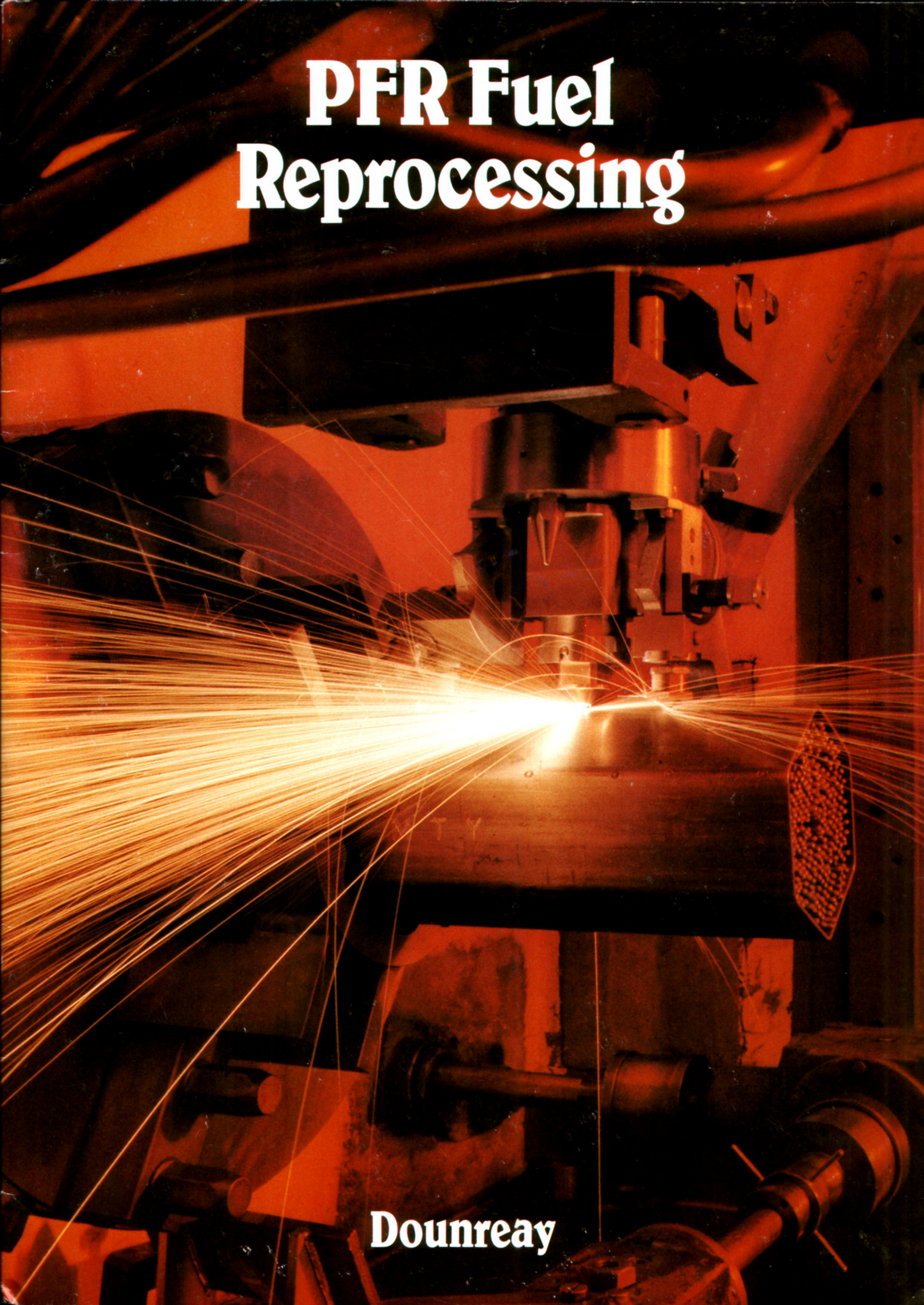
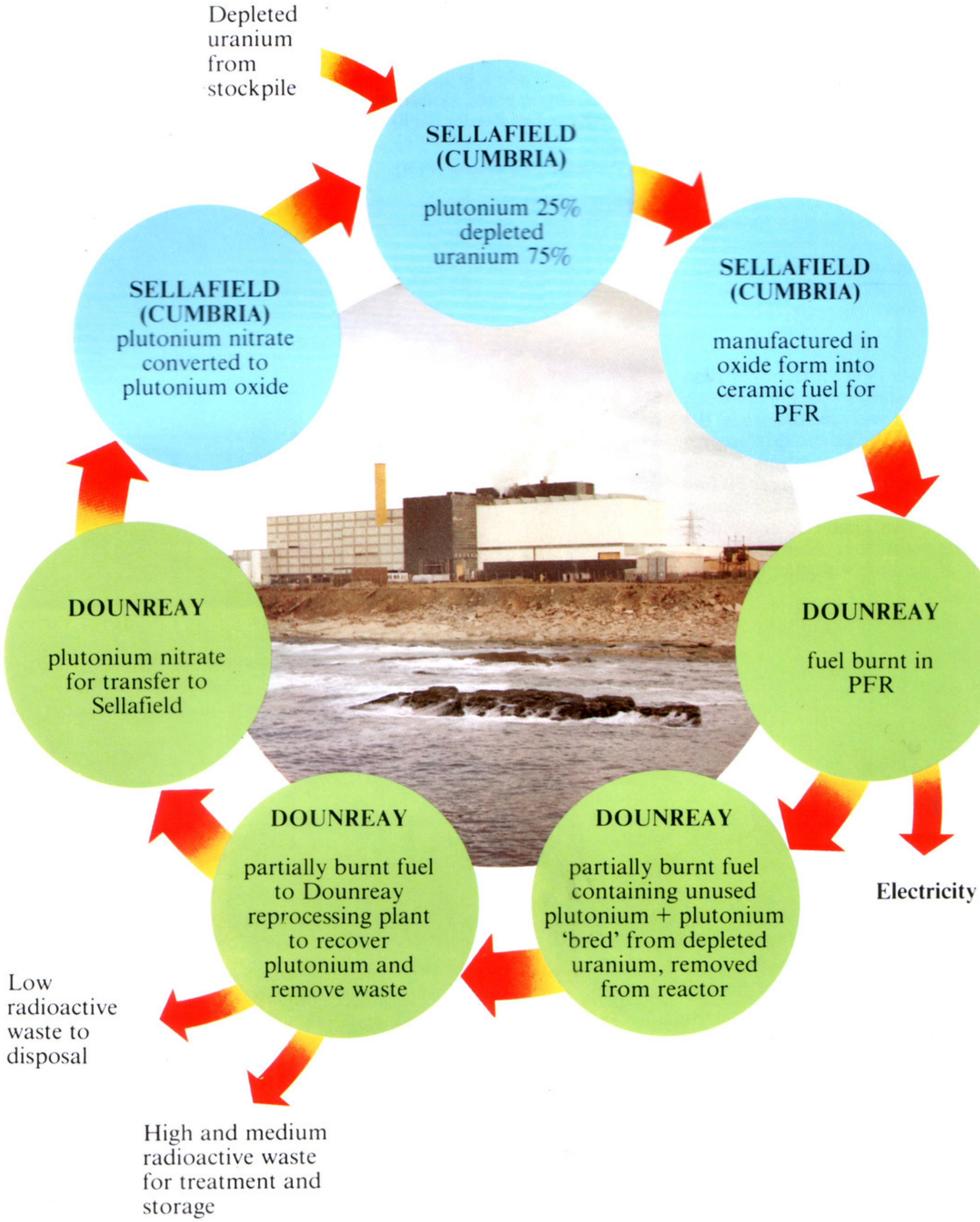
PFR Fuel Reprocessing



Dounreay

The PFR fuel cycle

In general terms, the PFR fuel cycle is the sequence of steps involved in supplying, using and testing fuel for nuclear power generation.



