FACTSHEET:

Operating a nuclear power reactor

Overview

Three different types of nuclear power reactors have operated commercially in the UK – the first generation Magnox reactors, the second generation Advanced Gas Cooled Reactors and one Pressurised Water Reactor.

Nuclear power reactors generate thermal (heat) energy by nuclear fission. This is the splitting of an unstable heavy nucleus into two smaller ones, with the release of energy. In a power reactor, the fuel is the radioactive isotope uranium-235.

To maintain the power efficiency of a reactor, some of the spent (used) fuel is periodically removed from the reactor and replaced with fresh fuel. On average, about one-third of the fuel is replaced every 12 to 18 months but this depends on the design of the reactor and how long the reactor has been running.

Routine operation of a nuclear power reactor does not produce a lot of radioactive waste. The main operational wastes are used clothing and cleaning materials, components replaced during maintenance, and ion-exchange resins used to extract radioactive and chemical contamination from liquids, such as the cooling pond waters.

Types of nuclear power reactors

Three different types of nuclear power reactors have operated commercially in the UK:

- **the first generation Magnox reactors, located at 11 sites in the UK**. These reactors use uranium metal fuel contained in a 'magnesium non-oxidising' alloy sleeve, which gave the reactors their name. The first Magnox reactor was located at Calder Hall in Cumbria, and began generating electricity in 1956. All but one of these reactors are now closed and are being prepared for decommissioning. The last operating Magnox reactor, at Wylfa in Wales, is scheduled to close in 2015
- **the second generation Advanced Gas Cooled Reactors (AGR), located at 8 sites in the UK**. These reactors use an enriched uranium oxide fuel. The first AGR began generating electricity in 1976, and all of these reactors remain operational
- **one Pressurised Water Reactor (PWR)** at Sizewell in Suffolk that also uses an enriched uranium oxide fuel. This reactor began generating electricity in 1995 and remains operational

Government has stated that nuclear power is and will continue to be a key part of the UK's low-carbon energy mix*.

A series of new reactors have been proposed to help meet the UK's future energy demands. The designs include PWRs and boiling water reactors (BWRs).

** BIS (2013), The UK's Nuclear Future*

Nuclear fission in a power reactor

All commercial nuclear power reactors generate thermal (heat) energy by nuclear fission. This is the splitting of an unstable heavy nucleus into two smaller ones, with the release of energy.

In a power reactor, the fuel is the radioactive isotope uranium-235. This isotope captures a free neutron to form the heavier uranium-236 isotope. The addition of an extra neutron into the nucleus makes this isotope unstable and so it spontaneously fissions (splits apart) into two smaller atoms, known as fission products, releasing further neutrons and heat energy. This is the essential process used to produce energy in a nuclear power reactor.

As well as generating heat energy, the fission process also releases other free neutrons. These neutrons can, in turn, be captured by other surrounding uranium-235 atoms. If there is a sufficient 'critical mass' of uranium, then a continuous chain reaction can begin.

To ensure the efficiency of the fission process, the free neutrons need to be slowed down to ensure they are captured by the uranium-235 atoms. This is done using a moderator material which is usually water or graphite, depending on the reactor design.

The fission reactions can be controlled or stopped altogether by inserting control rods into the reactor. These are made from materials that absorb neutrons without undergoing fission.

Plutonium can also be formed in nuclear fuel when uranium-238 captures a free neutron to form uranium-239. This uranium isotope then undergoes multiple decay steps to produce plutonium-239. This isotope is also radioactive but has a long half-life (approximately 24 thousand years) so it can accumulate in the nuclear fuel.

