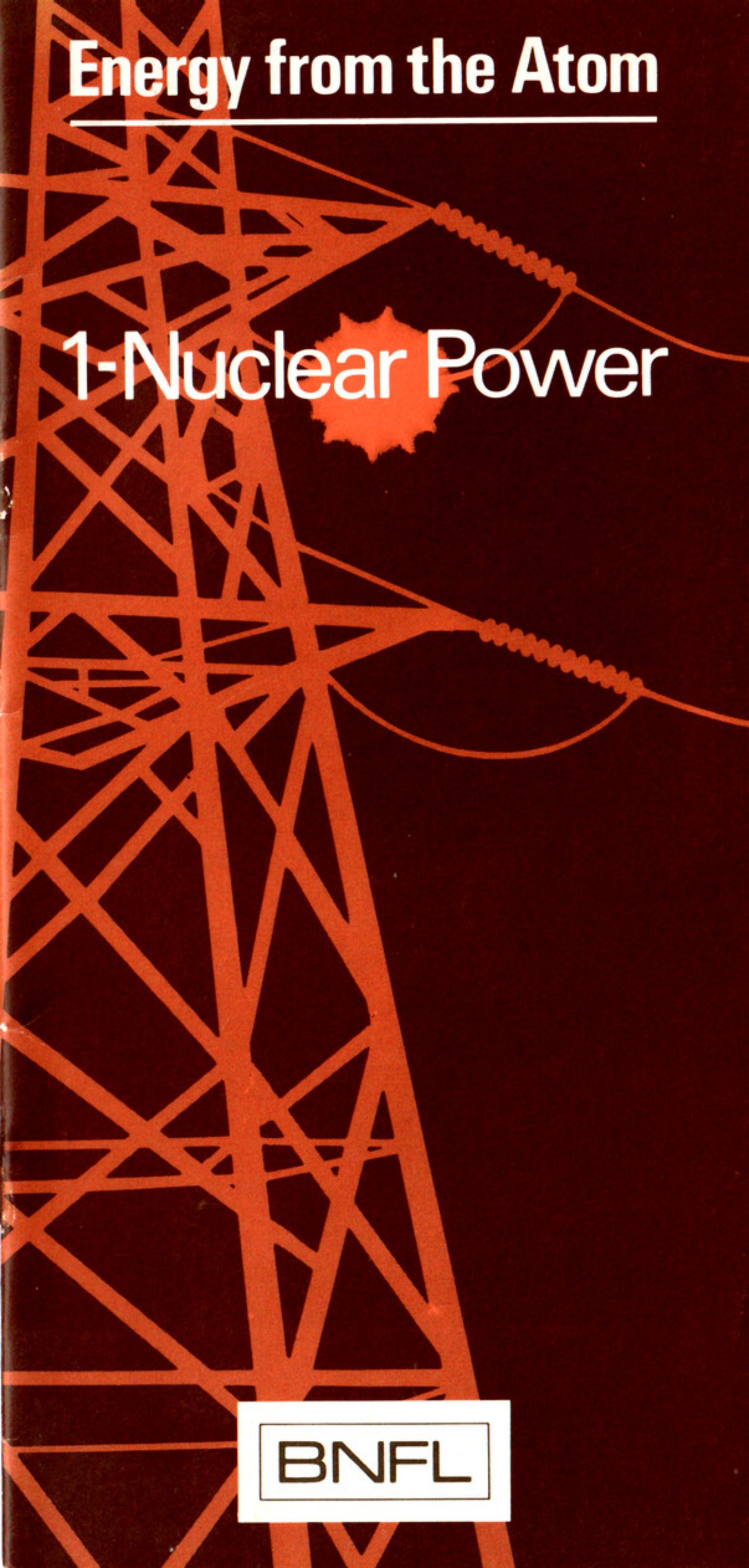
Energy from the Atom

1-Nuclear Power



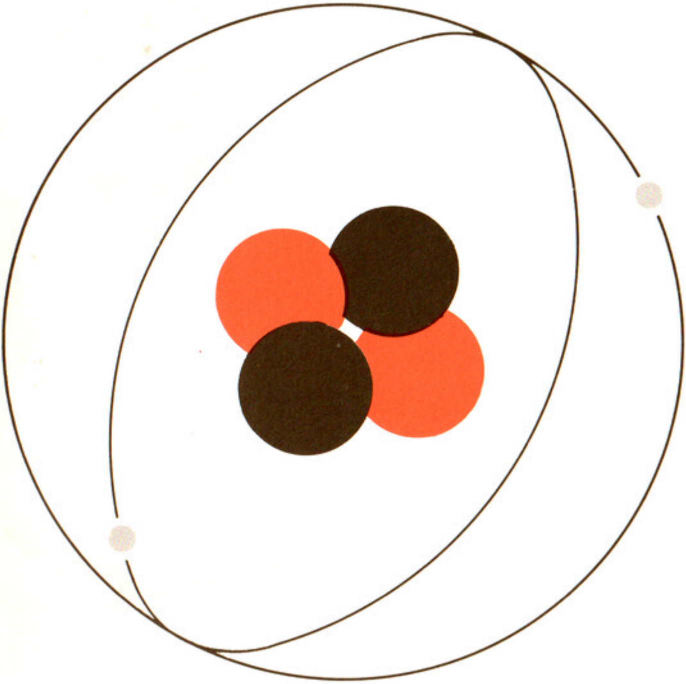
BNFL

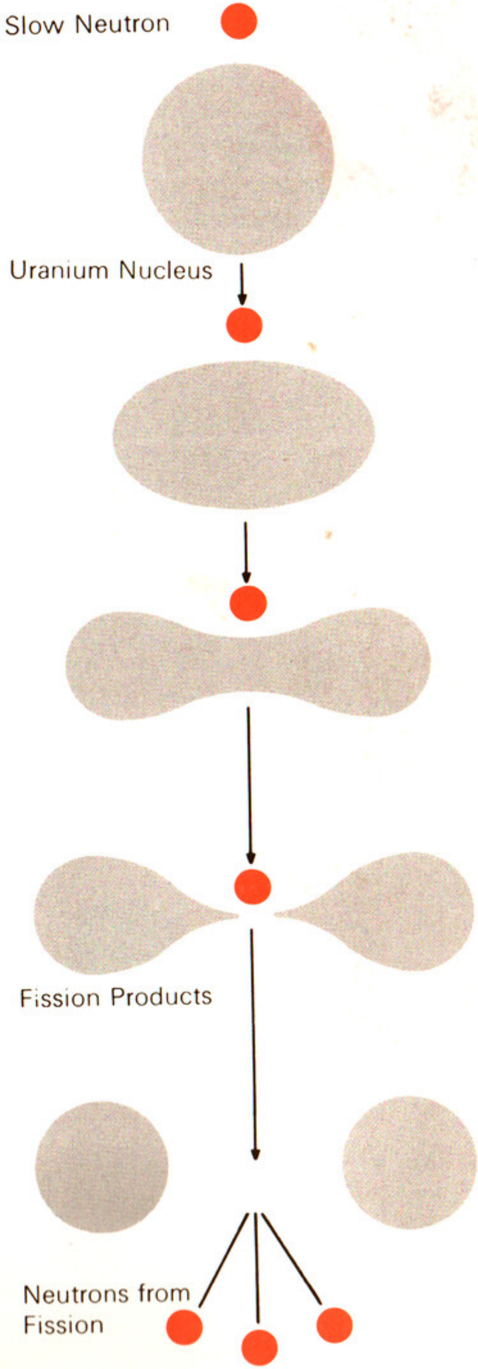
People and all things around us are made of atoms, each about a hundredth of a million of an inch across. They consist of a nucleus with electrons circulating around it, rather like planets revolving about the sun.

The nucleus itself is not a solid unit. It is made up of two different kinds of particles called protons and neutrons.