Background

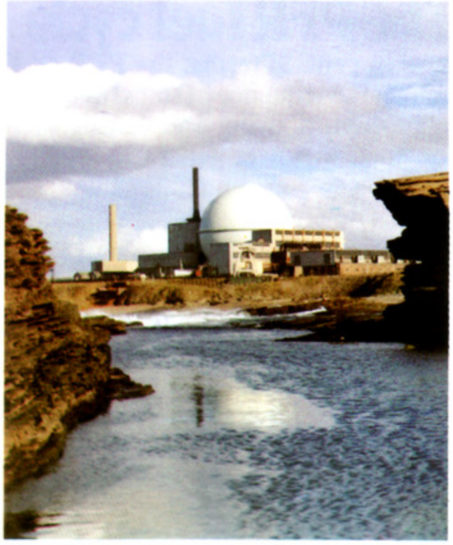
The experimental Dounreay Fast Reactor (DFR) of 15MW(e) power which operated from 1960 to 1977—when its role was taken over by the Prototype Fast Reactor (PFR)—was served on the Dounreay site by plants specifically designed for the reprocessing, conversion and refabrication of highly enriched uranium fuel. These provided a total fuel cycle capability to support the operation of DFR. Indeed Dounreay could claim to be the first nuclear complex in which all fuel-cycle services were situated on the same site as the reactor.

The history of irradiated fast-reactor fuel reprocessing in the UK therefore extends back to 1961 when the first discharge of irradiated DFR fuel was reprocessed. Since then tens of tonnes of irradiated enriched uranium fuel have been reprocessed.

The next stage in the development of the fast reactor system in the UK began in 1966 when construction of the PFR commenced at Dounreay. In 1972 it was decided that the irradiated PFR fuel should be reprocessed at Dounreay by modifying and extending the existing DFR fuel reprocessing plant for that purpose.

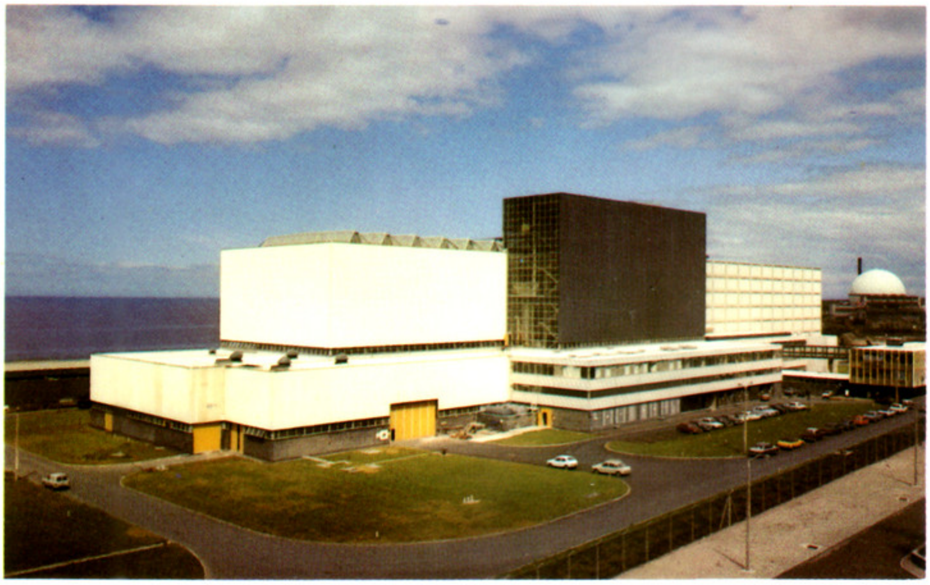
The conversion of the reprocessing plant from its original function of dealing with fuel from the DFR (15MW(e)) to that of serving the PFR (250MW(e)) involved an extensive modification exercise which provided novel and valuable experience in stripping out and adapting highly radioactive cells and plant.

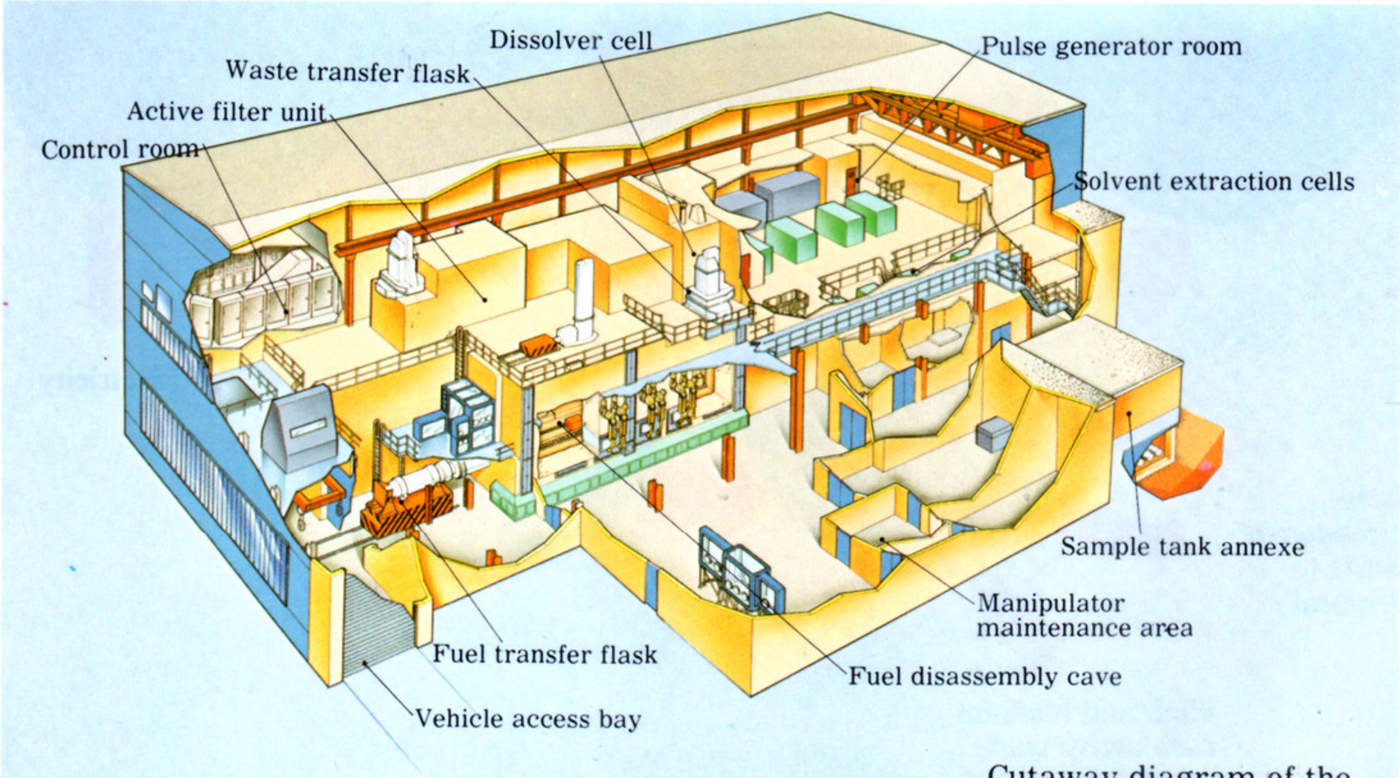
The refurbished plant reprocessed its first PFR fuel in 1980.



