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 the chain reaction to occur.
- 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 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) 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 liquid at high pressure, into a secondary circuit where steam is generated for the turbine.
- A BWR generates steam directly by boiling the primary 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 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 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, 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 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 1600°C and gain their efficiency by operating at temperatures of 700-950°C. The helium can drive a gas turbine directly or be used to make steam.

Nuclear power reactor types: typical characteristics

Characteristic	PWR	BWR	AGR	PHWR (Candu)	LWGR (RBMK)	FBR
Active core height, m	4.2	3.7	8.3	5.9	7.0	1.0
Active core diameter, m	3.4	4.7	9.3	6.0	11.8	3.7
Fuel inventory, tonnes	104	134	110	90	192	32
Vessel type	Cylinder	Cylinder	Cylinder	Tubes	Tubes	Cylinder
Fuel	UO_2	UO_2	UO_2	UO_2	UO_2	PuO_2/ UO_2
Form	Enriched	Enriched	Enriched	Natural	Enriched	-
Coolant	H_2O	H_2O	CO_2	D_2O	H_2O	Sodium
Steam generation	Indirect	Direct	Indirect	Indirect	Direct	Indirect
Moderator	H_2O	H_2O	Graphite	D_2O	Graphite	None
Number in operation*	272	84	16	47	15	2

* as of 28.05.12

- There are two types of HTR 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.
- While the size of individual reactors is increasing well over 1000 MWe, there is increasing interest in small units down to about 10 MWe.
- The International Framework for Nuclear Energy Cooperation (IFNEC) – formerly the Global Nuclear Energy Partnership (GNEP) – envisages fabrication and leasing of fuel for conventional reactors. The used fuel would be returned to the countries supplying the fabricated fuel and reprocessed to recover uranium and actinides, leaving only fission products as high-level waste. The actinide mix can then be burned in fast reactors.

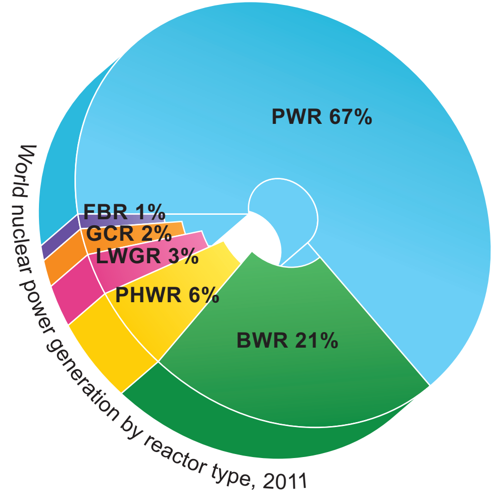
Tianwan nuclear power station in China

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.

World Nuclear Association

NUCLEAR POWER REACTOR CHARACTERISTICS

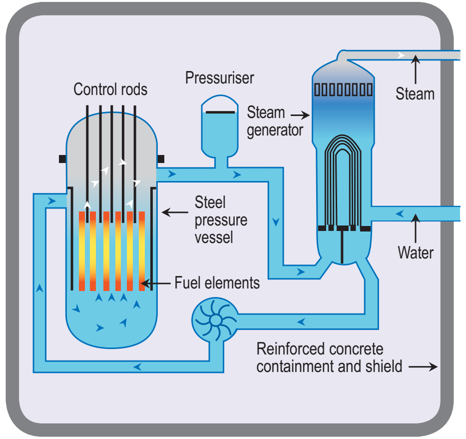


Nuclear power & reactors worldwide

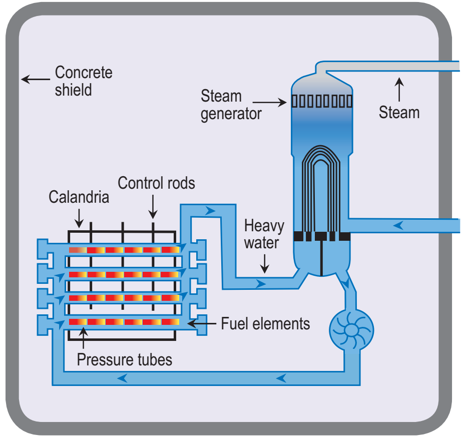
	Nuclear electricity generation, 2011 (billion kWh)	Share of total electricity production, 2011 (%)	Number of reactors in operation*	Nuclear generating capacity* (MWe)
Argentina	5.9	5.0	2	935
Armenia	2.4	33.2	1	376
Belgium	45.9	54.0	7	5943
Brazil	14.8	3.2	2	1901
Bulgaria	15.3	32.6	2	1906
Canada	88.3	15.3	17	12,044
China	82.6	1.8	15	11,881
Czech Rep	26.7	33.0	6	3764
Finland	22.3	31.6	4	2741
France	423.5	77.7	58	63,130
Germany	102.3	17.8	9	12,003
Hungary	14.7	43.2	4	1880
India	28.9	3.7	20	4385
Iran	0	0	1	915
Japan	156.2	18.1	50	44,396
Mexico	9.3	3.6	2	1600
Netherlands	3.9	3.6	1	485
Pakistan	3.8	3.8	3	725
Romania	10.8	19.0	2	1310
Russia	162.0	17.6	33	24,164
Slovakia	14.3	54.0	4	1816
Slovenia	5.9	41.7	1	696
South Africa	12.9	5.2	2	1800
South Korea	147.8	34.6	23	20,787
Spain	55.1	19.5	8	7448
Sweden	58.1	39.6	10	9399
Switzerland	25.7	40.8	5	3252
Ukraine	84.9	47.2	15	13,168
UK	62.7	17.8	16	10,038
USA	790.4	19.2	104	101,607
Total**	**2518**	**13**	**433**	**371,422**

