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British Energy

Reactor Types

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A reactor is the nuclear equivalent of the furnace part of a steam-raising boiler. Whereas a conventional boiler uses heat produced by burning coal or gas, a reactor uses the heat generated by fission (see Fission). This heat is removed by a coolant (gas or water) which then produces steam, either indirectly through steam generators (boilers) or by boiling the water coolant. The steam drives turbine generators which produce electricity.

Thermal Reactors

The fission, or chain reaction, which generates the heat in a reactor is kept going by the collision of neutrons with the uranium fuel. In a thermal reactor, the neutrons are slowed down by a moderator - graphite or water - to make collisions more likely. Nuclear physicists refer to neutrons generated by fission as 'fast' neutrons but once they have been slowed down by the moderator they are called 'thermal' neutrons. There are accordingly, two kinds of reactor, thermal and fast, the latter having no moderator (see below). All the world's commercial reactors are thermal reactors.

Magnox Gas-Cooled Reactor

Magnox is the trade name of the magnesium alloy cladding around the natural uranium fuel of this type of reactor. The design is peculiar to the UK although UK Magnox reactors were also exported to Tokai Mura in Japan and Latina in Italy. The coolant is carbon dioxide at a pressure of about 20 bar (1 bar = 1 atmosphere or 15 lbs/square inch) and the moderator is graphite. Early designs have the core inside a steel pressure vessel with a concrete shield surrounding it and the steam generators outside. Later designs have a concrete pressure vessel with the steam generators contained within it. Magnox reactors have a low output per unit volume of core and a lot of fuel elements. The gas temperature is raised to around 400 deg C, producing lower quality steam than a coal-fired boiler. Overall thermal efficiency – the proportion of the energy in the fuel which is converted to electricity - is about 30%. Typical electrical output is 300 MW.

Advanced Gas-Cooled Reactor (AGR)

As the name suggests, this type is an advance on the Magnox reactor. The design is unique to the UK where it is operated by British Energy. The coolant is carbon dioxide at a pressure of 40 bar and the outlet temperature of the gas is 650 degC. The uranium dioxide fuel is enriched to about 3% U-235 (natural uranium is 0.7% U-235) and clad in stainless steel cans; the moderator is graphite. The reactor and steam generators are housed within a concrete pressure vessel the walls of which are about 6 metres thick. Typical electrical output of an AGR is 660MW and its thermal efficiency is about 40%.

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. The UK has one commercial operating PWR power station - Sizewell 'B'. Water, pressurised to about 150 bar and acting as both moderator and coolant, is pumped through the core. The fuel is uranium dioxide enriched to about 3.2%, contained in Zircaloy (zirconium alloy) tubes. As it is under pressure, the water does not boil and in the steam generators it heats the water in a secondary circuit to produce steam at about 70 bar and 280 degC. Thermal efficiency is about 32%. The reactor is contained within a concrete biological shield and this in turn is contained within a secondary containment. The design is very compact, because water is a more effective moderator than graphite. PWR outputs range from about 300MW to 1,300MW.

Boiling Water Reactor (BWR) The BWR is effectively a PWR without the steam generator. Water at a pressure of about 70 bar 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 is returned to the pressure vessel to complete the circuit. The fuel is uranium dioxide canned in Zircaloy with an enrichment similar to that of a PWR. The power density of a BWR is about half that of a PWR with lower pressures and temperatures. Its thermal efficiency is similar at about 32%. The advantage of not having a steam generator is somewhat offset by the disadvantages of a single cooling system which passes steam from the core through the turbines, causing contamination throughout the plant. BWR output range is slightly lower than that of the PWR, up to around 900MW.

Boiling Water, Graphite Moderated Reactor (RBMK)

The Soviet designed RBMK reactor is a hybrid of the graphite moderated and water cooled reactors. It is only found in the former Soviet Union. The core is an assembly of graphite blocks not unlike the core of a Magnox reactor. Through this core run the pressure tubes which contain the fuel. Water is pumped through the pressure tubes where it boils to steam which 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 as well as the graphite, water and steam in the pressure tubes moderate the neutrons in the core. It was this complexity which led to the explosion of an RBMK at Chernobyl in 1986 following numerous breaches of safety procedures.

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. Heavy water is water which instead of being an oxide of hydrogen (H_2O) is an oxide of heavy hydrogen, or deuterium (D_2O). Deuterium, like graphite, acts as a neutron moderator. In the CANDU reactor the fuel tubes pass through a tank of heavy water. The heavy water, pumped through the tubes at a pressure of 90 bar, is heated by the nuclear reaction. The water passes to a steam generator as it does in a PWR. The CANDU does not, however, require the pressure vessel of a PWR as the pressure tubes provide the containment. Fuel is natural uranium oxide contained in Zircaloy tubes. The average power density is about one-tenth of 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%. British energy's Bruce power plant in Ontario is such a reactor, for more information on that go to the bruce power web site www.brucepower.com

Fast Reactors

In a fast reactor, the neutrons from the chain reaction are not slowed down and they remain at high energy, hence the name 'fast' neutrons. To maintain a chain reaction, sufficient neutrons must be produced by fission to collide with the fuel to produce more neutrons. The absence of a moderator means that the fuel must contain a higher proportion of fissile material (plutonium or uranium 235). The fast reactor uses two other techniques to ensure sufficient collisions occur. Firstly, the fuel pins include fertile material (depleted uranium - known as the blanket) above and below the fissile plutonium fuel. This uranium captures some of the fast neutrons from the plutonium fuel fission and changes into more plutonium which helps to keep the chain reaction going. Secondly, in place of a moderator, the core is surrounded by a reflector. This causes neutrons, which would otherwise leave the core, to bounce back, increasing the chances of collisions with the fuel, thus maintaining the chain reaction.

A fast reactor core, with no moderator, is very compact and therefore has a high power density. (The 250 MW(e) Prototype Fast Reactor (PFR) at Dounreay has a core the size of a large dustbin). It is therefore usually cooled by liquid sodium which is very efficient at removing heat. Sodium has the advantage that it can be heated to 560 degC without being pressurised so the reactor does not need a pressure vessel to produce high temperature steam. With a boiling point over 900 degC, it has a valuable safety margin over the normal operating temperature. It also has the very attractive safety feature that it can maintain cooling by natural convection should cooling pumps fail. (Gas cooled AGR's also have this feature).

Fast reactors are sometimes called breeder reactors. This is because they breed their own fuel from the fuel blanket while they are running. It is possible to design a fast reactor such that the amount of plutonium it makes while running is more than enough to replace the plutonium which is consumed. A breeder reactor can literally produce enough plutonium to fuel a series of subsequent reactors and therefore, once you have built one fast reactor, you can 'breed' others with no need for new fuel to be manufactured other than in the fast reactors themselves. Alternatively, fast reactors can be designed to use up 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 curtailed and the PFR at Dounreay shut down in 1994. Fast reactor development is now mainly confined to France, Japan and Russia.

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