the atom, transferring their momentum to other particles, ionizing them. Ionization changes the molecule, potentially causing bodily harm or effecting DNA. When the body tries to repair itself, it may create cancer as the cell's DNA is altered. Alpha radiation is made up of a helium nucleolus and looses its energy very quickly, and cannot penetrate skin. Beta particles can penetrate a bit further, but gamma radiation can pass completely through a person and can cause more harm.

"We must not let ourselves be swept off our feet in horror at the danger of nuclear power. Nuclear power is not infinitely dangerous. It's just dangerous, much as coal mines, petrol repositories, fossil-fuel burning and wind turbines are dangerous."

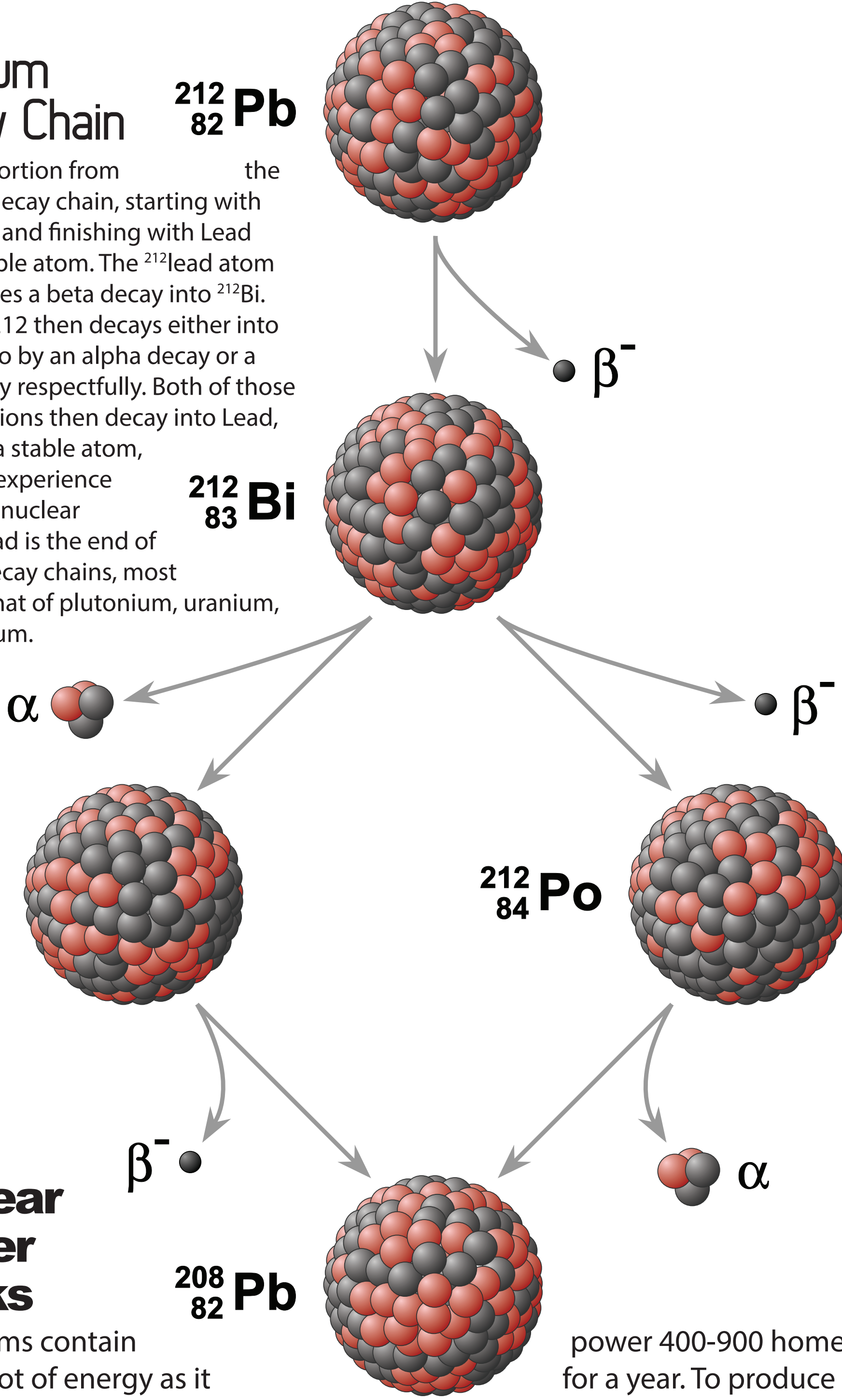
-David J. C. MacKay

Green Energy

Environmental engineering is a fairly new field working to improve the environment. Green energy is a large component of the discipline, as the demand for clean power rises.