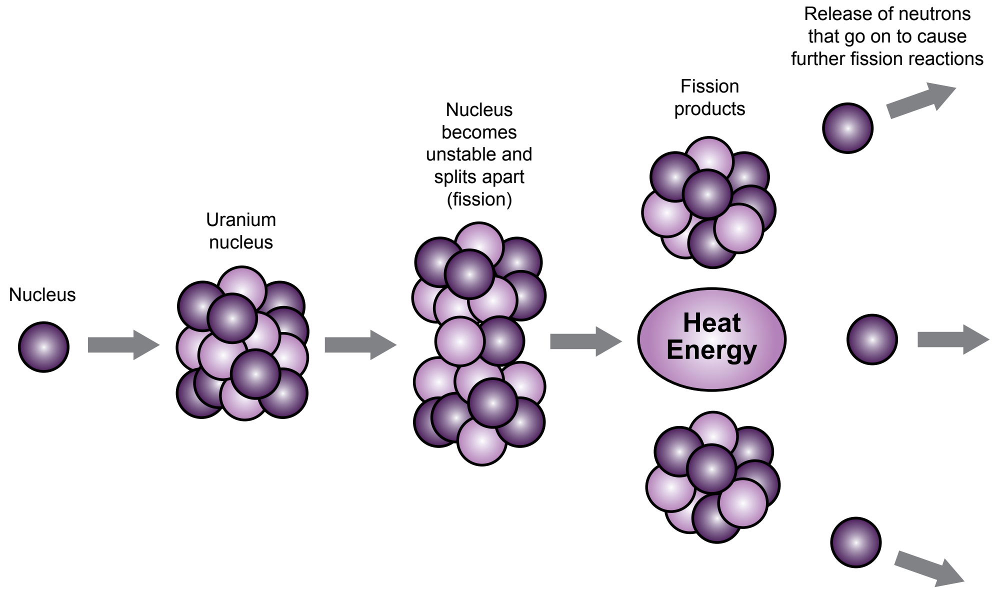


Image: The nuclear fission of the isotope uranium-235 initiated by the capture of a free neutron.

Anatomy of a nuclear power reactor

All nuclear power reactors aim to do the same thing - they use the heat generated from nuclear fission to create steam. This steam can then be used to drive turbines for electricity generation, in exactly the same way as other types of power station.

Although there are various different reactor designs, there are a number of common features. These are summarised below:

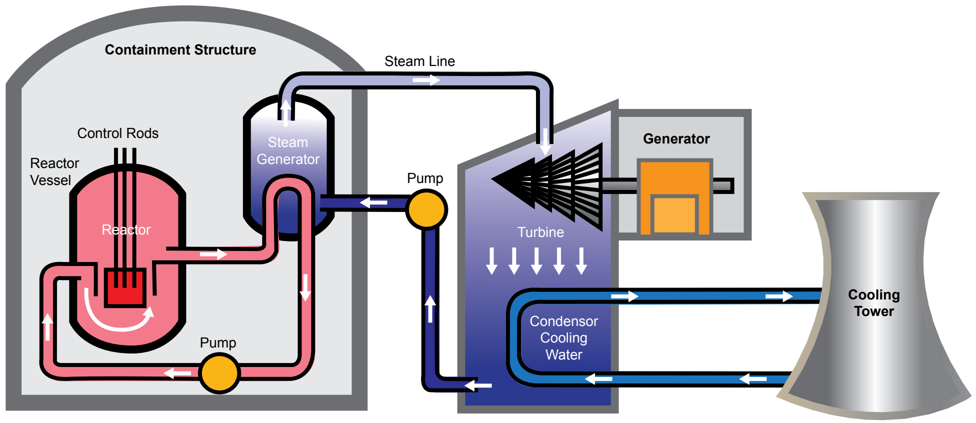
Fuel – The fuel contains the fissile material responsible for sustaining the nuclear fission chain reaction. Fuel types include uranium metal (Magnox reactors) or uranium oxide pellets (AGR and PWR reactors).

Fuel Cladding – The reactor fuel is contained within a cladding material. This protects the fuel and also contains the products of the fission reactions. The cladding material must be corrosion resistant and must not absorb neutrons. Cladding material types include magnesium alloy in Magnox reactors, stainless steel in AGRs and zirconium alloy in PWRs.

Moderator – The moderator slows down neutrons so that the uranium atoms can readily absorb the neutrons required for fission. The moderator must slow down the neutrons, but not absorb the neutrons itself. A typical moderator is graphite.

Coolant – The coolant draws heat away from the central part of the reactor (the reactor core) and takes it to the heat exchanger, where steam can be generated in a separate, secondary circuit. The coolant must be easy to pump, have good heat transfer properties and be non-corrosive. The coolant must not absorb neutrons. Typical coolants include carbon dioxide (gas), water, molten metal or molten salts.

Control mechanisms – The chain reaction is controlled by using materials that absorb neutrons. Typically, these materials are in the form of control rods, which can be moved in and out of the reactor core as required. Example control rod materials include cadmium, hafnium, boron and gadolinium. In some reactor designs, neutron absorbers, such as boric acid, can also be added to the coolant.



The reactor core is contained within a highly-engineered reactor pressure vessel (RPV).

The coolant used to remove heat directly from the reactor core is contained within a sealed 'primary coolant circuit'. Heat is extracted from the primary coolant circuit using a heat exchanger, which allows the transfer of heat to a separate, secondary circuit containing water. As the water in the secondary circuit heats up, it turns to steam, which is then used to spin a turbine connected to a generator for electricity.

After the steam in the secondary circuit has passed through the turbine, it must be cooled again (condensed) so that the water can be reused. To do this, a separate cooling circuit and second heat exchanger is used.

