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# The Nuclear **Fuel Cycle**

This Factfile briefly summarises the main aspects of the nuclear fuel cycle.


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## Summary

This Factfile summarises the main aspects of the nuclear fuel cycle:

- the mining of uranium,
- its processing to make it suitable for use in nuclear reactors to produce electricity,
- the reprocessing of spent fuel to produce new fuel and
- the treatment of wastes.

## Mining

Uranium is a slightly radioactive material which is found at low concentrations throughout the world - it is about as common as tin. The average concentration in the Earth's crust is about 2.7 parts per million.

In a few areas, major deposits of uranium have been found. These are in Canada, Australia, Africa, Russia and the USA. The average uranium ore concentration at operating mines is about 1%.

The type of mine developed depends on the nature of the deposit. Surface or open pit mines are used where the deposits are shallow. Underground mining has to be undertaken where the deposits are more than 100m below the surface.

Surface mines involve large surface areas and removal of large quantities of material. Underground mines have only small surface openings, involve less material movement but require that the uranium is present in higher concentration to be economically viable. Underground mines require careful ventilation to protect miners against radiation exposure.

In suitable geological conditions, a method of in-situ leaching of the uranium can be used. The deposits must be in sandstone and below the water table in a confined aquifer. The uranium can then be dissolved in a chemical solution and recovered by means of wells, leaving the rock undisturbed.

## Milling

The process of milling extracts uranium from the ore produced in the mine.

It is carried out close to the mine and produces a uranium concentrate generally called "yellow cake" which is cheaper to transport.

The yellow cake typically contains more than 60% of uranium.

The chemical process employed is termed leaching. A strong acid or alkaline solution is used to dissolve the uranium which is later precipitated from the solution as a concentrate.

The waste from the mill, called mill tailings, is 99% of the weight of the original ore.

## Conversion or Processing

Purification and conversion is needed since yellowcake is not directly usable as nuclear reactor fuel.

Chemical means can be used to convert uranium concentrate to uranium hexafluoride.

The uranium hexafluoride is used to develop fuel for reactors using enriched fuel. Fuel for some reactors is based on natural uranium and does not involve conversion.

## Enrichment

Natural uranium consists mainly of two forms (termed isotopes) uranium$^{235}$ (0.7%) and uranium$^{238}$ (99.3%).

Only 0.7% of natural uranium is capable of undergoing fission which is the process used to produce nuclear energy in a nuclear reactor.

Uranium$^{235}$ is the most important isotope since it undergoes fission much more readily than uranium$^{238}$ in nuclear reactors.

In most types of reactor, a higher concentration of $uranium^{235}$ is used - this is produced by a process termed enrichment.

Two means of enrichment can be employed:

- gas centrifuge process
- gas diffusion

Both use gaseous uranium hexafluoride as the feed. The $uranium^{235}$ concentration is increased to 2 - 4%.

Enriched uranium hexafluoride is converted to enriched uranium oxide as the input for fuel production.

## Fuel Manufacture

The enriched uranium dioxide is manufactured into small pellets and loaded into tubes, called "pins", made either of stainless steel or a zirconium alloy.

These pins are constructed into an assembly in a geometric array - 36 for an Advanced Gas Cooled Reactor and some 300 for a Water Reactor. Many assemblies are then used in a reactor.

Magnox reactors use elements made of natural uranium in cans of magnesium alloy.

## Electricity Generation

Fuel loaded into nuclear reactors undergoes fission (splitting) of the $uranium^{235}$ atoms and this process releases energy. This energy is used to heat water and produce steam which drives a turbine. The turbine in turn drives a generator producing electricity which is distributed by the electricity grid system.

During operation of the reactors, a proportion of the uranium atoms is transformed into other elements by fission or by absorption of neutrons. These elements include fission products which are radioactive wastes and also plutonium.

## Used Fuel Storage

Fuel is kept in the reactors for typically 4 - 6 years depending on the reactor type. After this time, the build up of waste products in the fuel rod makes it less efficient.

When fuel is removed it is still emitting both radiation and heat and it is therefore stored in a special facility to allow the heat and radiation to reduce naturally.

## Reprocessing and Recycling

Used fuel contains 96% uranium, 1% plutonium and 3% radioactive wastes.