Right:
The Dounreay Fast Reactor (DFR).

Below:
The Prototype Fast Reactor (PFR).





Cutaway diagram of the fast reactor fuel reprocessing building

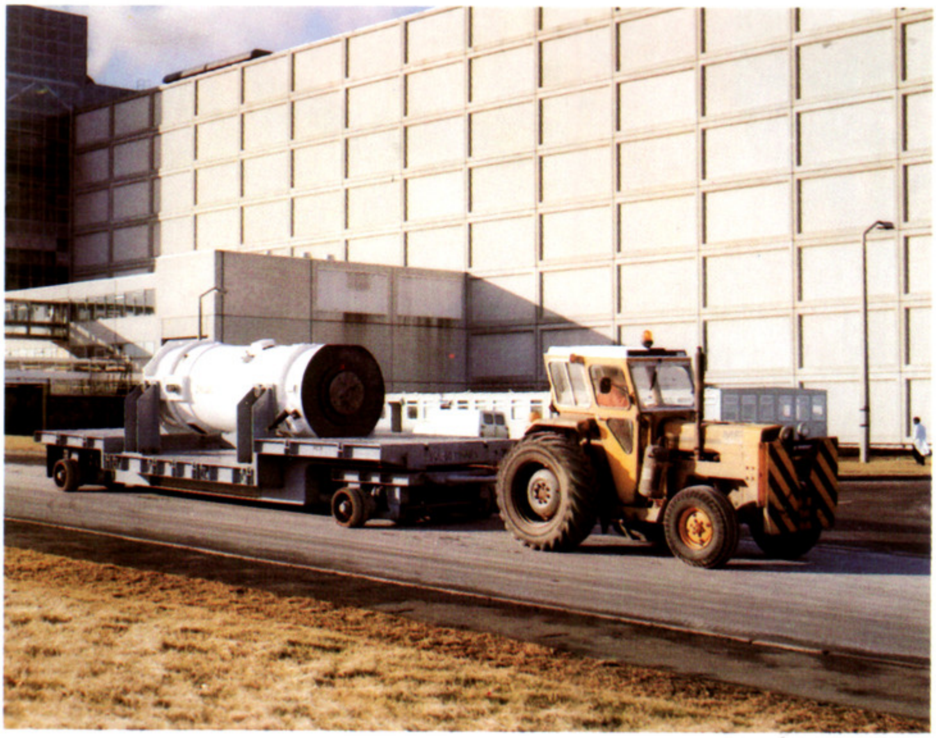
Irradiation (burning) of fuel

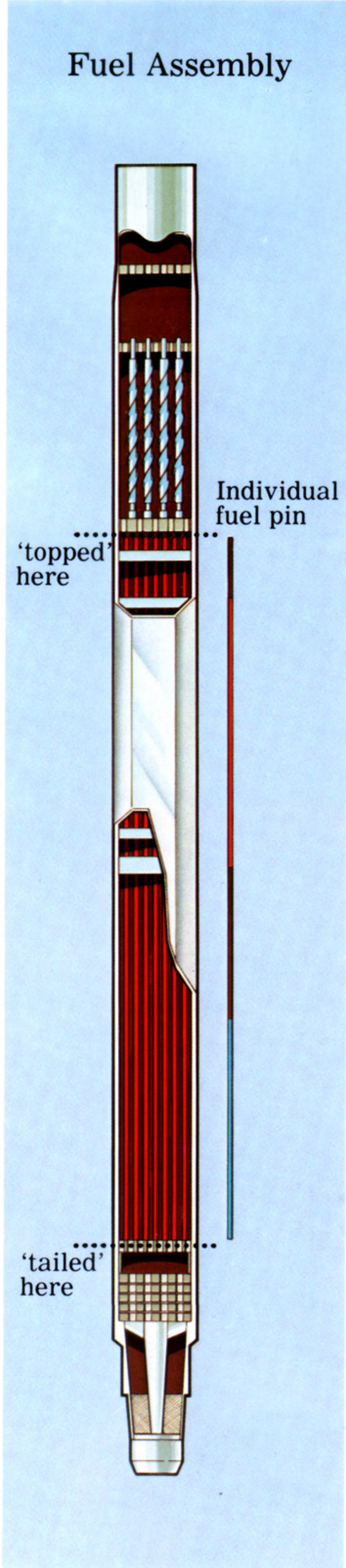
In the PFR there is a cylindrical core which contains the central fuel charge—ceramic pellets of mixed oxides of plutonium (one part) and uranium (three parts) surrounded by a "blanket" of depleted uranium oxide ceramic pellets. Fission of the plutonium generates heat (taken away by the sodium coolant to raise steam to drive the turbines), fission products and neutrons. Some of these neutrons cause further fission in plutonium and others which are captured by the uranium in the core and blanket transmute this into plutonium. The fuel and blanket material are in the form of hermetically sealed pins of which there are 325 in each of the 78 hexagonal fuel assemblies. There is a limit to the amount of plutonium that can be burnt in a fuel assembly. This is dominantly due to the geometrical changes which occur in the cladding of the fuel pin due to the changes in volume of the fuel when fissioned and the effect of neutrons. In the PFR an individual fuel assembly is removed and replaced after about 10% of the fuel is consumed.

The used fuel assembly, when unloaded from the core, is kept in a fuel store, under sodium in the reactor, for about a month while the fission product heat reduces. It is then transferred, inside a protective container, to a sodium-cooled storage tank at the adjoining post-irradiation caves—heavily shielded compartments in which highly active materials can be safely kept, handled or examined by remote manipulation.

After approximately a further six months, to allow further reduction in the heat, the end sections of the fuel assembly are cut off by a laser. The portion containing partially used fuel and blanket is then cleaned to remove any trace of sodium before being transported in a shielded container to the reprocessing plant.

Shielded flask transferring 'topped' and 'tailed' fuel assembly from the PFR to the fuel reprocessing plant.

