Unit-2

Nuclear Energy

FUNDAMENTAL FORCES IN THE UNIVERSE

Four fundamental forces:

1. Gravity.
2. The weak force.
3. Electromagnetism.
4. The strong force.

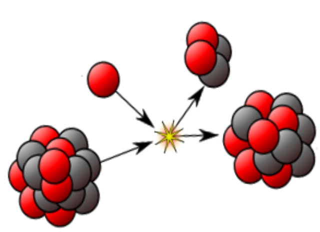
These are called the four fundamental forces of nature, and they govern everything that happens in the universe.

1. **Gravity:-** Gravity is the attraction between two objects that have mass or energy, whether this is seen in dropping a rock from a bridge, a planet orbiting a star or the moon causing ocean tides. Gravity is probably the most intuitive and familiar of the fundamental forces, but it's also been one of the most challenging to explain. Isaac Newton was the first to propose the idea of gravity, supposedly inspired by an apple falling from a tree. He described gravity as a literal attraction between two objects.
2. The weak force:- The weak force, also called the weak nuclear interaction, is responsible for particle decay. This is the literal change of one type of subatomic particle into another. So, for example, a neutrino that strays close to a neutron can turn the neutron into a proton while the neutrino becomes an electron.
3. Electromagnetic force:- The electromagnetic force, also called the Lorentz force, acts between charged particles, like negatively charged electrons and positively charged protons. Opposite charges attract one another, while like charges repel. The greater the charge, the greater the force. And much like gravity, this force can be felt from an infinite distance. As its name indicates, the electromagnetic force consists of two parts: the electric force and the magnetic force. At first, physicists described these forces as separate from one another.
4. The strong nuclear force:- The strong nuclear force, also called the strong nuclear interaction, is the strongest of the four fundamental forces of nature. It's 6 thousand trillion trillion (that's 39 zeroes after 6!) times stronger than the force of gravity.

WHAT IS NUCLEAR FORCE?

Nuclear force is one of the four fundamental forces of nature, the others being gravitational and electromagnetic forces. In fact, being 10 million times stronger than the chemical binding forces, they are also known as the strong forces. In this section, we will discuss this force in detail. *We can define nuclear force as:*

The nuclear force is a force that acts between the protons and neutrons of atoms.



The nuclear force is the force **that binds the protons and neutrons in a nucleus together**. This force can exist between protons and protons, neutrons and protons or neutrons and neutrons. This force is what holds the nucleus together.

The charge of protons, which is +1*e,* tends to push them away from each other with a strong electric field repulsive force, following Coulomb's law. But nuclear force is strong enough to keep them together and to overcome that resistance at short range.

BINDING ENERGY

Nuclear binding energy is the energy required to **split a nucleus of an atom into its component parts: protons and neutrons**, or, collectively, the nucleons. The binding energy of nuclei is always a positive number, since all nuclei require net energy to separate them into individual protons and neutrons.

MASS DEFECT

Nuclear binding energy accounts for a noticeable difference between the actual mass of an atom's nucleus and its expected mass based on the sum of the masses of its non-bound components. Recall that energy (E) and mass (m) are related by the equation: $E=mc^2$

Here, c is the speed of light. In the case of nuclei, the binding energy is so great that it accounts for a significant amount of mass.

The actual mass is always less than the sum of the individual masses of the constituent protons and neutrons because energy is removed when the nucleus is formed. This energy has mass, which is removed from the total mass of the original particles. This mass, known as the mass defect, is missing in the resulting nucleus and represents the energy released when the nucleus is formed.

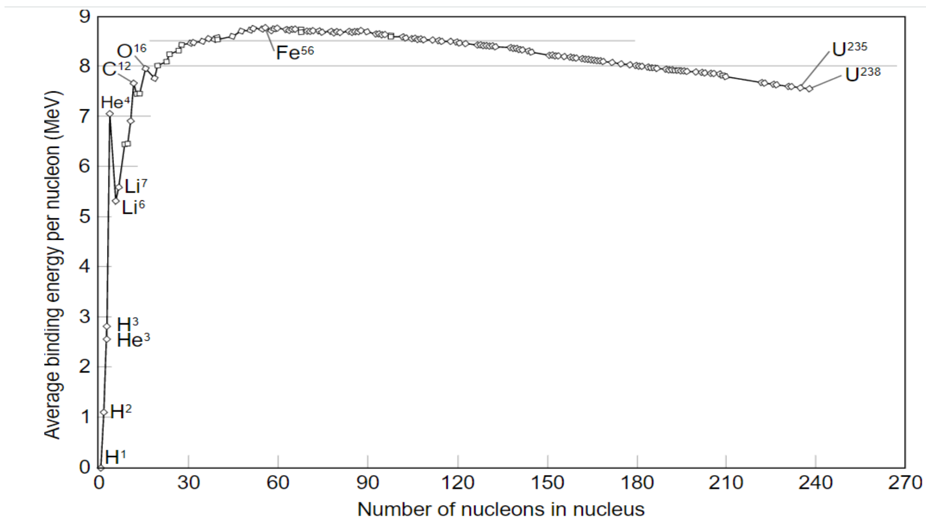
NUCLEAR BINDING ENERGY

Once mass defect is known, nuclear binding energy can be calculated by converting that mass to energy by using E=mc2. Mass must be in units of kg.