Thorium Decay Chain

This is a portion from the thorium decay chain, starting with Lead 212, and finishing with Lead 208; a stable atom. The ^{212}lead atom experiences a beta decay into ^{212}Bi. Bismuth 212 then decays either into ^{20}Ti or ^{212}Po by an alpha decay or a beta decay respectfully. Both of those daughter ions then decay into Lead, which as a stable atom, does not experience any more nuclear decay. Lead is the end of several decay chains, most notable that of plutonium, uranium, and thorium.



How nuclear power works

Atoms contain a lot of energy as it is difficult to hold hundreds of positively charged particles together, that are constantly trying to repel each other. When an atom undergoes nuclear fission, a portion of the molecule breaks off is released with a large amount of energy. Depending on the atom fissining, anywhere between .5 and 4 MeV may be released. For the entire decay chain of one uranium 235 atom, 200Mev of energy is released. 1 gram fissioned in a reactor produces enough energy to power 400-900 homes for a year. To produce the same amount of energy requires 3 metric tons of coal, or 600 gallons of gasoline. The energy density of uranium is 80,620,000,000,000 (80.620 million million) joules of energy per kilogram of uranium. In comparison, gasoline is 48,000,000 (48 million) joules per kilogram, coal is 24 million, and tnt is 4.6 million joules per kilogram. The energy density of nuclear power requires significantly fewer resources than the other leading forms of energy

See how nuclear reactors work on page 5 →

Know Your Terms

Nuclear Decay: When an unstable atom breaks apart into smaller atoms, releasing a large amount of energy

Half-life: The time it takes for half of the material to decay

Alpha radiation: Nuclear decay that releases two protons and two neutrons. Can only penetrate several cm of air, and not human skin

Beta particle: An electron is released during decay. Much further penetration

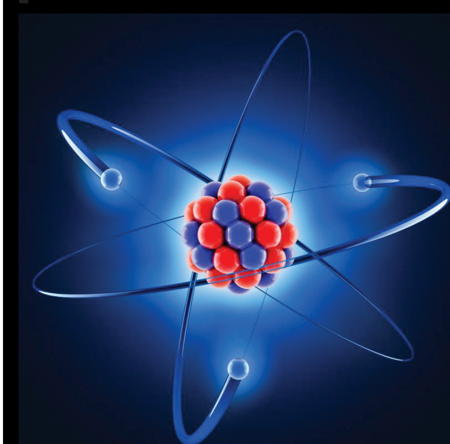
Gamma radiation: High energy photons that penetrate far and are highly ionizing

Ionization: Removing an electron from other elements making them unstable and liable to change

Fission: When an atom splits into smaller atoms, releasing a large amount of energy

Fusion: When atoms combine to form a larger one, releasing much more energy than in fission

Critical Mass: The concentration of fissible atoms is great enough to spontaneously fission and become self sustaining



Particle Physics Power

1ev = $1.6*10^{-19}$j

1 joule = $6.25*10^{18}$ electrons or ev

1 joule = the energy needed to power a 1 watt light bulb for 1 second

1Mev = 1 million electron volts

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Shielding: Radiation reflector

Units of nuclear physics

Radiation doses are the most useful measure of exposure, with the rem and the sievert (sv), which measure the equivalent absorbed dose of radiation, taking into account the biological effectiveness of the different types of radiation.

