Words for Nuclear Power (alphabetical)

(2,600 words)

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The number in parentheses after each word refers to the order in which they are used in the slide lecture "Nuclear Power Generation: Part 1 – Words to describe the process."

Alpha particles (8a) - are the nucleus of a helium atom (2 protons and 2 neutrons). After an alpha particle is radiated, the mass of the remaining nucleus is 4 units smaller and its atomic number is lower by 2 units. Alphas are very active and interact with everything, so they do not go very far. If you hold an alpha source in your hand the dead layer of skin or a single sheet of paper will stop all alpha particles. They are a health hazard if ingested or inhaled.

Atom (2) – The smallest unit of an element retaining its identity is an atom. Atoms combine to form the molecules of familiar chemical compounds such as carbon dioxide (CO_2) or ethanol (C_2H_5OH). The atom itself is made up of Protons, Neutrons, and Electrons.

Atomic number (6) – This is the proton count of an element. Elements exist or have been synthesized with atomic numbers for 1 to 115, and Uranium at 92 is the heaviest naturally occurring element that has been found in reasonable quantity. After Plutonium had been synthesized, it was found in nature in extremely tiny quantities. Most of the very large elements spontaneously decay after a short time.

Beta particles (8b) - are high-energy electrons emitted by the nucleus as it converts a neutron to a proton. They penetrate better than alphas and do mess up the electrical nature of atoms, but have so much smaller mass that they don't knock things around like alphas. For the lower energy betas a thin sheet of aluminum is adequate shielding, but for the beta particles with higher energy a low density, thicker shielding is used to avoid the secondary radiation produced when the betas strike other materials.

Burn (10) – We all know what burning is, but I want to emphasize a specific aspect of this process. You know from your high school chemistry that burning is a rapid, exothermic (heat producing), oxidation reaction. In power production from coal, natural gas, or oil, the carbon in these mixtures is combined with oxygen to produce the oxide accompanied by useful heat. This is a chemical reaction and involves the element's electrons.

Nuclear forces are a great deal larger than the forces acting on electrons so the nucleus is totally unaffected. Nuclear forces are millions of times greater than the greatest force unleashed by a chemical reaction including explosives.

Thus in the chemical world the amount of fuel is very much larger than that required for a nuclear reaction. The weight of the waste from burning coal is about 20,000 times greater than the waste from a nuclear reactor. On a volume basis the comparison is even more extreme.

Chain reaction (13) – A process in which the splitting of U-235, U-233, or PU-239 isotopes produces the neutrons necessary to split further U-235, U-233, or PU-239.

Containment (17) – U.S. reactors are built inside an extremely strong reinforced concrete building that houses the reactor vessel, a steam generator (if any) and much of the safety piping necessary to remove the residual heat in a reactor once it is shut down. The number of openings are kept to a minimum and can be blocked to isolate the reaction vessel and nearly all radiation in case of a major failure.

Control rods (16) – Rods that may be inserted into a reactor to slow or nearly stop the fission process by absorbing neutrons. Boron is often used since it absorbs rather than slows neutrons.

Effective neutron multiplication factor – K (20) – the average number of neutrons from one fission that cause another fission. The remaining neutrons either are absorbed in non-fission reactions or leave the system without being absorbed. The value of K determines how a nuclear chain reaction proceeds. Power reactors are constructed to operate with K = 1. (Actually a bit less than 1 to account for the “delayed” neutrons from the fission products). See *Negative void coefficient*.

Electron (5) – A negatively charged portion of each element. The number of electrons balances the number of protons except during a chemical reaction. Electrons are not part of the nucleus but the portion of the atom that is affected in a chemical reaction.

Element (1) – The smallest substance into which any chemical can be divided. For example the molecule CO_2 can be divided into the elements Carbon and Oxygen. These in turn cannot be further divided chemically but can be changed by nuclear processes. Similarly the molecule water (H_2O) can be divided into the elements Hydrogen and Oxygen.

Enrichment (14) – The process of increasing the percentage of U-235 in natural uranium (which is a mixture of 0.7% U-235 and 99.3% U-238).

For light water reactors uranium-235 is increased to 3–5 % or 4 to 7 times.

For sodium moderated and research reactors up to 20% or 7 to 28 times.

For military applications the enrichment is carried to about 90% U-235.

