

## 4. Overview of Fission-Based Nuclear Reactors

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### **Abstract:**

This chapter introduces the basics of nuclear reactors and gives an overview of their use around the world. It explains different types of reactors used to produce large amounts of electricity and briefly covers how reactors work and what key parts they include. The chapter also looks at how nuclear energy production has grown over time worldwide. It highlights how nuclear plants operate in response to varying power needs from the grid and outlines some limitations they face.

**Key words:** Nuclear fission reactor, Nuclear power, Fission.

### **1. Introduction:**

Nuclear fission is a process where the nucleus of a heavy atom (called fissile material) breaks apart into two or more smaller nuclei. This splitting also releases some particles and a large amount of energy. Examples of such fissile materials include  $U^{235}$  and  $Pu^{239}$ . When a  $U^{235}$  nucleus absorbs a neutron, the energy gets shared among the 236 particles (protons and neutrons) in the nucleus. This makes the nucleus unstable, causing it to split into smaller parts, releasing 2 or 3 more neutrons. These released neutrons can then cause more fission in other  $U^{235}$  nuclei, leading to a continuous series of reactions called a chain reaction. During this process, a large

amount of energy is released, which is used to produce electricity in different types of nuclear fission reactors.  $U^{235}$  is the only naturally found isotope that can easily split (fission) using slow (thermal) neutrons, which makes it useful as fuel in nuclear reactors. However, it is only about 0.7% of natural uranium.  $U^{238}$  and  $Th^{232}$  are also found in nature, but they cannot easily split. Instead, they are called fertile isotopes because they can be changed into fissile materials through nuclear reactions. When a  $U^{235}$  atom splits (undergoes fission), it releases around 200 million electron volts (MeV) of energy, which is about  $3.2 \times 10^{-11}$  joules. This means that 1 kilogram of  $U^{235}$  can produce roughly 82 terajoules (TJ) of energy.  $U^{233}$  releases a similar amount of energy, while  $Pl^{239}$  releases slightly more about 210 MeV per fission. To compare, burning one atom of carbon in fossil fuels (like coal or oil) releases only about 4 electron volts, or  $6.5 \times 10^{-19}$  joules [1]. Some heavy atoms, like  $U^{235}$  can undergo fission when a neutron is added to their nucleus. During this process, the atom splits into smaller, lighter elements. These lighter elements need fewer neutrons to stay stable, so each fission usually releases two to three extra neutrons. These free neutrons can strike other  $U^{235}$  atoms, causing them to split as well. This sets up a chain reaction [2].

If left uncontrolled, this reaction can grow rapidly like in an atomic bomb. But if the reaction is carefully managed, it can be used safely in a nuclear reactor. For the chain reaction to remain stable in a reactor, on average, only one neutron from each fission should go on to cause another fission. During fission, energy is released that pushes the resulting lighter fragments (fission products) and extra neutrons apart at very high speeds. Most of this energy becomes kinetic energy of the fission fragments. Since these fragments are heavy and highly charged, they don't travel far. Instead, they collide with nearby

atoms in the fuel, transferring their energy and causing the fuel's temperature to rise. On the other hand, the high-energy neutrons produced during fission have no electric charge, so they can easily move through the fuel and other parts of the reactor without much resistance.

Around 85% of the energy released during nuclear fission comes out almost immediately after the reaction takes place. The remaining energy is given off gradually as the fission products (the fragments left after the atom splits and emits neutrons) go through radioactive decay. This decay process helps the unstable fragments become more stable over time. Even after the fission reaction stops, these fragments continue to release energy. This leftover energy must be carefully managed in the design and operation of any nuclear reactor.

## **2. Fission-Based Nuclear Reactors-**

As nuclear reactor technology developed, many reactor designs were created using different combinations of fuel, moderator, and coolant. Several were built as experimental reactors to test their efficiency and commercial viability. Some designs failed due to technical problems, while others were discontinued for political reasons despite showing promise. A few prototype reactors operated successfully and produced electricity, providing valuable experience. Over time, attention shifted to a small number of reliable designs suitable for commercial power generation. Today, six main types of nuclear reactors exist; the first five are widely used in the power industry, while the sixth remains experimental (Table 1). All currently operating commercial nuclear reactors work on the basic concept of nuclear fission and typically use uranium or plutonium (a byproduct of uranium) as fuel. Today's reactors mainly generate power by splitting  $U^{235}$ , which is the only

naturally occurring fissile material and makes up about 0.72% of natural uranium. All uranium isotopes found in nature are radioactive and can undergo fission, but only  $U^{235}$  is fissile, meaning it can sustain a chain reaction triggered by neutrons. Nuclear reactors are categorized into different generations based on features such as fuel type, efficiency, moderator used, operating pressure, and power output. These classifications also reflect the progress in reactor technology over time [3]. Currently, a variety of fission-based reactor types are in use, as outlined in Table 1.

