Nuclear fission and types of nuclear reactor

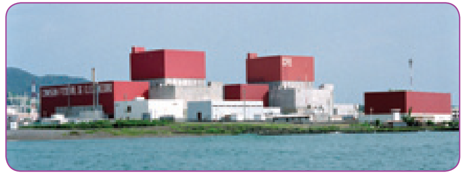
- Like all other thermal power plants, nuclear reactors work by generating heat, which boils water to produce steam to drive the turbogenerators. In a nuclear reactor, the heat is the product of nuclear fission.
- Uranium and plutonium nuclei in the fuel are bombarded by neutrons and split into two parts, 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 (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 liquid 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 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 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 (HTRs) - not yet in commercial operation - offer an alternative to conventional designs. They use graphite as the moderator and helium as the coolant. HTRs 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 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*	271	88	18	47	15	1

* as of 09.06.11

- 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.



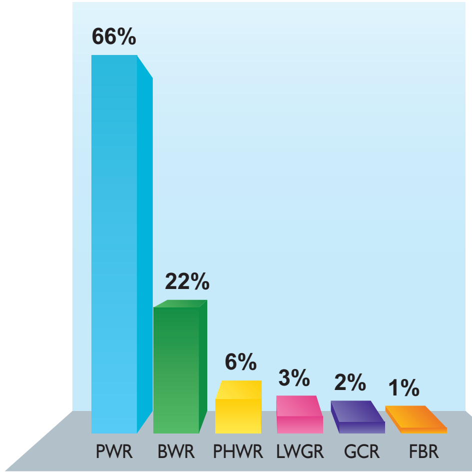
The Laguna Verde nuclear power plant in Mexico

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



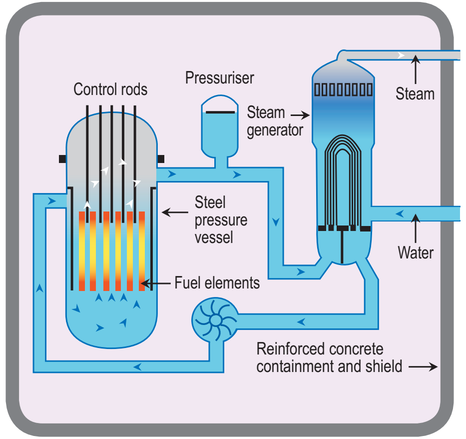
World nuclear power generation by reactor type, 2010

Nuclear power & reactors worldwide

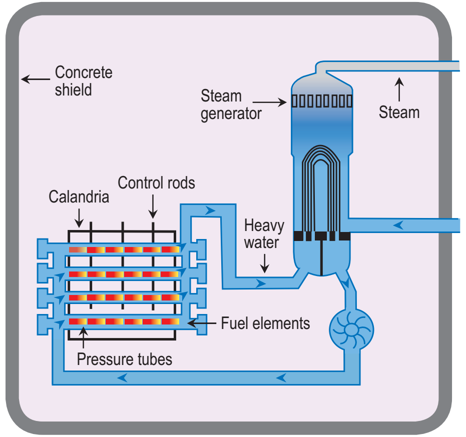
	Nuclear electricity generation, 2010 (billion kWh)	Share of total electricity production, 2010 (%)	Number of reactors in operation*	Nuclear generating capacity* (MWe)
Argentina	6.7	5.9	2	935
Armenia	2.3	39.4	1	376
Belgium	45.7	51.2	7	5943
Brazil	13.9	3.1	2	1901
Bulgaria	14.2	33.1	2	1906
Canada	85.5	15.1	18	12,679
China	71.0	1.8	14	11,271
Czech Rep	26.4	33.3	6	3722
Finland	21.9	28.4	4	2741
France	410.1	74.1	58	63,130
Germany	133.0	28.4	17	20,339
Hungary	14.7	42.1	4	1880
India	20.5	2.9	20	4385
Japan	280.3	29.2	51	44,642
Mexico	5.6	3.6	2	1600
Netherlands	3.8	3.4	1	485
Pakistan	2.6	2.6	3	725
Romania	10.7	19.5	2	1310
Russia	159.4	17.1	32	23,084
Slovakia	13.5	51.8	4	1816
Slovenia	5.4	37.3	1	696
South Africa	12.9	5.2	2	1800
South Korea	141.9	32.2	21	18,716
Spain	59.3	20.1	8	7448
Sweden	55.7	38.1	10	9399
Switzerland	25.3	38.0	5	3252
Ukraine	84.0	48.1	15	13,168
UK	56.9	15.7	18	10,745
USA	807.1	19.6	104	101,421
Total**	**2630**	**14**	**440**	**376,442**

