## 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.
- 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 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.
- 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, 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 reactor which first produced power in 1984, has generated over 337 billion kWh of electricity, more than any other reactor.
- With a cumulative load factor of 93.3% since first power in 2007, the Cernavoda 2 PHWR in Romania leads the way on lifetime performance, closely followed by Germany's Emsland, a PWR.
- 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 2014, 45 nuclear power reactors achieved load factors of more than 95%.
- Over 16,100 reactor-years of operating experience have so far been accumulated.
- Total nuclear electricity supplied worldwide in 2014 was 2411 billion kWh, about 11% of total electricity generated that year.

## 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 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 | 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 operable*** | 277 | 80 | 15 | 49 | 15 | 2 |

*as of 31.12.14

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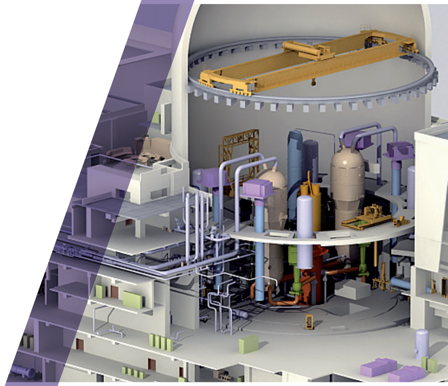


# Nuclear Power Reactor Characteristics

www.world-nuclear.org

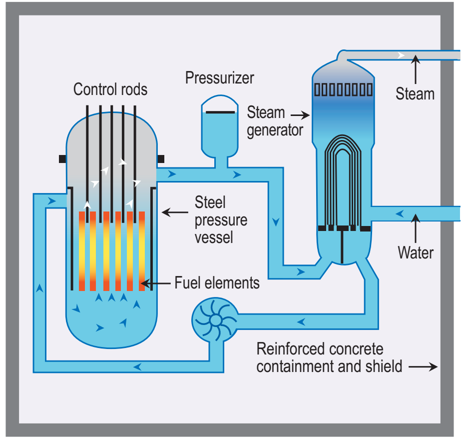
# Nuclear power & reactors worldwide

| Location | Nuclear electricity generation, 2014 (billion kWh) | Share of total electricity production, 2014 (%) | Number of operable reactors* | Nuclear generating capacity* (MWe) |
|---|---|---|---|---|
| Argentina | 5.3 | 4.0 | 3 | 1627 |
| Armenia | 2.3 | 30.7 | 1 | 376 |
| Belgium | 32.1 | 47.5 | 7 | 5943 |
| Brazil | 14.5 | 2.9 | 2 | 1901 |
| Bulgaria | 15.0 | 31.8 | 2 | 1906 |
| Canada | 98.6 | 16.8 | 19 | 13,553 |
| China | 123.8 | 2.4 | 26 | 23,144 |
| Czech Rep | 28.6 | 35.8 | 6 | 3904 |
| Finland | 22.6 | 34.6 | 4 | 2741 |
| France | 418.0 | 76.9 | 58 | 63,130 |
| Germany | 91.8 | 15.8 | 8 | 10,728 |
| Hungary | 14.8 | 53.6 | 4 | 1889 |
| India | 33.2 | 3.5 | 21 | 5302 |
| Iran | 3.7 | 1.5 | 1 | 915 |
| Japan | 0 | 0 | 43 | 40,480 |
| Mexico | 9.3 | 5.6 | 2 | 1600 |
| Netherlands | 3.9 | 4.0 | 1 | 485 |
| Pakistan | 4.6 | 4.3 | 3 | 725 |
| Romania | 10.8 | 18.5 | 2 | 1310 |
| Russia | 169.1 | 18.6 | 34 | 25,264 |
| Slovakia | 14.4 | 56.8 | 4 | 1816 |
| Slovenia | 6.1 | 37.2 | 1 | 696 |
| South Africa | 14.8 | 6.2 | 2 | 1830 |
| South Korea | 149.2 | 30.4 | 24 | 21,677 |
| Spain | 54.9 | 20.4 | 7 | 7002 |
| Sweden | 62.3 | 41.5 | 10 | 9487 |
| Switzerland | 26.5 | 37.9 | 5 | 3333 |
| Ukraine | 83.1 | 49.4 | 15 | 13,107 |
| UK | 57.9 | 17.2 | 16 | 10,038 |
| USA | 798.6 | 19.5 | 99 | 98,792 |
| Total** | 2411 | 11 | 436 | 378,995 |

