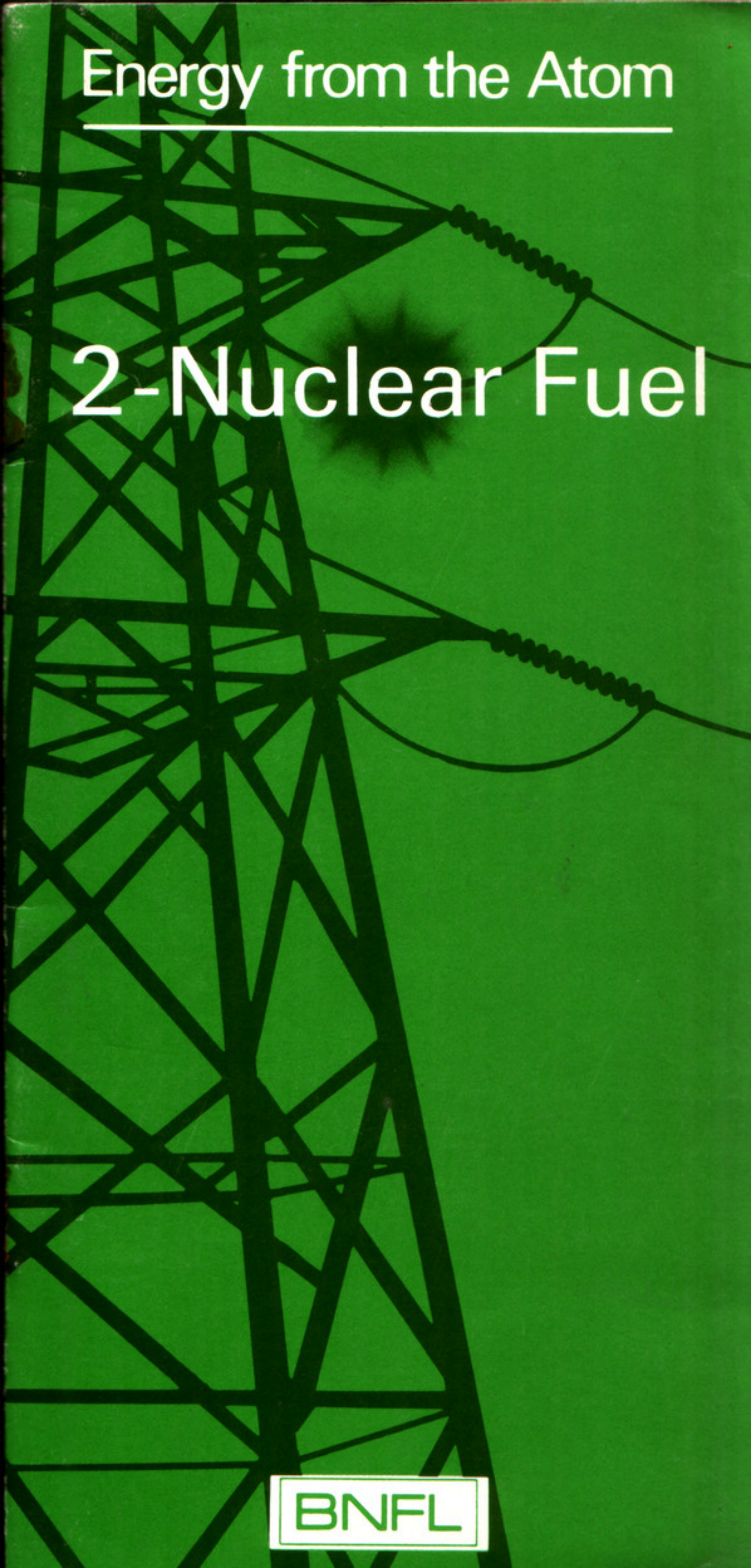
Energy from the Atom

2-Nuclear Fuel

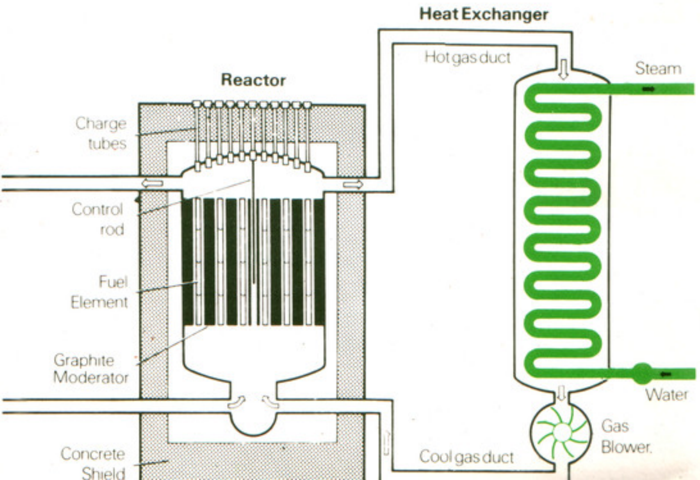


BNFL

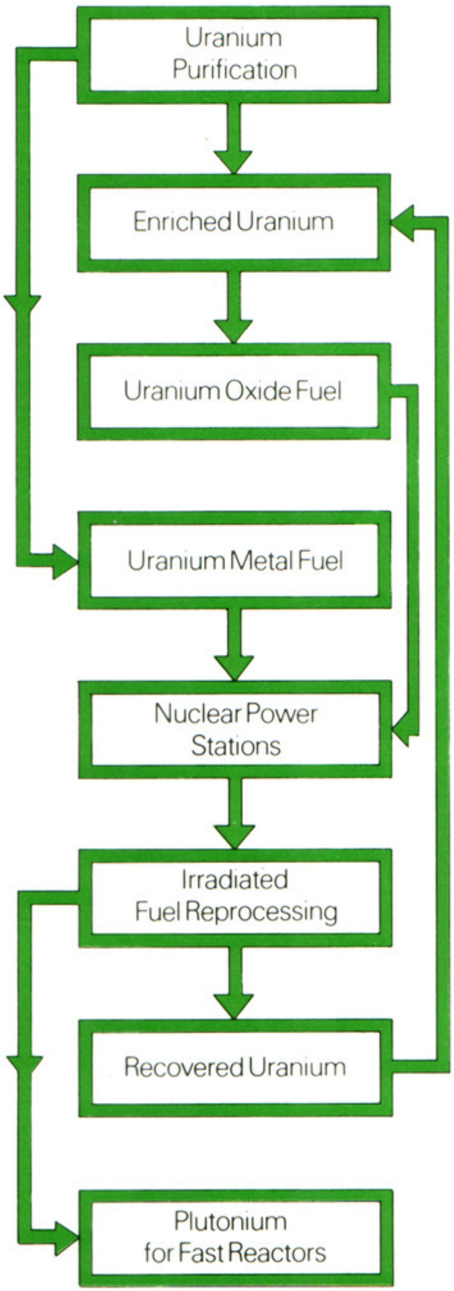
Nuclear power is now part of our everyday lives. The enormous energy of the atom has been safely harnessed to make electricity by using the heat which arises in the core of a nuclear reactor. In the reactor uranium atoms fission to give off energy in the form of heat. This is transferred via a coolant from the reactor to water boilers where steam is raised to drive turbo-alternators which produce electricity.

At the heart of a nuclear reactor is the uranium fuel from which energy is released. Nuclear fuel can take various forms and may remain in a reactor core producing power for up to nine years. It is then reprocessed to extract unused uranium and valuable by-product plutonium and to remove, for safe storage, the radioactive waste fission products which have arisen during the fuel's time in the reactor.

