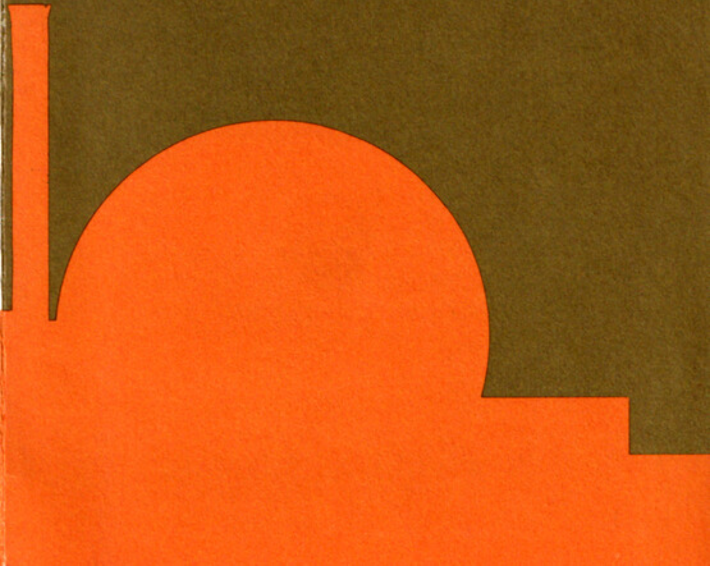
Nuclear Power: How and Why



Nuclear Power: How and Why

Why do we need nuclear power?

At present half of the world's energy demand is met by oil. At the rate it is now being used, supplies are likely to be exhausted in 30 years. Coal is plentiful in some parts of the world, but there are practical limits to its production rate and coal will increasingly be needed to replace oil for some uses, to produce gas and as a raw material for the chemical industries.

Meanwhile the world's population is increasing at a rate which is expected to cause it to double over the next 40 years. The poorer countries will need more fuel for farming, fertilisers and irrigation and for developing industries to help them raise standards of living to the levels that most Europeans take for granted. Even though we all save fuel wherever we can, more energy will be needed every year.

The sun, the winds, the waves and the tides are unlikely to meet more than a small fraction of our energy needs for many years. But nuclear power is already available and can generate electricity cheaper than in coal or oil-fired power stations. Every ton of uranium fed into a nuclear power station produces as much heat as about twenty thousand tons of coal. Taken over the lifetimes of the stations, the low fuel cost of nuclear stations more than outweighs the higher cost of building them.

How far has it got?

More than 25 years ago future energy shortages were already foreseen. Engineers and scientists in many countries were trying to harness the power of the atom—nuclear fission—to the large-scale production of electricity.

Britain was among the leaders. In October 1956 H.M. the Queen opened Calder Hall, the world's first commercial nuclear power station.

Calder Hall has exceeded its designers' best hopes. It is still working well and should continue to do so for many years. It has been the prototype of the British "Magnox" reactors, used in the world's first full-scale programme of commercial nuclear power. And it is the grandparent of Britain's second—Advanced Gas-cooled Reactor—programme.

Sixteen nuclear power stations are working in Britain now. Together they can provide up to 14% of our electricity. When the stations under construction at Dungeness, Hartlepool and Heysham come on power about 20% of our electric power will be nuclear. Further nuclear stations are planned and by the end of the century about half of Britain's electricity could come from nuclear power.

There are large nuclear development programmes in other countries. In France it is planned that half the country's electricity will come from nuclear power by about 1985.

How safe is nuclear power?

Government figures show that the nuclear industry is one of the safest industries to work in. The nuclear industry has, from its beginning, given great attention to health and safety and operates under Acts, Regulations, Codes of Practice, etc., based on internationally-accepted safety standards. Independent safety inspections are made by the Health and Safety Executive and Inspectorates of Government Departments.

Nuclear reactors cannot blow up like atom bombs. To prevent lesser accidents elaborate safety systems are built into every reactor and fuel plant.

All the activities of the British nuclear power industry add to our average annual radiation dose less than one per cent of what we have always been getting from outer space and the materials of the Earth's crust. It is less than the additional radiation that we would get from a single chest X-ray, and many times less than the additional radiation resulting from moving house from chalk downs to granite hills.

What is a nuclear power station?

Most of the plant is just like that in a coal or oil-fired power station. The difference is that the heat for raising steam to drive the turbines is produced by the "fission" (splitting) of atomic nuclei in a "reactor" instead of the burning of coal or oil in a furnace.

The heat produced by the reactor is taken to the boilers by the "coolant"—a liquid or gas which circulates through the reactor. This does the same job as the furnace gases in a coal or oil-fired station. In most of the reactors in Britain at present the coolant is carbon dioxide gas.