Table 1: presents nuclear facilities that are either active or scheduled to start functioning in the near future. (Data: World Nuclear Organization) ([www.wna.org](http://www.wna.org))

Reactor type	Fuel	Coolant	Moderator
Pressurized water reactor (PWR)	Enriched $UO_2$	Water	Water
Boiling water reactor (BWR)	Enriched $UO_2$	Water	Water
Pressurized heavy water reactor (PHWR)	Natural $UO_2$ Heavy	Heavy water	Heavy water
Advanced gas-cooled reactor (AGR)	Natural U (metal),	$CO_2$	Graphite
Light-water graphite reactor (LWGR)	Enriched $UO_2$	Water	Graphite
Fast breeder reactor (FBR)	$PuO_2$ and $UO_2$	Liquid Sodium	None

**I. Pressurized water reactor (PWR):** A Pressurized Water Reactor (PWR) is a type of light-water nuclear reactor that uses ordinary water as both a coolant and neutron moderator. Water flows through the reactor core at high

pressure to absorb heat produced during nuclear fission. The heat is then transferred to a secondary loop, where steam is generated to drive a turbine and produce electricity. PWRs use enriched uranium dioxide ( $\text{UO}_2$ ) fuel, which is formed into fuel rods and grouped into fuel assemblies. Each assembly typically contains 200-300 rods, and a large reactor may contain 150-250 assemblies holding about 80-100 tons of uranium. Water in the reactor also acts as a moderator, slowing down fast neutrons so they can effectively cause fission. However, because water absorbs some neutrons, the uranium fuel must be enriched in  $\text{U}^{235}$  to maintain the chain reaction. The coolant water enters the reactor core at about 548 K and leaves at around 588 K, remaining liquid due to the high pressure in the system. [4].

Advantages: Pressurized water reactors exhibit high operational stability because their power output naturally decreases as the temperature rises. This self-regulating behavior simplifies reactor control and enhances safety. Additionally, the turbine system operates in a separate secondary circuit, isolated from the reactor's primary loop. As a result, the water used in the turbine loop remains free from radioactive contamination.

**II. Boiling Water Reactor (BWR):** A Boiling Water Reactor (BWR) is a type of nuclear reactor used to generate electricity by using nuclear fission to heat water. The reactor core contains fuel rods made of enriched uranium dioxide ( $\text{UO}_2$ ). When fission occurs, heat is released, which boils the water inside the reactor vessel. The produced steam directly drives a turbine connected to a generator to produce electricity. In a BWR, water acts as both coolant and neutron moderator, slowing fast neutrons to thermal neutrons to sustain the chain reaction. Control rods regulate the reaction by absorbing excess neutrons and can stop the reaction if required. After passing through the turbine, the steam is condensed back into water and

recycled to the reactor. Compared to a Pressurized Water Reactor (PWR), a BWR does not require a separate steam generator, operates at lower pressure, and has simpler design with fewer pumps, reducing cost and mechanical complexity [5].

### III. Pressurized Heavy-Water Reactor (PHWR): A

Pressurized Heavy-Water Reactor (PHWR) is a type of nuclear reactor that uses heavy water ( $D_2O$ ) as both a moderator and a coolant, and typically uses natural uranium as fuel. The PHWR operates on the principle of nuclear fission, where the nuclei of  $U^{235}$  atoms split when struck by neutrons, releasing a large amount of energy in the form of heat. This heat is used to generate steam, which drives turbines to produce electricity. Natural uranium fuel rods are inserted into horizontal pressure tubes surrounded by heavy water. Heavy water acts as a moderator, slowing down fast neutrons to thermal energies, which makes them more likely to induce fission in  $U^{235}$ . Heavy water also serves as a coolant, carrying heat away from the reactor core to the steam generator. The heat transferred to the secondary loop is used to convert water into steam, which then drives the turbines to generate electricity. The Pressurized Heavy-Water Reactor utilizes natural, non-enriched uranium dioxide ( $UO_2$ ) as its fuel material. The moderator is a substance placed in the reactor core to reduce the speed of neutrons produced during fission. In a pressurized heavy-water reactor (PHWR), heavy water (deuterium oxide,  $D_2O$ ) is used as the moderator to effectively slow down the fast-moving neutrons. A key benefit of the Pressurized Heavy-Water (PHW) reactor is that it operates using natural uranium, eliminating the need for enriched fuel. Additionally, the use of heavy water as a moderator significantly enhances the reactor's efficiency and results in lower fuel usage [6].