Magnox Reactor



The Nuclear Fuel Cycle



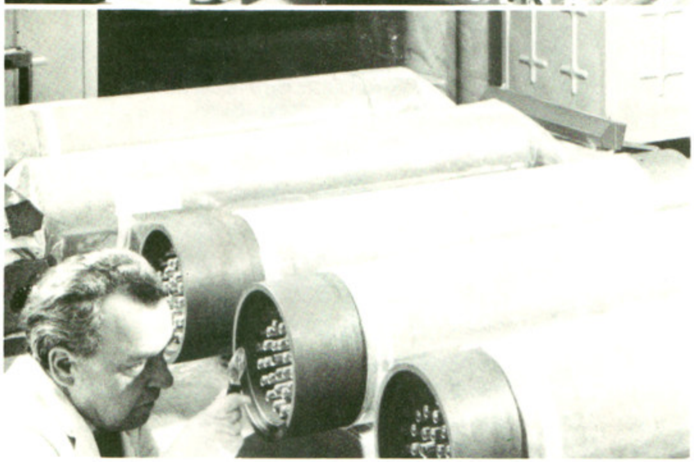
Nuclear Fuel

British Nuclear Fuels Limited (BNFL) has been manufacturing and reprocessing nuclear fuels for over a quarter of a century. In this time, many millions of fuel elements have been manufactured and, after use in the reactor, reprocessed for nuclear power stations in this country and overseas. BNFL's work is carried out at three main centres of operation. Nuclear fuel elements are manufactured at Springfields Works, Salwick, near Preston; fuel enrichment for more modern types of reactor is carried out at Capenhurst Works, near Chester and fuel reprocessing is done at Sellafield, in Cumbria.

Uranium for use in nuclear reactors must be extremely pure because impurities can absorb neutrons and interfere with the nuclear fission, or "atom splitting," process.

Uranium ore concentrates are imported by Springfields from such countries as Canada, Africa, USA and Australia and are first dissolved in nitric acid. Extremely pure uranium nitrate is produced, from which is formed uranium tetrafluoride. For metal fuelled reactors this is converted to natural uranium metal billets from which rods are manufactured. It can also be made into uranium hexafluoride for enrichment and conversion to the more efficient enriched uranium oxide fuel.

Magnox fuel element line at BNFL Springfields



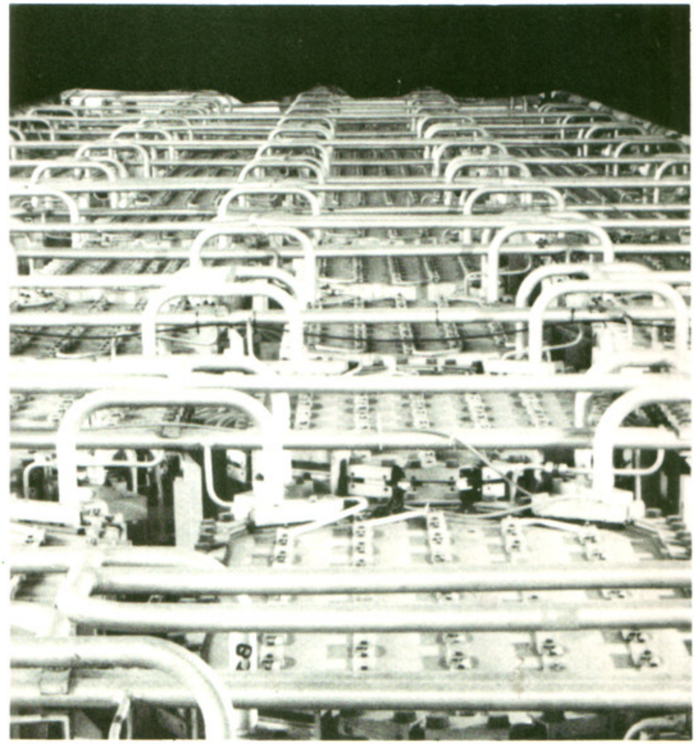
Advanced Gas-cooled Reactor fuel element assemblies

Uranium metal rods are used as fuel in the first nuclear power stations constructed in the UK. These are known as Magnox stations because the fuel rods are encased in a can of magnesium alloy.

Nuclear reactors developed since the Magnox stations have been designed to operate at higher temperatures and greater power. Their performance is based on the use of the improved uranium oxide fuel which has been enriched in the fissile material, uranium 235.

