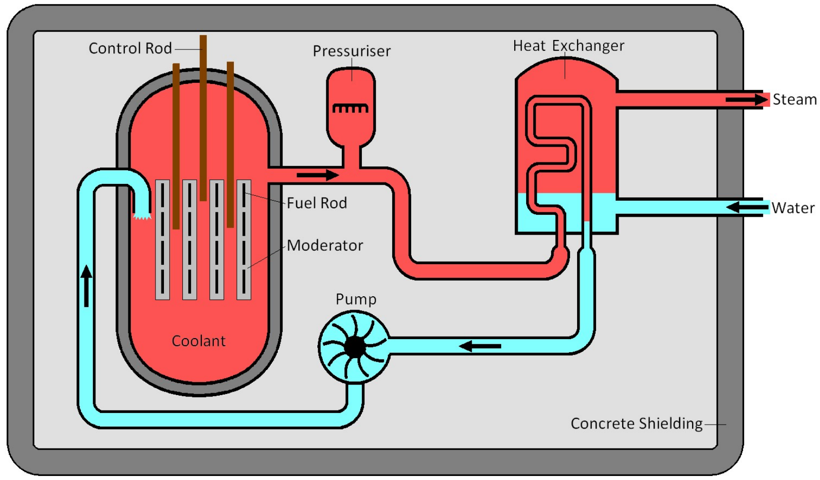
Nuclear Reactors



Generating Electricity

This is a typical nuclear fission reactor. A nuclear power station is similar to a power station powered by the combustion of fossil fuels or biomass. In such a station, the fuel is burnt in a boiler, the heat this produces it uses to heat water into steam in the pipes that cover the roof and walls of the boiler. This steam is used to turn a turbine which is connected to a generator that produces electricity. Steam enters the cooling towers where is it condensed into water to be used again.
In a nuclear fission reactor, the heat is produced in a different way.

Components of a Nuclear Reactor

Fuel Rods

This is where nuclear fission reactions happen. They are made or Uranium and there are hundreds of them spread out in a grid like pattern.
Natural Uranium is a mixture of different isotope. The most common are U^{238} which accounts for 99.28% and U^{235} which accounts for only 0.72% of it. 238 will only undergo fission when exposed to very high-energy neutrons whilst 235 will undergo fission much more easily. The Uranium that is used in fuel rods has a higher percentage of 235 and is said to be ***enriched***. This is so more fission reactions may take place.

Moderator

Role: The neutrons that are given out from nuclear fission are travelling too fast to cause another fission process. They are released at 1×10^7 m/s and must be slowed to 2×10^3 m/s, losing 99.99975% of their kinetic energy. The neutrons collide with the atoms of the moderator which turns the kinetic energy into heat. Neutrons that are travelling slow enough to cause a fission process are called ***thermal neutrons***, this is because they have the same amount of kinetic energy as the atoms of the moderator (about 0.025 eV at 20°C).
Factors affecting the choice of materials: Must have a low mass number to absorb more kinetic energy with each collision and a low tendency to absorb neutrons so it doesn't hinder the chain reaction.
Typical materials: graphite and water.

Coolant

Role: Heat is carried from the moderator to the heat exchanger by the coolant. The pressuriser and the pump move the hot coolant to the heat exchanger, here hot coolant touches pipes carrying cold water. Heat flows from hot coolant to cold water turning the water into steam and cooling the coolant. The steam then leaves the reactor (and will turn a turbine) as the coolant return to the reactor.
Factors affecting the choice of materials: Must be able to carry large amounts of heat (L11 The Specifics), must be gas or liquid, non-corrosive, non-flammable and a poor neutron absorber (less likely to become radioactive).
Typical materials: carbon dioxide and water.

Control rods

Role: For the reactor to transfer energy at a constant rate each nuclear fission reaction must lead to one more fission reaction. Since each reaction gives out two or more we must remove some of the extra neutrons. The control rods absorb neutrons, reducing the amount of nuclear fission processes occurring and making the power output constant. They can be lowered further into the fuel rods to absorb more neutrons and further reduce the amount of fission occurring. Some neutrons leave the reactor without interacting, some travel too fast while other are absorbed by U^{238} nuclei. If we need more neutrons we can raise the control rods.
Factors affecting the choice of materials: Ability to absorb neutrons and a high melting point.
Typical materials: boron and cadmium.

Nuclear safety aspects

Nuclear Reactor Safety

There are many safety features and controls in place designed to minimise the risk of harm to humans and the surrounding environment.

Fuel Used

Using solids rather than liquids avoids the danger of leaks or spillages. They are inserted and removed from the reactor by remote controlled handling devices.

Shielding

The reactor core (containing the fuel, moderator and control rods) is made from steel and designed to withstand high temperatures and pressures.

The core itself is inside a thick, leak proof concrete box which absorbs escaping neutrons and gamma radiation.

Around the concrete box is a safety area, not to be entered by humans.

Emergency shut-down

There are several systems in place to make it impossible for a nuclear disaster to take place:

If the reactor needs stopping immediately the control rods are inserted fully into the core, they absorb any neutrons present and stop any further reactions from happening.

Some reactors have a secondary set of control rods held up by an electromagnet, so if a power cut happens the control rods fall into the core.

If there is a loss of coolant and the temperature of the core rises beyond the safe working limits an emergency cooling system floods the core (with nitrogen gas or water) to cool it and absorb any spare neutrons.

Nuclear Waste Disposal

There are three levels of waste, each is produced, handled and disposed of in different ways:

High-level Radioactive Waste

What it is? Spent fuel rods from the reactor and unwanted, highly radioactive material separated from the spent fuel rods.

How do we get rid? The spent fuel rods are taken from the reactor and stored in cooling ponds with in the power station to allow most of the short-term radioactivity to die away. It is then transported to a processing plant. Here it is encased in steel containers and kept under water.

The cladding is eventually removed and the fuel rods are separated into unused uranium and plutonium and highly radioactive waste.

The uranium and plutonium is kept in sealed container for possible future use.

The waste is converted into powder, fused into glass blocks, sealed in air-cooled containers for around 50 years before being stored deep underground in a stable rock formation.

Time scale? Up to a year in the cooling ponds. Radioactive waste can remain at dangerous levels for thousands of years.

Intermediate-level Radioactive Waste

What it is? Fuel element cladding, sludge from treatment processes, contaminated equipment, hospital radioisotopes and containers of radioactive materials.

How do we get rid? Sealed in steel drums that are encased in concrete and stored in buildings with reinforced concrete. Also stored deep underground in a suitable location that has a stable rock formation and low water flow.

Time scale? Thousands of years.

Low-level Radioactive Waste

What is it? Worn-out laboratory equipment, used protective clothing, wrapping material and cooling pond water.

How do we get rid? Sealed in metal drums and buried deep underground in a supervised repository. Treated cooling pond water is released into the environment.

Time scale? A few months.