* as of 01.06.12 — Sources: WNA, IAEA

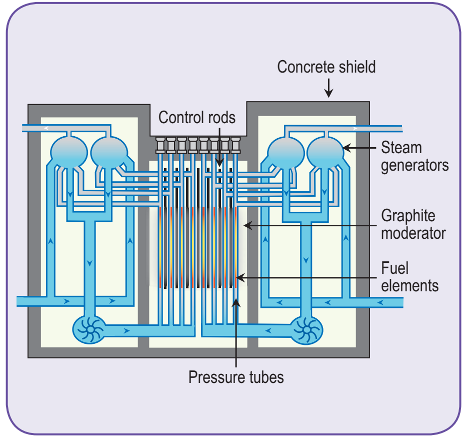
** The world total includes 6 reactors on Taiwan with a combined capacity of 4927 MWe, which generated a total of 40.4 billion kWh in 2011, accounting for 19.0% of its electricity generation.



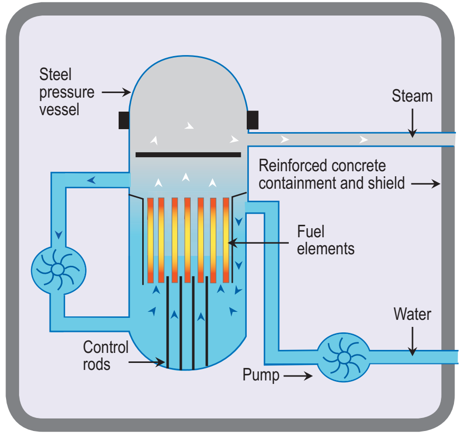
A typical Pressurized Water Reactor (PWR)



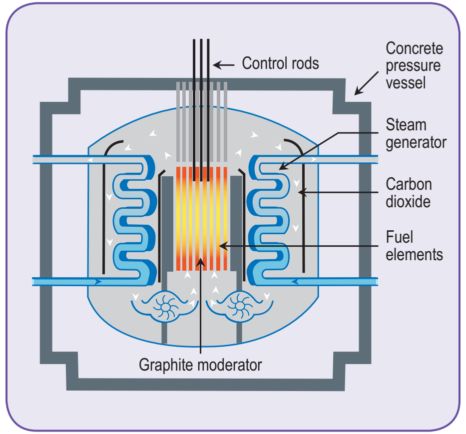
A typical Pressurized Heavy Water Reactor (PHWR/Candu)



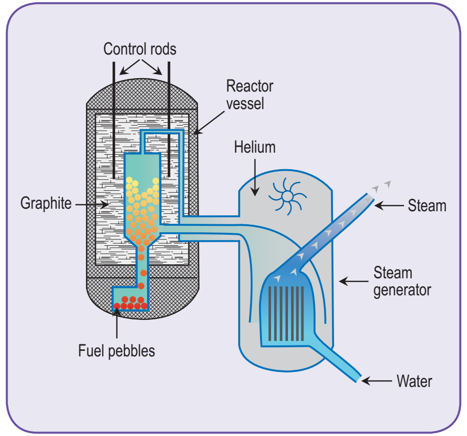
A Light Water Graphite-moderated Reactor (LWGR/RBMK)



A typical Boiling Water Reactor (BWR)



An Advanced Gas-cooled Reactor (AGR)



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 four 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 1984 generated over 304 billion kWh of electricity before being shut down in August 2011, has produced more power than any other reactor.
- With a cumulative load factor of 93.8% since first power in 1998, the Wolsong 3 PHWR in South Korea leads the way on lifetime performance closely followed by sister unit Wolsong 4.
- In 1994, Pickering-7, a Candu reactor, set a world record of 894 days continuous power production. Candu plants can 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.
- In 2011, 55 nuclear power reactors achieved load factors of more than 95%.
- As of June 2012, 14,870 reactor-years of operating experience had been accumulated in the course of generating a total of some 66,300 billion kWh.
- Total nuclear electricity supplied worldwide in 2011 was 2518 billion kWh, over 13% of total electricity generated that year.

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