

The various activities associated with the production of electricity from nuclear reactors are referred to collectively as

# THE NUCLEAR FUEL CYCLE



**IAEA**

International Atomic Energy Agency





# THE NUCLEAR FUEL CYCLE

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## INTRODUCTION

This brochure describes the nuclear fuel cycle, which is an industrial process involving various activities to produce electricity from uranium in nuclear power reactors. The cycle starts with the mining of uranium and ends with the disposal of nuclear waste.

The raw material for today's nuclear fuel is uranium. It must be processed through a series of steps to produce an efficient fuel for generating electricity. Used fuel also needs to be taken care of for reuse and disposal.

The nuclear fuel cycle includes the 'front end', i.e. preparation of the fuel, the 'service period' in which fuel is used during reactor operation to generate electricity, and the 'back end', i.e. the safe management of spent nuclear fuel including reprocessing and reuse and disposal.

If spent fuel is not reprocessed, the fuel cycle is referred to as an 'open' or 'once-through' fuel cycle; if spent fuel is reprocessed, and partly reused, it is referred to as a 'closed' nuclear fuel cycle.



# URANIUM MINING

Uranium is a common metal that can be found throughout the world. It is present in most rocks and soils, in many rivers and in sea water. Uranium is about 500 times more abundant than gold and about as common as tin.

There are three ways to mine uranium: open pit mines, underground mines and in situ leaching where the uranium is leached directly from the ore.

The largest producers of uranium ore are Kazakhstan, Canada and Australia. The concentration of uranium in the ore could range from 0.03% up to 20%.



URANIUM is a common, slightly radioactive material that occurs naturally in the Earth's crust.





# URANIUM MILLING

Milling is generally carried out close to a uranium mine. The mined uranium ore is crushed and chemically treated to separate the uranium.

The result is 'yellow cake', a yellow powder of uranium oxide ( $U_3O_8$ ). In yellow cake the uranium concentration is raised to more than 80%.

After milling, the yellow cake concentrate is shipped to a conversion facility.



In a mill, URANIUM is extracted from crushed ore to enable the conversion process.



# CONVERSION

Natural uranium consists primarily of two isotopes, 99.3% is U-238 and 0.7% is U-235. The fission process by which heat energy is released in a nuclear reactor, takes place mainly in U-235. Most nuclear power plants require fuel with U-235 enriched to a level of 3–5%.

To increase the concentration of U-235, uranium must be enriched. Since enrichment happens in gaseous form, yellow cake is converted to uranium hexafluoride gas ( $UF_6$ ) at a conversion facility.

$UF_6$  gas is filled into large cylinders where it solidifies. The cylinders are loaded into strong metal containers and shipped to an enrichment plant.



'YELLOW CAKE' is converted into gas to prepare it for enrichment.



# ENRICHMENT

Uranium is enriched in U-235 by introducing the gas in fast-spinning cylinders ('centrifuges'), where heavier isotopes are pushed out to the cylinder walls.

Uranium can also be enriched using older technology by pumping  $UF_6$  gas through porous membranes that allow U-235 to pass through more easily than heavier isotopes, such as U-238.



ENRICHMENT increases the proportion of the U-235 isotope.



## FUEL FABRICATION

Enriched uranium ( $UF_6$ ) cannot be directly used in reactors, as it does not withstand high temperatures or pressures. It is therefore converted into uranium oxide ( $UO_2$ ). Fuel pellets are formed by pressing  $UO_2$ , which is sintered (baked) at temperatures of over  $1400^\circ C$  to achieve high density and stability.

The pellets are cylindrical and are typically 8–15 mm in diameter and 10–15 mm long.

They are packed in long metal tubes to form fuel rods, which are grouped in 'fuel assemblies' for introduction into a reactor.



REACTOR FUEL is in the form of ceramic pellets.





# ELECTRICITY GENERATION

Once the fuel is loaded inside a nuclear reactor, controlled fission can occur. Fission means that the U-235 atoms are split. The splitting releases heat energy that is used to heat water and produce high pressure steam. The steam turns a turbine connected to a generator, which generates electricity.

The fuel is used in the reactor for 3–6 years. About once a year, 25% to 30% of the fuel is unloaded and replaced with fresh fuel.



A nuclear power plant produces electricity by (1) HEATING water to (2) GENERATE steam that (3) MAKES the turbine rotate to (4) ENABLE the generator to produce electricity.



