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 into two parts, releasing energy in the form of heat, as well as more neutrons. These new 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 fission to occur.

• The chain reaction is controlled by the use of control rods, which can be inserted into the reactor core either to slow or stop the reaction by absorbing neutrons.

• In BWRs (Boiling Water Reactors) and PWRs (Pressurised Water Reactors), collectively known as LWRs (Light Water Reactors), the light water (H_2O) coolant is also the moderator.

• PHWRs (Pressurised Heavy Water Reactors) use heavy water (deuterium oxide) as moderator. Unlike LWRs, they have separate coolant and moderator circuits. Coolant may be light or heavy water.

• A PWR generates steam indirectly: heat is transferred from the primary reactor coolant, which is kept in liquid form at high pressure, into a secondary circuit where steam is generated for the turbines.

• A BWR generates steam directly by boiling the primary coolant. The steam is separated from the remaining liquid water in steam separators positioned above the core, and passed to the turbines.

• 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.

• 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 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, this is the reactor type involved in the Chernobyl accident in 1986.

• 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. FBRs normally use liquid metal, such as sodium, as the coolant.

• 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 feature a high degree of safety through reliance on passive safety features. They have ceramic-coated fuel capable of handling temperatures exceeding 1600°C and gain their efficiency by operating at temperatures approaching 950°C. The helium can drive a gas turbine directly or be used to make steam.

Nuclear power reactor types: typical characteristics

Characteristic	PWR	BWR	GCR	AGR	PHWR (Candu)	LWGR (RBMK)	FBR
Active core height, m	4.2	3.7	7.6	8.3	5.9	7.0	1.0
Active core diameter, m	3.4	4.7	14.0	9.3	6.0	11.8	3.7
Fuel inventory, tonnes	104	134	300	110	90	192	32
Vessel type	Cylinder	Cylinder	Cylinder	Cylinder	Tubes	Tubes	Cylinder
Fuel	UO_2	UO_2	U	UO_2	UO_2	UO_2	PuO_2/ UO_2
Form	Enriched	Enriched	Natural	Enriched	Natural	Enriched	-
Coolant	H_2O	H_2O	CO_2	CO_2	D_2O	H_2O	Sodium
Steam generation	Indirect	Direct	Indirect	Indirect	Indirect	Direct	Indirect
Moderator	H_2O	H_2O	Graphite	Graphite	D_2O	Graphite	None
Number in operation*	264	92	4	14	44	16	2

* as of 01.06.09

• There are two types of HTGR design, classified according to how the fuel particles are compacted into fuel assemblies. In pebble bed reactors, the particles, together with moderator material, are compressed into spherical pebbles about 6cm in diameter. The pebbles are loosely stacked within the reactor vessel and cooled by helium. The alternative design has fuel particles incorporated into replaceable graphic blocks (typically hexagonal prisms) of various configurations, with passages for the helium coolant.

• Several other radically-improved reactor designs with enhanced performance, safety and operating lifetimes are at various stages of licensing in several countries, and new build by 2020 is likely to utilise several of these.

• While the size of individual reactors is increasing well over 1000 MWe, there is increasing interest in small units down to about 10 MWe.

Kaiga nuclear power plant, Karnataka, India

Nuclear fuel performance

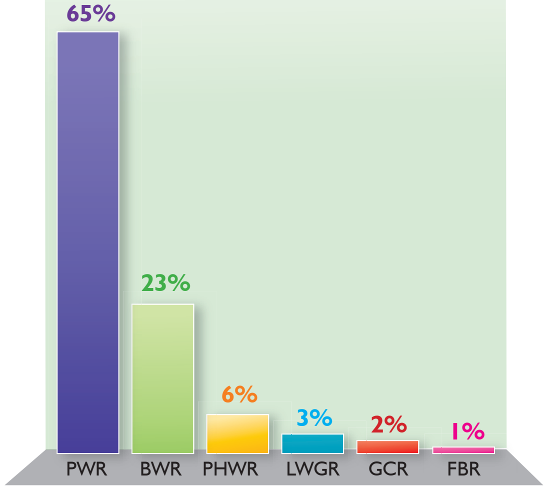
• Burn-up, expressed as megawatt days per tonne of fuel (MWd/t), indicates the amount of electricity generated from a given amount of fuel.