Enriched Nuclear Fuel

Gas Centrifuge plant at BNFL Capenhurst



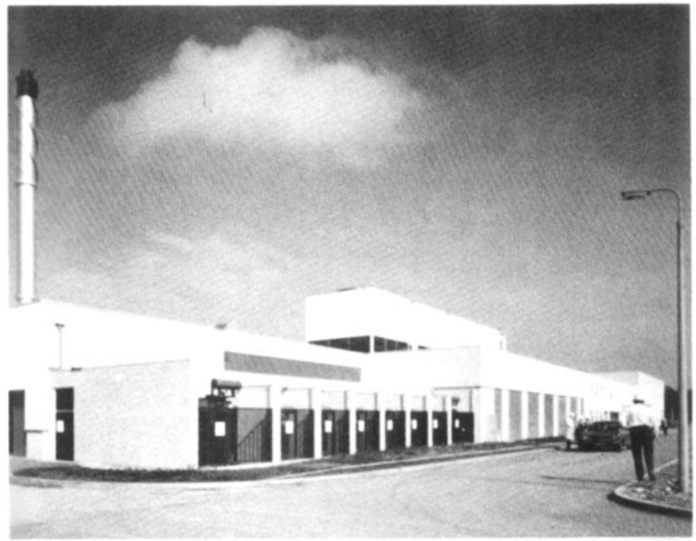
Enriching fuel means making it more effective and economic. The enrichment process is based on the use of uranium hexafluoride (UF_6) in its gas phase, and can be carried out in two ways, by gaseous diffusion or by the gas centrifuge process.

The gas diffusion process is a kind of "molecular sieving" operation in which the uranium hexafluoride gas is pushed through filters with very fine holes which allow the molecules containing uranium 235 to pass through more readily than those containing uranium 238. Since each "sieving" operation increases the concentration of uranium 235 only very slightly it has to be done hundreds of times in succession.

Enrichment by the new gas centrifuge process is also dependent on the use of uranium hexafluoride gas. The gas is fed into rapidly rotating centrifuges, which spin the gas at high speed causing the heavier uranium 238 to settle near the wall of the machine and the lighter uranium 235 to settle near the centre; thus a partial separation of the two uranium isotopes is achieved in each centrifuge. By arranging for a flow of gas from the middle of one centrifuge to the machine 'up' the plant and for a second gas flow from near the wall of the centrifuge to the machine 'down' the plant, the separation process is repeated, thus increasing the amount of separation achieved by a single centrifuge.

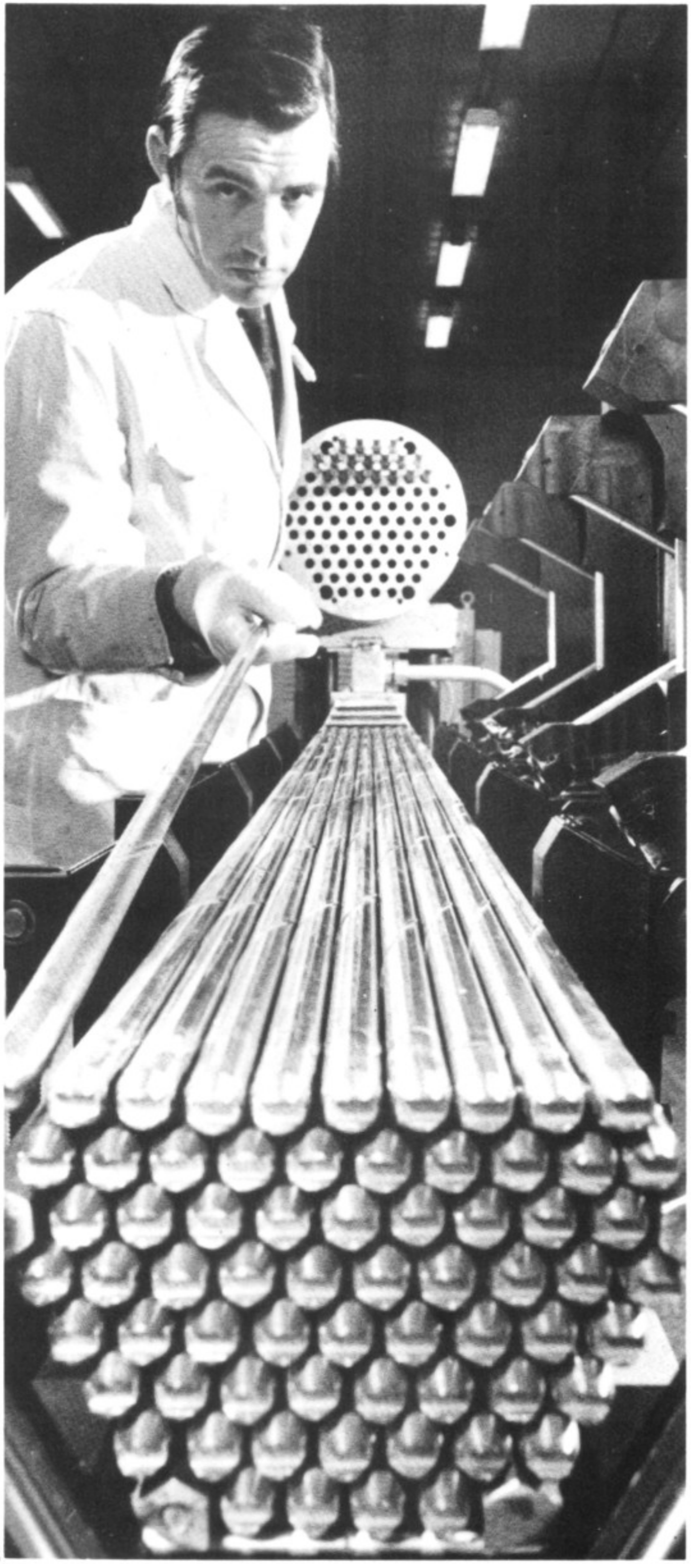
By further repetition of the process in a number of centrifuges connected in a series, a centrifuge cascade is formed which will provide the degree of enrichment necessary (typically 4 to 5 times the natural abundance of uranium 235) for nuclear fuel.