Unit	Description	Equivalent
Rem (roentgen equivalent man)	A unit of equivalent absorbed dose of radiation which takes into account the relative biological effectiveness of different forms of ionizing radiation, or the varying ways in which they transfer their energy to human tissue. The dose in rem equals the dose in rad multiplied by the quality factor (Q). For beta and gamma radiation, the quality factor is taken as one, that is, rem equals rad. For alpha radiation, the quality factor is taken as 20, that is, rems equal 20 times rads. Rem is essentially a measure of biological damage. For neutrons, Q is typically taken as 10.	Rem = rad x Q
Sievert (Sv)	A unit of equivalent absorbed dose equal to 100 remz	1Sv = 100 rem
Rad (radiation absorbed dose)	A unit of absorbed dose of radiation. Rad is a measure of the amount of energy deposited in tissue.	1 rad = 100 erg/gram
Curie (Ci)	The traditional unit of radioactivity, equal to the radioactivity of one gram of pure radium-226.	1 CI = 37 billion dps = 37 billion Bq
(Becquerels)	The standard international unit of radioactivity equal to one disintegration per second.	1 Bq = 27 pCi

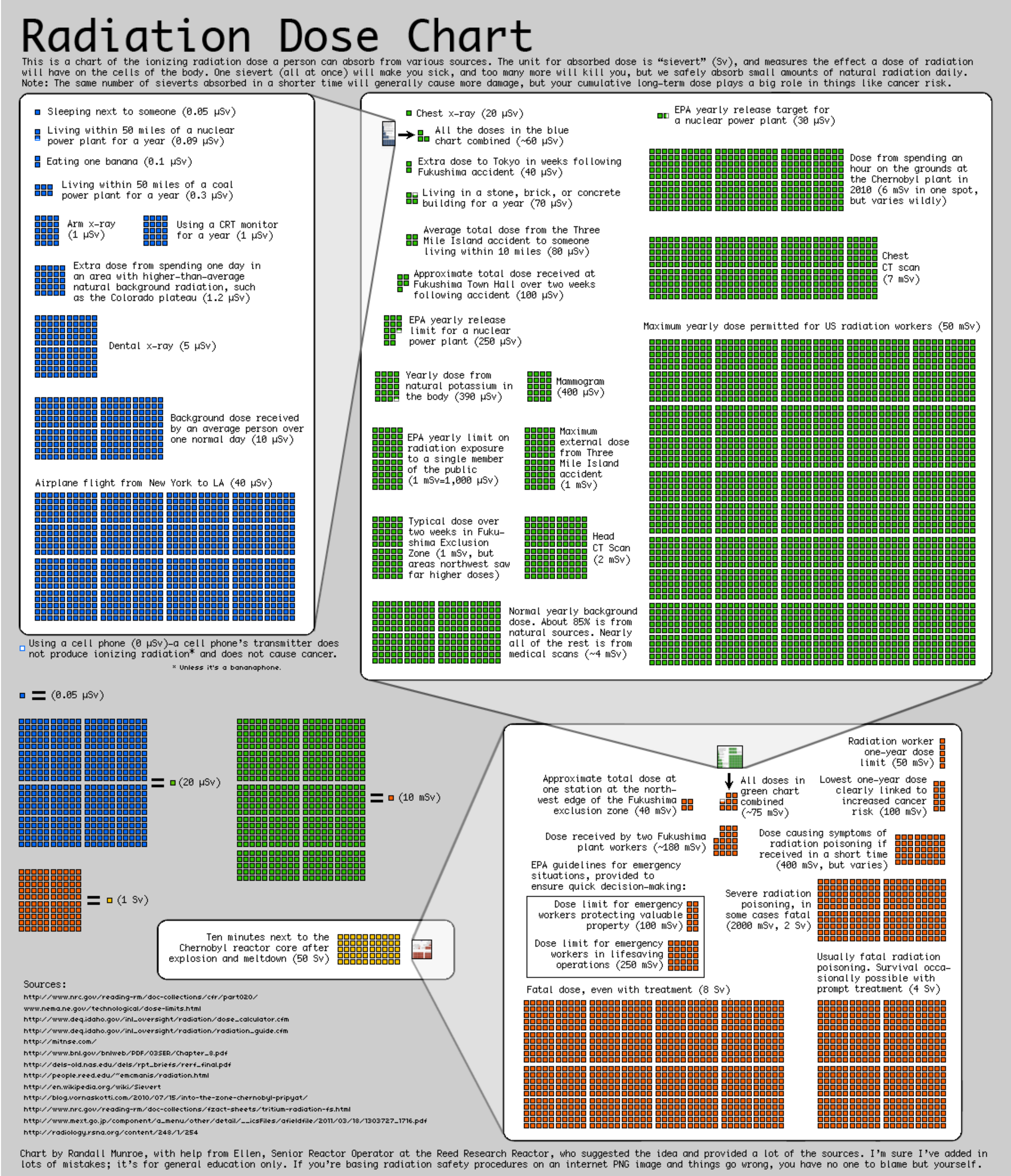
Health risks with prolonged exposure