Some atoms, including certain atoms of uranium, break into fragments when a single neutron is added to the central nucleus. When this happens the uranium atom splits into two smaller atoms and energy is released in the form of heat.

An atom of helium has two protons and two neutrons in its nucleus, around which orbit two electrons.




Slow Neutron
Uranium Nucleus
Fission Products
Neutrons from Fission

Nuclear Fission

Two or three neutrons are also given off which can split further nuclei to continue the process. The continuing splitting process is called a chain reaction and is the basis of nuclear power.

Uranium fuel in a nuclear reactor gets hot as the atoms split in the uranium. A coolant fluid, gas or liquid, flows over the hot fuel transferring the heat from the core of the reactor to boilers where water is converted to steam and used to drive turbo-generators to produce electricity.

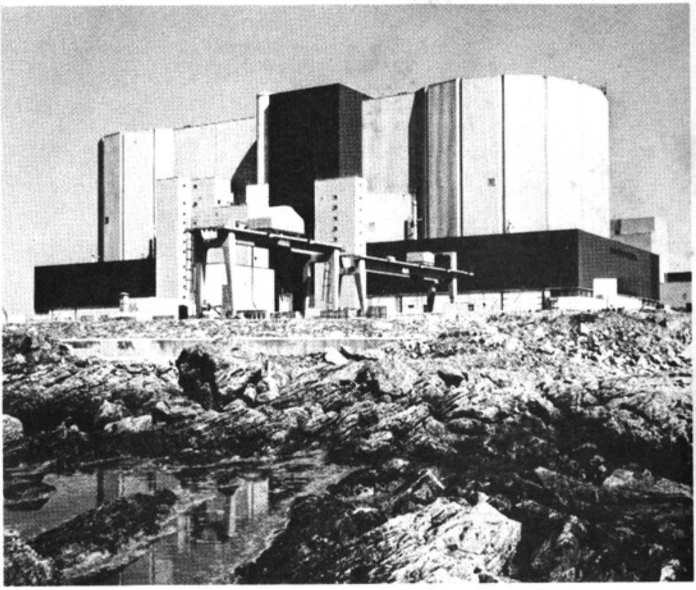
The only significant difference between a nuclear power station and a coal or oil-fired station is that the heat which produces steam for the generating equipment comes from nuclear fuel in a reactor and not from coal or oil burned in a furnace.

Uranium fuel in a reactor is surrounded by what is known as a moderator. This slows down the flying neutrons to ensure that the splitting process is carried out efficiently. The moderator can be graphite, heavy or ordinary water.

In the majority of the nuclear power stations operating in Britain, both the fuel and the moderator are enclosed in a reactor vessel which is connected to a number of water boilers. Heat from the reactor is transferred by a coolant gas, carbon dioxide, to the boilers where steam is produced to drive the turbines.

Britain was the first country to prove that economic nuclear power was possible. In 1956, Calder Hall at Windscale Works, Cumbria, became the first large-scale nuclear power station to operate in the world. It has been producing electricity steadily and safely ever since, as also has its sister station at Chapelcross at Annan

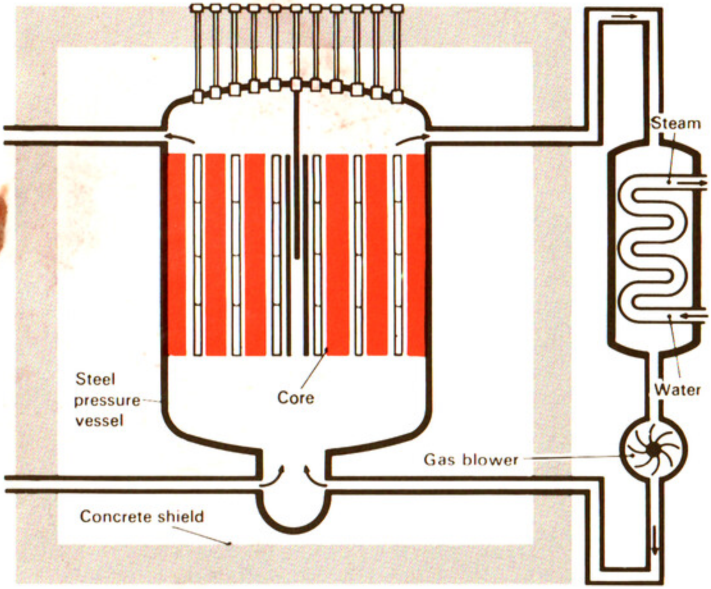
Wylfa nuclear power station on Anglesey has two 590 MW(e) Magnox reactors.



