Handbook of Nuclear Reactors

First Edition

A Technical Writing Sample
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What is Nuclear Power?

Isotope -
Each of two or more forms of the same element that contain equal numbers of protons but different numbers of neutrons in their nuclei.

Fission -
The action of dividing or splitting something into two or more parts.

Chain Reaction -
A chemical reaction or other process in which the products themselves promote or spread the reaction, which under certain conditions may accelerate dramatically.

Nuclear energy is produced when the core of an atom is split or when the core is fused together. Each core is made of protons and neutrons which provide positive and negative charges.

When talking about nuclear power today there are usually two images that come to mind: a power plant and a mushroom cloud. Each uses the process of splitting the atom, or what is known as nuclear fission.

When the atom splits it releases energy and turns one nucleus into two or more resulting nuclei.

Uranium-235 (U-235) is the most common isotope of uranium used in nuclear power plants and nuclear weapons due to the fact that it is unstable. When an atom of uranium-235 is hit with a neutron, the atom splits.

A common result is an atom of Barium, an atom of Krypton, and three free neutrons. The three neutrons are then propelled from the atoms which then hit three more atoms of Uranium-235. These atoms will then split and release more energy and repeat the process. This chain reaction is what creates enough energy to run nuclear reactors or destroy entire landscapes. When the chain reaction is in a reactor setting the chain reaction is controlled while the weaponized version is an uncontrolled chain reaction.

Below in Figure 1 is a picture from the International Atomic Energy Agency's (IAEA) website (www.iaea.org) showing what the splitting of an atom looks like and the resulting chain reaction.

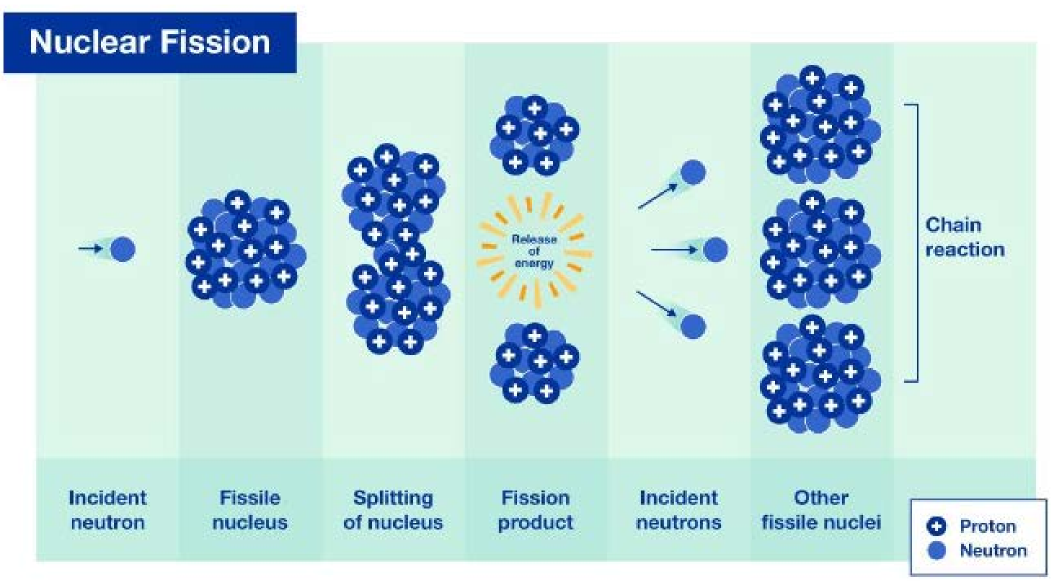


Figure 1: Splitting the Atom.

Did you know...?

Over 400 nuclear reactors in 32 countries provide about 10 percent of the world’s electricity.

Fusion -
The process or result of joining two or more things together to form a single entity.

Did you know...?

A running joke in the field of nuclear power is saying ‘Nuclear fusion is only twenty years away’. Nuclear fusion has only been twenty years away for decades.

When the atom splits it releases energy. In a controlled environment like a reactor we can harness that energy to generate power.

The energy that is released produces heat which warms water until it becomes steam. The steam then spins turbines which activates an electric generator to create electricity.

On the IAEA’s website they profile five main types of reactors: water cooled reactors, gas cooled reactors, fast reactors, molten salt reactors, and small modular reactors.

Water cooled reactors account for more than 95 percent of all operating civilian reactors in the world and the majority of reactors under construction today are water-cooled like in Figure 2 below.

When the process of generating electricity is done there is typically nuclear waste left over. Nuclear waste has varying degrees of radioactivity and must be disposed of properly.

Nuclear waste must be processed and then is often stored under ground. The next generation of advanced reactors which could be under construction by 2030 will generate much less nuclear waste.

The reason nuclear fusion is such an important concept is because fusion doesn’t produce any nuclear waste at all. The only by-product from the fusing of two hydrogen atoms is helium.

R & D for nuclear fusion has been in production since the 1950’s, but only recently have we had a successful attempt which resulted in more power generated vs. power used.

