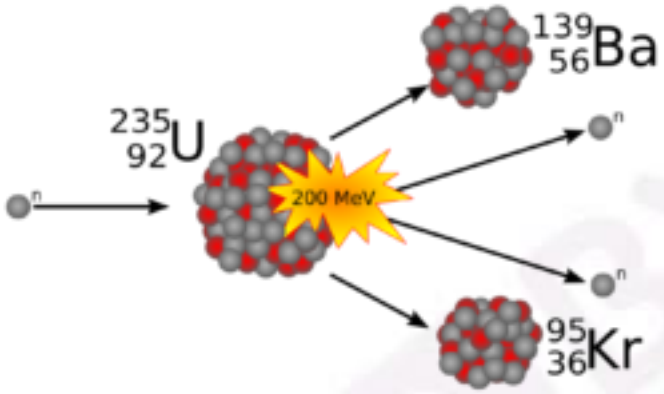
Nuclear Reactor [UPSC Science & Technology]

The modern "Atomic Age" is attributed to the age of discovery and developments in the field of nuclear fission. After India's 3 stage Nuclear Power Program that was conceived soon after Independence to meet the security and energy demands, India commissioned its first Nuclear power plant in Tarapur, Maharashtra. Students preparing for the IAS Exam must be aware of this and topics related to it.

A nuclear reactor, part of the Nuclear Plant is an important concept in Science & Technology which is part of General Studies paper-3 in the UPSC Syllabus. In this article, one can learn about the types and working of nuclear reactors. We have also mentioned topics that can be related to Nuclear Reactors for the UPSC 2020 Exam.

What is a Nuclear Reactor?

A nuclear reactor is the most important part of a nuclear power plant. It is where the nuclear chain reactions occur that produce energy by fission. The heat thus produced can be used to produce electricity.



The main purpose of a reactor is to contain and control the energy released. Uranium is used as the nuclear fuel in the reactors.

The heat produced by nuclear reactions is used to convert the water into steam, which is further converted into carbon-free electricity by the help of turbines.

Main Components of a Nuclear Reactor

The main components of a nuclear reactor are listed below.

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  - **The Core**: It contains all the fuel and generates the heat required for energy production.
  - **The Coolant**: It passes through the core, absorbing the heat and transferring into turbines.
  - **The Turbine**: Transfers energy into the mechanical form.
  - **The Cooling Tower**: It eliminates the excess heat that is not converted or transferred.
  - **Neutron Moderator:** Moderators are used for reducing the speed of fast neutrons released from the fission reaction and making them capable of sustaining a nuclear chain reaction.
    - Usually, water, solid graphite and heavy water are used as a moderator in nuclear reactors.
    - Commonly-used moderators include regular (light) water (in 74.8% of the world's reactors), solid graphite (20% of reactors), heavy water (5% of reactors).

- **The Containment**: The enveloping structure that separates the nuclear reactor from the surrounding environment.

- **Neutron Poison :** A neutron poison (also called a neutron absorber or a nuclear poison) is a substance with a large neutron absorption cross-section.

Types of Nuclear Reactor

Based on various components and working principles of Nuclear Reactors, one can distinguish them into the following types discussed below. Even though all the commercial nuclear power reactors use Nuclear Fission, they can be classified into two categories based on the energy of neutrons that sustain the fission chain reaction.

- **Thermal Reactors**

  - Thermal reactors (the most common type of nuclear reactor) use slowed or thermal neutrons to keep up the fission of their fuel.
  - Boiling water reactors (BWR), Pressurized water reactors (PWR) and Heavy water reactors (HWR) operate with thermal neutrons.

- **Fast Neutron Reactors**

  - Fast neutron reactors use fast neutrons to cause fission in their fuel.
  - Very rare due to complexity and costs. They are more difficult to build and more expensive to operate.
  - Fast reactors have the potential to produce less radioactive waste because all fissile is fissionable with fast neutrons [fuel is highly enriched in fissile material].

Types of Nuclear Reactors	

Light Water Reactors (LWR)	• LWR is a type of Thermal Neutron Reactor.
	• Uses *Normal Water instead of Heavy Water* as its coolant and Neutron Moderator.
	• BWR & PWR are Light Water Reactors.
	• The BWR drives the steam turbine when the reactor core heats the water converting it into steam. Example: Fukushima Daiichi, Japan.
	• The PWR drives the steam turbine in two stages.
	  ○ Pressurized water has a higher boiling point. Reactor core heats the water without producing any steam in the core.
	  ○ This pressurized hot water then exchanges heat with a secondary low-pressure water unit which turns into steam.
	  ○ This steam drives the steam turbine.

Heavy Water Reactors	• HWR is also a type of Thermal Neutron Reactor. • Uses Heavy Water (deuterium oxide D2O) as its coolant and Neutron Moderator. • The HWR follows the working principle of the Pressurized Water Reactor. • Even though Heavy Water is very expensive, it allows the nuclear reactor to operate without any fuel enrichment due to the enhanced neutron economy. • This also allows the Nuclear reactor to use alternate fuel cycles.

Gas-Cooled Reactors	• BWR, LWR, HWR & PWR can't operate at very high temperatures and thus doesn't provide great thermal efficiency. • In Gas-Cooled reactors, gas is replaced as a coolant and that drives the turbine. • These reactors are called High-Temperature Gas-Cooled Reactors (HTGRs). • Gases like Helium & Carbon-Dioxide are used as coolants. • HTGRs provide high thermal efficiency (Upto 50%) as they can operate at high temperatures. • HTGRs can have multiple applications other than power production which involve heat processes like hydrogen fuel cells, water desalination, oil refineries, etc. • Gas being, not the most efficient coolant, HTGRs need a highly- efficient back-up coolant.
Fast Reactors	• The reactors discussed above use moderators that slow the high-energy (fast) neutrons down to low-energy (slow). • Fast reactors don't use moderators and use Fast Neutrons. • In order to sustain the fission reaction by fast neutrons, the fission material needs to be highly enriched. • Uranium enrichment is very expensive thus making the use of Fast reactors uneconomical.

Nuclear Reactors in India

The below table gives a list of the locations of the installed nuclear reactors in India:

1. Rajasthan (Rawatbhata)
2. Tamil Nadu (Kudankulam; Kalpakkam)
3. Gujarat (Kakrapar)
4. Uttar Pradesh (Narora)
5. Karnataka (Kaiga)
6. Maharashtra (Tarapur)

There are about five other projects under construction.

Also, read about the Kudankulam Nuclear Power Plant

UPSC Questions related to Nuclear Reactors

What was the objective behind formulating the Three Stages Nuclear Power Program?

- India has only 2% of the world's uranium reserves, on the other hand, India has 25% of the world's thorium reserves.
- Since India was not part of some of the international nuclear treaties, India was prevented from taking part in international trade in the nuclear field.
- India has a huge population and a growing economy, so to meet the energy demands, India had to rely heavily on imports of coal and crude oil.
- Hence, India had to devise methodologies to be self-sufficient in meeting energy demands arising due to a burgeoning population and economy; the 3 stage Nuclear Power Program was one of the answers to it.

What is Critical Mass?

- A critical mass is the smallest amount of fissile material needed for a sustained nuclear chain reaction.
- The critical mass of a fissionable material depends upon its nuclear properties, its density, its shape, its enrichment, its purity, its temperature, and its surroundings.
- When a nuclear chain reaction in a mass of fissile material is self-sustaining, the mass is said to be in a critical state in which there is no increase or decrease in power, temperature, or neutron population.