Reprocessing is used to separate the waste from the uranium and plutonium which can then be recycled into new fuel.

Reprocessing effectively reduces the volume of waste and limits the need to mine new supplies of uranium, thereby extending the lifetime of finite resources.

When the uranium has been separated it can be made into fresh fuel or mixed with the plutonium to produce a ceramic Mixed Oxide (MOX) fuel. This fuel can be used in conventional reactors.

If the fuel were not reprocessed, it would need to be stored and then disposed of - 100% of the fuel, rather than just 3%, would then become waste.

## Wastes

All parts of the nuclear fuel cycle produce some waste products which need to be carefully treated and handled to ensure compliance with appropriate safety standards.

The production of radioactive waste is minimised as far as reasonably practicable and the reuse and recycling of materials are encouraged.

Radioactive wastes from the nuclear fuel cycle are categorised as high, medium, or low level according to the intensity of radiation they emit. There are also essentially non-radioactive wastes resulting from, for example, mining and milling operations. This waste may contain toxic materials and requires careful management.

Low level waste is produced at all stages of the nuclear fuel cycle; intermediate waste arises mainly during reactor operations and reprocessing; high level waste comprises spent fuel and waste containing fission products from reprocessing.

Reprocessing 1 tonne of used nuclear fuel produces typically:

- 0.1 cubic metres of high level waste, containing nearly 99% of the radioactivity in the used fuel;
- 1 cubic metre of intermediate level waste, containing nearly 1% of the radioactivity in the used fuel;
- 4 cubic metres of low level waste containing 0.001% of the radioactivity in the used fuel.

All radioactive wastes have to be carefully managed to ensure high levels of safety are maintained.

