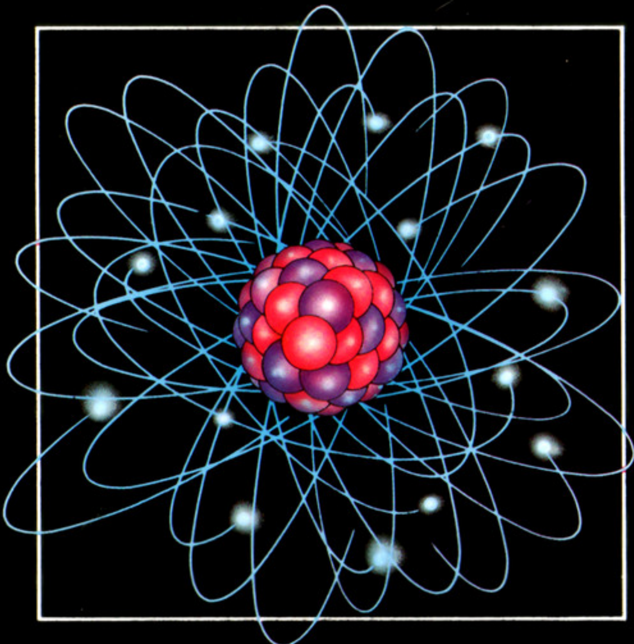
atoms AT WORK

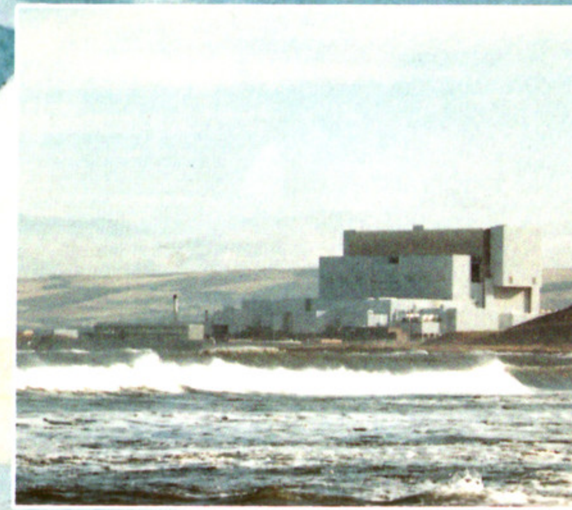


atoms at work

INTRODUCTION

Her Majesty Queen Elizabeth II opens the world's first full-scale nuclear power station at Calder Hall.

Since the discovery of radioactivity in 1896, our understanding and use of atomic energy has grown enormously. Nuclear weapons and nuclear reactors are the most obvious examples, but the use of radiation is widespread throughout medicine, industry and science. This booklet explains how and why atoms are used for civil purposes. It does not deal with the issues of the safety of nuclear power, or waste. These topics are dealt with in other leaflets available from the UKAEA.

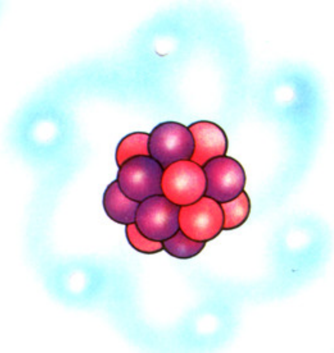


The new 1400MW Advanced Gas-cooled Reactor (AGR) at Torness.

Artist's impression of the Sizewell B Pressurised Water Reactor (PWR).

ATOMS ARE . . .

Hydrogen



Carbon

Uranium

Everything is composed of atoms. Atoms are very small — There are billions in a drop of ink.

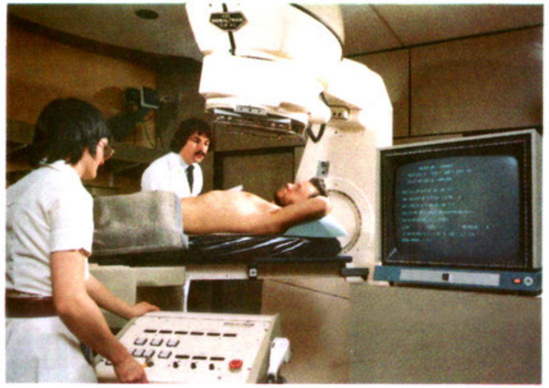
An atom can be thought of as a tiny solar system: a central sun or **nucleus** around which *'orbit'* **electrons**. The nucleus itself is made up of **protons** and **neutrons**.