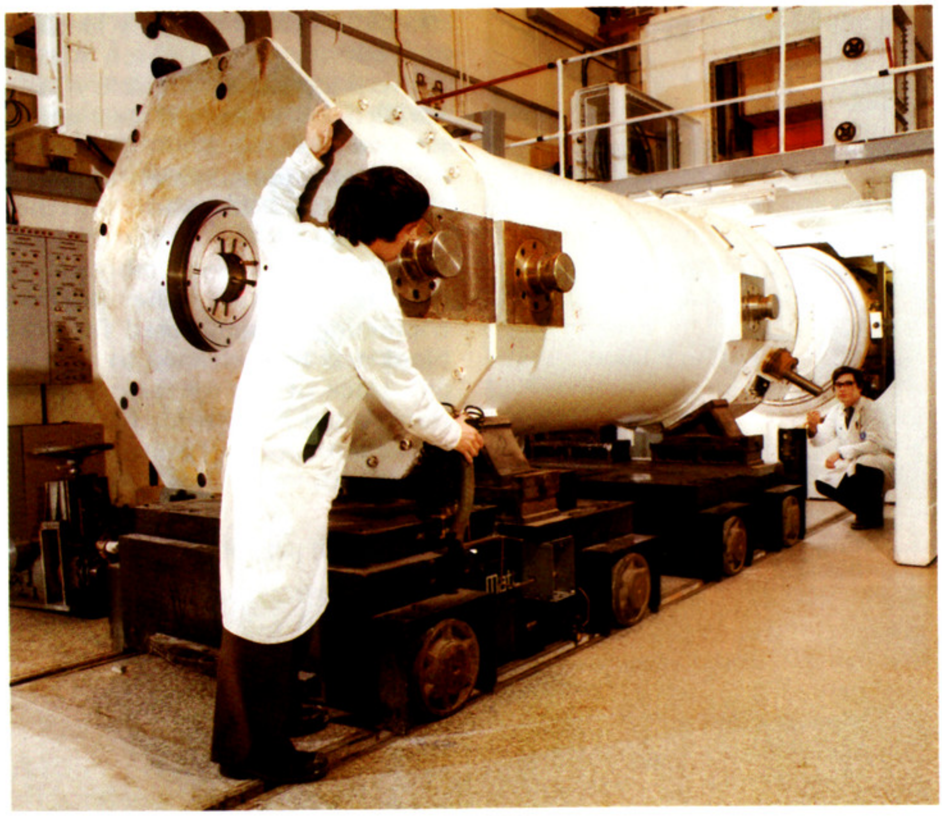




Reprocessing

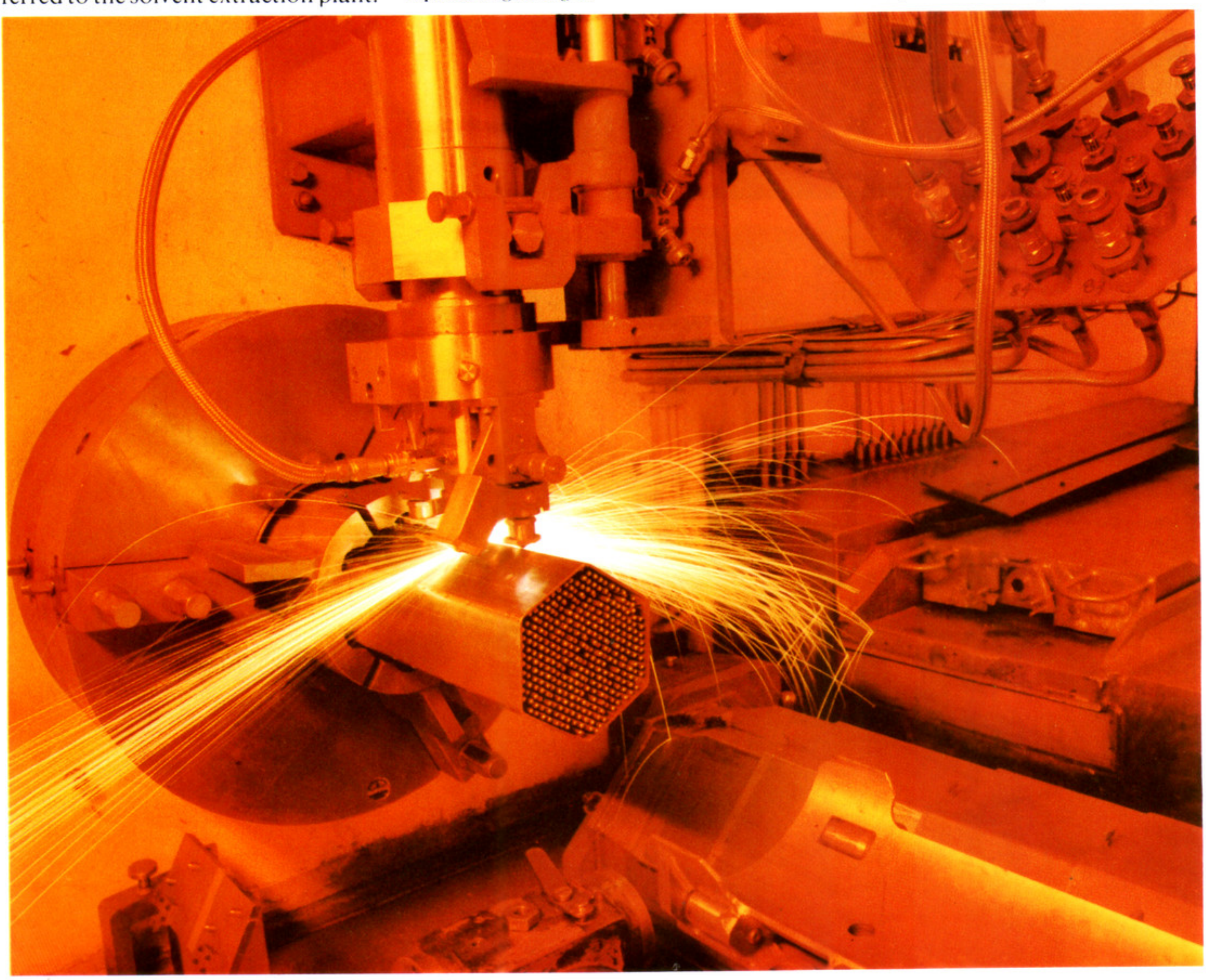
During the reprocessing operations the plutonium is separated for refabrication into fuel assemblies and nearly all the highly active waste material is isolated into a single stream.