Health risks increase with extended exposure overtime, ranging from cancers to genetic mutations. For every 10,000 people, 2,000 are likely to die from cancer that is not a result of radiation. If that same population were exposed to an accumulated dose of 1 rem, roughly five to six more people would get cancer. Most people receive 0.3 rem every year from natural background radiation.

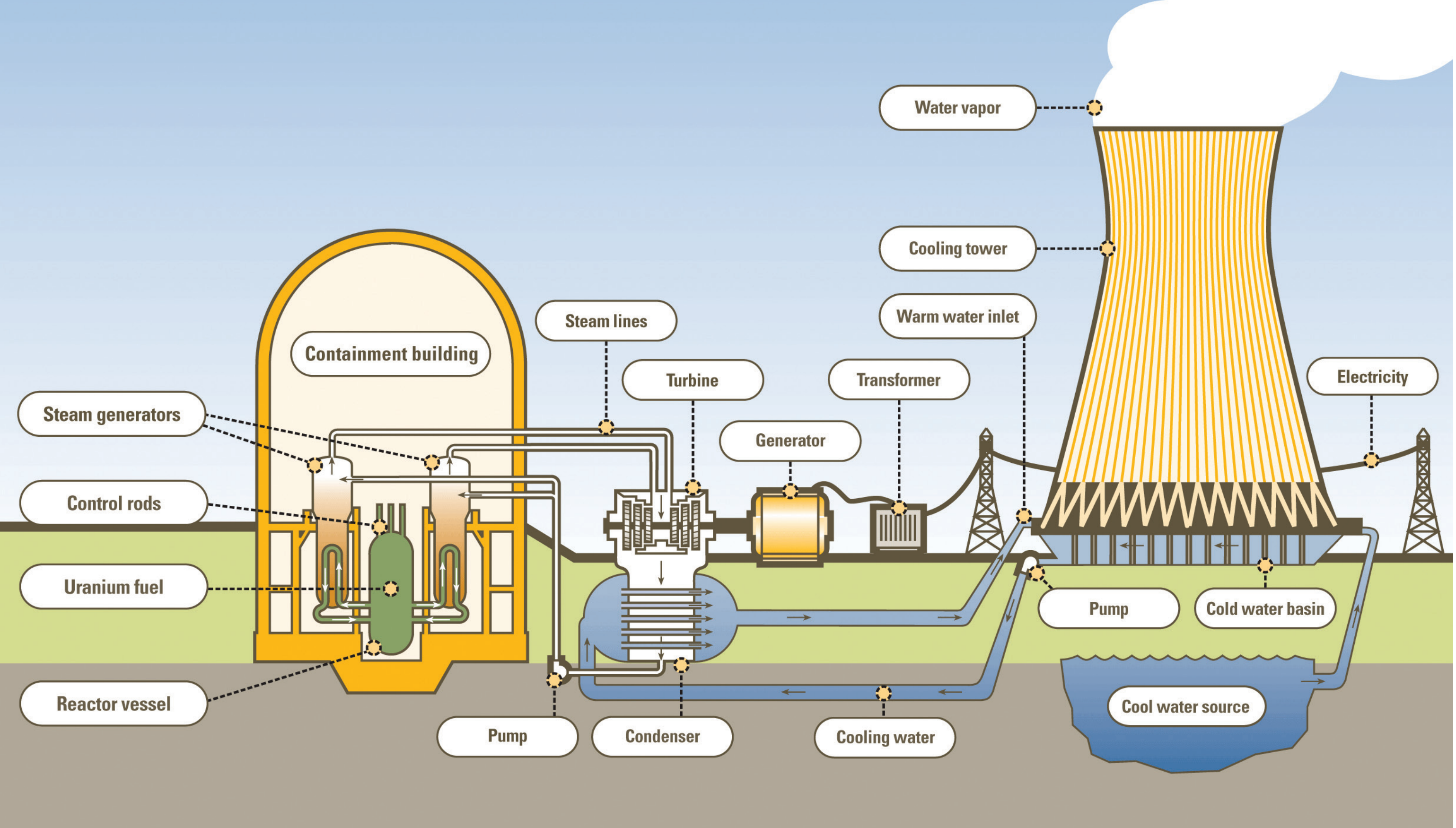
Radiation is naturally present in the environment and is the cause of over two thirds of a person's yearly accumulated dose. Naturally occurring radon is the major source of radiation that humans absorb on a daily basis. Radon is found in a majority of the rocks in the world, and as it defuses into the air, it decays and exposes humans to radiation; because it is commonly in rocks, it is often built into homes where it releases radiation over time. The second major component to average accumulated doses are from medical procedures such as dental x-rays, mammograms and CT scans. Nuclear power plants release very small doses of radiation into the environment. Living within 50 miles of a nuclear power plant for a year is a little less than the dose received from eating a single banana, while living within 50 miles of a coal power plant is roughly the same as the consumption of 3 bananas.