Normal hydrogen is the lightest atom with only one proton forming the nucleus. Carbon has six protons and six neutrons. Uranium the heaviest natural atom has 92 protons and more than 100 neutrons.

There are about 100 basic types of atom, such as hydrogen, carbon, iron, uranium. They form the chemical elements.

The atoms of natural uranium are basically of two forms, known as Uranium 235 (U 235) and Uranium 238 (U 238). The forms are chemically identical having the same number of electrons and protons. However U 238 has three extra neutrons in the nucleus and so the two forms have different physical properties. Atoms of an element with different numbers of neutrons are known as **isotopes**. Most elements have several isotopes.

Routine inspection of a jet engine using gamma radiation

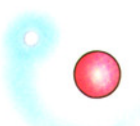


Computer controlled radiation therapy

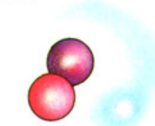
Sometimes an atom is unstable and gives off radiation. Elements with unstable atoms are said to be radioactive. Some of the heaviest elements such as uranium and radium are naturally radioactive and some of the lighter ones — potassium, carbon and hydrogen — have comparatively rare naturally occurring radioactive forms — **radioisotopes**.

The production and sale of radioisotopes is today a multi-million pound industry. In the words of Gordon Dean, former chairman of the United States Atomic Energy Commission, "they are used to treat the sick, to learn about disease, to improve manufacturing processes, to increase the productivity of crops and livestock and to help man to understand the basic processes of his body, the living things around him and the physical world in which he exists".

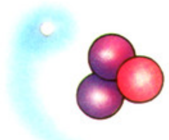
These many applications result from the properties of radioisotopes.



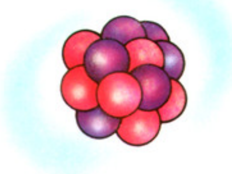
Hydrogen



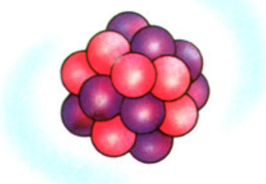
Deuterium



Tritium



Carbon 12



Carbon 14

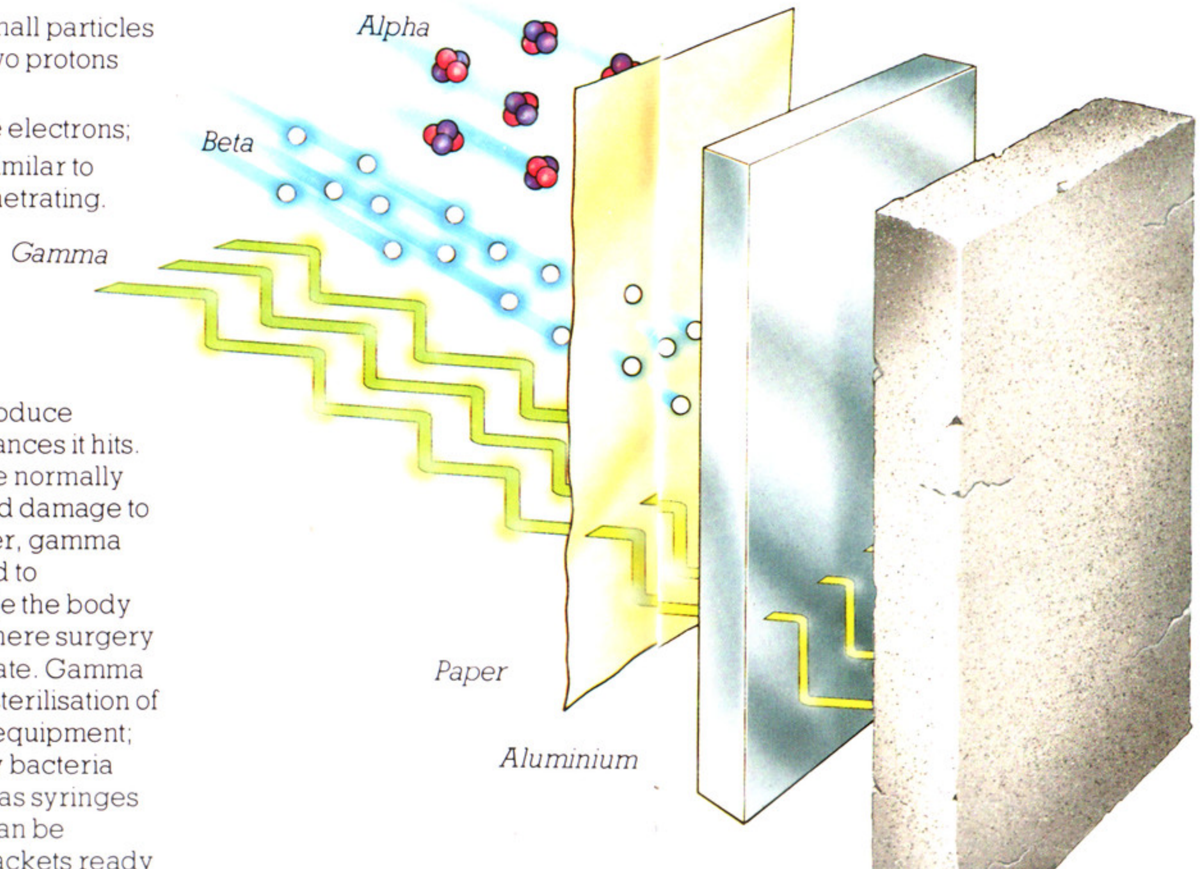
A T O M S   D O . . .