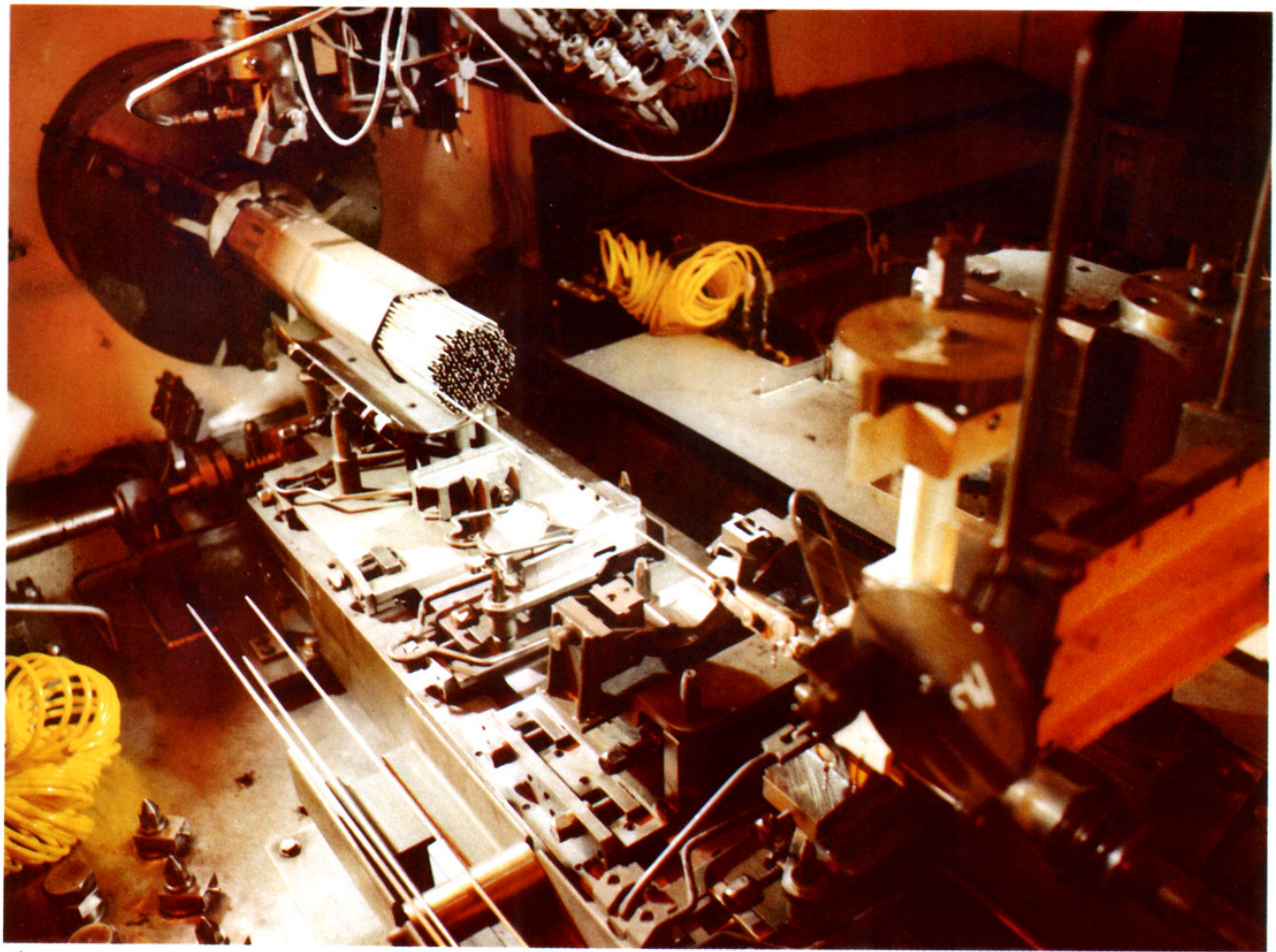
When a fuel assembly arrives at the reprocessing plant a laser is used to cut away parts of the outer hexagonal container to gain access to the ends of the fuel pins. The 325 pins are extracted individually and chopped into short lengths. These are transferred in a perforated stainless steel basket to batch dissolver where they are dissolved in concentrated nitric acid. Each batch consists of 150 litres of acid containing about 30 kg of dissolved fuel. The batch is filtered to remove coarse insolubles such as the stainless steel cladding and then centrifuged to remove finer insolubles. The resulting liquor is passed through an "accountancy" tank for sampling, volume measurement and chemical analysis. It is then transferred to the solvent extraction plant.



Above:
Fuel assembly about to be transferred from shielded flask to fuel disassembly cave for reprocessing to begin.

Below:
In the fuel disassembly cave the end of the fuel assembly's hexagonal outer wrapper is removed by laser cut to expose the fuel pins.

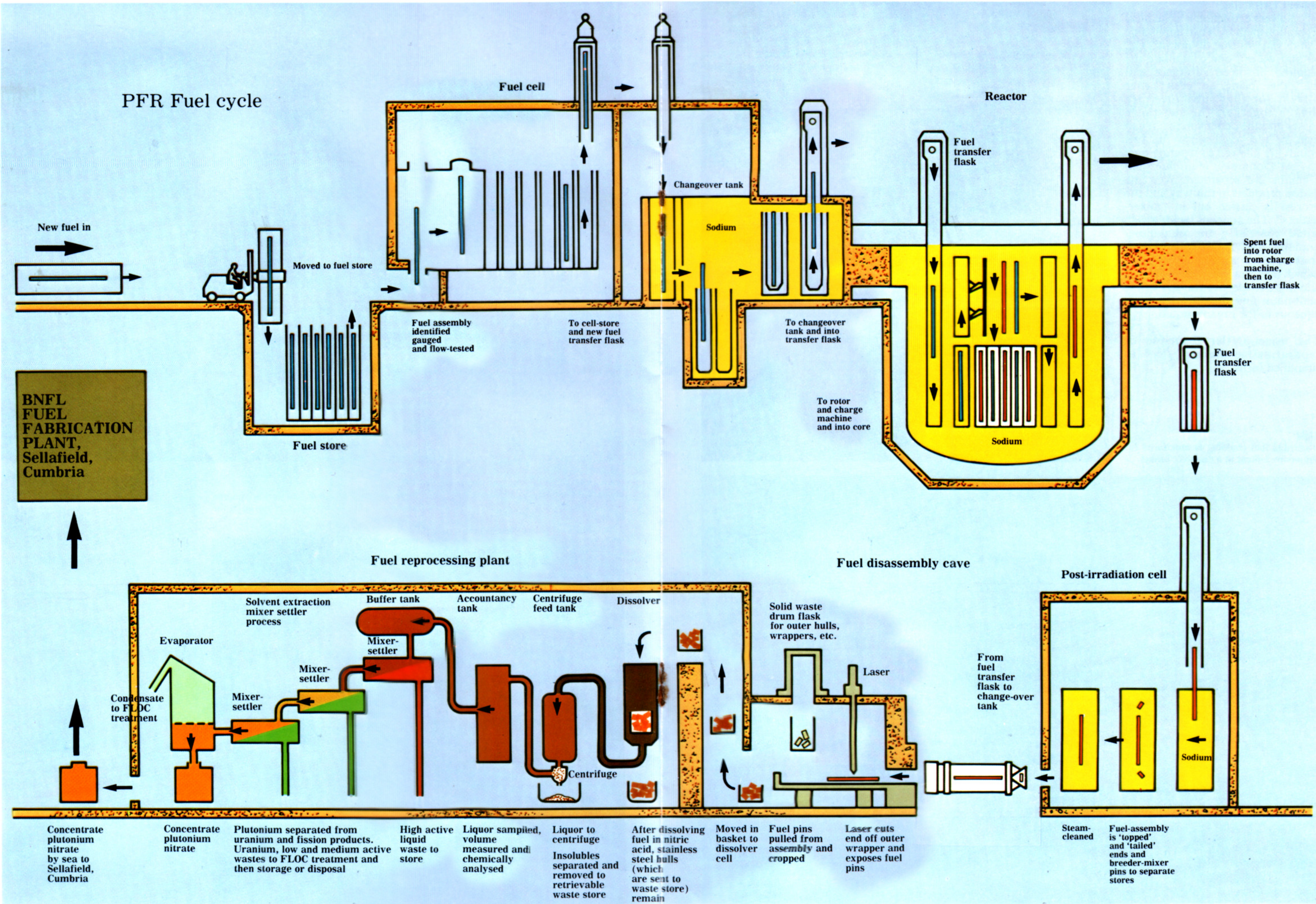




Above:
The exposed fuel pins are individually extracted for cropping.

Below:
Operating face of fuel disassembly cave.

Right:
The cropped pieces of fuel pins are poured into a basket before being removed to the dissolver.