The Chart (left) from the EPA's website shows the symptoms caused by radiation exposure. Acute illnesses from immediate exposure to radiation are often more severe but require much larger doses.

Exposure (rem)	Health Effect	Time to Onset (without treatment)
5-10	changes in blood chemistry	
50	nausea	hours
55	fatigue	
70	vomiting	
75	hair loss	2-3 weeks
90	diarrhea	
100	hemorrhage	
400	possible death	within 2 months
1,000	destruction of intestinal lining	
	internal bleeding	
	and death	1-2 weeks
2,000	damage to central nervous system	
	loss of consciousness;	minutes
	and death	hours to days



The above graphic was created by Randall Monroe as a response to the Fukushima Daiichi disaster and the media's misinformation about radiation doses. The chart is a great illustration of the relative levels of radiation exposure that people are exposed to. Randall Munroe is a former NASA Roboticist who now creates the "*romance, sarcasm, math, and language*" based web comic XKCD. While the information is not completely exact, it is an excellent representation of radiation doses from different sources



Nuclear Power Plant Terms

Fuel rod: A metal tube that contains pellets of the nuclear fuel used to produce power.

Criticality: A sustained chain reaction of nuclear fission under a controlled state in a reactor.

Moderator: A material that slows down the speed of the neutrons that cause fission, allowing for a controlled reaction

Control Rod: A material that is highly adsorbent of neutrons, slowing down the fission reaction

Natural uranium: Uranium with a concentration of .7% or less of ^{235}U, the isotope that sustains fission.

Low enriched uranium: Reactor grade fuel with a concentration of 3-4% ^{235}U, allowing it to be used in a light water reactor

How a nuclear power plant works

Nuclear power plants are fundamentally the same as a coal or oil power plant; they generate of steam to drive electric generators. In a coal or oil plant, the fuel is burned to heat up a reservoir of water, which is then fed through a steam turbine that generates electricity. A nuclear plant works a little differently, but has the same basic concept.

The core component of the plant is the nuclear fuel that it uses, as there are three basic types that dictate the rest of the reactor. Uranium is the main fuel source that is used, with the differences being in the ratio of ^{235}U to ^{238}U. ^{235}U is much more likely to fission that ^{238}U which is likelier to reflect neutrons, or undergo fusion into a highly reactive form of plutonium. In the core of most plants is an assembly of metal rods that are filled with pellets of the uranium oxide fuel (most common). The rod assemblies are submerged in a tank of a moderating matereal (most commonly light or heavy water, or graphite), which reduces the energy of the radioactive neutrons flying from one fuel rod to another. Water is a very effective moderator that is capable of cutting the radiation in half every 7 centimeters; as reactors are typically submerged by several meters of water, virtually 100% of the radiation is absorbed.

The most common reactor type is a Mark III light water reactor, which uses light water (ordinary water) as the neutron moderator, which also doubles as the water that is converted to steam. Along with the fuel rods, there are other rod assemblies called control rods that are used to absorb the radioactive neutrons that sustain the chain reaction; slowing down the reaction. There are always enough control rods inserted into the reactor to prevent the reactor from turning critical and melting down. Additional rods are inserted or removed deepening on the power demands of the plant; the more rods inserted, the less the power that will be generated.

