FACTSHEET:

Uranium enrichment and fuel manufacture

Overview

The uranium oxide powder produced from overseas mining and milling is called yellowcake. Yellowcake must be processed further before it can be used as a nuclear fuel. The two main steps in this process are uranium enrichment and fuel manufacture.

Uranium enrichment involves taking natural uranium and increasing the concentration of uranium-235 isotope, which is the essential component of nuclear fuel. This is usually done in a centrifuge to separate uranium-235 from the heavier and more abundant and heavier uranium-238 isotope.

Fuel manufacture involves taking the enriched uranium and turning it into a solid fuel pellet form. Many pellets are then encased (clad) within individual metal fuel rods. Multiple fuel rods are arranged into complete fuel assemblies that can be used in nuclear power reactors.

Uranium enrichment and fuel manufacture produces some operational wastes but not in large amounts. These typically include storage containers, used protective clothing and cleaning materials, and equipment components replaced during maintenance.

Enrichment does produce large amounts of a by-product material, known as depleted uranium. This is not considered as a waste because of its potential energy value and also because it has a number of industrial and defence uses.

Yellowcake – the raw material for nuclear fuel

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Image: Yellowcake is the raw material for manufacturing nuclear fuel. Source Uranium Energy Corp, US

Nuclear Decommissioning Authority

Uranium enrichment

Yellowcake is a uranium oxide which contains uranium isotopes in their natural proportions. The majority is uranium-238 (more than 99%) with the remainder being uranium-235 (about 0.7%) and uranium-234 (less than 0.1%).

The uranium-235 isotope is needed to power a nuclear reactor. However, the small amount of this isotope that occurs naturally is not sufficient to sustain a nuclear chain reaction. This means it has to be concentrated ('enriched') before the fuel can be manufactured.

Most commercial nuclear power reactors require low enriched uranium (LEU) fuel with a uranium-235 content of between 3 to 5% to operate efficiently. Submarine reactors and nuclear weapons require more highly enriched uranium (HEU) with a uranium-235 content greater than 20%.

Separating isotopes

It is not possible to separate isotopes of the same element using chemical processes because they all have the same chemical properties. Separation of uranium-235 can only be achieved by taking advantage of the small mass difference between it and the slightly heavier uranium-238 isotope. The main method used to enrich uranium-235 is the gas centrifuge.

Converting to a gas

To form a gas suitable for centrifuging, the uranium oxide is converted to uranium hexafluoride (UF_6) which is commonly referred to as 'hex'. This is done using a complex multi-stage wet process.

The hex is a white crystalline solid at normal temperatures and pressures, but readily forms a gas at about 60°C.

At the enrichment plant, UF_6 is heated and the gas produced is then fed into a centrifuge to be enriched.

Gas centrifuge

A gas centrifuge is used to enrich the uranium-235 isotope needed in nuclear fuel. A centrifuge is a machine with a cylinder which rotates rapidly separating the contents based on their mass.

The UF_6 gas is fed into a centrifuge where it is spun rapidly at over 50,000 revolutions per minute. This causes the heavier uranium-238 to become concentrated towards the outer part of the cylinder and the uranium-235 to be concentrated towards the centre.

Separation of isotopes by gas centrifuge is not total, and so the slightly enriched gas from one cylinder is fed into another, along a cascade, in a continuous process. At the same time, the slightly depleted gases are fed back to the beginning of the cascade to be centrifuged again.

Fuel manufacture

The enriched UF_6 ‘hex’ extracted from the gas centrifuge is converted back to a solid uranium oxide (UO_2) in a high temperature kiln, together with steam and hydrogen.

This process produces a ceramic powder which is then ground to ensure evenly sized granules. This powder is then fed into dies, compressed and heated in a furnace to form the solid ceramic fuel pellets used in most nuclear power reactors.

Most fuel pellets are around one centimetre diameter, and many pellets are encased (clad) within individual metal fuel rods. Multiple fuel rods are arranged into complete fuel assemblies.

Different reactor types each require a different fuel assembly design.

All of the advanced gas cooled reactors (AGR) and the Sizewell B pressurised water reactor (PWR) currently operating in the UK use uranium oxide (UO_2) fuel.

The older Magnox reactors used a special type of fuel made of natural uranium metal but these reactors have now reached or are reaching the end of their operational lifetimes. No new metal fuel is required.

Mixed oxide (MOX) fuel

MOX fuel combines uranium with plutonium that is recovered during the reprocessing of spent (used) fuel. MOX fuel used to be manufactured at Sellafield for overseas customers but this operation has now stopped.

No UK reactors use MOX fuel. However it may be used in the future, depending on commercial decisions on new reactor designs and their operation.

Radioactive wastes produced by enrichment and fuel manufacture

Uranium enrichment and fuel fabrication produce small amounts of LLW and ILW, such as:

- used ‘hex’ storage and transport containers
- solid waste ‘cake’ made largely of silica and produced during the purification of yellowcake
- typical operating wastes such as ion-exchange resins, paper and filters

Depleted uranium

The uranium enrichment process produces very large volumes of depleted UF_6 ‘tails’ as a by-product (containing about 0.25% uranium-235). These ‘tails’ are drawn from the gas centrifuges after the enriched UF_6 has been obtained, and then solidified.

These depleted tails are not considered to be a waste because of their potential energy value due to the remaining uranium-235, and because they have other possible uses.

They may be re-enriched or converted to depleted uranium (DU) metal. DU metal is very dense and has many industrial and defence uses, such as in bullets and trim weights in commercial airplanes.