Nuclear fission and types of nuclear reactor

- Like all other thermal power plants, nuclear reactors work by generating heat, which boils water to produce steam to drive the turbogenerators. In a nuclear reactor, the heat is the product of nuclear fission.
- Uranium and plutonium nuclei in the fuel are bombarded by neutrons and split usually into two smaller fragments, releasing energy in the form of heat, as well as more neutrons. Some of these released neutrons then cause further fissions, thereby setting up a chain reaction.
- The neutrons released are 'fast' neutrons, with high energy. These neutrons need to be slowed down by a moderator for the chain reaction to occur.
- In BWRs (boiling water reactors) and PWRs (pressurized water reactors), collectively known as LWRs (light water reactors), the light water (H_2O) coolant is also the moderator.
- PHWRs (pressurized heavy water reactors) use heavy water (deuterium oxide, D_2O) as moderator. Unlike LWRs, they have separate coolant and moderator circuits. Coolant may be light or heavy water.
- The chain reaction is controlled by the use of control rods, which are inserted into the reactor core either to slow or stop the reaction by absorbing neutrons.
- In the Candu PHWR, fuel bundles are arranged in pressure tubes, which are individually cooled. These pressure tubes are situated within a large tank called a calandria containing the heavy water moderator. Unlike LWRs, which use low enriched uranium, PHWRs use natural uranium fuel, or it may be slightly enriched Candu reactors can be refuelled whilst on-line.
- A PWR generates steam indirectly: heat is transferred from the primary reactor coolant, which is kept liquid at high pressure, into a secondary circuit where steam is produced for the turbine.
- A BWR produces steam directly by boiling the water coolant. The steam is separated from the remaining water in steam separators positioned above the core, and passed to the turbines, then condensed and recycled.
- In GCRs (gas-cooled reactors) and AGRs (advanced gas-cooled reactors) carbon dioxide is used as the coolant and graphite as the moderator. Like heavy water, a graphite moderator allows natural uranium (in GCRs) or very low-enriched uranium (in AGRs) fuel to be used.
- The LWGR (light water graphite reactor) has enriched fuel in pressure tubes with the light water coolant. These are surrounded by the graphite moderator. More often referred to as the RBMK.
- In FBR (fast breeder reactor) types, the fuel is a mix of oxides of plutonium and uranium; no moderator is used. The core is usually surrounded by a 'fertile blanket' of uranium-238. Neutrons escaping the core are absorbed by the blanket, producing further plutonium, which is separated out during subsequent reprocessing for use as fuel. FBRs normally use liquid metal, such as sodium, as the coolant at low pressure.
- High temperature gas-cooled reactors (HTGRs), not yet in commercial operation, offer an alternative to conventional designs. They use graphite as the moderator and helium as the coolant. HTGRs have ceramic-coated fuel capable of handling temperatures exceeding 1600ºC and gain their efficiency by operating at temperatures of 700-950ºC. The helium can drive a gas turbine directly or be used to make steam.
- While the size of individual reactors is increasing well over 1200 MWe, there is growing interest in small units down to about 10 MWe.

Reactor facts and performance

- Electricity was first generated by a nuclear reactor on 20 December 1951 when the EBR-I test reactor in the USA lit up four light bulbs.
- The 5 MWe Obninsk LWGR in Russia, which commenced power generation in 1954, and was the first to supply the grid and was shut down on 30 April 2002.
- Calder Hall, at Sellafield, UK, was the world's first industrial-scale nuclear power station, becoming operational in 1956. The plant finally shut down on 31 March 2003.
- Grohnde, a 1360 MWe German PWR which first produced power in 1984, has generated over 356 billion kWh of electricity, more than any other reactor.
- With a cumulative load factor of 91.7% since first power in 2015, the Shin-Wolsong 2 PWR in South Korea leads the way on lifetime performance, closely followed by Germany's Emsland, also a PWR.
- In September 2016, unit 2 of the Heysham II AGR plant in the UK set a new world record of 940 days continuous power production, breaking the previous record of 894 days set in 1994 by Pickering 7.
- In 2016, 61 nuclear power reactors achieved load factors of more than 95%, compared with 50 the previous year.
- Over 17,000 reactor-years of operating experience have so far been accumulated.
- Total nuclear electricity supplied worldwide in 2016 was 2490 billion kWh, about 11.5% of total electricity generated that year.