Nuclear binding energy can also apply to situations when the nucleus splits into fragments composed of more than one nucleon; in these cases, the binding energies for the fragments, as compared to the whole, may be either positive or negative, depending on where the parent nucleus and the daughter fragments fall on the nuclear binding energy curve. If new binding energy is available when light nuclei fuse, or when heavy nuclei split, either of these processes result in the release of the binding energy. This energy—available as nuclear energy—can be used to produce nuclear power or build nuclear weapons. When a large nucleus splits into pieces, excess energy is emitted as photons, or gamma rays, and as kinetic energy, as a number of different particles are ejected.

Nuclear binding energy is also used to determine whether fission or fusion will be a favorable process. For elements lighter than iron-56, fusion will release energy because the nuclear binding energy increases with increasing mass. Elements heavier than iron-56 will generally release energy upon fission, as the lighter elements produced contain greater nuclear binding energy. As such, there is a peak at iron-56 on the nuclear binding energy curve.

Nuclear binding energy curve:- This graph shows the nuclear binding energy (in MeV) per nucleon as a function of the number of nucleons in the nucleus. Notice that iron-56 has the most binding energy per nucleon, making it the most stable nucleus.



It is observed that the mass of a nucleus is always less than the mass of constituent (free) nucleons. This difference in mass i called as mass defect and is denoted as Dm.

If m_n: mass of a neutron;

m_p: mass of a proton

M (Z, A): mass of bounded nucleus

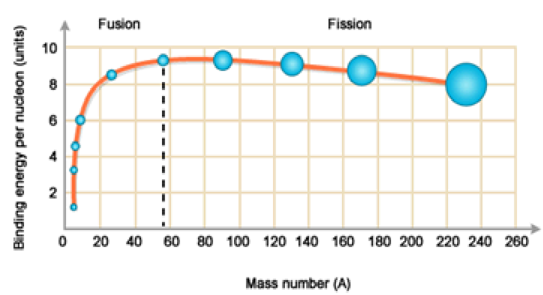
Then, $\Delta m = Z . m_p + (A – Z). m_n – M (Z, A)$

This mass-defect is in form of energy and is responsible for binding the nucleons together. From Einstein's law of inter-conversion of mass into energy:

$E = mc^2$ (c: speed of light; m: mass)

Binding energy,

$$B.E = \Delta m \cdot c^2$$



Generally, Δm is measured in amu units. So let us calculate the energy equivalent to 1 amu. It is calculated in eV (electron volts; 1 eV =1.6 x10^{-19} J)

E (= 1 amu = 1.67 × 10^{-27} $(3×10^8)^2$ / 1.6 × 10^{-19}) eV = 931 × 10^8 eV = 931 MeV

=> B.E. = Δm (931) MeV

There is another quantity which is very useful in predicting the stability of a nucleus called as Binding energy per nucleons.

B.E. per nucleons = Δm (931) / A MeV

Problem 1:–:

If mass of proton = 1.008 amu and mass of neutron = 1.009 amu, then the binding energy per nucleon for $_4Be^9$ (mass = 9.012 amu) will be:

(A) 0.0672 MeV (B) 0.672 MeV

(C) 6.72 MeV (D) 67.2 MeV

Solution:-

Mass defect,

Δm = (4 × 1.008 + 5 × 1.009) – 9.012

= 9.077 – 9.012 =0.065 amu

BE/A = 0.065 × 931 / 9 = 6.72 MeV

Radioactive Decay Rates:- Radioactive decay is the loss of elementary particles from an unstable nucleus, ultimately changing the unstable element into another more stable element. There are five types of radioactive decay: alpha emission, beta emission, positron emission, electron capture, and gamma emission. Each type of decay emits a specific particle which changes the type of product produced. The number of protons and neutrons found in the daughter nuclei (the nuclei produced from the decay) are determined by the type of decay or emission that the original element goes through.

Decay Rates:- Due to the smaller size of the nucleus compared to the atom and the enormity of electromagnetic forces, it is impossible to predict radioactive decay. The atomic nucleus which is in the center of the atom is buffered by surrounding electrons and external conditions. Because of this, the study of decay is independent of the element's environment. In other words, the decay rate is independent of an element's physical state such as surrounding temperature and pressure. For a given element, the decay or disintegration rate is proportional to the number of atoms and the activity measured in terms of atoms per unit time. If "A" represents the disintegration rate and "N" is number of radioactive atoms, then the direct relationship between them can be shown as below:

$$A \propto N$$

$$A = \lambda N$$

where

A is the Total activity and is the number of decays per unit time of a radioactive sample.

N is the total number of particles in the sample.

λ is the constant of proportionality or decay constant.