• 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 burnups of up to 50 000 to 60 000 MWd/t achievable.

• With a typical burnup 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.

Power Reactors - characteristics



World nuclear power generation by reactor type, 2008

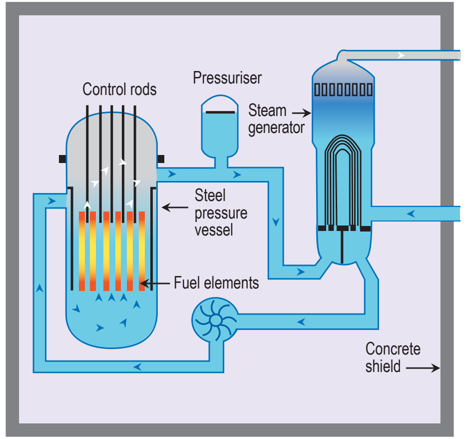
World Nuclear Association
www.world-nuclear.org

Nuclear power and reactors worldwide

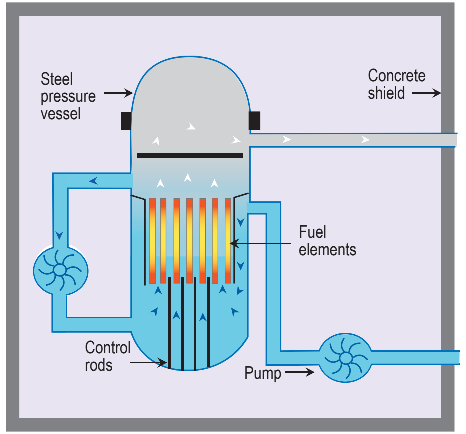
	Nuclear electricity generation, 2008 (billion kWh)	Share of total electricity production, 2008 (%)	Number of reactors in operation*	Nuclear generating capacity* (MWe)
Argentina	6.8	6	2	935
Armenia	2.3	39	1	376
Belgium	43.4	54	7	5728
Brazil	14.0	3	2	1901
Bulgaria	14.7	33	2	1906
Canada	88.6	15	18	12 652
China	65.3	2	11	8587
Czech Rep	25.0	33	6	3472
Finland	22.0	30	4	2696
France	418.3	76	59	63 473
Germany	140.9	28	17	20 339
Hungary	14.0	37	4	1826
India	13.2	2	17	3779
Japan	240.5	25	53	46 236
Korea (S.)	144.3	36	20	17 716
Lithuania	9.1	73	1	1185
Mexico	9.4	4	2	1310
Netherlands	3.9	4	1	485
Pakistan	1.7	2	2	400
Romania	7.1	18	2	1310
Russia	152.1	17	31	21 743
Slovakia	15.5	56	4	1688
Slovenia	6.0	42	1	696
South Africa	12.7	5	2	1842
Spain	56.4	18	8	7448
Sweden	61.3	42	10	9016
Switzerland	26.3	39	5	3237
Ukraine	84.3	47	15	13 168
UK	52.5	14	19	11 035
USA	809.0	20	104	101 119
Total**	**2601**	**15**	**436**	**372 500**

* as of 01.06.09 Sources: WNA, IAEA

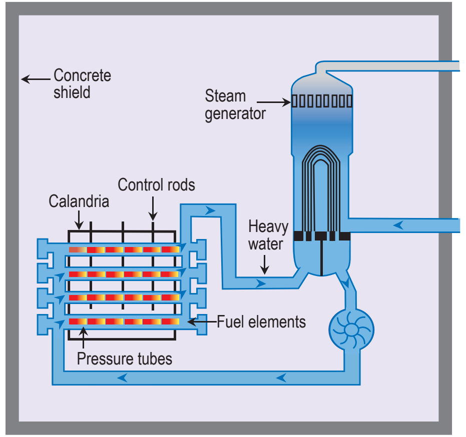
** The world total includes 6 reactors on Taiwan with a combined capacity of 4927 MWe, which generated a total of 39.3 billion kWh in 2008, accounting for 17.1% of its electricity generation.



