



The Fuel Cycle

The “fuel cycle” is a succession of technical steps that describe the entire life-cycle of the fissile materials and radioactive substances associated to nuclear fuel.

It covers the various facilities and activities used for nuclear fuel production and management.

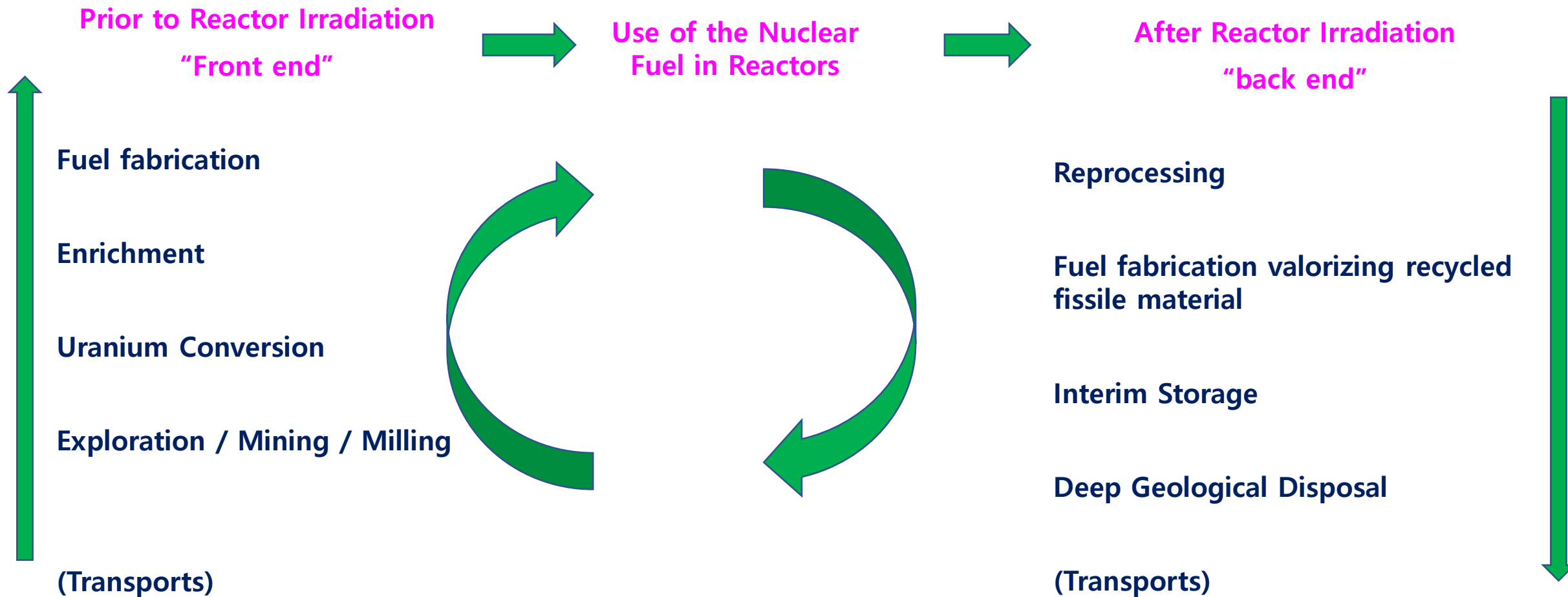
It usually starts with the initial stage of gathering natural Uranium (mining) and includes the potentially final stage of disposal (deep geological disposal).

Countries’ fuel cycle may differ depending on the :

- Type of reactors used (CANDU, PWR, BWR... Breeder?... Th?...)
- Reactor type envisaged for the next generation
- Number and nature of nuclear facilities operated on the National ground
- **Spent fuel management strategies**
 - When spent fuel is not reprocessed, the fuel cycle is referred to as an “open” fuel cycle
 - when the spent fuel is reprocessed, the fuel cycle is referred to as a “closed” fuel cycle



Basic Overview of the Various Stages of the Fuel Cycle





The Front End Stages – Prior to Reactor Irradiation – 1/2

Exploration / Mining / Milling

- Field studies to look for uranium deposits (geophysical techniques and sampling)
- Mining :
 - Mechanical extraction of Uranium ore (eg. Uraninite) from earth's crust (open-pit or underground)
 - Chemical extraction through direct dissolution of the ore (in situ leaching)
- Grinding the uranium containing material to a uniform particle size
- Processing of the uranium containing material through chemical treatment to yield U_3O_8 (yellow cake)

Uranium Conversion / Purification

- U_3O_8 is transformed into Uranium fluoride (UF_6) to prepare it for the enrichment stage
- For Magnox or Candu reactor fleets, U_3O_8 is transformed into UO_2