Decay Rate & Chemical Kinetics:- Since the decay rate is dependent upon the number of radioactive atoms, in terms of chemical kinetics, one can say that radioactive decay is a first order reaction process. Even though radioactive decay is a first order reaction, where the rate of the reaction depends upon the concentration of one reactant (r = k [A][B] = k [A}) , it is not affected by factors that alter a typical chemical reactions. In other words, the reaction rate does not depend upon the temperature, pressure, and other physical determinants. However, like a typical rate law equation, radioactive decay rate can be integrated to link the concentration of a reactant with time. Also, radioactive decay is an exponential decay function which means the larger the quantity of atoms, the more rapidly the element will decay. Mathematically speaking, the relationship between quantity and time for radioactive decay can be expressed in following way:

$$\frac{dN}{dt} = -\lambda N$$

$$\frac{dN(t)}{dt} = -\lambda N$$

$$\frac{dN(t)}{N(t)} = -\lambda dt$$

$$\ln N(t) = -\lambda t + C$$

- C is the constant of integration
- $N(t)$ is the amplitude of N after lapse of time t
- λ is the decay rate constant.

Ways to Characterize Decay Constant

There are two ways to characterize the decay constant: mean-life and half-life. In both cases the unit of measurement is seconds. As indicated by the name, m life is the average of an element's lifetime and can be shown in terms of following expression

$$N_t = N_o e^{-\lambda t}$$

$$1 = \int_0^\infty c \cdot N_0 e^{-\lambda t} dt = c \cdot \frac{N_0}{\lambda}$$

Rearranging the equation:

$$c = \frac{\lambda}{N_o}$$

Decay Rate Half-Life

Half-life is the time period that is characterized by the time it takes for half of the substance to decay (both radioactive and non-radioactive elements).The rate decay remains constant throughout the decay process. There are three ways to show the exponential nature of half-life.

$$N_t = N_o \left(\frac{1}{2}\right)^{t/t_{1/2}}$$

$$N_t = N_o e^{-t/\tau}$$

By comparing Equations 1, 3 and 4, one will get following expressions

$$\ln\left(\frac{1}{2}\right)^{t/t_{1/2}} = \ln(e^{-t/\tau}) = \ln(e^{-\lambda t})$$

or with $\ln(e) = 1$, then

$$\frac{t}{t_{1/2}} \ln\left(\frac{1}{2}\right) = \frac{-t}{\tau} = -\lambda t$$

By canceling t on both sides, one will get following equation (for half-life)

$$t_{1/2} = \frac{\ln(2)}{\lambda} \approx \frac{0.693}{\lambda}$$

or combining equations 1B and 11

$$A = \frac{0.693}{t_{1/2}} N$$

NUCLEAR ENERGY

The **energy released during nuclear fission or fusion, especially when used to generate electricity.**

Nuclear power is the use of nuclear reactions that release nuclear energy to generate heat, which most frequently is then used in steam turbines to produce electricity in a nuclear power plant. Nuclear power can be obtained from nuclear fission, nuclear decay and nuclear fusion reactions.

Nuclear power in India

Nuclear power is the fifth-largest source of electricity in India after coal, gas, hydroelectricity and wind power. As of March 2018, India has **22 nuclear reactors in operation in 7 nuclear power plants, with a total installed capacity of 6,780 MW**.

Operational nuclear power plants in India

Power station	Operator	State	Type	Units	Total capacity (MW)
Kaiga	NPCIL	Karnataka	PHWR	220 x 4	880
Kakrapar	NPCIL	Gujarat	PHWR	220 x 2	440
Kudankulam[115]	NPCIL	Tamil Nadu	VVER-1000	1000 x 2	2,000
Madras (Kalpakkam)	NPCIL	Tamil Nadu	PHWR	220 x 2	440
Narora	NPCIL	Uttar Pradesh	PHWR	220 x 2	440
Rajasthan	NPCIL	Rajasthan	PHWR	200 x 1 220 x 4	1,080
Tarapur	NPCIL	Maharashtra	BWR PHWR	160 x 2 540 x 2	1,400
Total					**6,680**

Advantages of nuclear energy

1- **Produces large amount of energy:** Nuclear reactions release a million times more energy, as compared to hydro or wind energy. Hence, a large amount of electricity can be generated by the use of this type of energy source. Presently, approximately 10-15% of the world's electricity is generated through nuclear energy. Did you know that one kilogram of uranium-235 approximately produces as much energy as 1,500 tons (1,500,000 kilograms) of coal?

2-It is green energy: One of the biggest advantages of this energy is that greenhouse gases (carbon dioxide, methane, ozone, chlorofluorocarbon) are not released during the operation of the plant. Without human errors, accidents, or natural calamities, the nuclear reactors work very well and can go on for a long time without the need for refueling. Secondly, once constructed, the plant requires very few people to operate it.

3-**No air pollution**: The burning of fossil fuels leads to the production of carbon dioxide and smoke. It is a menace to the environment as well as human life. Production in a nuclear power plant does not emit smoke. Hence, there is no direct air pollution. However, disposal of radioactive waste is a major issue today.