The water in the reactor heats up as the radioactive particles collide with it. This water is circulated through the system into the area where it is allowed to produce vast amounts of steam and drive generators. The water is then condensed, cooled, and circulated back through the plant in a closed loop. The water is circulated with several large electric generators that constantly pump thousands of gallons of water through the plant, keeping the system cool.

Safety Mechanisms

There are several fail-safe prostheses in place in the event of a natural disaster or power loss that shuts down the electric generators. In the event of power loss, backup diesel generators are activated that continue to circulate water though the plant as the reactors are shut down. In an emergency shutdown procedure, all of the available control rods are inserted into the core of the reactor in order to stop the nuclear reaction. The rods can be automatically inserted, or manually inserted. There are also assemblies of control rods suspended above the reactor by an electromagnet, which on the event of a power loss, would shut off the reactor automatically.

The entire system is in a closed loop that does not let the moderator water out into the environment, even though it is not radioactive (see the sidebar about the effects of heavy water on humans). The waste generated by the most common reactors is depleted uranium which is much less radioactive than natural uranium, as it has less than .3% ^{235}U. After a life cycle of 18-72 months, the fuel is less viable as it has less concentrations of fissible ^{235}U and a higher concentration of plutonium, which is only useful in higher output reactors or nuclear weapons.

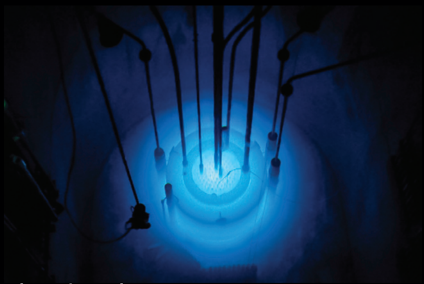
The spent fuel is stored in a fuel pool for three to ten years for cooling. The spent fuel pool is typically over 15 meters deep (with only 6 meters necessary to completely eliminate the radiation), with the walls constructed of reinforced concrete, and other radiation absorbing materials. During this cooling period, the water is held at roughly 50 C to keep the rods cool. The air is also circulated to prevent the build up of hydrogen from the splitting of the water molecules.

There is debate on what to do with the spent fuel after it has had sufficient time to cool. For a time nuclear waste was stored in dry cask storage in deep geological repositories, most notably in the deserts of Nevada and New Mexico. The casks themselves prevent the reduced radiation from escaping, and provide a secure means of storage. The depleted uranium, which is much less radioactive, can also be used for shielding against other forms of radiation, depleted uranium munitions, and other applications that require extremely dense materials.

> **"No one in the United States has become seriously ill or has died because of any kind of accident at a civilian nuclear power plant"**

New age of atomic energy

The United States Atomic Energy Commission was formed after WWII in 1946, and was established to further atomic research for civilian applications. The military soon lost control over the production of nuclear power as the AEC had established control. The AEC transformed into the Nuclear Regulatory Commission which they then gained more regulatory power to ensure the sfety and security of nuclear power.



Blue doppler shift from the fast moving radiation traveling through the moderator in a light water reactor