Various types of radiation can be emitted from radioactive elements:

Alpha: Streams of small particles each consisting of two protons and two neutrons;

Beta: Streams of free electrons;

Gamma: Radiation similar to X-rays but more penetrating.



Radiation can produce changes in the substances it hits. The sources used are normally low-powered to avoid damage to living tissue. However, gamma radiation can be used to penetrate deep inside the body to kill cancer cells where surgery may not be appropriate. Gamma rays are used in the sterilisation of disposable medical equipment; the radiation kills any bacteria and equipment such as syringes and scalpel blades can be supplied in sealed packets ready for instant use.

If radioactive isotopes are heated, cooled, melted, converted into glass, or combined with other chemicals, their radioactivity is not affected. So they are widely used as tracers, that is, as labels to follow the movement of materials through chemical systems, environmental pathways, even inside the human body.

All radiation penetrates matter to some extent. Alpha radiation can travel a few centimetres in air but can be stopped by a sheet of paper, by clothing or by the top layer of skin. Beta radiation can travel a few metres in air but can be stopped by a fairly thin sheet of aluminium or glass.

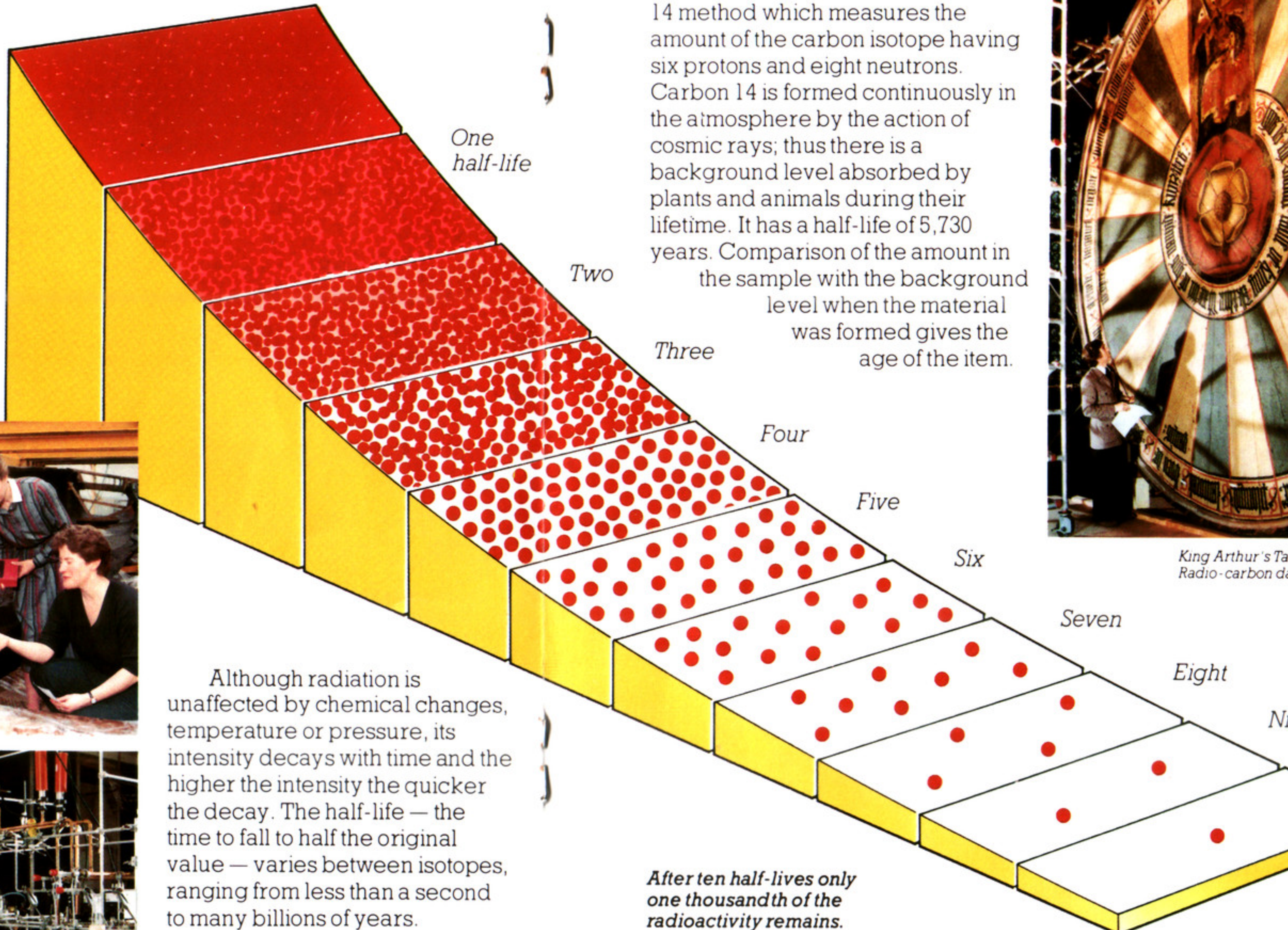
