Different types of nuclear power

Reactor Types

A reactor is the nuclear equivalent of the furnace in a steam-raising boiler. Whereas a conventional boiler uses heat produced by burning coal or gas, a reactor uses the heat generated by nuclear fission. This heat is removed by a coolant to create steam, either by boiling the coolant or indirectly through steam generators, to drive turbine generators which produce electricity.

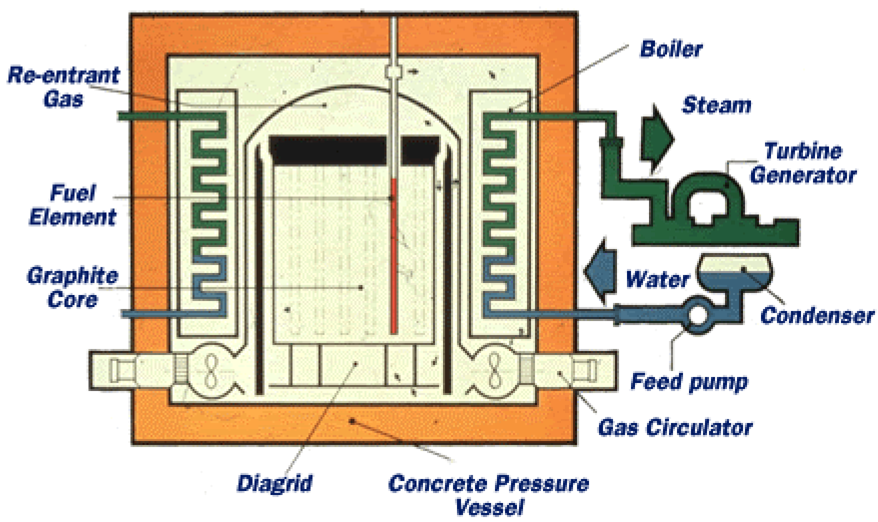
Thermal Reactors

The fission, or chain reaction, which generates the heat in a reactor is sustained by the collision of neutrons with the uranium within the fuel. Nuclear physicists refer to the neutrons generated by fission as 'fast' neutrons, or 'thermal' neutrons once they have been slowed down. There are accordingly two kinds of reactor, fast and thermal. In a thermal reactor, a moderator such as graphite or water is used to slow the neutrons and make collisions more likely. In a fast reactor there's no moderator (see "Fast Reactors" below). All the world's current commercial reactors are thermal reactors.

Advanced Gas-Cooled Reactor (AGR)

This is the type of reactor operated by British Energy and is unique to the UK. As the name suggests, it is an advance on the earlier UK Magnox design. The uranium dioxide fuel is enriched to about 3% U-235 (natural uranium is only 0.7% U-235) and clad in stainless steel cans with a graphite moderator and carbon dioxide coolant. The reactor and steam generators are housed within a steel reinforced concrete pressure vessel, the walls of which are several metres thick. An AGR's thermal efficiency is about 42%, generating a typical electrical output of upto 660MW.

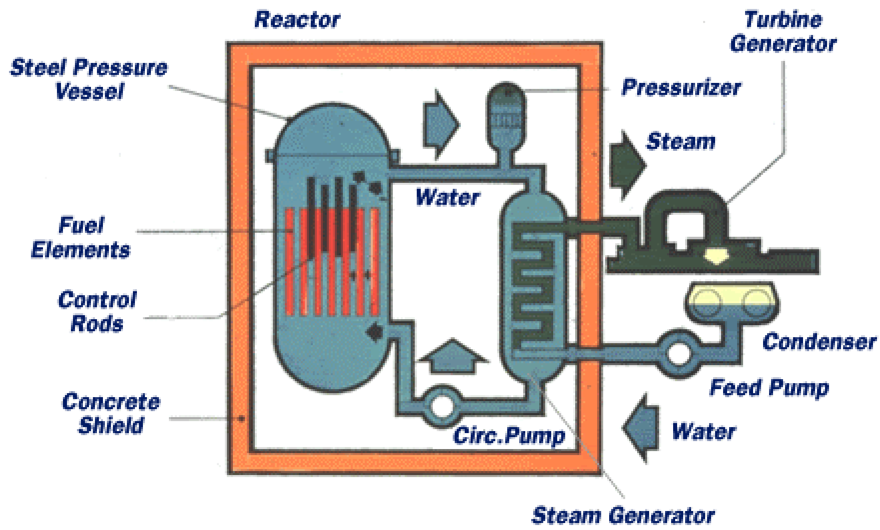
Advanced Gas-cooled Reactor (**AGR**)