4-Fuel independence: Nuclear reactors make use of uranium as fuel. Fission reaction of a small amount of uranium generates a large amount of energy. Currently, the reserves of uranium found on the Earth are expected to last for another 100 years. Secondly, using this type of energy source can make many nations energy independent, and not dependent on those unearthing fossil fuels.

5- Space limitations: Nuclear power plants don't require a lot of space; they do not need a large plot like a wind farm or a solar park. But they have to be built near a large body of water for cooling purposes - using the water as a heat sink. They are usually found on the coast, so there is no risk to drinking water sources.

6- **Nuclear energy is by far the most concentrated form of energy** - a small mass of fuel produces a lot of energy. This reduces transport costs - (although the fuel is radioactive and therefore each transport that does occur is expensive because of security implications). Less uranium is needed to produce the same amount of energy as coal or oil, which lowers the cost of producing the same amount of energy. Uranium is also less expensive to procure and transport, which further lowers the cost. One characteristic of nuclear energy is its higher efficiency level over other energy sources such as fossil fuels. This is due to the high density of the energy produced by nuclear power plants.

Moreover, less fuel is required to process nuclear energy as opposed to processing oil and coal.

7- Nuclear power is a reliable type of energy source. It does not depend on the weather. When a nuclear power plant is functioning properly, it can run uninterrupted for up to 540 days. This results in fewer brownouts or other power interruptions. The running of the plant is also not contingent on whether or foreign suppliers, which makes it more stable than other forms of energy.

8-We can control the output from a nuclear power plant to fit our needs. It is relatively easy to control the output - although the time factor for altering power output is not as small as for fossil fuel power plants. It is said to have a long 'startup' time. It cannot respond immediately to demand. That is why electricity companies try to 'even out' demand by using tariffs that encourage use at off-peak time periods.

9- Nuclear power produces a small volume of waste although that waste is radioactive.

10- **Low maintenance**: Investing in nuclear power plants to produce energy since these plants do not need regular maintenance as well as operation can last between 40-60 years. Consequently, there is no need to shut down the plants any time soon once they have been built. Also, with the abundant supply of Uranium, there is an assurance of sufficient supply even if demands increase.

Disadvantages of nuclear energy

1- **Radiation:** Accidental release of harmful radiation is one of the biggest drawbacks of the use of nuclear energy for electricity generation. The fission process releases radiation, but, is controlled in a nuclear reactor. Now, if these safety measures fail, the radiation may come in contact with the environment, resulting in severe damage to the ecosystem and loss of life.

2- **Nonrenewable:** Although they produce a large amount of energy, nuclear reactors depend on uranium, which is an exhaustible fuel. Its extinction can again cause a grave problem. Once exhausted, the reactors will be of no use, will have to be shut down, but will remain to occupy a large area of land and to contaminate the environment.

3- **Can be used for developing nuclear weapons**: This type of energy can be used for the production and proliferation of nuclear weapons. Nuclear weapons make use of fission, fusion, or combination of both reactions for destructive purposes. They are a major threat to the world as they can cause large-scale devastation. Their effects can be observed for many generations (e.g., atomic bombings of Hiroshima and Nagasaki).

4- **Huge building cost:** Though a large amount of energy can be produced from a nuclear power plant, it requires a large capital cost. Around 8-15 years are required to develop a single plant. It is not very feasible to build a nuclear power plant by many countries. Secondly, one cannot ignore the fact that the nuclear reactors will work as long as uranium is available. Despite the low maintenance costs of nuclear power plants, a substantial amount of investment is needed to build these plants. Around 2 billion dollars is needed to build a 1,000-megawatt power plant and timetable can take up to five years.

5- **Nuclear waste:** The waste produced after fission reactions contains unstable elements, and is highly radioactive. It is very dangerous to the environment as well as human health and remains so for hundreds of years. It needs professional handling and should be kept isolated from the living environment. The radioactivity of these elements reduces over a period, after decaying. Hence, they have to be carefully stored and disposed of. It is very difficult to store radioactive elements for a long period. The disposal of nuclear waste is expensive.

6- **Nuclear power plant accidents:** There have been two most disastrous nuclear power plant accidents to date: the Chernobyl disaster that occurred at the Chernobyl Nuclear Power Plant (1986) in Ukraine, and the Fukushima Daiichi nuclear disaster (2011) in Japan. A large amount of radiation was released into the environment after these incidents, leading to fatalities, damage to nature, and land. One cannot deny the possibility of a repetition of such disasters in the future.

7- **Transport of fuel and waste:** Transport of uranium fuel and the radioactive waste is very difficult. Uranium emits some amount of radiation, and hence, needs to be handled with care. Secondly, the nuclear waste produced is more hazardous and needs extra protection. All transportation means should follow the international safety standards. Although no accidents or spills are reported as of now, the transportation process is still challenging.