Water used for cooling the steam in the second heat exchanger can be drawn from a local river, lake or the sea. This water is never in contact with radioactive materials and can be discharged back to the environment afterwards. An important aspect of the design of nuclear power reactors is ensuring that the primary, secondary and cooling water circuits are all separate from each other, to prevent radioactive materials from escaping the reactor core.

NDA Nuclear Decommissioning Authority

Operation of a power reactor

The normal operation of a commercial power reactor involves a number of activities and processes that lead to wastes being produced. These activities include wastes from reactor maintenance, refuelling, and the storage and transport of spent fuel.

Routine liquid and gaseous discharges must be authorised by the environmental regulators and be strictly controlled and monitored.

Reactor maintenance

Routine maintenance and refurbishment is undertaken periodically to replace used reactor core components at the end of their operational lives. These activities lead to the production of wastes, including items such as used control rods, control rod chains and monitoring equipment.

Refuelling

Periodically, the spent (used) fuel assemblies are removed from the reactor core and replaced with fresh fuel. Typically, approximately one third of the fuel is replaced every second or third year, but this depends on a wide range of factors, including the reactor type, its operating time and efficiency. Most reactors need to be shut down whilst refuelling takes place.

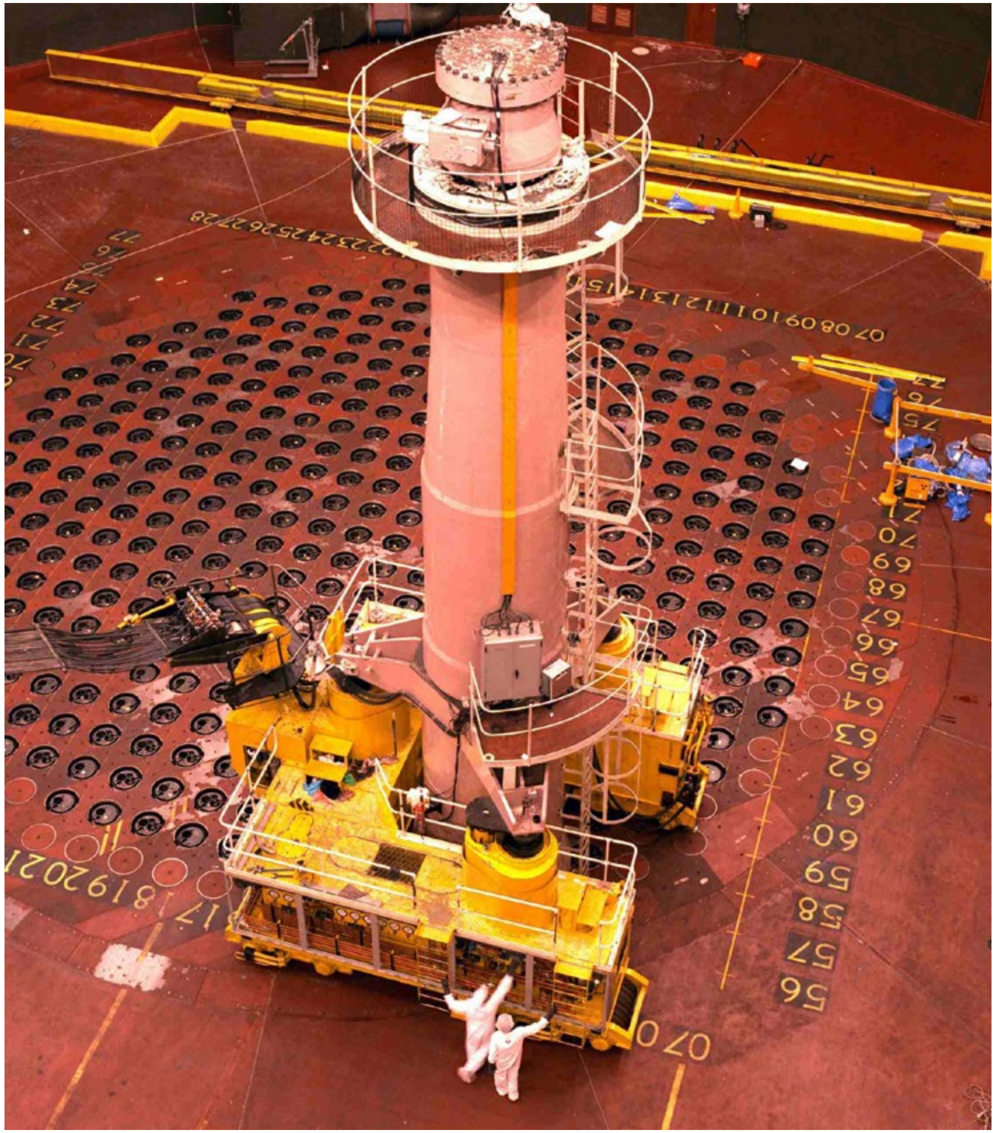


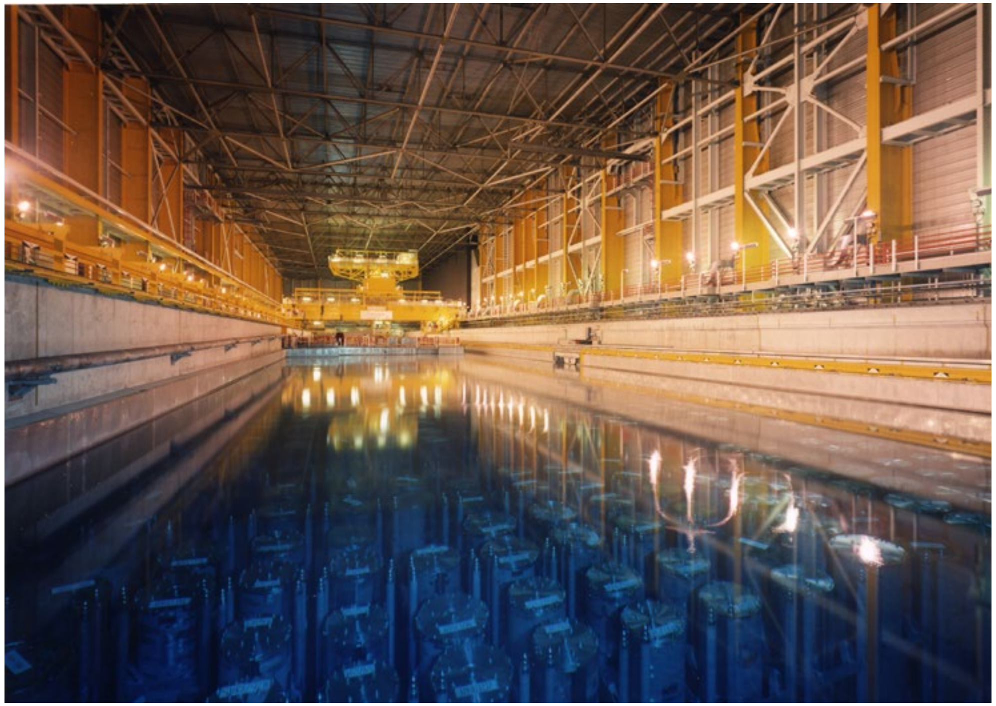
Image: The refuelling machine at the Wylfa Magnox reactor.

Nuclear Decommissioning Authority

Storage of spent fuel

Spent fuel assemblies removed from the reactor core are placed in water filled cooling ponds for a minimum of 90 days. This allows any short-lived radioactivity to decay and the spent fuel to cool. Some corrosion of the metallic parts of the fuel assemblies can occur, leading to a build-up of sludge in the cooling pond.