Fission (11) – Most atoms ignore or absorb free neutrons that come their way. However, the uranium-235 nucleus splits instead. The ensuing nuclear reaction breaks a uranium-235, uranium-233 or plutonium-239 (produced when U-238 captures neutrons) into 2 lighter mass fragments generally in the mass range 72 to 160. It also produces on average 2.4 free neutrons (from U-235) of which one is needed to initiate the next fission.

All fragments possess tremendous kinetic energy. This kinetic energy is absorbed and converted to heat (about 2.7 million times more than that from chemical burning).

Gamma rays (8c) - are at the high end of the electromagnetic spectrum and carry a lot of energy. They are sufficiently penetrating that they can look through steel to find cracks or voids. They can easily knock an electron out of an atom and create a charged ion. This is great for killing bacteria but has the same effect on human cells. Too much gamma radiation will kill you. Lead is one the most effective shielding materials, each centimeter attenuating the gamma radiation by about 2/3, but if space is not a constraint about 10 times that thickness of concrete will provide the same attenuation. Earth works nearly as well as concrete requiring only about 25% more thickness.

Half-life (9) - One half-life indicates the period in which half the nuclei in a sample will emit radiation and decay to another element or isotope. Nuclei with short half-lives are very radioactive, but are gone in short order, so we must deal with those products that are still radioactive. Nuclei with long half-lives will be around a long time, but are only weakly radioactive.

For example, Uranium-238 has a half-life of 4.47 billion years, which accounts for its weak radioactivity as well as its continued presence on our planet long after its formation. Its slow decay produces so little radiation over human time scales that it can be easily handled.

On the other hand radon (its most stable isotope is Rn-222, 86 protons, 136 neutrons) has a half-life of 3.8 days. The only reason we ever have it, is because it is formed routinely from U-238 via a very time consuming six-step decay process. Two of the steps involve half-lives of 245,000 years and 75,000 years, so only the large amount of the initial uranium has produced any significant amount of radon. Since its alpha particle decay is rapid, it is quite radioactive. However the danger arises because it is a gas and can be inhaled, giving the weakly penetrating alpha particles access to unprotected membrane.

Cesium-137 and Strontium-90 are two of the most dangerous nuclear reactor products as they have intermediate half-lives of about 30 years, emit significant radiation and are going to be around for a long time. Fortunately their quantities are small.

Isotope (7) – Isotopes are atoms with the same number of protons but different numbers of neutrons. For example, carbon has 7 isotopes of which 3 are naturally occurring. Carbon-12 has 6 protons and 6 neutrons and is stable. Carbon-13 has 6 protons and 7 neutrons and is also stable but exists in low quantity. Carbon-14 has 6 protons and 8 neutrons and is somewhat radioactive with a half-life of 5,730 years. This radioactivity is what makes carbon-14 useful in dating carbon compounds since its ratio to carbon-12 decays over time.

Much of our discussion of reactors will bear on two naturally occurring isotopes of uranium – Uranium-238 which is 99.3% of the total and Uranium -235 which is the remaining 7 tenths of one percent. Only the U-235 isotope breaks apart readily when struck with thermal (low speed) neutrons. When U-235 splits apart it produces fragments with a tremendous amount of kinetic energy. This kinetic energy produces the heat that is so useful in generating electricity. U-235 and U-238 both have 92 protons and electrons. so they undergo the same chemical reactions. But they have 143 neutrons and 146 neutrons respectively and thus differ slightly in mass. Separating these isotopes is done based on this slight mass difference and is very difficult and expensive.

Isotope separation (15) – Since enrichment of natural uranium is needed for most reactor designs several methods of separation have been developed, which depend on the difference in the mass of U-235 and U-238.

Starting in WWII the U.S. used gaseous diffusion to enrich the fraction of U-235. This requires vast plants since each stage only achieves a very slight increase in the percentage of U-235. Since the capital investment has been made, the U.S. continues to use this capability although it will likely be phased out because of high operating costs.

With the development of stronger materials and superior bearings, most other nations use about 3,000 very-high-speed, cascaded, centrifuges to separate the isotopes. Most countries use this technology and the U.S. now has a demonstration plant and will build a full-scale centrifuge separation facility by 2012.

kWt (19) – Kilowatt thermal. It is the highest power rating of the heat source. It should be distinguished from kWe which is the power rating of a plant in terms of its highest possible electrical output. It is not possible to convert heat to electricity with 100% efficiency. Conversion efficiencies of 30% or more are considered good. The energy difference is usually dissipated as waste heat. Some plants use the heat directly or a portion of it (such as nuclear submarines), so the kWe term does not describe the entire potential of a electrical generating plant. However, if all possible heat is used for generating electricity the kWe term offers a comparison that incorporates plant efficiency.