in Southern Scotland, which began operating in 1958. Both stations generate about 200 megawatts of electricity using four reactors. Between them the two stations have generated well over 60 thousand million units of electricity.

Based on the successful development of Calder Hall and Chapelcross, Britain pressed ahead with the world's first programme of commercial-size nuclear power stations. These are known as "Magnox" stations because the uranium metal rods are contained in a magnesium alloy (magnox) container or can. The first commercial station came into operation at Berkeley in Gloucestershire in 1962. There are now nine of these stations in operation, each with two reactors. They have been safe, reliable, economic and have become known as the "nuclear workhorses" of our electricity generating system. Year after year, their stamina and effectiveness have been well demonstrated. In a typical year they produce more than 11% of the

Magnox Reactors



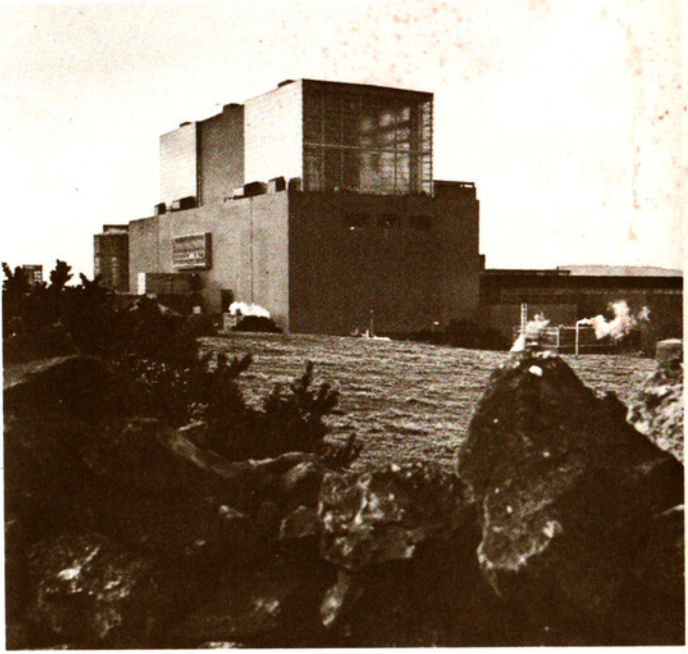
electricity generated in this country.

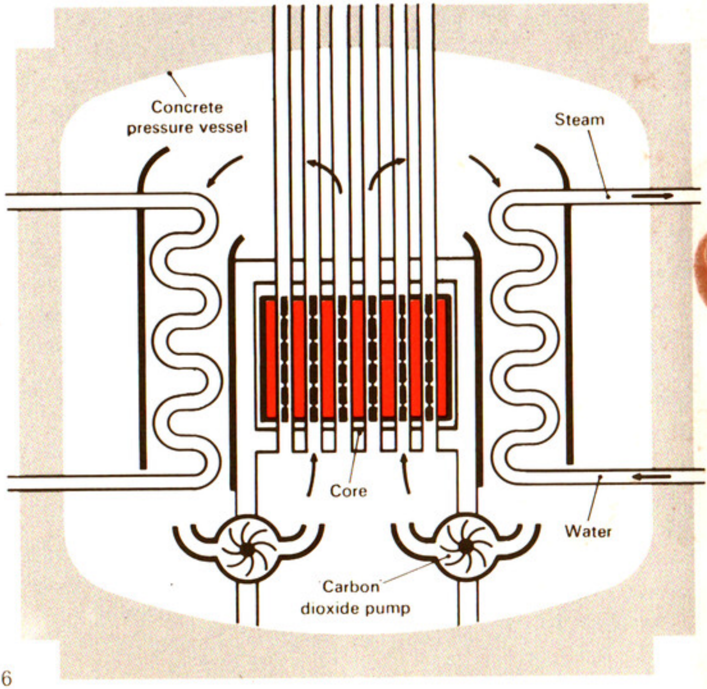
Some idea of the energy available through atomic power can be gauged from the fact that one 3½ft fuel element used in the Wylfa, Anglesey nuclear power station is equivalent to 150 tons of coal. Each of the two Wylfa reactors contain approximately 49,000 fuel elements and one fuel element can produce power continuously for the five years of its life in the reactor.