The gas centrifuge plant at BNFL Capenhurst



One of the world's first full-scale production plants for uranium enrichment by gas centrifuge has operated since 1977 at BNFL's Capenhurst Works. The new plant is producing enrichment for nuclear fuels at a more economic cost than previous methods and cheaper enriched fuel will ultimately mean cheaper power.

Most enriched reactor fuel is in the form of uranium oxide. Enriched uranium oxide is produced at Springfields by the Integrated Dry Route process; enriched uranium hexafluoride is reacted with steam and hydrogen in a rotary kiln and converted directly to uranium oxide in a powder form, from which fuel pellets are made.



Nuclear fuel must be contained in a suitable cladding or canning material for several reasons. Radioactive fission products accumulate in the fuel and are contained inside the can which also supports the fuel while it is in the reactor core and protects it from the coolant. Easy movement in and out of the reactor and secure location of the fuel in the core are also made easier by use of fuel cans.

Magnesium alloy cans are used to contain the fuel of the first generation nuclear power stations now operating in this country. The second generation of gas-cooled reactors, the Advanced Gas-cooled Reactors, uses uranium oxide fuel pellets enriched to about 2% U235 canned in stainless steel.

Enriched uranium oxide fuel is also used in the Steam Generating Heavy-Water-Moderated Reactor (SGHWR). The fuel pellets in this case are clad in a zirconium alloy.

Plutonium is the principal by-product obtained from spent fuel from a nuclear reactor. It is envisaged that this will be used for fuel in fast-breeder reactors being developed for commercial operation later this century. In theory by converting uranium 238 to plutonium, fast reactors are able to use up all the uranium that is fed to them. In this way they can obtain more than fifty times as much energy from a given weight of uranium as current reactor designs.
If used to its fullest extent, the 20,000 tonnes of uranium 238 already stored in the UK for future conversion in fast reactors is equivalent to more than 40,000 million tonnes of coal.

A fuel sub-assembly for Britain's Prototype Fast Reactor

Fuel Reprocessing

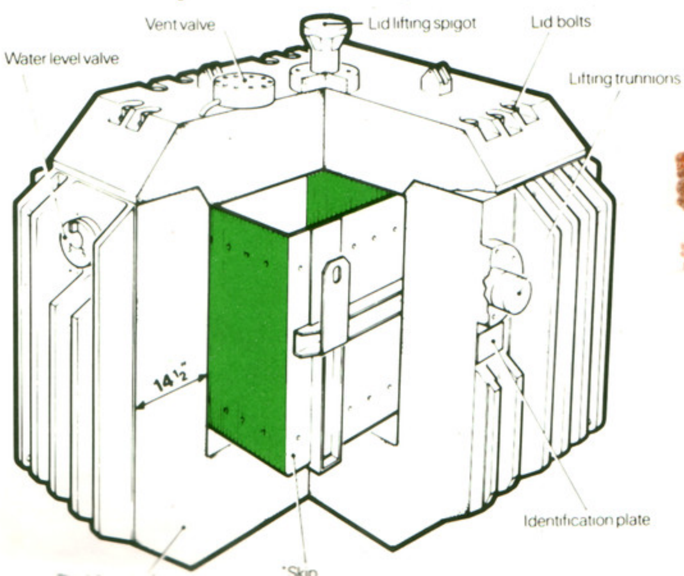
In a nuclear power reactor, uranium 235, which is the fissile component of uranium fuel, is slowly used up and must be replaced. After a time fuel elements have to be removed from a reactor and replaced by fresh fuel.