Gamma radiation and neutrons are both more penetrating but can be stopped by thick lead or concrete shielding.

Ion chambers being assembled for use in smoke detectors

The property of radiation to penetrate matter enables it to be used to measure the thickness of material or examine the structure by absorption of radiation passing through it. This has wide ranging applications from the control of manufacturing processes such as metal rolling and paper making to the in-situ examination of castings and pipe-welds.

RADIATION

After one half-life only half the radioactivity remains.

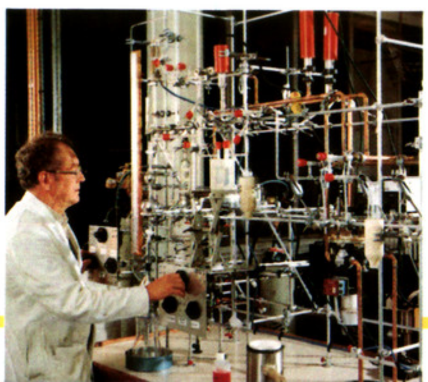


After ten half-lives only one thousandth of the radioactivity remains.

Because the decay rate is known for each element, archaeologists can use the amount of radioisotopes in an item for dating purposes. The most well known technique is the carbon 14 method which measures the amount of the carbon isotope having six protons and eight neutrons. Carbon 14 is formed continuously in the atmosphere by the action of cosmic rays; thus there is a background level absorbed by plants and animals during their lifetime. It has a half-life of 5,730 years. Comparison of the amount in the sample with the background level when the material was formed gives the age of the item.

King Arthur's Table, Winchester. Radio-carbon dated as 13th century.