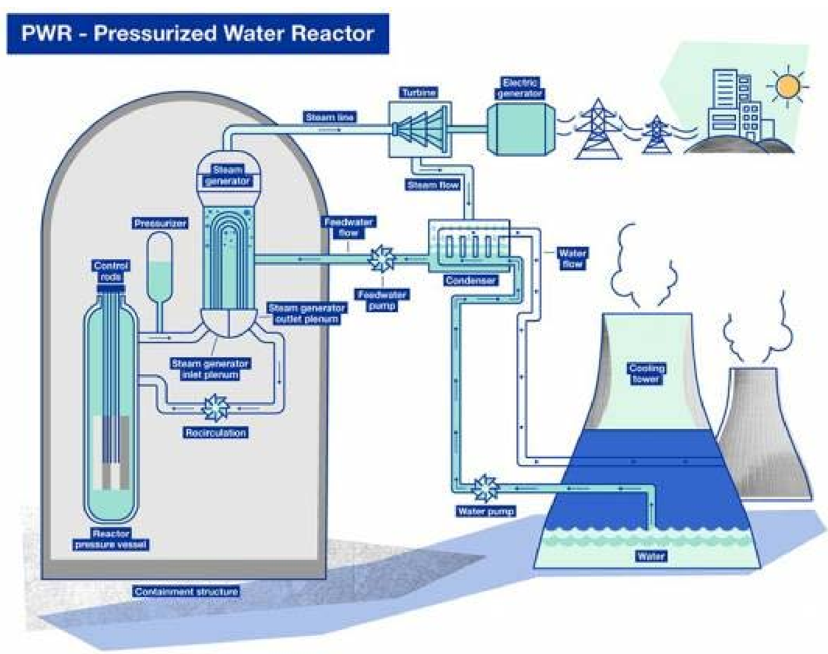


Figure 2: Diagram of a Pressurized Water Reactor

Uranium- 235

Radioactive -
Emitting or relating to the emission of ionizing radiation or particles

Proton -
A stable subatomic particle occurring in all atomic nuclei, with a positive electric charge equal in magnitude to that of an electron, but of opposite sign.

Neutron -
A subatomic particle of about the same mass as a proton but without an electric charge, present in all atomic nuclei except those of ordinary hydrogen.

Dalton -
A unit used in expressing the molecular weight of proteins, equivalent to atomic mass unit.

Did you know...?

All of the series of fifteen metallic elements from actinium (atomic number 89) to lawrencium (atomic number 103) in the periodic table are an actinide and all are radioactive.

Uranium-235 is comprised of 92 protons and 143 neutrons with an isotope mass of 235.0439299 Dalton (Da). It is an actinide and is radioactive, meaning it releases energy as it decays. Uranium is also a common element found in the earths crust and is about 500 times more common than gold.

Making up about 0.72% of natural uranium, U-235 is an isotope of uranium, meaning it has the same atomic number as uranium but has different number of neutrons in its nucleus. Natural uranium by comparison has an atomic mass of 238.0289 Da.

U-235 is the only naturally occurring fissle isotope, meaning it is capable of sustaining a nuclear fission reaction.

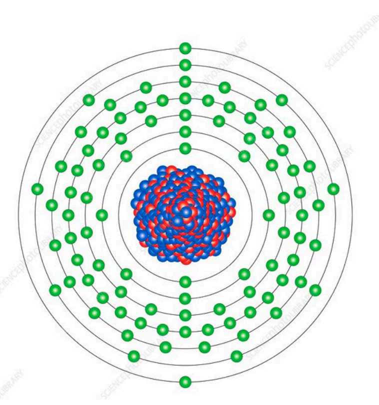


Figure 3: Atom Structure of Uranium-235

As previously stated, a fission chain reaction occurs when a neutron is introduced into the U-235 isotope and makes the atom unstable. The atom then splits and releases energy.

Each time an atom is split it releases 202.5 Mega electron Volts (MeV), or 3.24×10^{-11} Joules (J) of energy. The amount of energy from a gram of U-235 should result in about 5.12×10^{13} J.