### 3. Overview of Active Commercial Nuclear Power Plants

Commercial nuclear reactors play an important role in global electricity production by generating energy through controlled nuclear fission. As of 2025, hundreds of reactors operate in over 30 countries using technologies such as Pressurized Water Reactors (PWRs), Boiling Water Reactors (BWRs), and Pressurized Heavy Water Reactors (PHWRs). These reactors provide a reliable, low-carbon energy source and support energy security while helping the transition to cleaner energy. Modern reactor designs and improved safety systems have increased efficiency and sustainability. Table 2 presents information on the number, types, and power capacity of reactors that are operational, under construction, or planned worldwide.

Table 2. Nuclear reactors in service. World Nuclear Data ([www.myworldindata.org](http://www.myworldindata.org))

Country	Reactor Type	Number Operational	Capacity (MWe)
Argentina	PHWR	4	1666
Armenia	PWR	2	792
Bangladesh	PWR	2	1160
Belarus	PWR	2	2220
Belgium	PWR	8	5932
Brazil	PWR	3	3224
Bulgaria	PWR	6	3638
Canada	PHWR	25	15891
China	PHWR, PWR, FBR, HTGR	86	86167
Czech Republic	PWR	6	3963
Egypt	PWR	4	4400

Finland	PWR, BWR	5	4369
France	PWR, HWGCR, GCR, FBR	71	68549
Germany	PWR, BWR, PHWR, HWGCR, HTGR	33	26 235
Hungary	PWR	4	1 916
India	PHWR, PWR, FBR, BWR	27	12318
Iran	PWR	2	1889
Italy	PWR, BWR, GCR	4	1423
Japan	PWR, BWR, HWLWR, FBR, GCR	43	32403
Kazakhstan	FBR	1	52
Korea	PWR, PHWR	30	29526
Lithuania	LWGR	2	2370
Mexico	BWR	2	1552
Netherlands	PWR, BWR	2	537
Pakistan	PWR, PHWR	8	4469
Romania	PHWR	2	1300
Russian Federation	PWR, LWGR, FBR	51	35534
Slovak Republic	PWR, HWGCR	9	3651
Slovenia	PWR	1	696
South Africa	PWR	2	1854
Spain	PWR, BWR, GCR	10	8190
Sweden	PHWR, BWR, PWR	13	11062
Switzerland	PWR, BWR,	6	3352

	HWGCR		
Türkiye	PWR	4	4456
Ukraine	PWR, LWGR	21	18692
United Arab Emirates	PWR	4	5348
United Kingdom	GCR, FBR, PWR, SGHWR	47	16898
United States of America	PWR, BWR, PHWR, HTGR	135	116928

#### 4. Conclusion

Nuclear power is an efficient and important source of electricity that works on the principle of nuclear fission, releasing large energy from a small amount of fuel. Different reactor types such as Pressurized Water Reactor (PWR), Boiling Water Reactor (BWR), Pressurized Heavy-Water Reactor (PHWR), and Gas-Cooled Reactor (GCR) are used, each with different cooling systems, moderators, and safety features. Nuclear energy provides clean and reliable power with low carbon emissions, but it requires strict safety measures and proper radiation protection. Future developments such as Small Modular Reactor (SMRs), Generation IV reactors, and thorium-based fuel cycles can further improve nuclear technology and support sustainable, low-carbon energy production.

#### 5. References:

1. Rhodes, Richard (1986). *The Making of the Atomic Bomb*. New York: Simon & Schuster Paperbacks. pp. 135–138. ISBN 9781451677614.
2. Oldekop, W. (1982). *Electricity and Heat from Thermal Nuclear Reactors*. In: Thielheim, K.O. (eds) *Primary*

- Energy. Springer, Berlin, Heidelberg.  
[https://doi.org/10.1007/978-3-642-68444-9\\_5](https://doi.org/10.1007/978-3-642-68444-9_5).
3. Wang Y, Shen H, Duan D (2017) Nuclear reactors: generation to generation. American Academy of Arts and Sciences, Cambridge, MA.
  4. World Journal of Nuclear Science and Technology, Vol.14 No.4, October 31, 2024.
  5. Zohuri B, McDaniel P (2019) Advanced smaller modular reactors. Springer International Publishing, Cham.
  6. Power Reactors - Characteristics. 2010 WNA Pocket Guide, World Nuclear Association, July 2010.