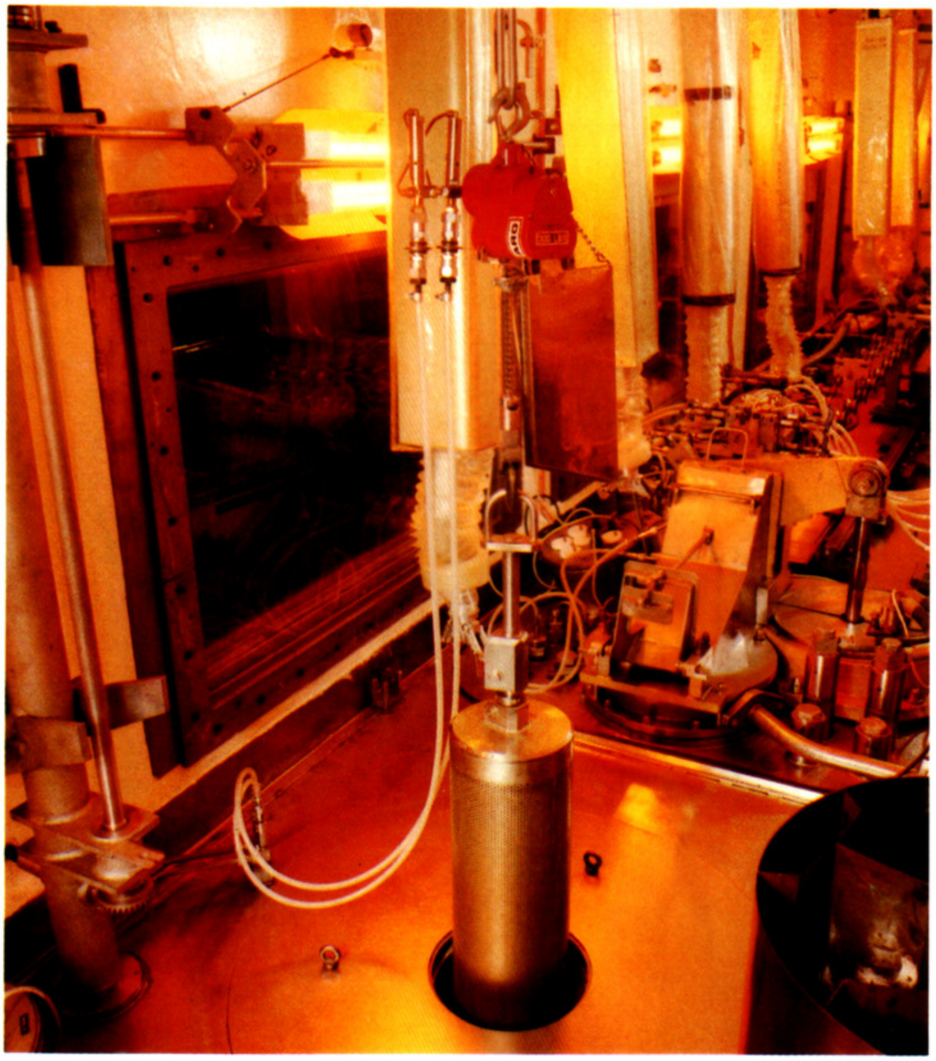

PFR Fuel cycle
New fuel in
Moved to fuel store
Fuel store
Fuel cell
Fuel assembly identified gauged and flow-tested
To cell-store and new fuel transfer flask
Changeover tank
Sodium
To changeover tank and into transfer flask
Reactor
Fuel transfer flask
Sodium
To rotor and charge machine and into core
Spent fuel into rotor from charge machine, then to transfer flask
Fuel transfer flask
BNFL FUEL FABRICATION PLANT, Sellafield, Cumbria
Fuel reprocessing plant
Fuel disassembly cave
Post-irradiation cell
Solvent extraction mixer settler process
Buffer tank
Accountancy tank
Centrifuge feed tank
Dissolver
Evaporator
Mixer-settler
Mixer-settler
Mixer-settler
Condensate to FLOC treatment
Centrifuge
Solid waste drum flask for outer hulls, wrappers, etc.
Laser
From fuel transfer flask to change-over tank
Sodium
Concentrate plutonium nitrate by sea to Sellafield, Cumbria
Concentrate plutonium nitrate
Plutonium separated from uranium and fission products. Uranium, low and medium active wastes to FLOC treatment and then storage or disposal
High active liquid waste to store
Liquor sampled, volume measured and chemically analysed
Liquor to centrifuge
Insolubles separated and removed to retrievable waste store
After dissolving fuel in nitric acid, stainless steel hulls (which are sent to waste store) remain
Moved in basket to dissolver cell
Fuel pins pulled from assembly and cropped
Laser cuts end off outer wrapper and exposes fuel pins
Steam-cleaned
Fuel-assembly is 'topped' and 'tailed' ends and breeder-mixer pins to separate stores

Solvent Extraction

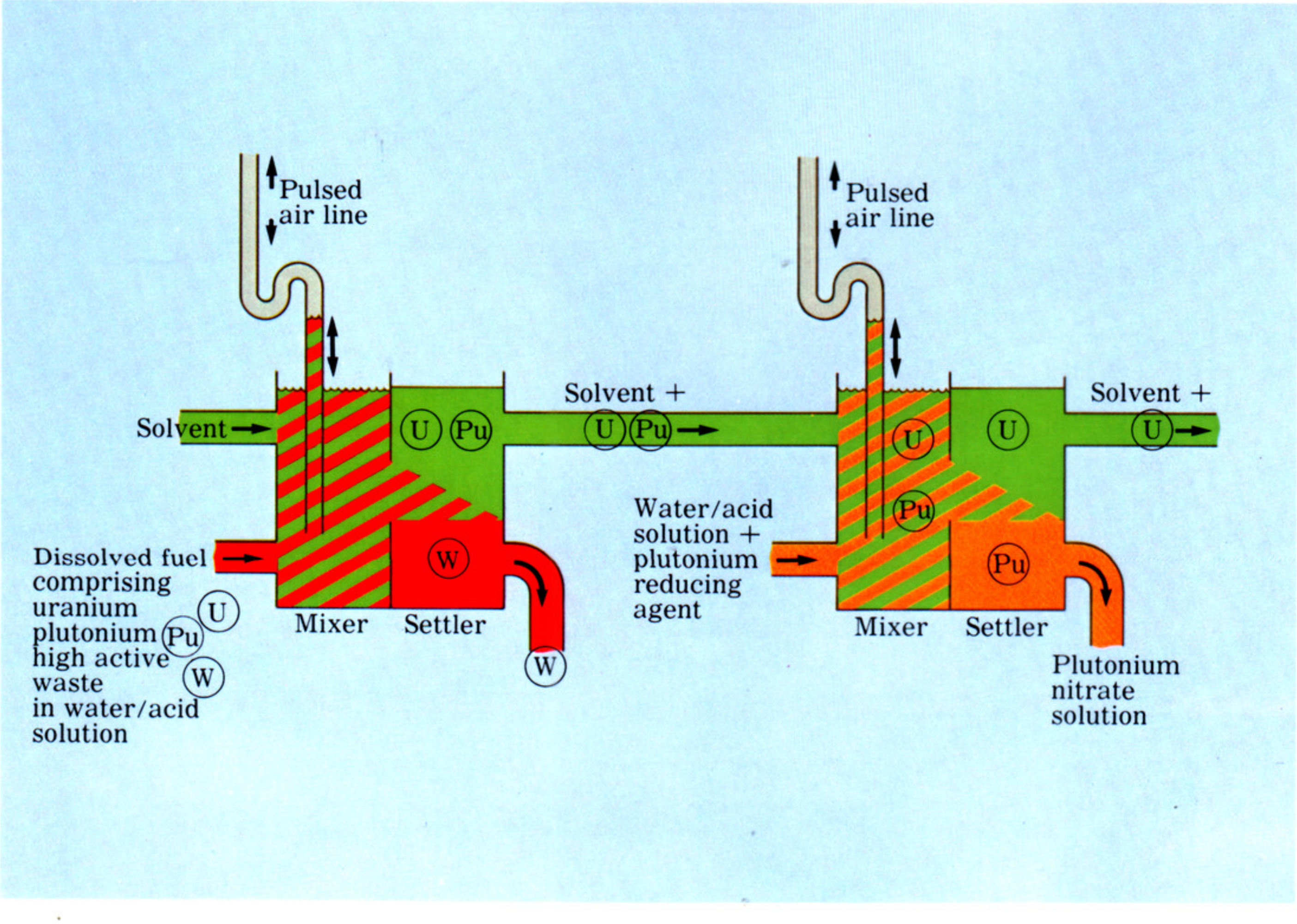
Solvent extraction is a chemical separation method. If two immiscible liquids (liquids that do not mix e.g. oil and water), one containing the required dissolved substance and the other being an even better solvent for that substance, are shaken together, the substance passes into the better solvent. It can then be recovered when the two liquids are allowed to separate out.