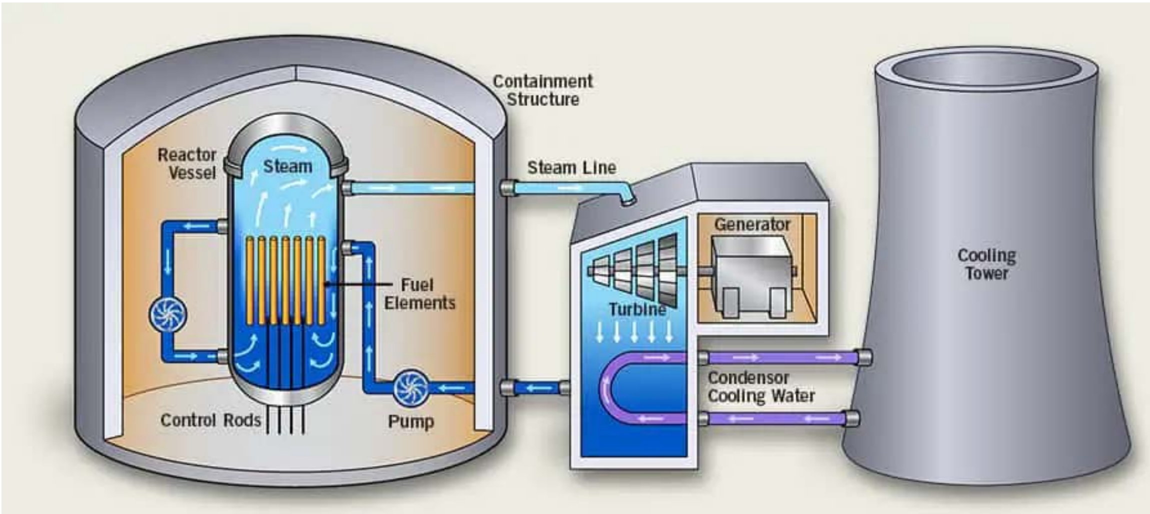
By comparison, 1 Ton of TNT produces about 4.184×10^{12} J of energy.

Uranium goes through a process of uranium enrichment to increase the 0.72% proportion of U-235 up to 94%. Typically, however, nuclear reactors utilize low-enriched uranium (LEU) which is around 5%. Anything below 20% is also considered low-enriched. Anything above 20% is considered high-enriched uranium (HEU) and is typically used for propulsion reactors, nuclear weapons, and some research reactors.

Uranium must go through various steps in order to become electricity. The process involves, exploration, mining and milling, processing, irradiating in reactors, reprocessing, and disposal.

Through the entire process uranium will go through all three states of matter: solid, liquid, and gas.

Nuclear Reactors



Deuterium -
A stable isotope of hydrogen with a mass approximately twice that of the usual isotope.

Did you know...?

Enriched water is called heavy water because it is significantly denser than ordinary water due to the greater mass of deuterium.

Did you know...?

Ordinary water is often referred to as H2O because it has two hydrogen atoms and one oxygen atom. Deuterium is referred to as D2O because it has two deuterium atoms and one oxygen atom.

Water Cooled Reactors

Water Cooled Reactors (WCR) represent 95 percent of all operating civilian power reactors in the world. They have been the cornerstone of the nuclear industry since the 20th century and will continue to be so well into the 21st century.

Many of the original WCRs were originally licensed to operate for 40 years, but due to advancements in technology these plants are being approved to extend their life span to 60 years and beyond.

The type of WCR that is most common worldwide is the Light water reactor (LWR) and it has two main types: the Pressurized Water Reactor (PWR) and the Boiling Water Reactor (BWR). The difference between the two is pressurized water reactors produce steam in separate steam generators, while the boiling water generators use the steam produced inside the reactor core directly in the steam turbine. Each uses Uranium-235.

Another type of WCR is the Heavy Water Reactor (HWR). HWRs use “enriched” water which is made up 99% deuterium, which is the heavier hydrogen isotope. The “enriched” water allows for the use of fuel that does not require enrichment.

Molten Salt Reactors

Molten salt reactors (MSR) have benefits which have brought renewed interests in developing them in recent years.

Two of those benefits include higher efficiencies and lower waste generation with some designs not requiring solid fuels. The absence of solid fuels elimin-

Did you know...?

MSRs adapt to a variety of nuclear fuel cycles which includes Uranium-Plutonium and Thorium-Uranium cycles.

Molten Salt -
Salt which is solid at standard temperature and pressure but has become liquid due to elevated temperature.

Renewable-
A source of energy that is not depleted by use, such as water, wind, or solar power.

Megawatt Hour-
A megawatt-hour is typically abbreviated as "MWh," and this term indicates the usage of 1,000 kilowatts in one hour.

Did you know...?

There are more than 80 small modular reactor designs and concepts globally.

nates them for manufacturing and the disposal of solid fuels.

Some more benefits in MSRs include operating at higher temperatures and low operating pressures. Higher operating temperatures leads to increased efficiencies in generating electricity, while low operating pressures can enhance operating safety by reducing the risk of large breaks and leaking coolant.

Currently, R & D for molten salt reactors is on the rise due to the previously stated benefits with current developments related to materials, safety features, reactor core designs, and economic models.

Small Modular Reactor

Small Modular Reactors (SMR) provide benefits which include the possibility to combine nuclear with alternative energy sources which includes renewables. SMRs also offer an option for more remote regions with less developed infrastructure.

A small modular reactor is a reactor that produces electricity of up to 300 Megawatts (MW(e)) per module. By comparison small coal-fired plants can have a daily output as low as 1600 Mega-Watt Hours (MWh) per day.

These SMRs are considered advanced reactors with advanced features, are designed and can be deployed to factories and utility stations as single or multi-module plants.

Globally, there are currently four SMRs in advanced stages of construction in Argentina, China, and Russia.

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