* as of 01.07.11 Sources: WNA, IAEA

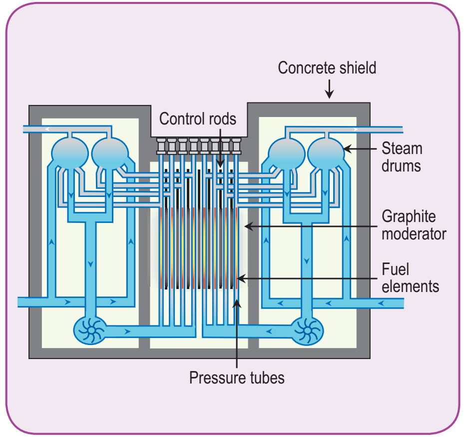
** The world total includes 6 reactors on Taiwan with a combined capacity of 4982 MWe, which generated a total of 39.9 billion kWh in 2010, accounting for 19.3% of its electricity generation.



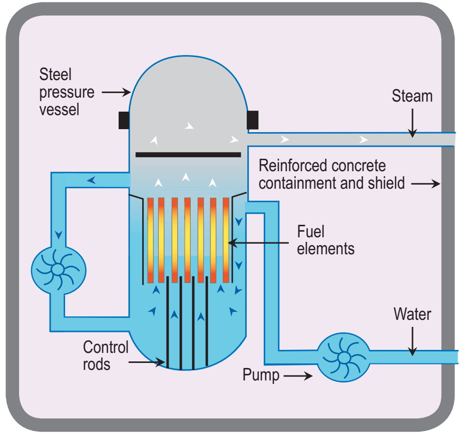
A Pressurised Water Reactor (PWR)



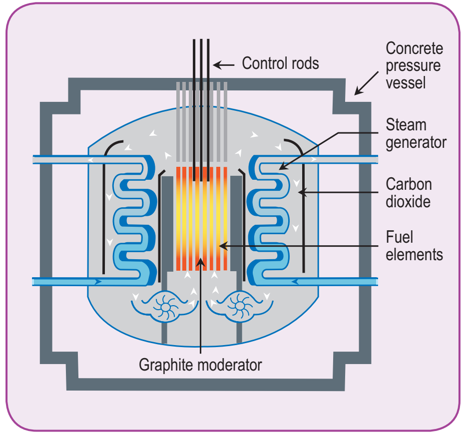
A Pressurised Heavy Water Reactor (PHWR/Candu)



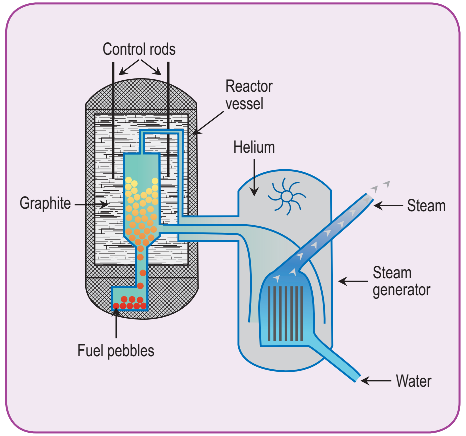
A Light Water Graphite-moderated Reactor (LWGR/RBMK)



A 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 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 304 billion kWh of electricity, has produced more power than any other reactor.
- With a cumulative load factor of 93.5% since first power in 1988, the Emsland PWR in Germany leads the way on lifetime performance followed by Wolsong units 4 and 3 (PHWRs) 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.
- Takahama-1's 2010 load factor was 105.1%, making the Japanese reactor the year's best performer, followed by River Bend and Comanche Peak-2 in the USA.
- As of June 2011, 14,500 reactor-years of operating experience had been accumulated in the course of generating a total of some 63,800 billion kWh.
- Total nuclear electricity supplied worldwide in 2010 was 2630 billion kWh, about 14% of total electricity generated that year.

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