The average cost of generating electricity in a nuclear power station is now little more than half the cost of generating the same electricity in an oil-fired station and less than two-thirds the cost of generating it in a coal-fired station.

Nuclear power stations also have a first-class safety record. The operating experience of the Central Electricity Generating Board with magnox stations is now equivalent to over 200 years. During that time no harm has been caused by radiation to any of their workers or members of the general public.

Hunterston 'B' Advanced Gas-cooled Reactor power station in Scotland began generating electricity early in 1976.





Advanced Gas-cooled Reactors

During the 1960s a further development of the magnox system led to the introduction of the Advanced Gas-Cooled Reactor, called the AGR, which operates at higher temperatures and efficiencies. The United Kingdom's second nuclear power programme is based on this system and there are five stations in various stages of commissioning or construction. Two further AGR stations are to be built in the 1980s.

The basic concept of the AGR is the same as for the magnox designs. A graphite moderator is used and carbon dioxide gas is the coolant. The fuel differs, however, consisting of enriched uranium oxide pellets encased in stainless steel tubes arranged in clusters.

Nuclear fuel is enriched by increasing the fissionable, or fissile, content of the fuel, *i.e.* the part which maintains the atom "splitting" process. Uranium consists mainly of two isotopes, uranium 238 and uranium 235, of which U235 is the more important since this is the "fissile" isotope on which the chain reaction depends. By increasing the U235 content in fuel it becomes more effective and economic; reactors are able to operate at higher temperatures, and increased power, and can be built in smaller, more compact, sizes.

The five AGR power stations are located at Hinkley Point, Hunterston, Dungeness, Hartlepool and Heysham. Early in 1976 electricity was first generated by heat from one of the Hinkley Point reactors, followed shortly by one of the reactors at Hunterston. It is confidently expected that these AGR power stations will provide electricity as economically and safely as their predecessors, the magnox reactors.

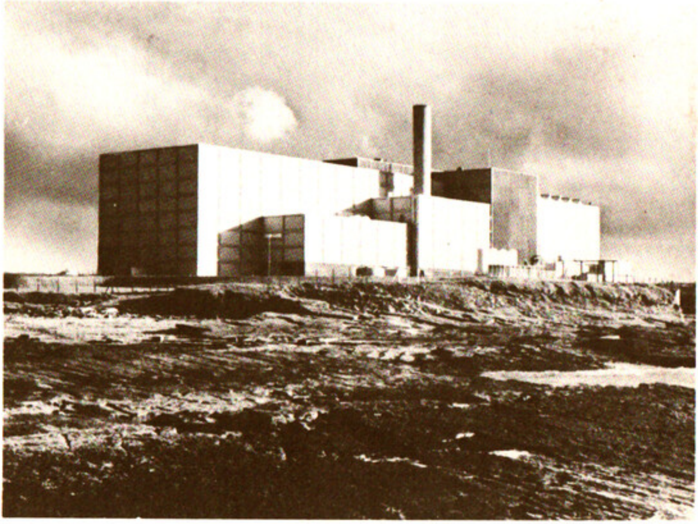
Fast Reactors

A fast reactor is unique in that it can produce more fuel than it consumes. A blanket of uranium fits around the reactor core in a position where it absorbs neutrons from the fuel. Plutonium is formed in this blanket which can be used, after extraction, to manufacture more fuel for the reactor. Thus, as fuel is burned-up in the core, more fuel is being manufactured in the blanket.