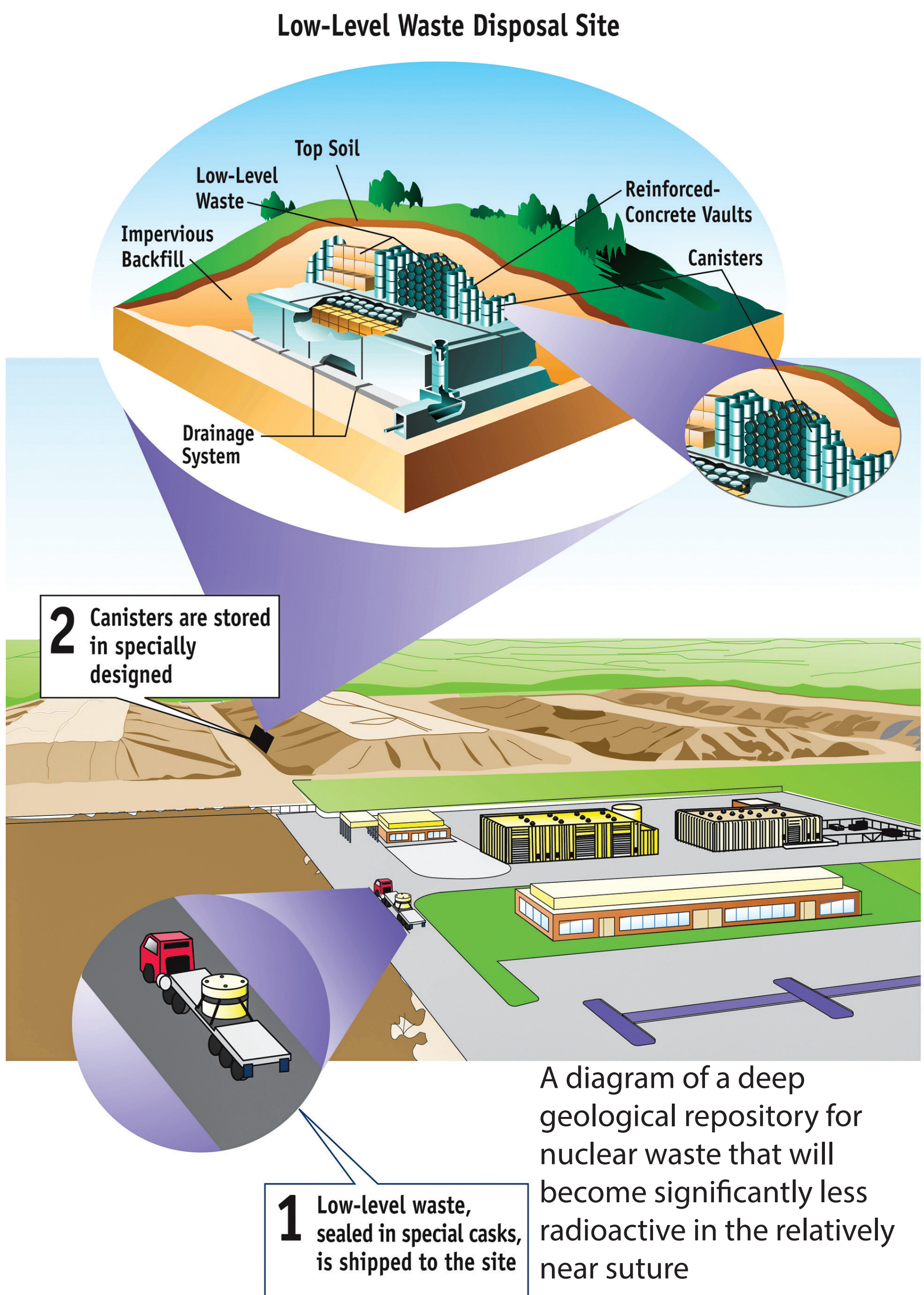
	Start	End
Uranium	100%	98.4%
U 235	4.20%	0.71%
Plutonium	0.00%	1.27%
Minor Actinides	0.00%	0.14%
Fission Products	0.00%	5.15%

Nuclear waste is primarily composed of ^{238}U, as only ^{235}U is used in most fast-reacotrs that are in current operation. Fission products are also produced from the ^{235}U that split. Currently the technology available is not able to reuse the ^{238}U as fuel, but it is entirely possible and is being researched. Once the technology becomes available, a vast amount of nuclear waste can be reused as fuel (near 90%).

Nuclear waste is stored in dry cask storage after it has cooled and decayed for 3-20 years in a spent fuel pool. The fuel rods are surrounded by an inert gas, inside of a layered wall of steel and concrete, with the hatch welded closed. The main elements in storage is ^{238}U which has such a high half life that it is not all that radioactive. The more dangerous atoms are the fission products which can remain radioactive for 1,000-10,000 years. After the 3-20 years of cooling, most of the short lived and highly radioactive particles have decayed away, reducing the overall contamination risk.

