APPENDIX C: FURTHER PROCESSING METHODS

The uranium oxide (U_3O_8) produced through mining and milling operations must undergo a series of additional processing steps in order to be transformed into a fuel that will generate electricity in a nuclear power plant. The required processes are conversion, enrichment and fuel fabrication.[1] Additionally, used nuclear fuel can be reprocessed to provide new fuel.

URANIUM CONVERSION

The conversion process refines the U_3O_8 and chemically converts it into uranium hexafluoride (UF_6) which readily changes from a solid form to a gas, which is necessary for the enrichment process.[2]

There are two well-established chemical methods for conversion, known as the 'wet' and 'dry' processes. The primary difference between the two techniques is in the way impurities, such as molybdenum and vanadium, are removed. In the wet conversion process they are removed in the second stage using a liquid solvent, and only very pure intermediate products are processed through to the later stages. The dry process does not use liquid solvents but instead removes impurities in the final fluorination stage. Both methods use fluidised bed reactors, employed extensively in chemical process industries, to carry out the chemical reactions that transform U_3O_8 into UF_6.

The final product is pure UF_6, which is transferred into specialised cylinders suitable for storage and transport to an enrichment plant.

WET CONVERSION PROCESS

The key feature of the wet conversion route is that U_3O_8 is pretreated using acid digestion and solvent extraction steps to remove impurity metals and other elements. This yields pure uranium trioxide (UO_3) which is then reacted with hydrogen fluoride (HF) to produce uranium tetrafluoride (UF_4). The final step involves reacting UF_4 with fluorine gas (F_2) in a separate vessel to give UF_6 which is liquefied before transfer into cylinders.[3]

For the production of heavy water reactor fuel, UO_3 is reacted with hydrogen gas (H_2) to produce UO_2 which is suitable for the fabrication of ceramic fuel pellets.

DRY FLUORIDE VOLATILITY PROCESS

In the dry conversion process, U_3O_8 is first heated in H_2 gas to produce UO_2. This compound is physically ground into a uniform size, such that it can be fed into a fluidised bed reactor and reacted with HF to produce UF_4. This compound is fluorinated with F_2 to give UF_6 which is further purified using a distillation process that removes impurities.[4]

ENRICHMENT

In order to be used as a fuel in light water reactors, uranium needs to be enriched in the ^{235}U isotope to between 3 per cent and 5 per cent from its natural abundance of 0.71 per cent. The process of uranium enrichment adjusts the ratio of the three natural uranium isotopes (^{234}U, ^{235}U and ^{238}U) to produce one with an increased proportion of ^{235}U. The remaining portion (commonly called the 'tails') is depleted in ^{235}U and is less radioactive. Uranium enrichment effort is measured and supplied in 'separative work' units. Separative work can be described as the amount of enrichment effort required to increase the concentration of ^{235}U in a set amount of uranium, to a given, higher ^{235}U concentration.[5]

CENTRIFUGES

Commercial enrichment is undertaken using large numbers of interconnected gas centrifuges: highly engineered, fast-rotating cylinders in which the UF_6 is subjected to a large centrifugal force. Heavier ^{238}U molecules move closer to the outer wall of the centrifuge than the lighter ^{235}U molecules. To achieve a high separation factor at each stage, modern centrifuges must rotate at speeds beyond that of sound, and therefore operate in a vacuum. The centrifuge process is difficult to master, since the high rate of rotation requires that the centrifuge be very strong and perfectly balanced, and capable of operating in such a state for many years without maintenance.

The stream that is slightly enriched in ^{235}U is then fed into successively higher stages of centrifuge to progressively enrich the ^{235}U. It requires tens of thousands of centrifuge stages to enrich commercial quantities of uranium. The other stream (the 'tails') is depleted uranium and is recycled back into the next lower stage of centrifuges.

LASER ENRICHMENT

Laser enrichment is based on molecular laser separation technology and has shown some promise as a possible commercial uranium enrichment technique. The process uses infrared lasers to selectively excite and ionise ^{235}U atoms in a stream of UF_6 giving high single-stage separation factors.[6] It is currently under development and has not yet been proven commercially, with one company recently discontinuing its efforts.[7]

FUEL FABRICATION

The final process step before uranium can be used as a fuel is fabrication into pellets within fuel 'bundles', either as enriched or natural fuel. Typically this is achieved in two key steps:

- UF_6 gas is chemically converted into a solid uranium dioxide (UO_2) powder
- UO_2 powder is fabricated into pellets which are then assembled into fuel bundles.

The UO_2 powder is pressed, compacted and sintered into dense ceramic pellets which are machined to the exact dimensions required. The pellets are typically loaded into zirconium tubes, which are assembled into the required fuel geometry. Light water reactors use fuel assemblies that are more than 3.5 m long. Heavy water reactors use short 50 cm bundles.

Nuclear fuel assemblies are specifically designed for particular types of reactors and are made to exacting standards. Many thousands of pellets have to go through rigorous quality assurance before being loaded into zirconium tubes. The product quality of the fuel assembly is a key factor for any power plant operation to assure safety and reliability. Fuel manufactured to the appropriate safety and design standards will support the reactor defence-in-depth approach.[8]

USED FUEL REPROCESSING

Used nuclear fuel can be reprocessed to recover fissile and fertile material in order to provide new fuel for existing and future nuclear power plants.

Only recycled uranium and plutonium can be reused in light water reactors as fresh fuel. Fast reactors can use recycled actinide components including uranium, plutonium, neptunium and americium as well as depleted uranium from the enrichment process. The fertile ^{238}U can be transformed into ^{239}Pu which can be burned in a fast reactor.

The reprocessing of used nuclear fuel is difficult. Full remote-handling operations are required, in 'hot cells'—heavily shielded rooms with thick concrete walls and thick lead-glass windows to protect operators. Hot cells have complex manipulator arms that are controlled by operators outside the cell.[9]

AQUEOUS REPROCESSING

Commercial used nuclear fuel reprocessing plants use the proven aqueous PUREX (Plutonium URanium EXtraction) process.[10] Used fuel is chopped into pieces and treated with strong acid. Most of the fuel dissolves and the liquid stream is subjected to multiple solvent extraction and ion exchange stages to partition groups of elements: uranium, plutonium, fission products and 'minor actinides'.

The products from fuel reprocessing can be fabricated into a fuel known as mixed oxide (MOX) fuel in a specialist fabrication facility. MOX fuel is manufactured from plutonium recovered from used reactor fuel, which is mixed with depleted uranium from the uranium enrichment process, at about 7 per cent to 10 per cent plutonium. This mixture is equivalent to approximately 4.5 per cent enriched uranium oxide fuel.[11]

PYROPROCESSING

Used nuclear fuel can also be treated with high temperature 'pyroprocessing' methods to achieve desired chemical separations. One of the main pyroprocessing techniques involves electrochemically treating the used fuel in one or more molten salt baths incorporating electrodes that allow for selectively separating used fuel components through voltage control. This strategy is particularly well suited for treating used metallic fast reactor fuels.

Another strategy is to simply heat used fuel to high temperatures, either alone or with other materials, in order to separate and remove particular components. Pyroprocessing research and development programs have been under way for many years in countries including the US, Japan and Russia. It is being used in the US to treat used fuel from a shut-down pilot fast reactor, but pyroprocessing has not yet been deployed in the commercial nuclear industry.[12]

NOTES

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12 ibid.

Transcripts and submissions can be found at the Nuclear Fuel Cycle Royal Commission's website: www.nuclearrc.sa.gov.au/transcripts and www.nuclearrc.sa.gov.au/submissions