8- **Decommissioning of nuclear power stations is expensive and takes a long time.**

Selection of Site

- Availability of water - NPP requires ample amount of water for cooling and steam generation.
- Disposal of Waste – Dangerous waste/residue obtained

  It needs to be disposed deep under the ground in sea so that radioactive effect is eliminated.
- Away from populated area – For health safety
- Nearest to the load centre
- Other Factors – Accessibility to the road and rail are general considerations.

NUCLEAR FUSION &NUCLEAR FISSION

Nuclear fusion is a reaction through which two or more light nuclei collide into each other to form a heavier nucleus. This reaction takes place with elements which have a low atomic number, such as Hydrogen. It is the opposite of nuclear fission reaction in which heavy elements diffuse and form lighter elements. Both nuclear fusion and fission produce a massive amount of energy.

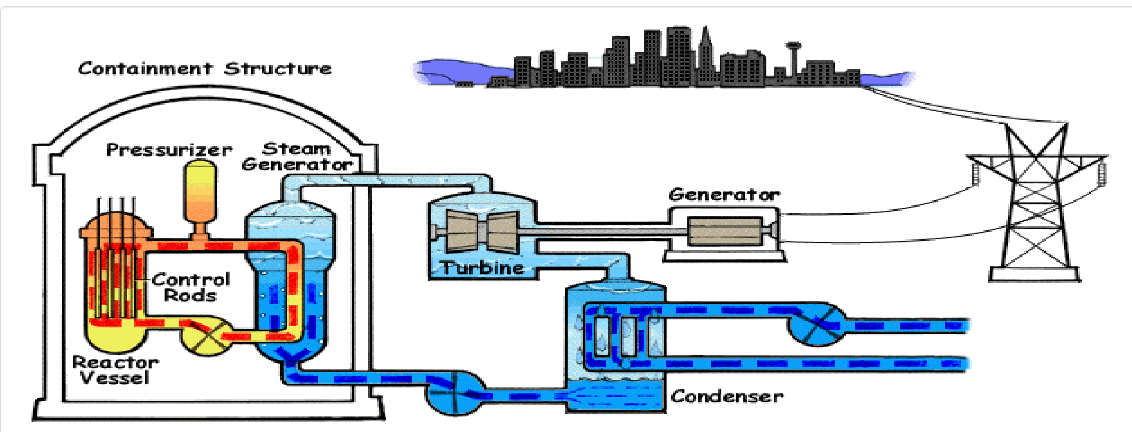
Difference between Nuclear Fission and Nuclear Fusion

Nuclear Fission	Nuclear Fusion
Breaks a heavy atom into two or more smaller ones.	Brings two or more small atoms together to form one large atom.
Does not happen naturally.	The universe is full of instances of nuclear fusion reactions. Every star uses it to produce energy.
Produces a great deal more energy than chemical reactions but still not as much as fusion.	Produces many times more amount of energy than fission.
Does not require a lot of energy to split an atom into two.	Requires a lot of heat and pressure for the process to happen.

WHAT IS A NUCLEAR REACTOR?

A nuclear reactor is a system that contains and **controls sustained nuclear chain reactions**. Reactors are used for generating electricity, moving aircraft carriers and submarines, producing medical isotopes for imaging and cancer treatment, and for conducting research.

Fuel, made up of heavy atoms that split when they absorb neutrons, is **placed into the reactor vessel (basically a large tank) along with a small neutron source. The neutrons start a chain reaction where each atom that splits releases more neutrons that cause other atoms to split**. Each time an atom splits, it releases large amounts of energy in the form of heat. The heat is carried out of the reactor by coolant, which is most commonly just plain water. The coolant heats up and goes off to a turbine to spin a generator or drive shaft.



Main components

- **The core** of the reactor contains all of the nuclear fuel and generates all of the heat. It contains low-enriched uranium (<5% U-235), control systems, and structural materials. The core can contain hundreds of thousands of individual fuel pins.
- **The coolant** is the material that passes through the core, transferring the heat from the fuel to a turbine. It could be water, heavy-water, liquid sodium, helium, or something else. In the US fleet of power reactors, water is the standard.
- **The turbine** transfers the heat from the coolant to electricity, just like in a fossil-fuel plant.

- **The containment** is the structure that separates the reactor from the environment. These are usually dome-shaped, made of high-density, **steel-reinforced concrete. Chernobyl did not have a containment to speak of.**
- **Cooling towers** are needed by some plants to dump the excess heat that cannot be converted to energy due to the laws of thermodynamics. These are the hyperbolic icons of nuclear energy. They emit only clean water vapor.

Control Rods

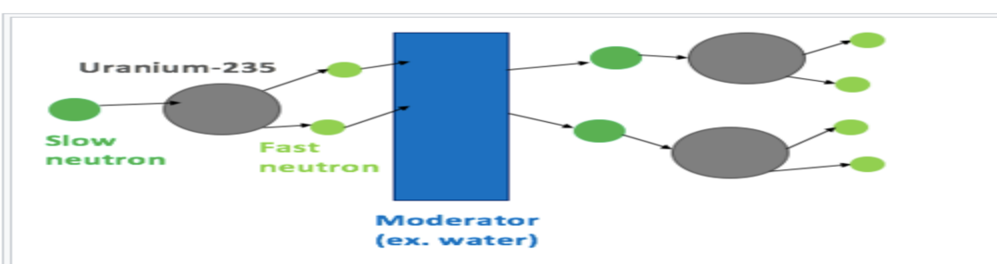
Control rods are an important safety **system of nuclear** reactors. Their prompt action and prompt response of the reactor is indispensable. Control rods are used for maintaining the desired state of fission reactions within a nuclear reactor (i.e. subcritical state, critical state, power changes) They constitute a key component of an emergency shutdown system (SCRAM).