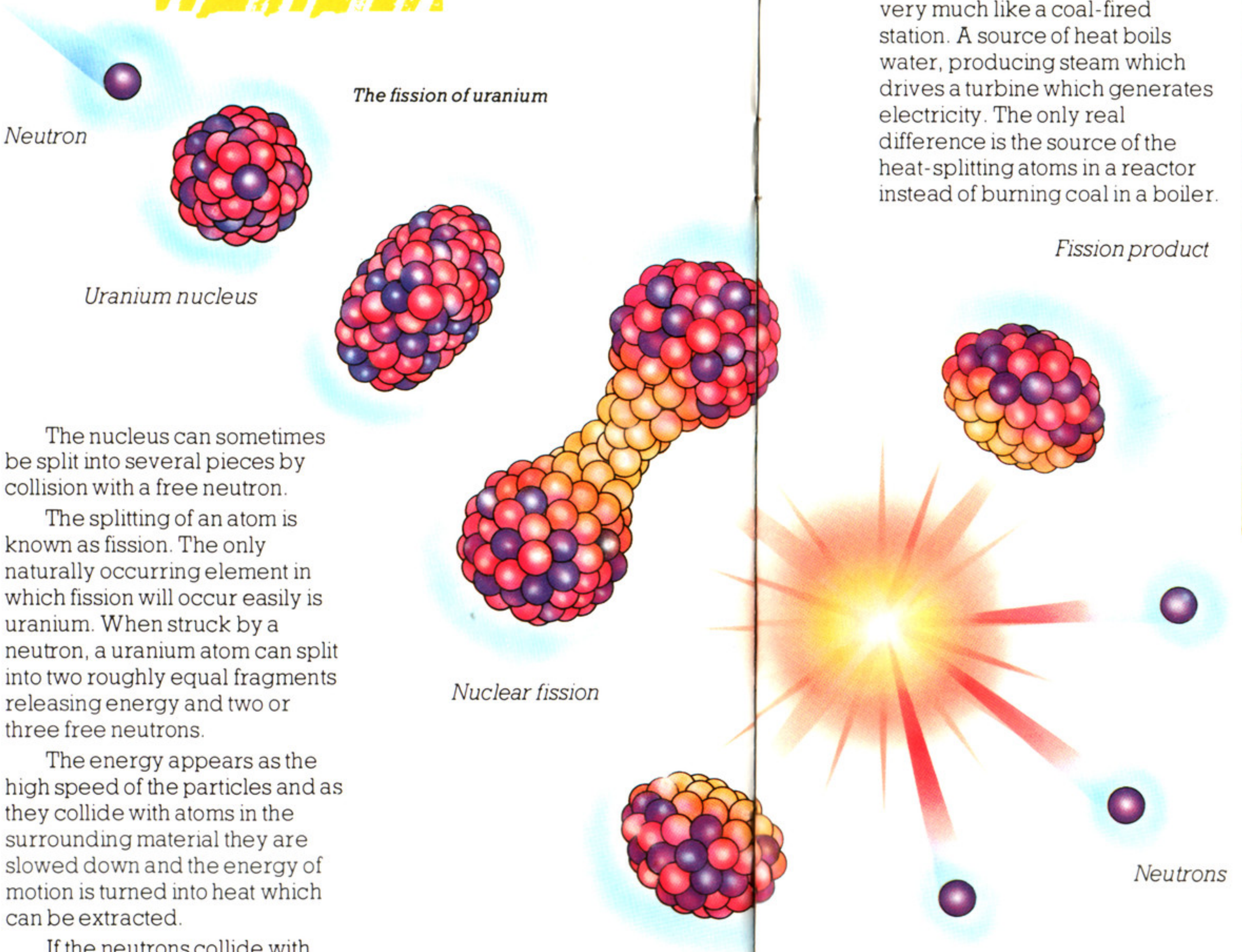
Carbon dating of a long boat, found near Spalding Moor, showed it to be well over 2,000 years old.



Although radiation is unaffected by chemical changes, temperature or pressure, its intensity decays with time and the higher the intensity the quicker the decay. The half-life — the time to fall to half the original value — varies between isotopes, ranging from less than a second to many billions of years.

Purification of carbon-dioxide gas that will subsequently be analysed for Carbon 14 atoms.