Moderator (12) – Slow moving (thermal) neutrons are more likely to cause the next fission. Neutrons produced in the fission process are moving way too fast to cause the next fission of the U-235. Rather, they are quite likely to escape the reaction vessel without carrying the chain reaction forward. Therefore a speed reducer (moderator) is used which slows down the neutrons without absorbing them. Water is such a moderator and is used in many reactor designs. U-238 also absorbs some neutrons and so serves as a moderator, but it also increases its absorption as temperature increases, reducing the neutrons available to split U-235. This provides a further level of automatic reactor control.

Negative void coefficient (21) – All western power reactors are designed to have a negative void coefficient. This means that the amount of moderator near the fuel rods is strictly limited so that any loss of moderator or decrease in its density ("voids") allows more neutrons to escape and the fission process to slow down. The amount of moderator (water in a light water reactor) is carefully computed for the desired operating temperature. If the temperature moves above this point the moderator becomes less dense permitting more neutrons to escape not participate in the fission process. Thus the laws of physics are used to automatically control the reactor.

Neutron (4) – Part of the nucleus of all elements (except the very smallest), it has no charge. It adds its weight of 1 AMU to an element without changing its chemical properties. It does however change its nuclear properties, and is essential to nuclear reactors.

Neutron radiation (8d) - features a neutral particle, so neutrons don't grab electrons and are not easily absorbed. When emitted from a fission reaction they travel at very high speeds, bump into anything in their path without being absorbed, and transfer their kinetic energy to it. They must be slowed down by a moderator to be absorbed. Water is a good moderator and improves if laced with boron. It is also a fine shielding material for neutron radiation. Neutron bombardment can change the properties of materials in unfortunate ways, such as making them more brittle. Therefore, careful material selection for reactors is important. Zirconium metal has shown remarkable durability in a high neutron environment.

Positive void coefficient (22) – Some older Soviet power reactors and some research reactors are designed with a positive void coefficient. In these reactors the reactivity increases if the moderator which is often also the coolant decreases in density or "voids."

Proton (3) – Part of the nucleus of an atom that has a positive charge. The proton has a weight of 1 atomic mass unit (AMU, extremely small quantity, in pounds, a decimal followed by 26 zeros and a 4). The proton gives an element its chemical properties. The proton counts of a few common elements are: Hydrogen 1, Helium 2, Carbon 6, Nitrogen 7, Oxygen 8, Iron 26, Copper 29, Silver 47, Tungsten 74, Gold 79, Lead 82, Uranium 92, and Plutonium 94.

Radioactive (8) – Many isotopes are not stable and emit radiation in the process of moving toward a non-radioactive nucleus. Elements above bismuth (atomic number 81) have no known stable isotopes although the rate at which they decay varies a great deal.

Unlike toxic chemicals, which can often be changed to benign forms via chemical reaction, radiation is a nuclear property and remains, regardless of the chemical compound in which the atom is bound.

We are concerned with 4 types of radiation in reactor processes:

a) Alpha particles are the nucleus of a helium atom (2 protons and 2 neutrons).

b) Beta particles are high-energy electrons emitted by the nucleus as it converts a neutron to a proton.

c) Gamma rays are at the high end of the electromagnetic spectrum and carry a lot of energy.

d) Neutron radiation features a neutral particle, so neutrons don't grab electrons and are not easily absorbed.

Secondary water system (18) – In pressurized water reactors there are two types of water circulation loops. The primary water system circulates the high-pressure water through the reactor and the steam generator. The secondary water system circulates the steam/water from the steam generator through the turbine and condenser and back to the steam generator. Both loops are served by redundant piping.

Under-moderated (23) – As a control and safety feature all U.S. power reactors (and almost all around the world) are designed so an increase in power beyond the optimum is met with negative feedback. See also *Negative void coefficient*.

Rupture of a primary pipe also decreases the water slowing the reaction. Of course other provisions are necessary to deal with the residual heat if the primary loop is non-operative since the water is also the heat transfer agent.