Pressurised Water Reactor (PWR)

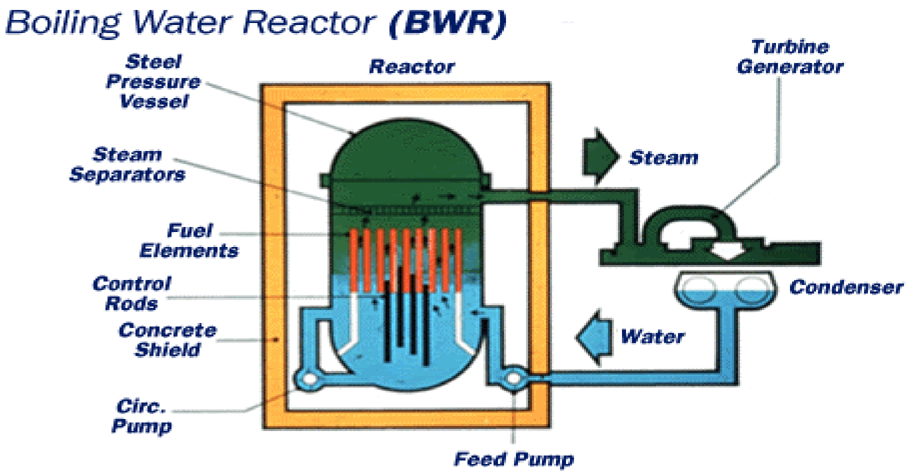
This is the most common type of commercial reactor and was originally developed in the USA for submarine propulsion. Nearly 60% of the world's commercial reactors are PWRs, including the Sizewell 'B' plant in the UK. The fuel is uranium dioxide enriched to about 4%, contained in zirconium alloy tubes. Pressurised water acts as both moderator and coolant and heats water in a secondary circuit via a steam generator to produce steam. The reactor is encased in a concrete biological shield within a secondary containment. The design is very compact because water is a more effective moderator than graphite. A PWR's thermal efficiency is about 32%.

Pressurised Water Reactor **(PWR)**



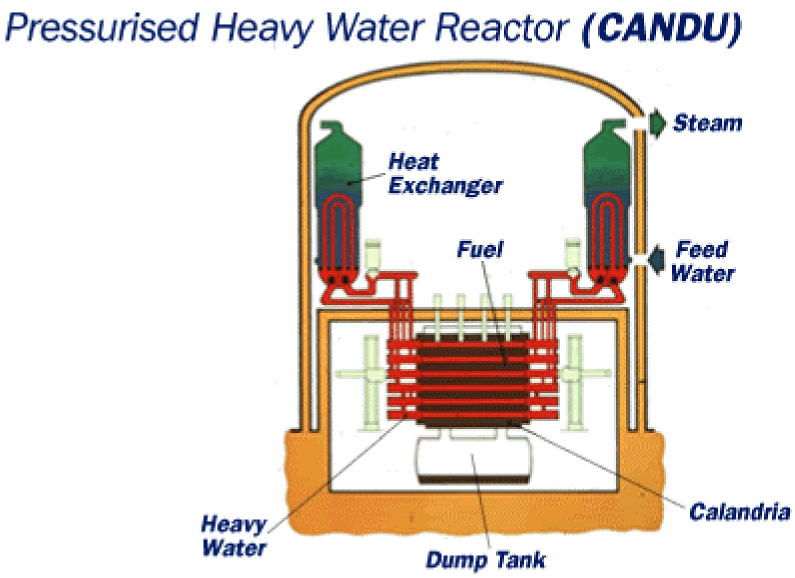
Boiling Water Reactor (BWR)

A BWR is effectively a PWR without the steam generator. Water is pumped through the core, again acting as both moderator and coolant, inside a pressure vessel. About 10% of the water is converted to steam and passed to steam turbines. After condensing it returns to the pressure vessel to complete the circuit. The fuel is similar to that of a PWR, but the power density (power produced per unit volume of core) is about half, with lower pressures and temperatures. The cost advantage of not having steam generators is offset by the disadvantages of a single cooling system, which can potentially cause contamination throughout the steam plant if fuel can failures occur. A BWR's thermal efficiency is again about 32%.