Control rods are rods, plates, or tubes containing a neutron absorbing material (material with high absorbtion cross-section for thermal neutron) such as boron, hafnium, cadmium, etc., used to control the power of a nuclear reactor. By absorbing neutrons, a control rod prevents the neutrons from causing further fissions.

Neutron moderator

Neutron moderators are a type of material in a nuclear reactor that work **to slow down the fast neutrons (produced by splitting atoms in fissile compounds like uranium-235), t**o make them more effective in the fission chain reaction. This slowing or moderation of the neutrons allows them to be more easily absorbed by fissile nuclei, creating more fission events (see Figure 1).

Materials used for moderation need to a very specific set of properties. First, a moderator cannot absorb neutrons itself. This means that the moderator should have a *low* neutron absorption cross-section. However, the moderator should be able to slow down neutrons to an acceptable speed.

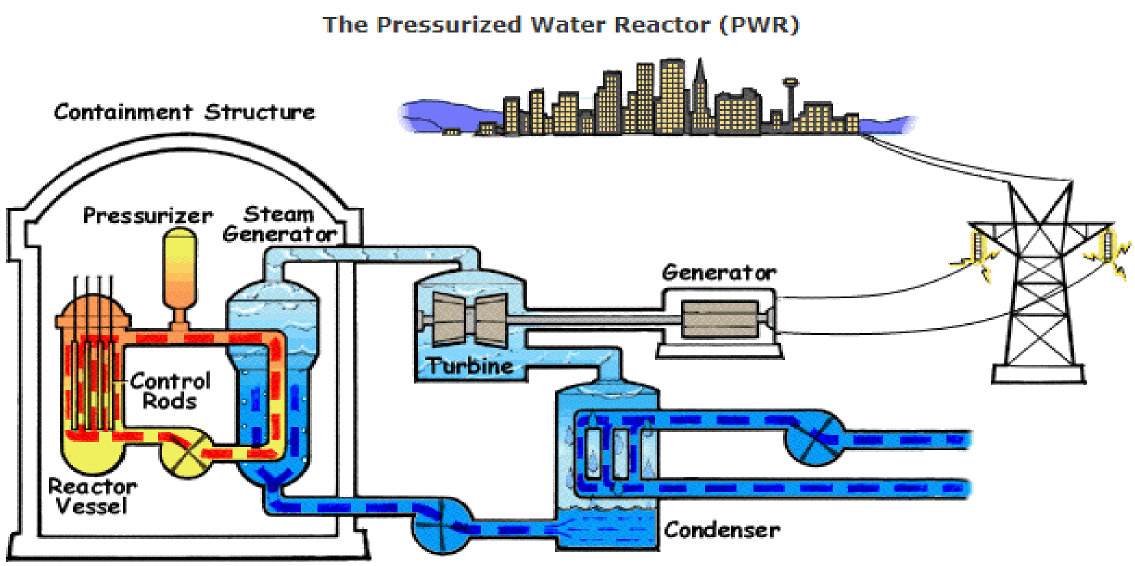


Types of Moderating Materials:- There are several different types of moderating materials, and each have places where they are used more effectively. Typically-used moderator materials include heavy water, light water, and graphite. The relative properties of these materials are compared below. The moderators vary in terms of their moderating abilities, as well as in their costs.

Types of Reactors

Reactor Type	Fuel	Moderator	Coolant
Pressurized water reactor (PWR)	Enriched UO_2	Water	Water
Boiling water reactor (BWR)	Enriched UO_2	Water	Water
Pressurized heavy water reactor "CANDU" (PHWR)	Natural UO_2	Heavy water	Heavy water
Gas-cooled reactor (GCR)	Natural U (metal), enriched UO_2	Graphite	Carbon dioxide
Light water graphite reactor (LWGR)	Enriched UO_2	Graphite	Water
Fast breeder reactor (FBR)	PuO_2 and UO_2	None	Liquid sodium