Irradiated or spent fuel is transported to BNFL's Sellafield site for reprocessing. Fission products which have accumulated in the fuel elements are removed for concentration and safe storage. Unused uranium and by-product plutonium are separated and recovered for future re-use.

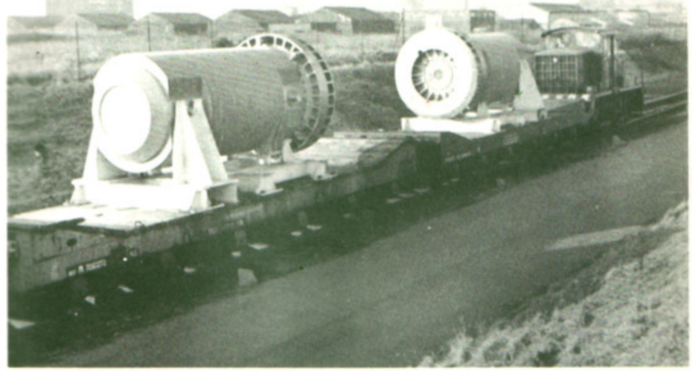
Most of the irradiated fuel consists of unused uranium (up to 99%) some by-product plutonium (up to 2%) and fission product waste (up to 3%).

Irradiated nuclear fuel is highly radioactive. It is carried to the reprocessing factory in extremely strong, thick-walled steel or steel and lead containers known as transport flasks. Each flask weighs at least 50 tons and can hold up to two tons of fuel.