Pressurised Heavy Water Reactor (CANDU)

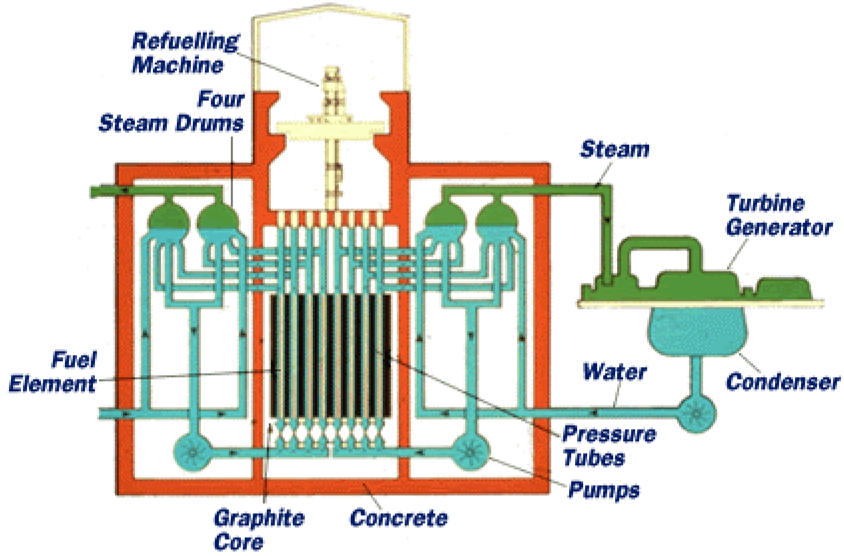
The CANDU reactor is so called because it is a Canadian design using Deuterium oxide (heavy water) as both coolant and moderator and natural Uranium fuel. Heavy water is an oxide of heavy hydrogen or deuterium (D_2O), rather than regular hydrogen (H_2O). Pressurised heavy water is pumped through horizontal fuel tubes and heated by the nuclear reaction before being passed to a steam generator as in a PWR, but without the need for a pressure vessel as the tubes provide the containment. The fuel is natural uranium oxide contained in Zircaloy tubes. The average power density is about one-tenth that of a PWR or four times that of an AGR. The output of CANDU reactors ranges up to 930MW with a thermal efficiency of about 30%.



Boiling Water, Graphite Moderated Reactor (RBMK)

The Soviet designed RBMK is a hybrid graphite-moderated and water-cooled reactor only found in the former Soviet Union. The core is an assembly of graphite blocks, not unlike the core of a Magnox reactor, through which run pressure tubes containing the fuel. Water is pumped through the pressure tubes, where it boils to steam and is piped to the steam turbines. The fuel is uranium dioxide, enriched to about 2%, contained in Zircaloy tubes. The reactors are physically very large with high electrical outputs of up to 1500MW. The physics of RBMK reactors are complex because the graphite, water and steam are all used to moderate the neutrons in the core. It was this complexity, plus numerous breaches of safety procedures, which led to the steam explosion at Chernobyl in 1986.

Boiling Water, Graphite Moderated Reactor **(RBMK)**



Fast Reactors

In a fast reactor, as the name suggests, the neutrons from the chain reaction are not slowed down and remain at high energy. The absence of a moderator means that, in order to maintain a chain reaction, the fuel must contain more fissile material (plutonium or uranium 235) typically around 20%. A fast reactor uses two other techniques to maintain the reaction. Firstly, the fuel rods include fertile material (depleted uranium U-238 – known as the blanket) above and below the fissile fuel to capture some of the neutrons and create more plutonium fuel. Secondly the core is surrounded by a reflector which causes escaping neutrons to bounce back, increasing the chances of collision with the fuel and sustaining the chain reaction.

A fast reactor core, since it has no moderator, is very compact (the 250 MW(e) Prototype Fast Reactor (PFR) at Dounreay had a core the size of a large dustbin), giving it a high power density. It is usually cooled by a liquid sodium alloy, which is very efficient at removing heat. Sodium has the advantage that it can be heated to 5600°C without being pressurised, so the reactor does not need a pressure vessel to produce high temperature steam. With a boiling point over 9000°C, it has a valuable safety margin over the normal operating temperature.

Like gas cooled AGRs, it also has the very attractive safety feature that it can maintain cooling by natural convection should cooling pumps fail.

Fast reactors are sometimes called ‘breeder’ reactors because they breed their own fuel from the fuel blanket as they run. It is possible to design a fast reactor so that the amount of plutonium it makes while running is more than enough to replace the plutonium which is consumed. A breeder reactor can also produce enough plutonium to fuel further reactors, so once you have built one you can 'breed' others without mining new fuel. Alternatively, they can be designed to use up excess stocks of plutonium.

The UK is no longer developing the fast reactor, as commercial application of this type of reactor is perceived to be 30-40 years away. Its participation in the European Fast Reactor Programme has been suspended and the PFR at Dounreay shut down in 1994. Development is now mainly confined to France, Japan, China, India and Russia.