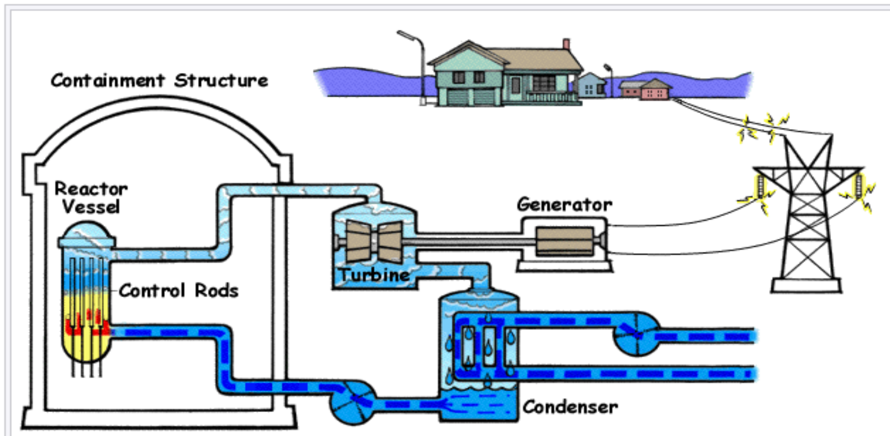
1. The Pressurized Water Reactor (PWR):-



The pressurized water reactor (PWR) is a type of nuclear reactor used to the generate electricity and propel nuclear submarines and naval vessels. They make use of light water (ordinary water, as opposed to heavy water) as their coolant and neutron moderator. It is one of three types of light water reactors, with the others being the boiling water reactor and the supercritical water cooled reactor.

Pressurized water reactors must use enriched uranium as their nuclear fuel, because of their use of light water. This is because light water would absorb too many neutrons if natural uranium was used, so the fuel content of fissile Uranium-235 must be increased. This is done through a uranium enrichment process, in which the concentration of Uranium-235 is increased from 0.7% to around 4%.

2. Boiling water reactor



Boiling water reactors (BWR) are a type of nuclear reactor that use light water (ordinary water, as opposed to heavy water) as their coolant and neutron moderator. They are the second most used reactor for nuclear power generation in the world, next to the pressurized water reactor (PWR)—with 75 in operation as of 2018.

With maximum operating temperatures of around 285oC, the Carnot efficiency (maximum efficiency) of boiling water reactors in the production of power is 46%. However, the realistic efficiency of these reactors in power production is around 33-34%.

Boiling water reactors must operate at fairly high pressures in order for the water to perform adequately; at high pressures the water can remain in liquid form at temperatures much higher than its normal 100oC boiling point. Therefore, boiling water reactors operate at around 7 MPa—around 70 times higher than atmospheric pressure.

3. CANDU reactor:- A pressurized heavy water reactor is a type of nuclear reactor that makes use of heavy water as its coolant and moderator. Heavy water contains an isotope of hydrogen called deuterium. Deuterium absorbs fewer neutrons than hydrogen, which is extremely important as nuclear fission reactions require neutrons to carry out their chain reactions.The heavy water is kept under pressure which increases its boiling point so that it can operate at high temperatures without boiling.
   CANDU reactor is a type of nuclear reactor which was developed in Canada, and is currently used in nuclear power plants for electrical generation in various countries around the world. CANDU stands for CANada Deuterium Uranium, which reflects the key role of deuterium, or heavy water, which acts as the reactor's neutron moderator, a unique trait of the CANDU. The reactors are also different from other reactors because they are designed to utilize natural uranium as a fuel (as opposed to enriched uranium).

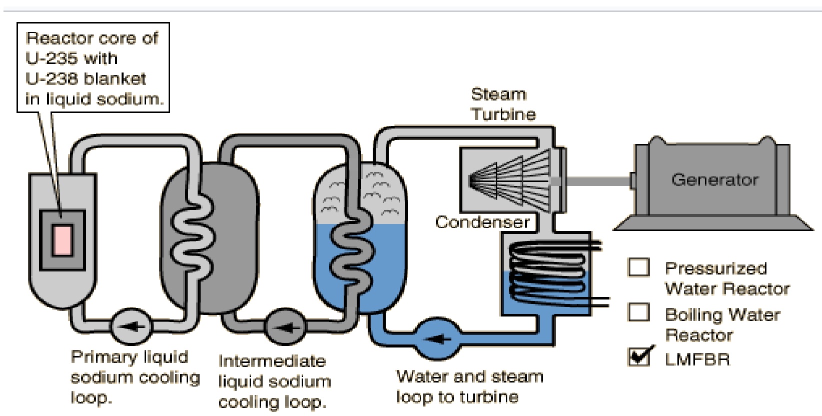
4. **Gas- Cooled reactor: -** Gas Cooled Graphite Moderator Reactor (GCGM) Fuel : Natural Uranium Coolant pressure : 7 bar Coolant temperature : 336 °C High Temperature Gas Cooled Reactor (HTGC) Fuel : Uranium carbide + thorium carbide (clad with graphite) Coolant pressure : 15 to 30 bar Coolant temperature : 700°C to 800°C Gas Cooled Reactor Gas Cooled Graphite Moderator Reactor (GCGM) High Temperature Gas Cooled Reactor (HTGC).

   Gas-Cooled Reactor Advantages: - 1. Simple Fuel Process 2. No corrosion 3. Graphite – stable at high temperature 4. CO2 eliminates the possibilities of explosion 5. Uranium carbide and graphite : resist high temperature

   Gas-Cooled Reactor Disadvantages:- 1. Fuel : More Quantity and costly 2. Power density : very low 3. More Fuel (initially) : High Critical Mass 4. More power for coolant circulation 5. Complicated consolation.