Magnox irradiated fuel transport flask

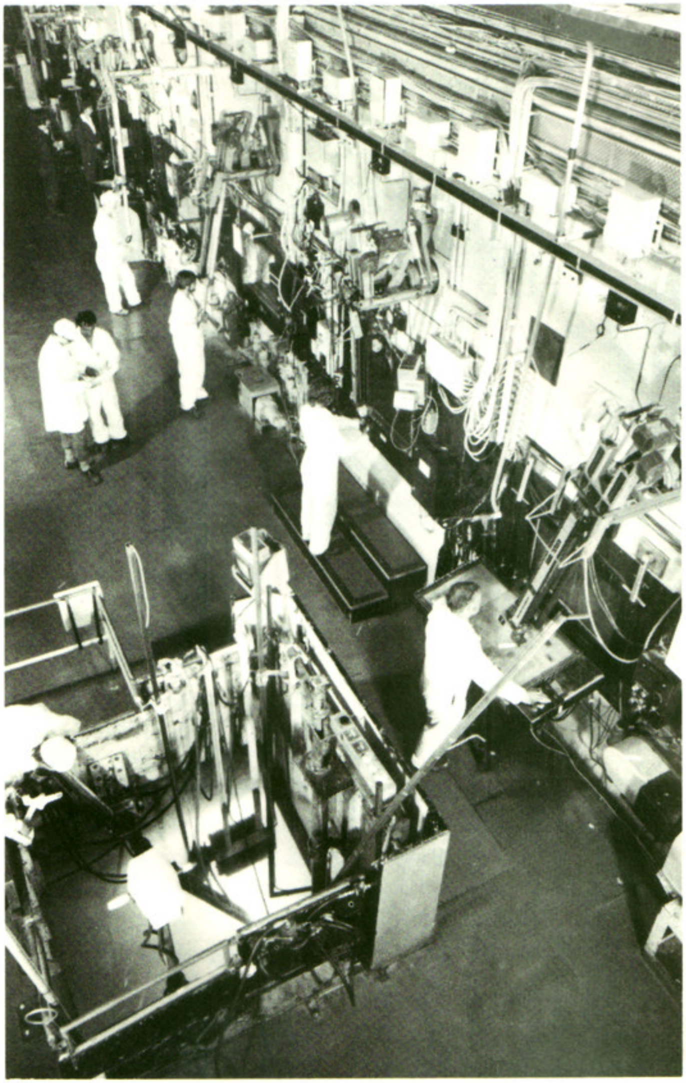


Rail transport of irradiated fuel flasks



These flasks are designed and tested to stringent international standards and to simulate accident conditions. Mechanical and thermal tests are carried out in sequence and in an impact attitude so that the maximum damage occurs to the package being tested. Tests include a free fall from a height of 9 metres onto an unbreakable concrete target, a fall onto a steel punch mounted on the target, exposure to fire at 800°C for 30 minutes and immersion in 15 metres of water without loss of radioactivity to the prescribed limit.

Magnox fuel decanning line at BNFL Windscale



Reprocessing uranium metal (Magnox) fuel starts by mechanically stripping the fuel element can from the uranium metal fuel rod. The rod is then dissolved in nitric acid. Fission products are removed from this solution, leaving uranium, which is depleted in its fissile uranium 235 content, and by-product plutonium. These are separated from each other chemically.

Fission product storage tank

1 Stainless steel external cooling and secondary containment jacket

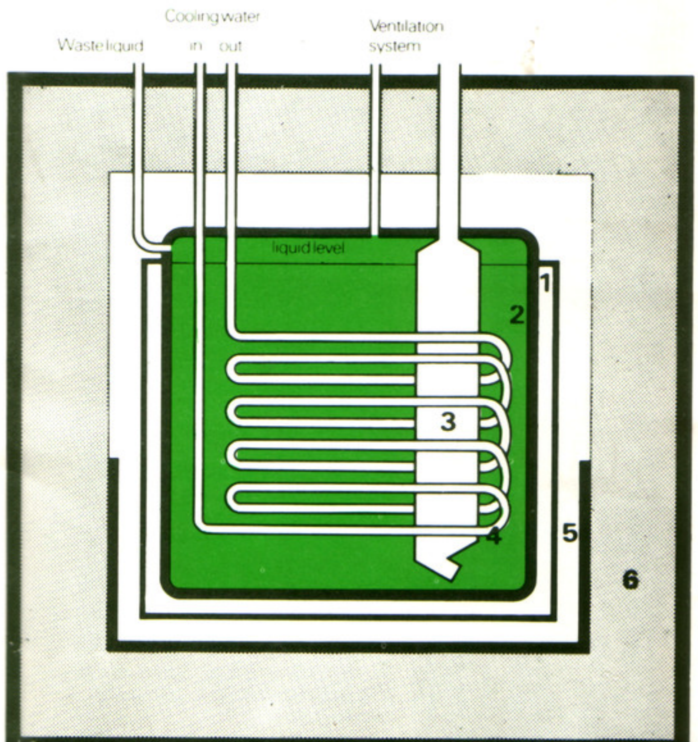
2 Stainless steel storage and primary containment tank