## SPENT FUEL STORAGE

The spent fuel assemblies removed from the reactor are very hot and radioactive. Therefore the spent fuel is stored under water, which provides both cooling and radiation shielding.

After a few years, spent fuel can be transferred to an interim storage facility. This facility can involve either wet storage, where spent fuel is kept in water pools, or dry storage, where spent fuel is kept in casks.

Both the heat and radioactivity decrease over time. After 40 years in storage, the fuel's radioactivity will be about a thousand times lower than when it was removed from the reactor.



During temporary STORAGE, the radioactivity and heat of spent nuclear fuel decreases significantly.



## REPROCESSING

The spent fuel contains uranium (96%), plutonium (1%) and high level waste products (3%). The uranium, with less than 1% fissile U-235 and the plutonium can be reused. Some countries chemically reprocess usable uranium and plutonium to separate them from unusable waste.

Recovered uranium from reprocessing can be returned to the conversion plant, converted to  $UF_6$  and subsequently re-enriched.

Recovered plutonium, mixed with uranium, can be used to fabricate mixed oxide fuel (MOX).



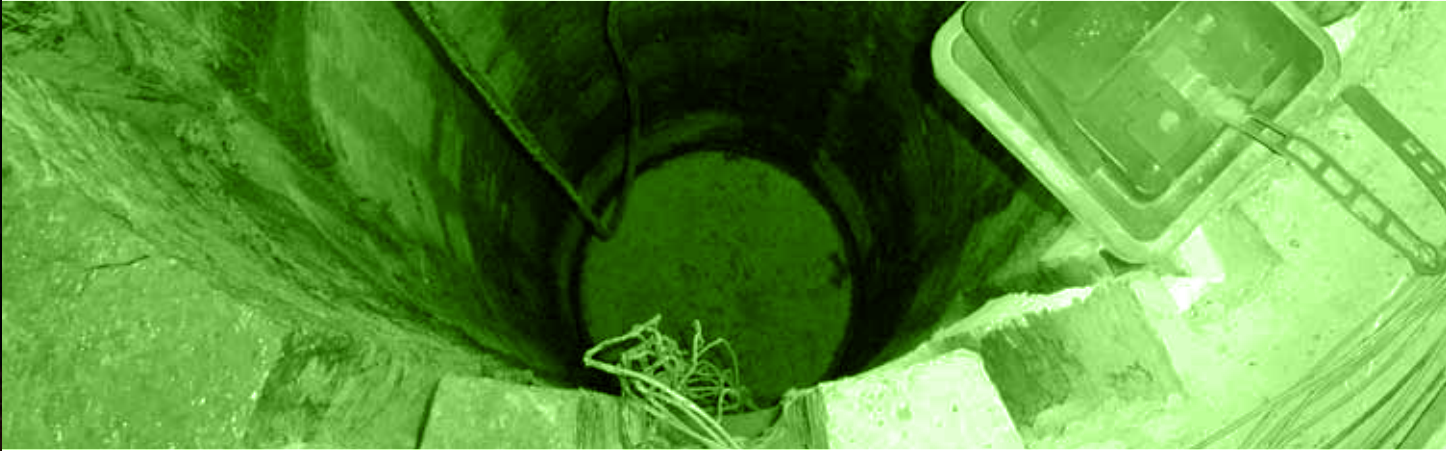
SPENT FUEL can be recycled to produce more power.



# SPENT FUEL AND HIGH LEVEL WASTE DISPOSAL

Spent nuclear fuel or high level waste can be safely disposed of deep underground, in stable rock formations such as granite, thus eliminating the health risk to people and the environment. The first disposal facilities will be in operation around 2020.

Waste will be packed in long-lasting containers and buried deep in the geological formations chosen for their favourable stability and geochemistry, including limited water movement. These geological formations have stability over hundreds of millions of years, far longer than the waste is dangerous.



NUCLEAR WASTE can be buried deep underground.



**IAEA**

International Atomic Energy Agency

Vienna International Centre, PO Box 100, 1400 Vienna, Austria

E-Mail: [info@iaea.org](mailto:info@iaea.org)

[www.iaea.org](http://www.iaea.org)

IAEA Division of Nuclear Fuel Cycle and Waste Technology

E-Mail: [NEFW.Contact-Point@iaea.org](mailto:NEFW.Contact-Point@iaea.org)

[www.iaea.org/OurWork/ST/NE/NEFW/index](http://www.iaea.org/OurWork/ST/NE/NEFW/index)

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