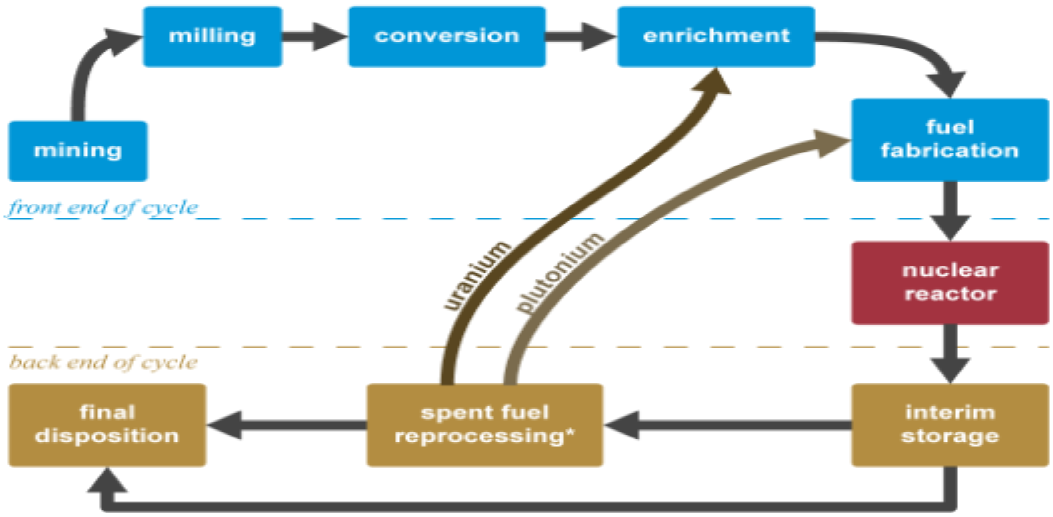
5. Light-water reactor:- The light-water reactor (LWR) is a type of thermal-neutron reactor that uses normal water, as opposed to heavy water, as both its coolant and neutron moderator – furthermore a solid form of fissile elements is used as fuel. Thermal-neutron reactors are the most common type of nuclear reactor, and light-water reactors are the most common type of thermal-neutron reactor.

6. Fast Breeder reactor:- There are two categories of breeder reactors, based on the speed of the neutrons. Fast breeder reactors which use uranium-238 as fuel and thermal breeder reactors which use thorium-232 as fuel. Fast breeders do not require moderation since the neutrons need to be moving fast, whereas thermal breeders make us of moderation to achieve slower-moving neutrons.



The most promising type of breeder reactor is the Liquid Metal Fast Breeder Reactor (LMFBR), which operates by using liquid sodium as its coolant, and breeds plutonium from uranium-238. It works by using highly enriched uranium, between 15-20% uranium-235 content, surrounded or "blanketed" by natural uranium-238 in the reactor core. No moderator is used to slow down the neutrons, because fast neutrons transmute uranium-238 much more efficiently than slow neutrons.

OPERATION AND FUEL CYCLES



There are several steps in the nuclear fuel cycle:

Mining – Depending on the depth and concentration of the uranium source, and the conditions of the surrounding rock, mining companies will extract uranium ore in one of three ways: open pit mining, underground mining or in-situ recovery.

Milling – To extract the uranium, the ore is crushed in a mill and ground to a fine slurry. The slurry is then leached in sulfuric acid, which produces a solution of uranium oxide ($U3O8$). The concentrate of this solution is called yellowcake.

Refining – A series of chemical processes separate the uranium from impurities, producing high-purity uranium trioxide ($UO3$).

Conversion – $UO3$ is converted to uranium dioxide ($UO2$) for use in heavy water reactors, or to uranium hexafluoride ($UF6$) for enrichment, before it can be used in light water reactors.

Enrichment – Uranium-235 is the uranium isotope that can be used in fission, but it makes up only 0.7% of naturally occurring uranium, which is not concentrated enough for light water reactors. So, enrichment processes increase the concentration of U-235 to about 3% – 5%. After undergoing enrichment, the $UF6$ is chemically transformed back into $UO2$ powder.

Fuel manufacturing – Natural or enriched $UO2$ powder is pressed into small cylindrical pellets, which are then baked at high temperatures, and finished to precise dimensions.

Electricity generation – Fuel is loaded into a reactor, and nuclear fission generates electricity. After fuel is consumed, it is removed from the reactor and stored onsite for a number of years while its radioactivity and heat subside.

Optional chemical reprocessing – After a period of storage, residual uranium or by-product plutonium, both of which are still useful sources of energy, are recovered from the spent fuel elements and reprocessed.

Disposal – Depending on the design of the disposal facility, the nuclear fuel may be recovered if needed again, or remain permanently stored. At some point in the future the spent fuel will be encapsulated in sturdy, leach-resistant containers and permanently placed deep underground where it originated.