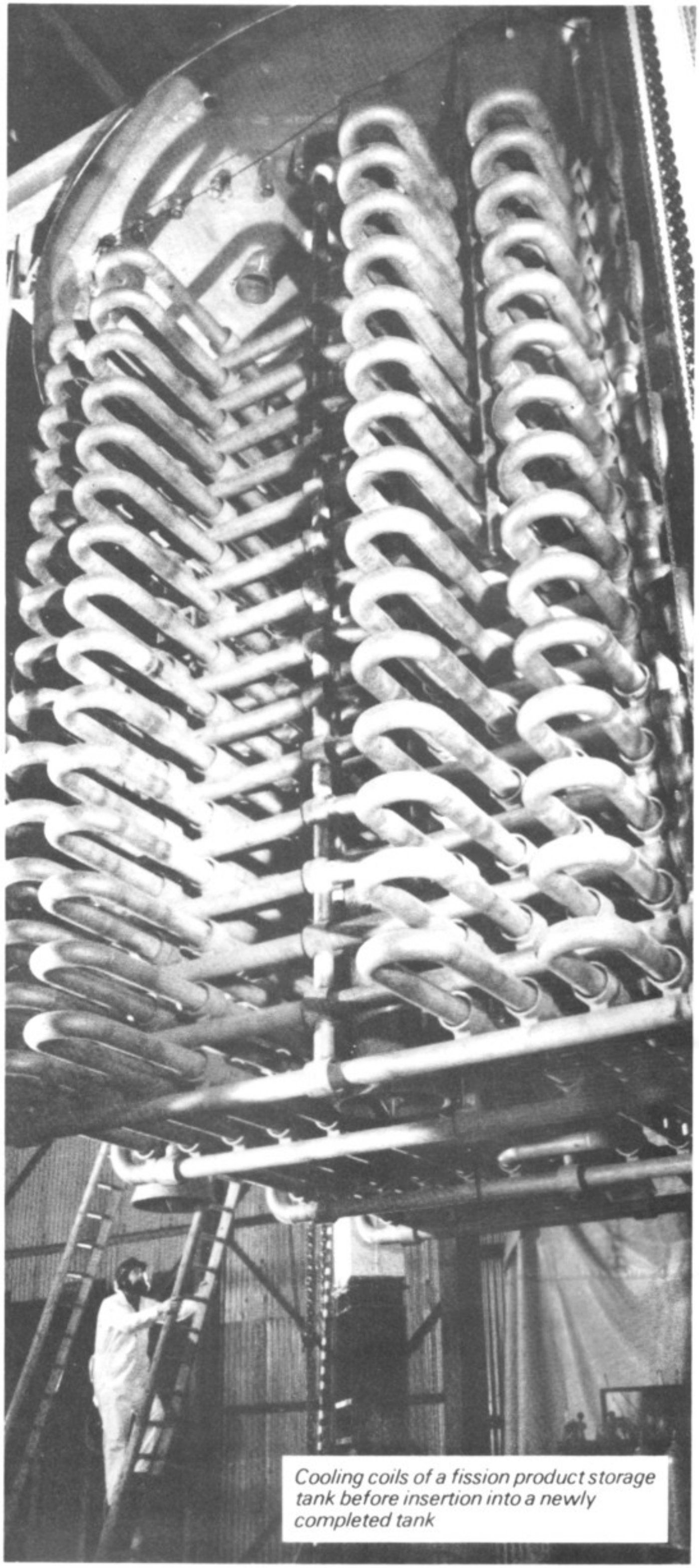
3 Air operated agitation system

4 Cooling water coils

5 Stainless steel liner to storage cell wall

6 Concrete shield wall and roof





Cooling coils of a fission product storage tank before insertion into a newly completed tank

All handling processes involving radioactive materials are carried out remotely until the fission products are removed.

The concentrated fission product waste extracted during reprocessing is at present stored in stainless steel tanks. The tanks are double-walled and are located in concrete vaults which are themselves lined with stainless steel.

The fission product waste that has accumulated in this country over the last 25 years is stored in some 15 stainless steel tanks at Sellafield. The total volume is about 1000 cubic metres.

The storage of liquid fission product waste is well established and safe, but there are advantages in making it solid for more effective disposal. A process to convert this waste to a solid, glass-like form for long term storage is being developed and will be installed at Sellafield in due course.

The process comprises three stages. These are calcination where the liquor undergoes evaporation and denitration to form a dry powder; vitrification, where the calcined waste mixes with inactive glass and is melted, and pouring, where the vitrified waste is "tapped" from the melter into a cylindrical stainless steel container which is then sealed and stored in an air cooled store.

The glass is chemically inert and practically insoluble so that the radioactive waste is permanently "locked-in."

Collecting plankton samples for analysis

Most of the radioactivity–99.96%–arising from the reprocessing of irradiated fuel at Sellafield is stored on the site. The remaining 0.04% is discharged to sea in extremely dilute form or, in the case of gases, up tall stacks, under the independent supervision of the Ministry of Agriculture, Fisheries and Food and the Department of the Environment.

Regular environmental monitoring is carried out by BNFL and by a number of Government Departments. Air, milk, fish, shell fish, seaweed, grass, soil and other samples are also collected and analysed regularly. The results of this monitoring have consistently shown that levels are well below the limits laid down by the International Commission on Radiological Protection.

BNFL

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