The fission process occurs with a very few naturally-occurring elements—particularly uranium. This is a widely distributed element that has few other uses. It is found in quite large quantities in Australia, Canada, the USA and Southern Africa. The process is kept going by the neutrons released in a nuclear chain reaction, just as the burning of coal or oil—a chemical chain reaction—is kept going by the heat it produces. But the fission process releases 10,000 to 20,000 times as much heat per ton of fuel fed in.

How does it work?

Natural uranium metal is made up of two sorts of atoms. Nearly all (known as the U-238 variety) do not readily undergo fission when hit by a neutron under reactor conditions—they are much more likely simply to absorb the neutron, thus stopping the chain reaction. But out of every 140 uranium atoms, one, known as a U-235 atom, is of a kind that will undergo fission, producing more neutrons; and this is more likely to happen with slow-moving neutrons—the so-called "thermal" neutrons—than with the fast neutrons that are produced by fission. We can thus build reactors which work with natural uranium provided that we have a material there—a "moderator"—to slow down the neutrons produced by fission to "thermal" speeds. These reactors are therefore called thermal reactors and the Magnox reactors which use graphite as a moderator are typical of this class.

How is the fuel made?

Uranium is made into nuclear fuel elements by British Nuclear Fuels Ltd. at Springfields, Lancashire.

A Magnox fuel element contains a 12-kilogram rod of uranium metal. The uranium is protected by a can to keep the fission products from escaping, without interfering with the passage of neutrons and heat. The canning material in the first programme of reactors is an alloy of magnesium called Magnox; it gives its name to the type of reactor that uses it.

Unlike other fuels, nuclear fuels "burn" without any obvious change in the size, shape or appearance of the elements. They do not give rise to bulky ash or harmful fumes. In a nuclear power station, such an element produces as much electricity as five 30-ton trucks of coal. A large power reactor contains about 30,000 fuel elements like this. They normally stay in the reactor for up to five years before being replaced. Careful design and scrupulous quality control guard against failures in service.

The fuel of Advanced Gas-cooled Reactors operates at a higher temperature than Magnox fuel, and produces even more heat from a given initial amount of uranium. It consists of pellets of uranium oxide, in which the uranium has been "enriched" by a separation process which increases the proportion of U-235 atoms. The pellets are canned in thin stainless steel tubes. Each pellet is equivalent to about 1½ tons of coal.

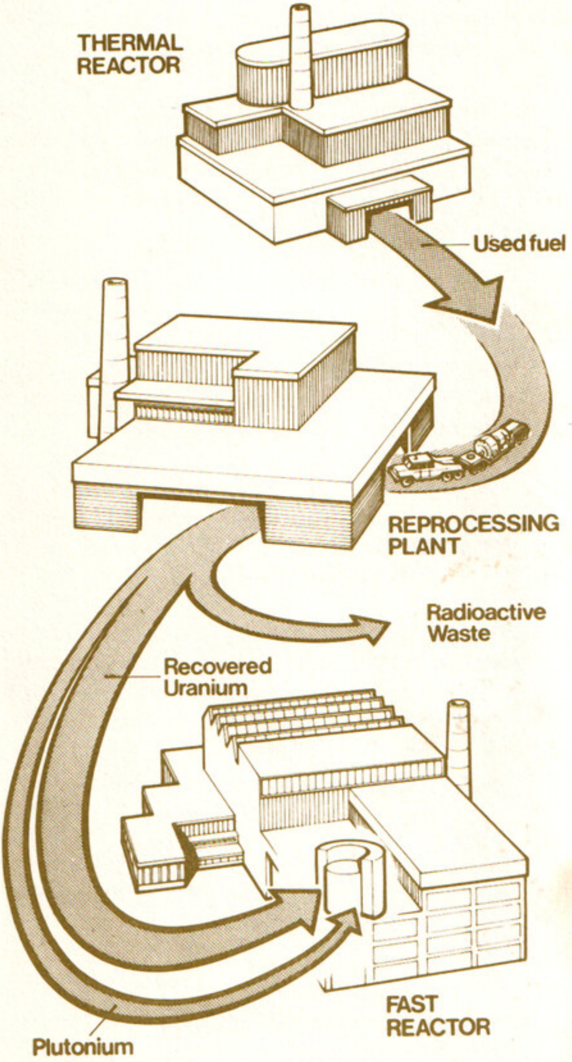
What happens to the used fuel?

As the fissionable uranium atoms are used up and turned into fission products, each fuel element becomes less effective. Eventually it has to be removed and replaced with a fresh one.

The spent fuel elements are taken in shielded containers (because their fission products are radioactive) to the reprocessing plant at Windscale in Cumbria.