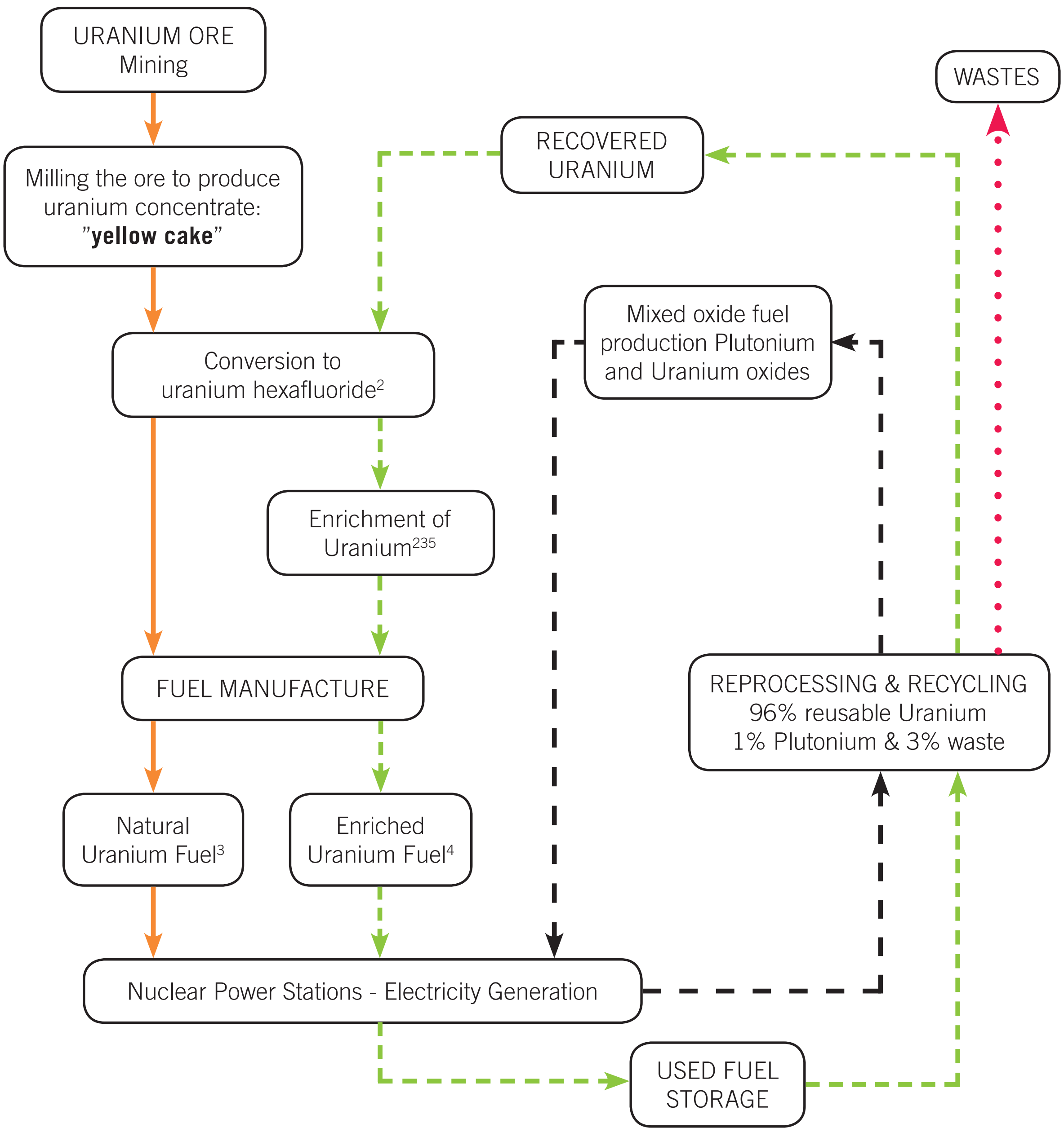
## UK Nuclear Facilities

| Activity | Location |
|---|---|
| Conversion of uranium ore to uranium hexafluoride | Springfields |
| Uranium enrichment | Capenhurst |
| Fuel manufacture | Springfields |
| Reactor Power Generation **Magnox** | Calder Hall[2]<br>Chapelcross[2]<br>Berkeley[2]<br>Bradwell[2]<br>Dungeness A[2]<br>Hinkley Point A[2]<br>Oldbury<br>Sizewell A[2]<br>Trawsfynydd[2]<br>Wylfa |
| Reactor Power Generation **AGR**[1] | Dungeness B<br>Hinkley Point B<br>Hartlepool<br>Heysham 1<br>Heysham 2<br>Hunterston B<br>Torness |
| Reactor Power Generation **PWR**[1] | Sizewell B[3] |
| Spent fuel reprocessing and recycling waste management | Sellafield |
| Solid low-level[4] waste disposal facility | Drigg |

**Notes:**

1. Owned by British Energy
2. Now in decommissioning phase.
3. At present British Energy store PWR fuel on site at Sizewell B after reactor power generation and do not send it for reprocessing.
4. At present there is no route in the UK for the ultimate disposal of either intermediate level waste or high level waste. Currently these wastes are securely held in stores above ground.

## The Nuclear Fuel Cycle[1]




**Notes:**

1. To aid clarity the detailed chemistry is not presented in this schematic.
2. Where fuel based on natural uranium is being made, this conversion is not required.
3. Magnox Reactors: natural uranium metal, CANDU Reactors: unenriched uranium dioxide.
4. AGRs and Light Water Reactors: enriched uranium dioxide.

**Sources:**

Uranium Institute fact sheets.
BNFL Briefing Note: Manufacturing Nuclear Fuel.

# Further Information

- **IET Energy related factfiles**
  http://www.theiet.org/factfiles/energy/index.cfm

# IET nuclear factfile series

- **The principles of nuclear power**
  http://www.theiet.org/factfiles/energy/nuc-prin-page.cfm
- **Nuclear reactor types**
  http://www.theiet.org/factfiles/energy/nuc-reac-page.cfm
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- **The nuclear fuel cycle**
  http://www.theiet.org/factfiles/energy/nuc-fuel-page.cfm
- **The radioactive decay of uranium$^{238}$**
  http://www.theiet.org/factfiles/energy/uranium238-page.cfm
- **Glossary of nuclear terms**
  http://www.theiet.org/factfiles/energy/nuc-terms-page.cfm

# Further Reading


- Wood, J. **Nuclear Power** (IET Power and Energy Series 52); Institution of Engineering and Technology (2007) ISBN 0863416683
- UI Facts - **The Nuclear Fuel Cycle** - B/01/1-97 The Uranium Institute The International Association for Nuclear Energy
- Nuclear Decommissioning Authority Strategy and Annual Plan
  http://www.nda.gov.uk

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