

## Chapter 11 Nuclear power

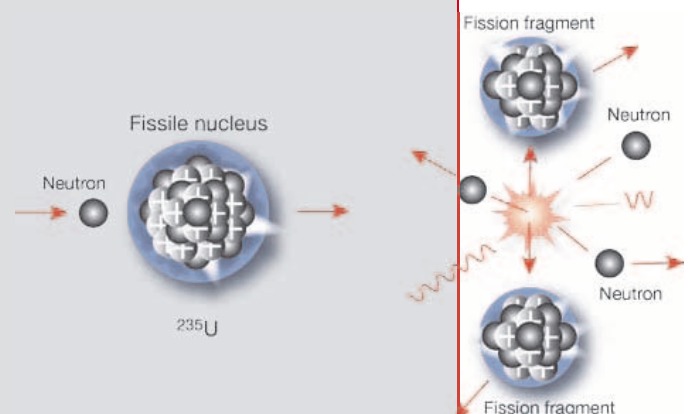
Nuclear reactors have been producing electricity since the 1950s and, in early 2003, there were 441 nuclear reactors operating in 30 countries with a total installed capacity of 359 GW.

### Nuclear reactors

Nuclear reactors depend on a reaction between neutrons and the atomic nuclei of the fuel for their operation. Uranium, the fuel for almost all reactors, consists principally of two isotopes, uranium-235 and uranium-238. In natural uranium, the fuel for early reactors, those isotopes are in the proportion of 0.7 per cent and 99.3 per cent, respectively, by weight. The *enriched uranium* used in most currently operating reactors contains about 2.5 per cent of uranium-235.

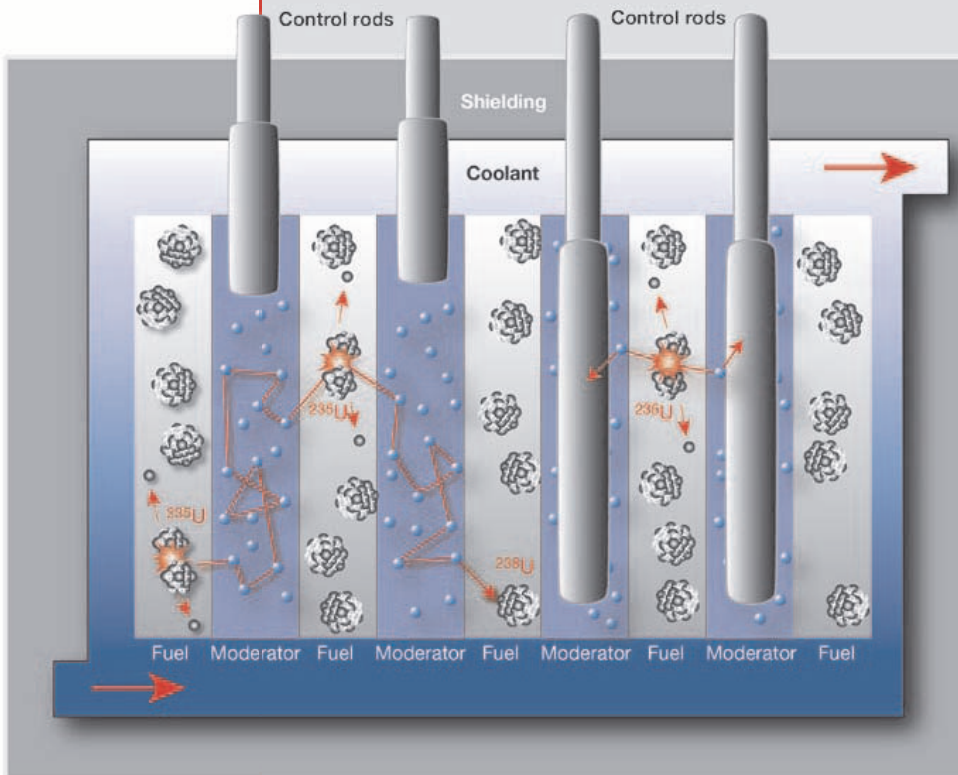
Energy is released when a uranium-235 nucleus absorbs a neutron and undergoes *fission*, that is, it splits into two large energetic fragments or *fission products*, accompanied by the release of several high energy or *fast neutrons* and some gamma radiation. The neutrons are slowed in the reactor so that they induce further fissions in the uranium-235. Such neutrons are often called *thermal neutrons* and the reactors that rely upon them *thermal reactors*. By contrast, when a nucleus of uranium-238 absorbs a fast neutron, it becomes uranium-239, which ultimately decays to form plutonium-239. This will also fission or capture neutrons to form isotopes of additional actinides, such as americium or curium. Consideration is currently being given to fuelling some reactors with mixed oxide fuel (known as MOX), which contains enriched uranium mixed with plutonium recovered from spent fuel by reprocessing. This is seen as a way of recycling fuel and controlling stockpiles of plutonium that can be used to make nuclear weapons.

The fuel in a nuclear reactor is assembled in an array called the *core*, which also contains the *moderator*, a material, generally water or graphite, that slows or thermalizes the neutrons. A coolant, usually water or gas, conducts heat away from the fuel and then passes through heat exchangers to make steam. The steam then drives turbine generators to make electricity.



Schematic diagram of uranium-235 fission

The fuel is sealed in metal containers, and the core is contained in a pressure vessel (or, in some designs, fuel elements are contained in separate pressure tubes). Massive concrete shielding helps to absorb the intense radiation emitted by the core during and after operation. Most reactors also have an additional containment building surrounding the reactors and usually the heat exchangers.



Schematic diagram of nuclear reactor

Fresh fuel is only mildly radioactive and can be handled without shielding. Once in the reactor, however, there is an enormous increase of activity due mainly to the fission products that have been generated in the fuel; this means that an accident at the reactor could release significant amounts of radioactive material. After removal from the reactor, the spent fuel remains hot and must be cooled to prevent melting, as well as shielded to reduce radiation exposure.

Although safety is a crucial issue for all nuclear power plants, there has been a particular focus since the Chernobyl accident and the breakup of the USSR on the safety of WWER and RBMK reactors. Thanks to the efforts of

specialists in eastern Europe and the former Soviet Union supported by many international co-operation projects, great progress has been made in upgrading the safety of these reactors.

**The main types of reactor are:**

*Pressurized water reactors (PWRs), boiling water reactors (BWRs) and WWER reactors (a Soviet reactor design similar to a PWR), all of which use water as moderator and coolant;*

*Heavy water reactors such as the Canadian-designed CANDU reactors, which use heavy water (water in which the*

*hydrogen atoms have been replaced with deuterium, an isotope of hydrogen) as a moderator and coolant;*

*Gas cooled reactors, which use carbon dioxide gas as a coolant and usually graphite as moderator; and*

*Water-cooled graphite-moderated reactors of the RBMK design developed originally in the USSR.*