At Dounreay, plutonium and uranium are separated from the fission products in this way and the process is carried out in "mixer-settlers". The aqueous (acid/water) liquid containing the plutonium, uranium and fission products is shaken with an organic liquid (which does not mix with the water) and there is selective transfer of the plutonium and uranium from the aqueous to the organic liquid.

The mixer-settler principle of separation is shown below in simplified form.



Right:
Discarded fuel cladding is monitored for plutonium content in a dissolver basket.



Mixer-Settler

The mixer-settler contains a number of troughs each of which consists on average of 10 pairs of alternate mixer and settler compartments separated by vertical partitions. Slots in these partitions allow flow through the trough. The aqueous and organic liquids are stirred together in each mixer and allowed to separate in each settler.

Isolation of fission products

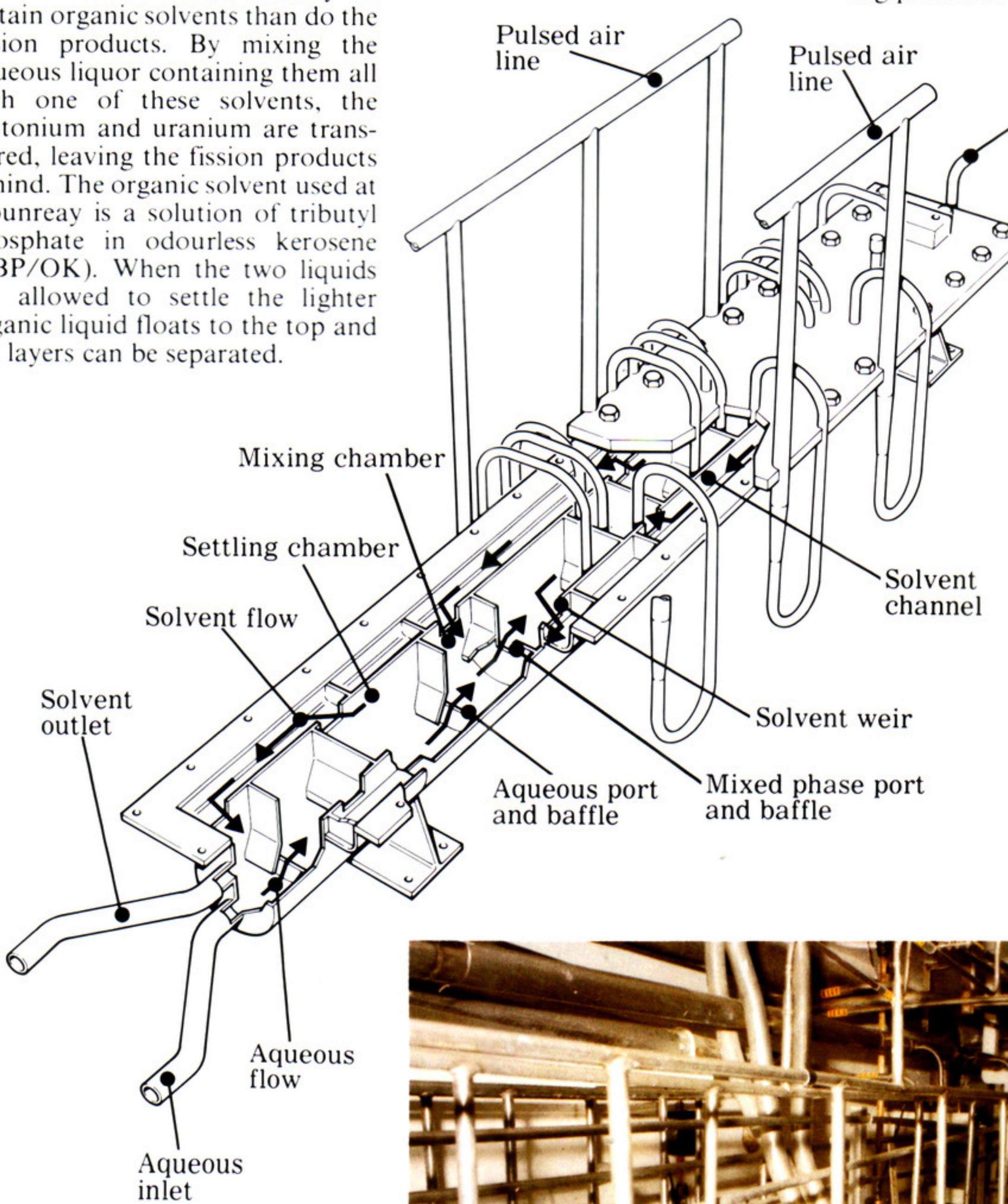
The plutonium and uranium dissolve much more readily in certain organic solvents than do the fission products. By mixing the aqueous liquor containing them all with one of these solvents, the plutonium and uranium are transferred, leaving the fission products behind. The organic solvent used at Dounreay is a solution of tributyl phosphate in odourless kerosene (TBP/OK). When the two liquids are allowed to settle the lighter organic liquid floats to the top and the layers can be separated.