CHAIN REACTION



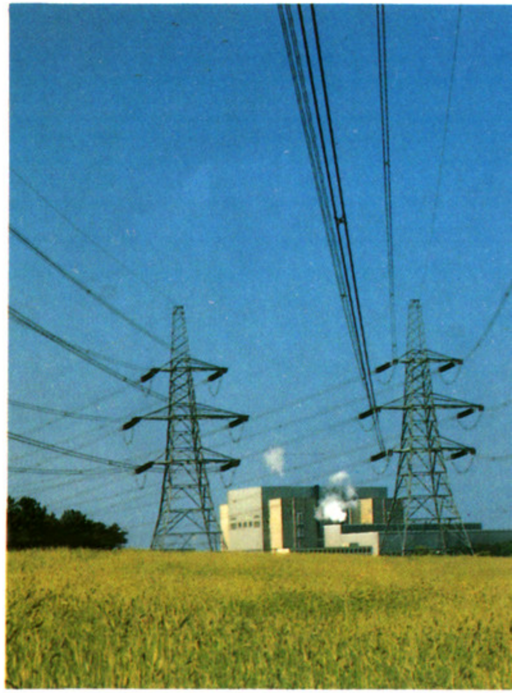
The nucleus can sometimes be split into several pieces by collision with a free neutron.

The splitting of an atom is known as fission. The only naturally occurring element in which fission will occur easily is uranium. When struck by a neutron, a uranium atom can split into two roughly equal fragments releasing energy and two or three free neutrons.

The energy appears as the high speed of the particles and as they collide with atoms in the surrounding material they are slowed down and the energy of motion is turned into heat which can be extracted.

If the neutrons collide with other uranium atoms, further fission can occur. This 'chain reaction' can release power continuously.

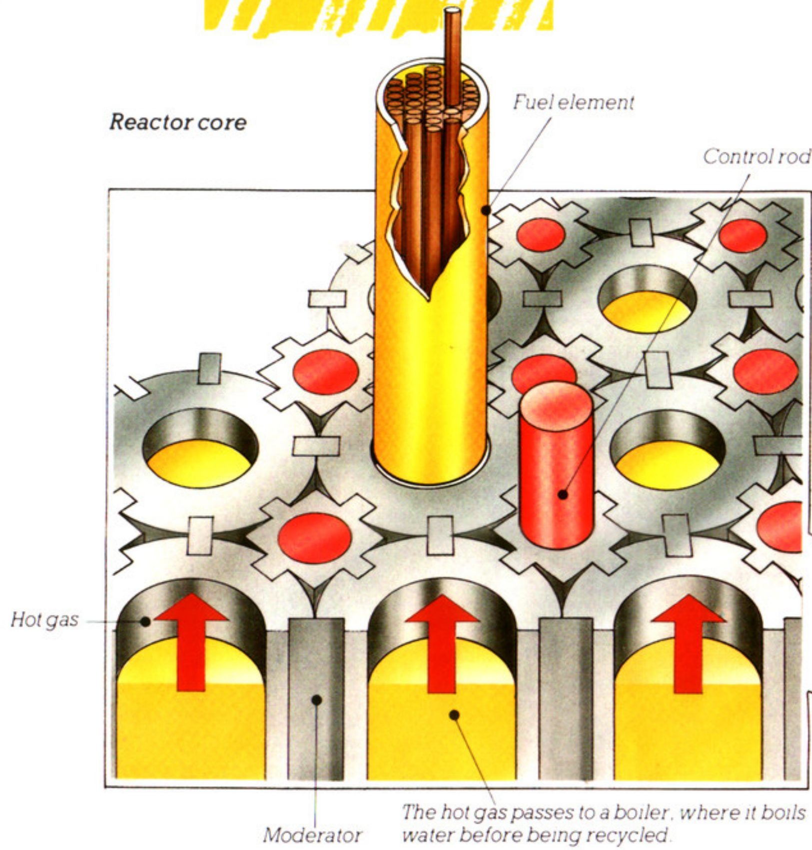
A nuclear power station is very much like a coal-fired station. A source of heat boils water, producing steam which drives a turbine which generates electricity. The only real difference is the source of the heat-splitting atoms in a reactor instead of burning coal in a boiler.



Weight for weight splitting uranium atoms releases several million times more energy than burning coal. However, the process is not easy.

Over 99% of uranium is U 238 and less than 1% U 235. Despite this, the probability of a slow moving neutron causing fission with U 235 is so much higher than that of any neutron, fast or slow, causing fission with U 238, that neutrons are deliberately slowed down.

NUCLEAR POWER TODAY



In a nuclear reactor, uranium is sealed into rods, grouped in clusters known as fuel elements. The rods are arranged so that a coolant, liquid or gas, can flow to remove the heat.