No moderator is used in a fast reactor and neutrons move around at high speed. Because there is no moderator the reactor core is small compared to other reactor systems, and the fuel is highly enriched in fissile atoms, either with more uranium 235 or plutonium 239, or a mixture of the two.

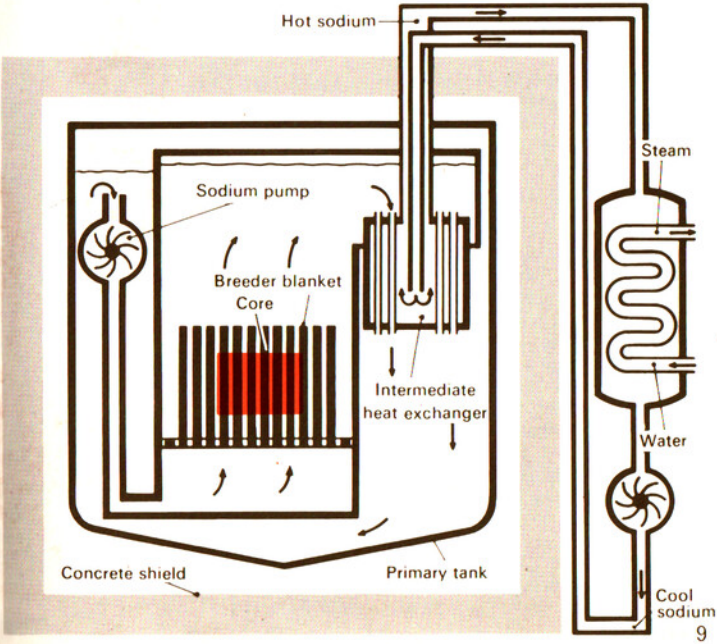
Vast quantities of heat are produced which need to be removed from the reactor core very quickly. Liquid sodium is used to do this and is continually pumped through the core to transfer heat to the steam generators.

The 250 MW(e) Prototype Fast Reactor at Dounreay in Scotland.



A 14 mW(e) experimental fast reactor operated at Dounreay in Scotland for 15 years. This permitted the testing and proving of a variety of types of fuel and also established the operating characteristics of sodium-cooled fast reactor systems. Heat from the reactor enabled electricity to be supplied to the North of Scotland Hydro Electricity Board on a regular and reliable basis.

A much larger fast breeder reactor power station, known as the Prototype Fast Reactor, is now operational at Dounreay and is capable of producing 250 megawatts of electricity. It paves the way for larger reactor stations of the same type, producing 1,000 megawatts of electricity and upwards, which might be built later in this century.



Fast reactors are in theory able to burn all the uranium that is fed to them, and in practice can produce more than 50 times as much energy from a given weight of uranium as current reactor designs. Furthermore they are capable of converting to useable nuclear fuel the 99 per cent of uranium 238 that the present nuclear power stations are unable to use. The 20,000 tons of uranium 238 already in stock in this country would, if used in fast reactors, be equivalent to more than 40,000 million tons of coal.

Experience in this country supports the view that the fast-breeder reactor will be a safe, reliable and economic source of power for the production of electricity. The fact that such a system also produces sufficient fuel for its own needs makes it an incomparable system to fulfil the world's long-term energy needs.

Radiation

Alpha A positively charged particle emitted in the radioactive decay of some heavy nuclei, for example uranium and radium; identical with the helium-4 nucleus.

Beta An electron, positive or negative, emitted from the nucleus in certain types of radioactive disintegration.

Cosmic rays Very penetrating ionising radiation which reaches the earth mainly from unidentified sources in outer space and occasionally from the sun.