The water in the ponds is actively circulated and cooled through heat exchangers. This water is also routinely filtered (through sand) and decontaminated through ion-exchange resins.



Transport of spent fuel

After it has cooled, spent fuel that is intended to be reprocessed is packed into special shielded flasks for transport to Sellafield.

The flasks are packed into specially designed transport containers. These containers are extremely strong and have thick lead and steel walls to shield the spent fuel, protecting workers and the public from radiation.

A transport container can be used for multiple journeys and is monitored and decontaminated between journeys to maintain safety.

Image left: A cooling pond for spent fuel at Sellafield.
Image above: Transport of spent fuel by rail.

Nuclear Decommissioning Authority

Radioactive wastes produced during power reactor operations

A broad range of wastes and materials are produced during normal operation of a power reactor and associated spent fuel cooling ponds, although the quantities are small compared to reactor decommissioning wastes.

Fuel element debris (FED) is produced when fuel is handled at the reactors. This is mostly Magnox metal, stainless steel, other alloys and some graphite.

Miscellaneous activated components (MAC) are produced during routine maintenance work. These are highly radioactive, usually metallic items.

Contaminated liquid wastes and sludges are also produced during normal operations. Magnox metal corrodes in water, and its corrosion products and sludge accumulate in the bottom of cooling ponds.

Spent ion exchange resins and sand filters used to clean cooling pond and other waters on site are routinely produced, as are filters used to clean gaseous discharges. Used protective clothing and equipment are also routinely produced as LLW.

The spent fuel removed during refuelling is not considered to be a waste because it has the potential to be reused in future. After cooling, some spent fuel is transferred to Sellafield for storage or to be reprocessed to recover uranium and plutonium that can be reused to manufacture new fuel.