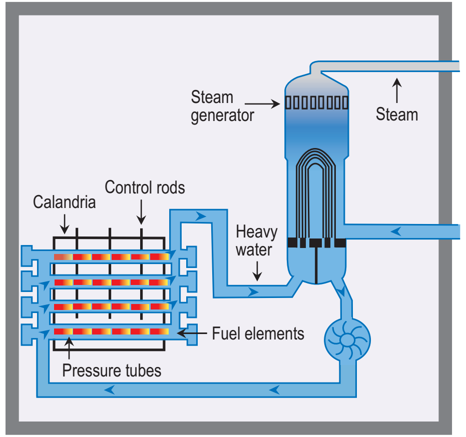
*as of 31.07.15

*Sources: World Nuclear Association, IAEA*

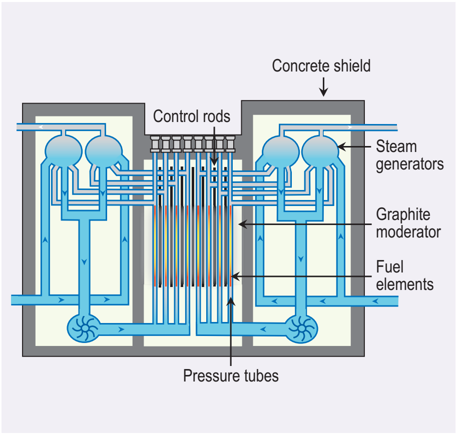
**The world total includes six reactors on Taiwan with a combined capacity of 4927 MWe, which generated a total of 40.8 billion kWh in 2014, accounting for 18.9% of its electricity generation.



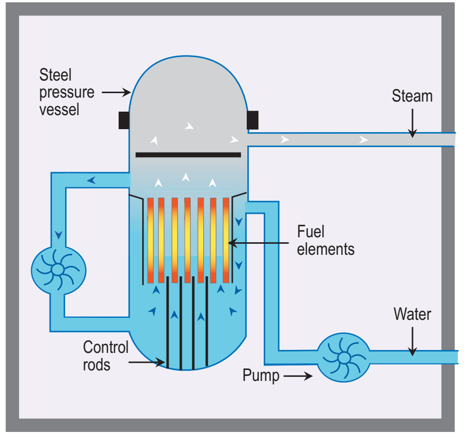

A Pressurized Water Reactor (PWR)



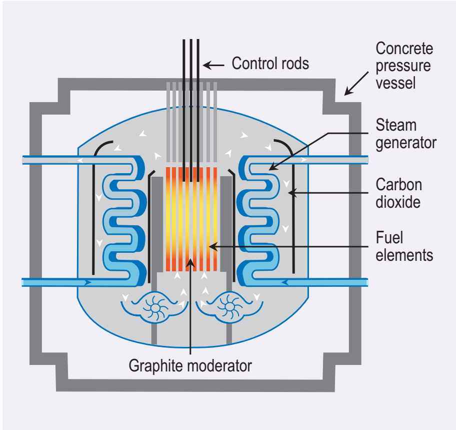

A Pressurized Heavy Water Reactor (PHWR/Candu)



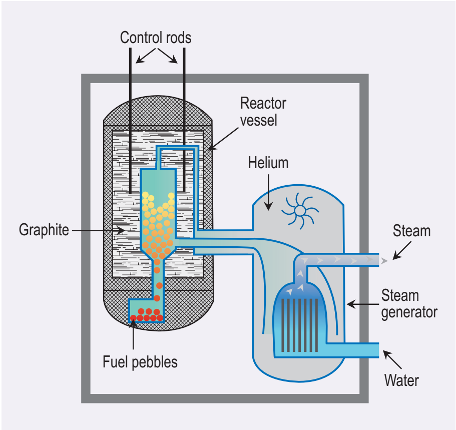

A Light Water Graphite-moderated Reactor (LWGR/RBMK)




A Boiling Water Reactor (BWR)




An Advanced Gas-cooled Reactor (AGR)




A High-Temperature Reactor (HTR)

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