Separation of plutonium from uranium

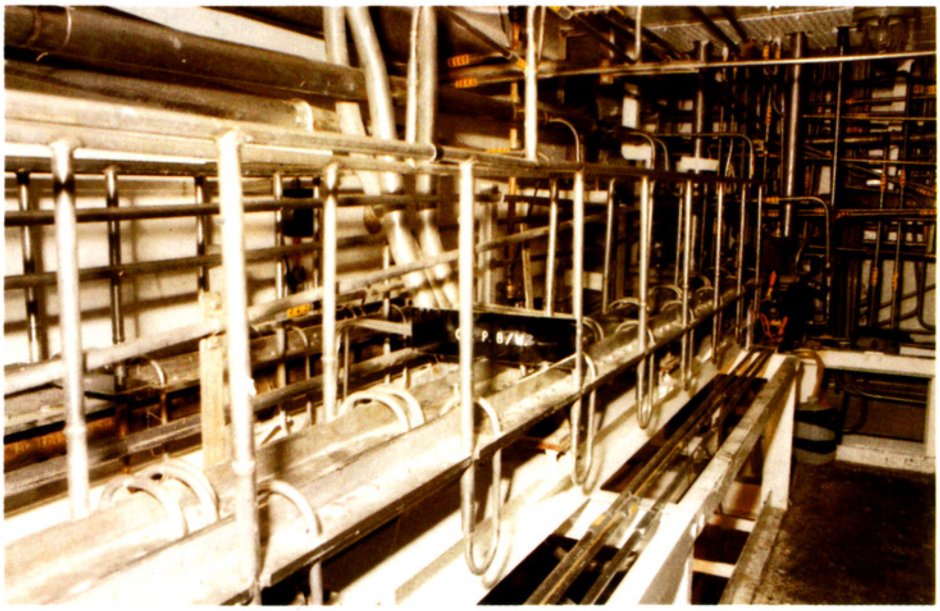
The solubility of plutonium in organic solvents depends on its "valency"—in simple terms on its combining power with other atoms. Up to this stage in the process the plutonium has a valency of 4. If it is reduced to 3 the complex that has been formed with TBP/OK becomes unstable. This reduction is achieved by shaking the organic liquid in an aqueous solution containing a mild reducing agent.

As a result of the instability the plutonium passes back into the aqueous liquid. The uranium is not affected by the reducing agent and therefore remains in the organic liquid. As before, physical separation can be carried out when the two layers have been allowed to settle. In practice the separation process is more complicated and requires repeated transfer for the best results.

The main end product of the solvent extraction procedure is an aqueous nitric acid solution containing plutonium.



A mixer-settler



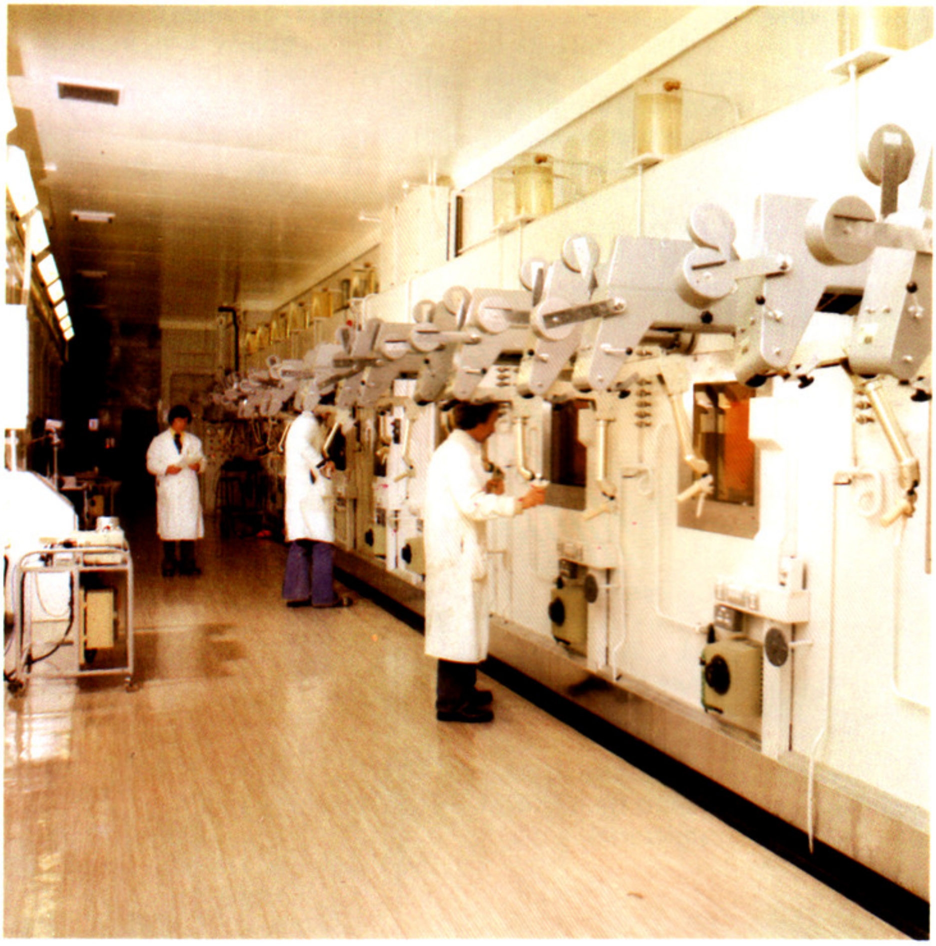
Right:
Mixer-settlers in operation.

This solution is washed with odourless kerosene to remove any remaining TBP and then transferred to intermediate storage tanks. The plutonium concentration is then increased by evaporation and the solution chemically treated to return the plutonium to its stable valency of 4 and to remove any impurities.

The plutonium nitrate liquor is then ready for transfer to Sellafield to be converted to plutonium oxide and used in the manufacture of new fast reactor fuel.

The wastes produced during reprocessing range from very high to very low radioactive levels and consequently some may be disposed of and some must be stored. The main types are:

—radioactive solids;
—highly active liquids;
—liquids of medium to low activity.



Right:
Prior to separation laboratory analysis of high active samples of dissolved fuel takes place in shielded caves using remote handling manipulators.

Below and right:
Once separated from high radioactive fission products, samples of plutonium nitrate can be safely analysed in laboratory glove boxes.

Waste management

Radioactive solids

Most of the solid waste results from the physical dismantling of the fuel assemblies i.e. highly radioactive stainless steel fragments of many shapes and sizes are produced for each fuel assembly and these must be removed from the reprocessing area. This is done by loading them into stainless steel, shielded drums which are removed to store—all the time being contained to prevent the release of radiation.

Highly Active Liquids

These contain the very active fission products. They are transferred to shielded tanks in the reprocessing plant for sampling and analysis and then despatched to underground storage tanks which are continuously cooled to remove the heat generated by the decaying fission products. The activity of these liquids falls by a factor of about 500 during the first five years of storage.

Vehicle, loaded with shielded flask used for plutonium nitrate, reversing onto vessel prior to shipment by sea to British Nuclear Fuels Ltd, Sellafield, Cumbria.

Liquids of low to medium activity

All the remaining aqueous wastes from the solvent extraction are collected in storage tanks in the solvent extraction plant where they are monitored, sampled and analysed. They are then piped to purpose-built vessels for treatment by the "FLOC" process. Essentially, a slurry containing the radioactive material is produced and separated from the water. The slurry is transferred to settling tanks where it is collected and stored for eventual recycling. The liquid residue is piped and held in tanks, where its activity is monitored to ensure that it is within the strict limits set by the Secretary of State for Scotland before being discharged to sea through an underground pipeline.

Below:
Fuel reprocessing plant control room from where all operations are monitored.

At British Nuclear Fuels Ltd. (BNFL), Sellafield, Cumbria, the reprocessed plutonium nitrate is converted into an oxide form for use in new fuel.

Right:
Trays of PFR plutonium/uranium pellets manufactured from reprocessed fuel removed from sinter furnace.

Below:
A new PFR fuel assembly at Sellafield.

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