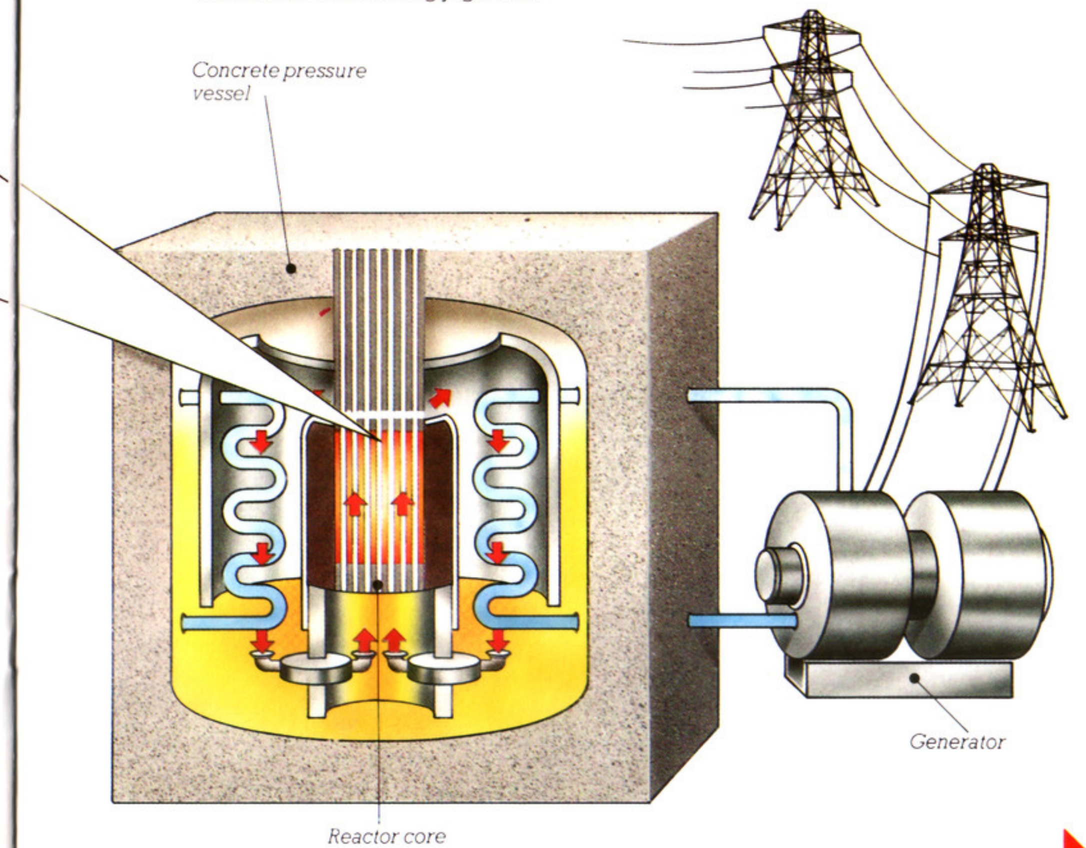
Other rods, containing boron which will absorb neutrons and thus stop the chain reaction, are used to control the power output. These 'control' rods are arranged so that they can be raised or lowered in channels between the fuel elements.

In present day reactors the whole assembly of fuel elements and control rods is embedded in a material known as a moderator (since it moderates the speed of the neutrons). This moderator can be graphite, water or heavy water. The reactor vessel is surrounded by a shield of concrete or steel many feet thick to contain the radioactivity created in the fission process.

These reactors appear in many types, for example Magnox, Advanced Gas Cooled (AGR), Pressurised Water (PWR), the names relating to the materials used.

All these types are known by the general term 'thermal reactors'. They use slow neutrons, and fission occurs with U 235 so that only a small percentage of the uranium fuel is 'burnt up'. So little in fact, that the million to one energy gain of nuclear power over chemical energy (burning coal) is reduced to 20,000 to one. Even so, 20,000 to one means that in producing electricity the quantities of fuel used (and the amount of waste generated) are very much less than the coal equivalent.

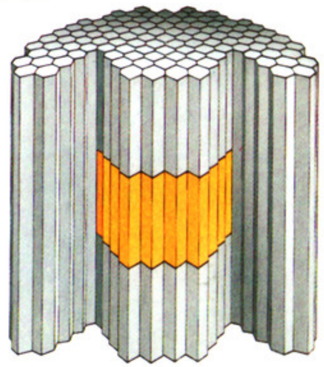
Much more of the uranium can be used however if it is first converted to plutonium.