Nuclear fuel performance

- The amount of electricity generated from a given amount of fuel is referred to as burn-up, expressed in megawatt days per tonne of fuel (MWd/t).
- Typically, PWRs now operate at around 40,000 MWd/t, with an enrichment level of about 4% uranium-235.
- Advances in fuel assembly design and fuel management techniques, combined with slightly higher enrichment levels of up to 5%, now make burn-ups of up to 50,000 to 60,000 MWd/t achievable.
- With a typical burn-up of 45,000 MWd/t, one tonne of natural uranium made into fuel will produce as much electricity as 17,000 to 20,000 tonnes of black coal.

Nuclear power reactor types: typical characteristics

Characteristic	PWR	BWR	PHWR (Candu)	LWGR (RBMK)	AGR	FBR
Active core height, m	4.2	3.7	5.9	7.0	8.3	1.0
Active core diameter, m	3.4	4.7	6.0	11.8	9.3	3.7
Fuel inventory, tonnes	104	134	90	192	110	32
Vessel type	Cylinder	Cylinder	Tubes	Tubes	Cylinder	Cylinder
Fuel	UO_2	UO_2	UO_2	UO_2	UO_2	PuO_2/UO_2
Form	Enriched	Enriched	Natural	Enriched	Enriched	-
Coolant	H_2O	H_2O	D_2O	H_2O	CO_2	Sodium
Steam generation	Indirect	Direct	Indirect	Direct	Indirect	Indirect
Moderator	H_2O	H_2O	D_2O	Graphite	Graphite	None
Number operable*	290	78	48	15	14	3

*as of 03.05.17

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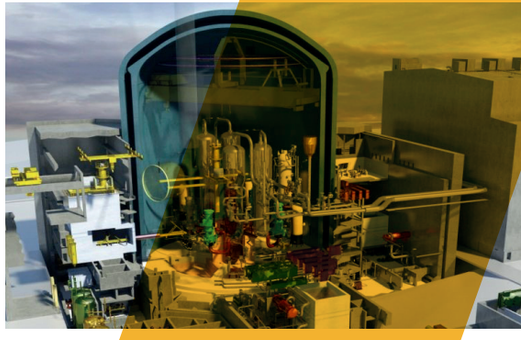
Pocket Guide