After a period of storage under water, while most of the radioactivity disappears, they are stripped of their cans, dissolved in acid and fed to the chemical separation plant. In this plant, operated largely by remote control through heavy shielding, three main product streams are separated:

Unused uranium (about 98%). Most is stockpiled for recycling in fast reactors.



By-product plutonium (about 1%) formed when neutrons are trapped in atoms of non-fissionable uranium. This is very valuable as the fuel of fast reactors.

Mixed long-lived radioactive fission products (about 1%) for storage or disposal.

What becomes of the wastes?

Nuclear power, like all industries, gives rise to wastes, but the amounts are small and their properties are well understood. Because they are, in general, radioactive they are subject to strict controls.

For some the activity is so low that they can be disposed of at once to the environment like normal trade wastes; some have to be held for a time to let their activity die down; others are kept in safe storage awaiting final disposal.

There are three main kinds of nuclear waste:

1. *Fuel cans, solid scrap and sludges:* These are mostly stored at the plant but some low activity scrap is enclosed in concrete and sunk to the deep ocean under international supervision.

2. *Effluent water:* This contains traces of chemicals, some of them radioactive but only at very low levels. It is pumped to the sea, or other waterway, under strict Government authorisations.

3. *Long-lived highly active fission products:* At present these are stored at the plant as a concentrated liquid. The tanks are shielded, kept cool and constantly monitored. After some years of cooling the liquid will be converted to steel-clad blocks of glass, specially resistant to radiation, heat and water. These blocks will be further cooled for some years in stores before being disposed of finally away from man's environment, probably by burying them deep in stable rock formations on land or by depositing them on or under the deep ocean bed.

Why do we need fast reactors?

Our present thermal reactors "burn" only a small proportion of the uranium (the U-235) fed to them; they also produce plutonium as a by-product when the U-238 absorbs neutrons. Most of this plutonium remains in the uranium which is eventually discharged. If it is separated from the unburned uranium, it can itself be used as nuclear fuel—and a much better one than uranium because it gives us more neutrons. This means that we can build a reactor which runs on "fast" neutrons, therefore called a "fast" reactor. We no longer need a moderator and we can produce fissions in U-238, giving us still more neutrons. The excess can be used by surrounding the core of the reactor with a "blanket" containing more U-238, in which these neutrons are absorbed to make more plutonium—more in fact that we have "burned", i.e. we can "breed" nuclear fuel. What this does therefore is to convert the otherwise useless U-238 to plutonium, which we can then destroy by returning it to the core and thus produce more energy.

In this way we can do two very valuable things. First we can get about 50 times as much energy from every ton of uranium mined as we would with thermal reactors alone. Secondly, we have a means of disposing of the plutonium formed in thermal reactors.

Britain has a stockpile of about 20,000 tons of U-238. Fast reactors can make this equal in energy output to 40,000,000,000 tons of coal— which is comparable with our total known coal reserves.

Even before Calder Hall was built British teams were working on the design of fast reactors. By 1959 an experimental power-producing fast reactor had been built at Dounreay in Scotland. It was run for 18 years giving most valuable information and generating 500 million units of electricity. The next step was the 250 megawatt Prototype Fast Reactor also built at Dounreay and completed in 1974.

What about nuclear fusion?

Joining up the nuclei of light atoms—nuclear fusion—can be made to give even more energy, weight for weight, than the fission of heavy ones.

Fusion is the process that keeps the sun and the stars burning and it needs extremely high temperatures. The raw materials of fusion power are deuterium and lithium, obtained respectively from water and from rocks. Little is needed and both are plentiful.

Work is going on in many countries on the scientific and technological problems of harnessing nuclear fusion to electric power generation. If the work is successful fusion may become an important source of electricity in the next century.

The most promising lines of research use powerful magnetic fields to hold the gases in place while heavy electric currents heat them towards the temperatures required to promote the fusion reaction—upwards of 100 million degrees C.

In the U.K. research is centred at Culham in Oxfordshire, where the joint European experiment JET is also situated.

What else has nuclear research given us?

The main use of nuclear reactors is for the large-scale generating of electricity. But they also produce radioactive by-products—radioisotopes—and these can be put to a great many useful purposes.

Some reactors like DIDO at Harwell, Oxfordshire, are specially adapted for producing radioisotopes by bombarding suitable "target" materials with neutrons. Used with sensitive measuring devices, radioisotopes make very good "labels" for studying the detailed movements of objects or materials of almost any sort. They can also be used as sources of penetrating radiation.

British-produced radioisotopes are prepared, and sold throughout the world, by The Radiochemical Centre Limited, Amersham.

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

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UK Atomic Energy Authority
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