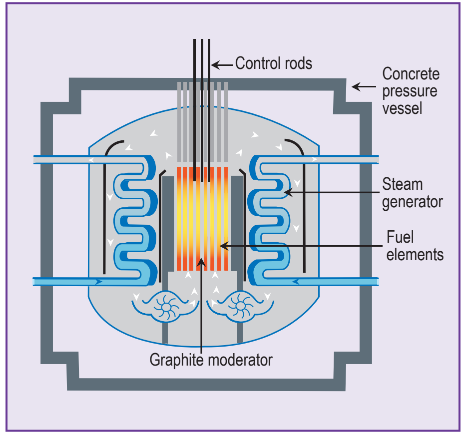
A typical Pressurised Water Reactor (PWR)



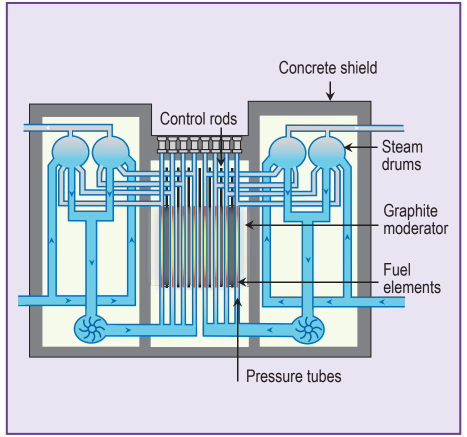
A typical Boiling Water Reactor (BWR)



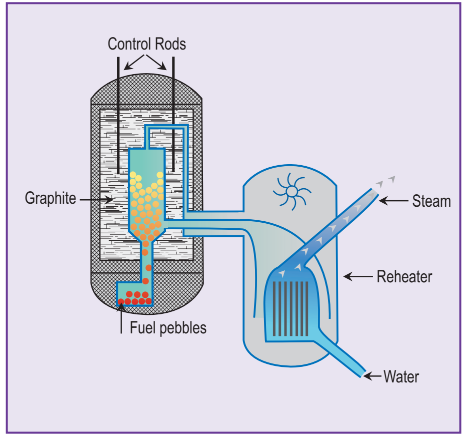
A typical Pressurised Heavy Water Reactor (PHWR/Candu)



An Advanced Gas Reactor (AGR)



A Light Water Graphite-moderated Reactor (LWGR/RBMK)



A High-Temperature Reactor (HTR)

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 4 light bulbs.
- The 5 MWe Obninsk LWGR in Russia, which commenced power generation in 1954, 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.
- Unterweser, a 1350 MWe German reactor which first produced power in 1978 and has since generated 279 billion kWh of electricity, has produced more power than any other reactor.
- With a cumulative load factor of 93.3% since first power in 1988, the Emsland PWR in Germany leads the way on lifetime performance followed by Wolsong-3 (a PHWR) and Ulchin-4 (a PWR), both in South Korea.
- In 1994, Pickering-7, a Candu reactor, set a world record of 894 days continuous power production. Candu plants refuel on-line.
- The world record for continuous production by a LWR (which must be shut down to refuel) is held by the LaSalle-1 BWR (1137 MWe) in the USA with a run of 739 days, which ended with a routine refuelling outage on 2 February 2006.
- Indian Point-3's 2008 load factor was 101.8%, making the US reactor the year's best performer, followed by Sequoyah-1 in the USA and Fukushima-II-1 in Japan.
- As of June 2009, 13 660 reactor-years of operating experience had been accumulated in the course of generating a total of some 58 600 billion kWh.
- Total nuclear electricity supplied worldwide in 2008 was 2601 billion kWh, about 15% of total electricity generated that year.

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