NUCLEAR POWER TOMORROW

Fast Reactors

Each uranium fission releases two or three neutrons but only one is needed to keep the chain of fission reactions going. So there are many spare neutrons. Some escape to be absorbed in the reactor shielding, in the moderator, and in non-reacting U 238, while the remainder are 'mopped up' by the control rods. The neutrons absorbed in U 238 create a new element; plutonium. It is therefore produced in thermal reactors as a by-product.



Core of the fast reactor plutonium fuel surrounded by uranium 238.

Plutonium is not waste but a fuel of greater potential value than U 235. Some of it undergoes fission in thermal reactors but the remainder is separated out when the spent fuel is reprocessed. It can be made into fresh fuel rods and used in a 'fast' reactor, so called because there is no moderator and the neutrons therefore are not slowed down. If the plutonium is surrounded by a blanket of U 238 the spare neutrons not required in the fission process create more plutonium in the blanket. Using fast reactors one tonne of uranium can produce more energy than one and a half million tonnes of coal.

Prototype fast reactor — Dounreay (PFR)

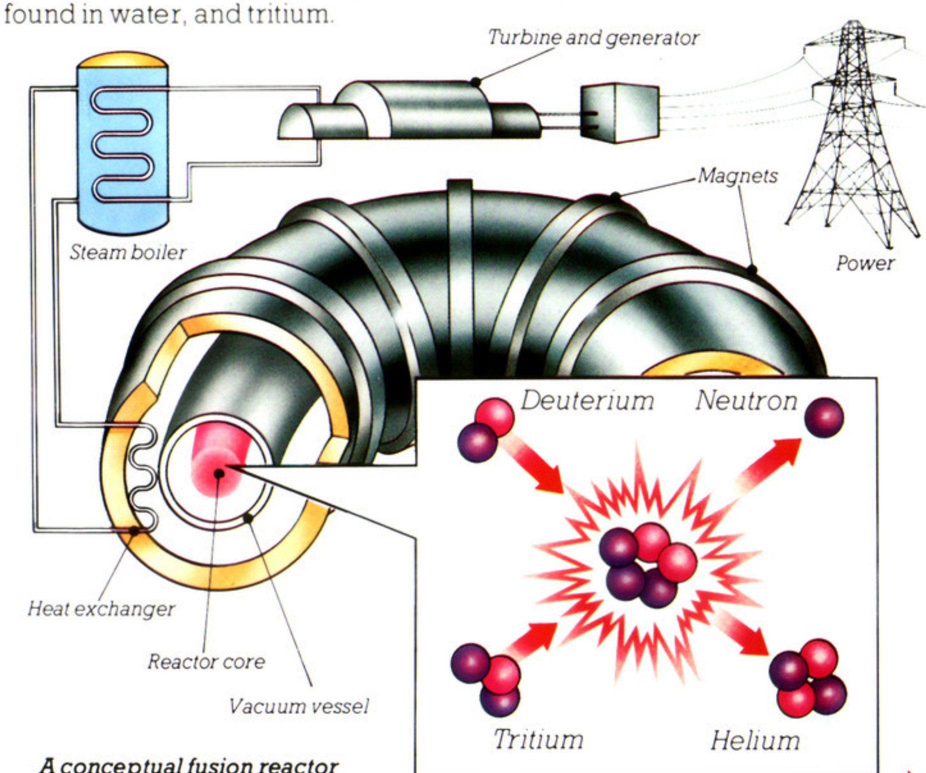
Nuclear Fusion

Nuclear fusion is the process which powers the sun and other stars. Researchers are trying to recreate these processes on earth under controlled conditions with the eventual aim of developing a nuclear fusion power station.

The reaction most likely to prove successful is that between two of the isotopes of hydrogen- deuterium, the 'heavy hydrogen' found in water, and tritium.

Deuterium and tritium are fused together to form helium and a neutron and release an enormous amount of energy. Reserves of deuterium are virtually unlimited, and tritium can be made from the light element, lithium, which is also plentiful.

So fusion offers the opportunity of an almost unlimited source of energy.



A conceptual fusion reactor

Published by Information Services Branch
United Kingdom Atomic Energy Authority
11 Charles II Street, London SW1Y 4QP
Designed by Wayne Boughen

Printed by Sawtells of Sherborne Limited   June 1988