Nuclear Power Reactor Characteristics

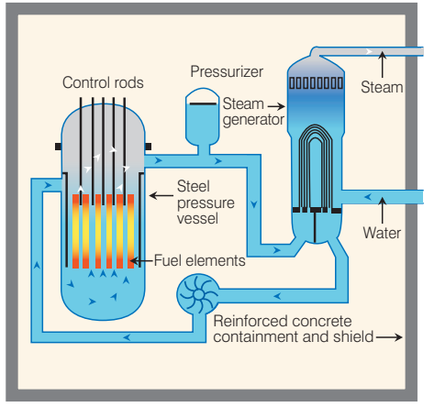
www.world-nuclear.org

Nuclear power & reactors worldwide

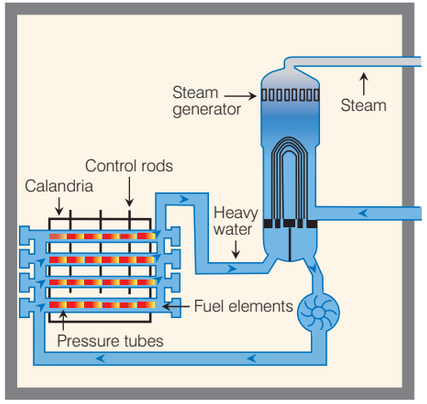
Location	Nuclear electricity generation, 2016 (billion kWh)	Share of total electricity production, 2016 (%)	Number of operable reactors*	Nuclear generating capacity* (MWe)
Argentina	7.7	5.6	3	1627
Armenia	2.2	31.4	1	376
Belgium	41.3	51.7	7	5943
Brazil	15.9	2.9	2	1896
Bulgaria	15.8	35.0	2	1926
Canada	97.4	15.6	19	13,553
China	210.5	3.6	36	32,637
Czech Rep	22.7	29.4	6	3904
Finland	22.3	33.7	4	2764
France	384.0	72.3	58	63,130
Germany	80.1	13.1	8	10,728
Hungary	15.2	51.3	4	1889
India	35.0	3.4	22	6219
Iran	5.9	2.1	1	915
Japan	17.5	2.2	42	39,952
Mexico	10.3	6.2	2	1600
Netherlands	3.8	3.4	1	485
Pakistan	5.1	4.4	4	1040
Romania	10.4	17.1	2	1310
Russia	179.7	17.1	35	26,865
Slovakia	13.7	54.1	4	1816
Slovenia	5.4	35.2	1	696
South Africa	15.2	6.6	2	1830
South Korea	154.2	30.3	25	23,081
Spain	56.1	21.4	7	7121
Sweden	60.6	40.0	9	8849
Switzerland	20.3	34.4	5	3333
Ukraine	81.0	52.3	15	13,107
UK	65.1	20.4	15	8883
USA	805.3	19.7	99	99,678
Total**	**2490**	**11.5**	**447**	**392,080**

*as of 01.05.17 *Sources: World Nuclear Association, IAEA*

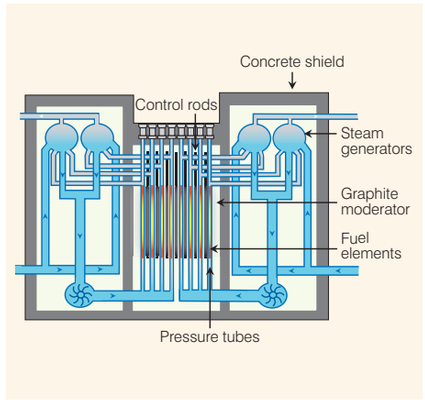
**The world total includes six reactors on Taiwan with a combined capacity of 4927 MWe, which generated a total of 35.1 billion kWh in 2016, accounting for 16.3% of its electricity generation.



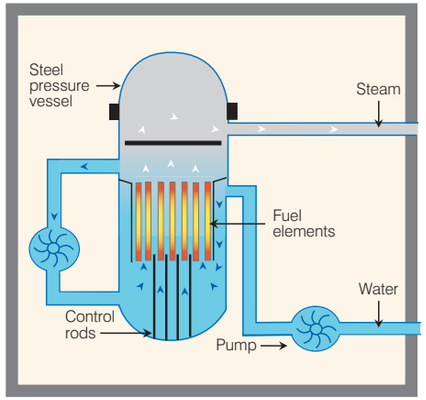
Pressurized water reactor (PWR)



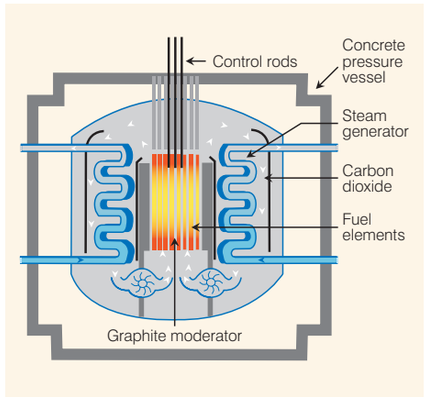
Pressurized heavy water reactor (PHWR/Candu)



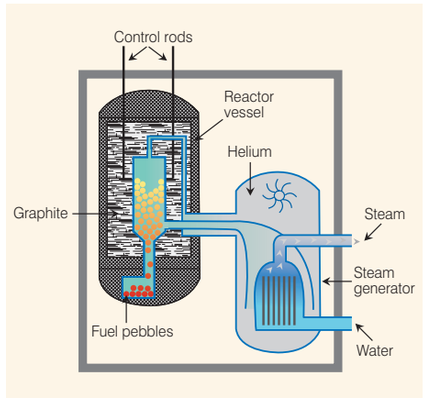
Light water graphite-moderated reactor (LWGR/RBMK)



Boiling water reactor (BWR)



Advanced gas-cooled reactor (AGR)



High-temperature reactor (HTR)

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