Criticality A state of affairs in which a sufficient quantity of fissile material is assembled in the right shape and concentration for a self-sustaining chain reaction to take place.

Curie The quantity of a radioisotope that decays at the rate of $3{\cdot}7 \times 10^{10}$ disintegrations/second; approximately equal to the activity of one gramme of radium (abbreviation Ci).

Disintegration Any process in which a nucleus sends out one or more particles (including photons) either spontaneously or on being hit.

Fission The splitting of a heavy nucleus into two (or very rarely more) approximately equal fragments—the fission products. Fission is accompanied by the emission of neutrons and the release of energy. It can be spontaneous, or it can be caused by the impact of a neutron, a fast charged particle or a proton.

Gamma Electromagnetic radiation emitted by the nuclei of radioactive substances during decay, similar in nature to X-rays.

Half life The time taken for the activity of a radioactive substance to decay to half its original value, that is for half the atoms present to disintegrate. Half-lives may vary from less than a millionth of a second to millions of years, according to the isotope and element concerned.

Ionising radiation Radiation which knocks electrons from atoms during its passage, thereby leaving ions in its path. Electrons and alpha particles are much more ionising than neutrons or gamma rays.

Isotopes Two atoms are said to be isotopes if they are of the same chemical element but have different masses. This means that isotopic nuclei contain the same number of protons but different numbers of neutrons. A radioisotope is a radioactive isotope.

Neutron A nuclear particle having no electric charge and the approximate mass of a hydrogen nucleus. It is found in the nuclei of atoms and plays a vital part in nuclear fission. Outside a nucleus a neutron is radioactive, decaying with a half-life of about 12 minutes to give a proton and an electron.

Nucleus The core of an atom, which may be said to comprise protons and neutrons. It is about 10 $^{-12}$cm in diameter (a millionth of a millionth of a cm). The detailed structure of nuclei is not fully known.

Proton The nucleus of the hydrogen atom. It carries unit positive charge and has unit mass.

Rad The unit of ionising Radiation Absorbed Dose. One rad is equal to an energy absorption of a hundred ergs per gram of tissue.

Radiation A term which embraces electromagnetic waves, in particular X-rays and gamma rays as well as streams of fast-moving charged particles (electrons, protons, mesons, etc.) and neutrons of all velocities, ie, all the ways in which energy is given off by an atom.

Radiation decay The property possessed by some atoms of disintegrating spontaneously with the emission of a charged particle and/or gamma radiation. The rate of radioactive decay is not affected by any normal change of temperature, electric or magnetic fields or chemistry.

Rem Unit of exposure which takes into account the biological effectiveness of the particular type of radiation. 1 rem = 1 rad × QF, where QF is the quality factor attributed to the radiation.

Roentgen The unit of exposure to X-ray or gamma radiation, based upon the capacity of the radiation to produce ionization in air. For a wide range of radiation energies, one roentgen will result in an absorbed dose in soft tissue of approximately one rad.

Specific activity The radioactivity of unit mass of a radioactive substance, usually expressed in curies per gram, *ie*, a measure of the intensity of the source.

X-rays Penetrating radiations, being electromagnetic waves similar to light but of much shorter wavelength. Generally speaking they are emitted when high speed electrons suffer an abrupt loss of energy. Whilst invisible, they can be detected by photographic films, luminescent screens and instruments.

BNFL

Published as a contribution to the wider understanding of nuclear power by

Information Services Department
British Nuclear Fuels Limited
Risley
Warrington WA3 6AS

Further information on atomic energy and its applications can be obtained from:

Information Services Branch
UK Atomic Energy Authority
11 Charles II Street
LONDON SW1Y 4QP

Information Services
Central Electricity Generating Board
Sudbury House
15 Newgate Street
LONDON EC1A 7AU

The Radiochemical Centre Ltd
White Lion Road
Amersham, Bucks HP7 9LL

299/50M/4R580
ISBN No. 85327