Nuclear Waste

The primary waste that escapes into the atmosphere near a nuclear power plant is pure water, with trace amounts of heavy water. Deuterium (heavy water) is formed in the core of the reactor when the hydrogen atoms in the water absorb a neutron and become an isotope. Deuterium is present in all water in extremely minute traces. The deuterium released by a nuclear power plant is a concentration of roughly 5% greater than normal (the normal concentration is roughly 0.0156% in all water). Heavy water is toxic to humans, but the chances of accidental poisoning is virtually impossible. In order to be harmed by heavy water, an individual would need to replace 50% of their body weight with pure deuterium, for a sustained period of several weeks. Several gallons of pure heavy water would need to be ingested, which is far from the minute concentration of less than .01% percent concentration of heavy water found around nuclear power plants. Radiation wise, an accumulated dose of 0.09 μSv is acquired over the period of a year living within 50 miles of a plant, roughly equivalent to eating a banana.



A diagram of a deep geological repository for nuclear waste that will become significantly less radioactive in the relatively near suture

Fossel fuel pollution

Coal pollution

The waste created by the burning of coal in a coal power plant is magnitudes greater than that of a nuclear plant. Coal power plants are the primary source of CO2 emissions in the nation. They are also responsible for acid rain, smog, and toxic air pollution. Filters are in place in the stacks of coal plants that help to reduce emissions, but they still contribute on average 3.5 million tons of CO2 per year, per plant. As trace amounts of radioactive materials such as radon and uranium are present in the earth, burning coal also produces radiation in addition to their other pollutants. The radiation is aerosolized by burning and is part of the ash that is released via the smoke stacks. The ash falls back to earth, is inhaled by humans and mixed into the soil where it is absorbed by crops and consumed by humans. The primary radioactive element is an isotope of radon, that primarily gives off alpha radiation, which is most harmful if ingested. A study conducted by nuclear physicist Dr Tayfun Buke examined the radioactive emissions of coal power plants and found that they release a dose roughly equal to .3μSv per year to inhabitants living within 50 miles of a plant. His findings conclude that the radiation produced by a single coal plant is not dangerous in it's minute doses. The radiation alone is from a coal power plant is over three times as that released from a nuclear power plant, and several times more dangerous due to the other forms of pollutants released into the atmosphere

> All the waste in a year from a nuclear power plant can be stored under a desk.
>
> -Ronald Reagan

Disasters

Nuclear disasters are the primary cause for negative public opinion on nuclear power. Almost every of the disasters associated with nuclear power are the direct result of human error and disregard of the strict safety protocols involved with a nuclear reactor.

The nuclear meltdown that happened in Ukraine's Chernobyl power plant. The main cause of the accident was that the crew was performing a test of the safety procedures during the event of a loss of power. The operators disabled numerous safety procedures and fail safes that ultimately led to the reactor melting down.

Most recently Japan's Fukushima Daiichi meltdown has been cited as another reason to fear nuclear power, but it was again the fault of the plant manager, and not nuclear power itself. Japan has regulations regarding the height of the seawall needed to prevent an incoming wave in the event of a natural disaster. The Fukushima plant manager did not build the seawall to regulations, and instead had it was several feet under specifications. The result was that the tsunami water breached the facility, and flooded and disabled the backup diesel generators responsible for cooling the reactors. The nuclear power plant in Onagawa, Japan was closer to the epicenter of the 2011 tsunami and survived nearly entirely intact, while Fukushima melted down. Yanosuke Hirai was the engineer in charge of building the plant several decades ago. He constructed the seawall to government specifications, and then some, increasing the margin of safety of the plant. His actions ensured that the plant was safe during the natural disaster.

Radiation map of the immediate fallout zone following the Chernobyl catastrophe

Next generation of clean power

The world's energy consumption is increasing at a rate that will soon eclipse the amount of energy that fossil fuels can seasonably produce. Renewable energy sources such as solar, wind, and hydroelectric are in use currently to supplement power needs in cities across the world. Limitations with current power production mean that not all of the available energy is able to be harnessed. Even with current limitations Costa Rica has been powered by renewable power since December 2014 Nuclear power produces energy several order of magnitudes greater than current renewable energy sources and fossil fuels. Advances in nuclear power plants will allow for extracting more power from radioactive elements, reducing waste, and increasing efficiency. Introducing nuclear power into facilities into more cities around the world will help to supplement the energy demand with a clean source of energy. Diversifying power producing with wind, solar, hydroelectric, and nuclear is the key to producing a fortified power network that is clean for the environment and future generations

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