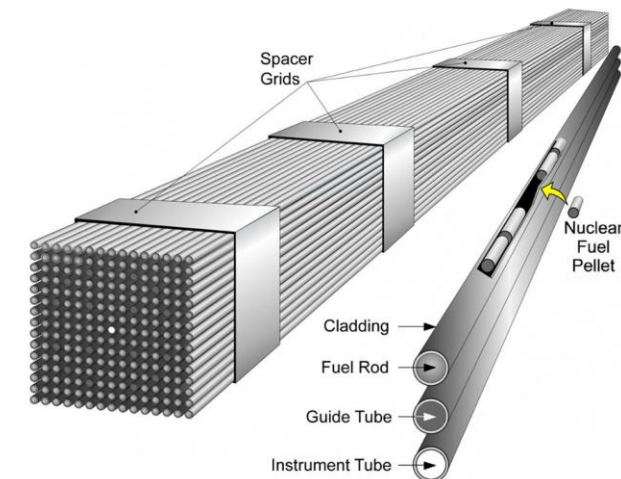
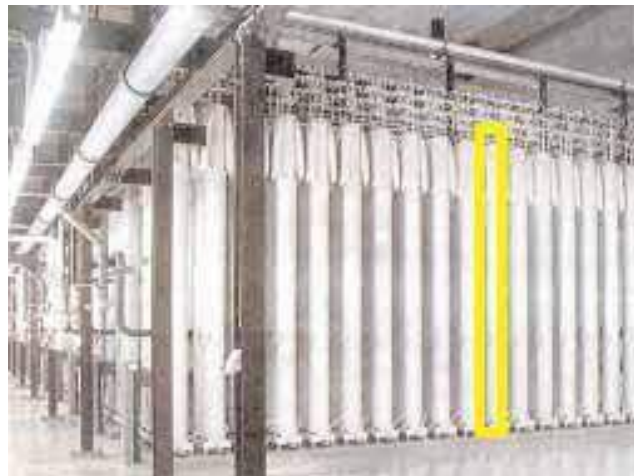
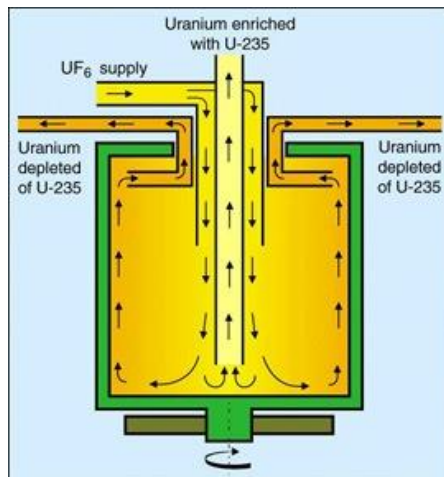
The Front End Stages – Prior to Reactor Irradiation – 2/2

Enrichment

- Natural Uranium holds (0,71%) of the fissile isotope U-235 and (not enough to sustain a nuclear reaction in PWR)
- Enrichment processes use the volatility of UF_6 and the U-235 / U-238 mass difference to increase the U-235 concentration
 - Gas diffusion
 - Centrifuge
- A typical enriched uranium for PWR contains 3 to 4 % U-235
- A part of the initial uranium being enriched, the byproduct of the process is “depleted” uranium (less than 0,71 % U-235)

Fuel fabrication

- Enriched UF_6 is transformed into UO_2 pellets that are sintered, ground and loaded into metal tubes (Zircaloy or stainless steel)
- Loaded metal tubes are assembled into “bundles” or “assemblies” of various size ready to be fed in reactors





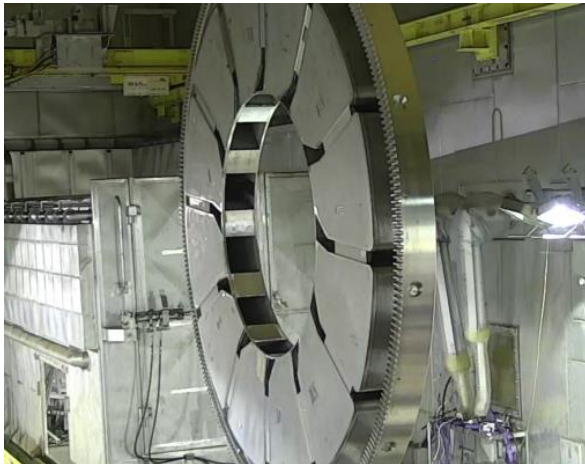
The Back End Stages – After Reactor Irradiation – 1/2

Reprocessing

- After irradiation, the fuel still contains 96% of fissile or fertile materials (Pu and U)
- Reprocessing separates:
 - Plutonium in the form of oxide
 - Uranium in the form of oxide (URT – uranium from reprocessing treatment)
 - High Level Waste : Minor actinides and fissions products that are immobilized in a glass matrix (conditioned in a stainless steel container)
 - Intermediate level waste : The activated metal part of spent nuclear fuel assemblies (compacted and conditioned in a stainless steel container)

Fuel fabrication valorizing recycled fissile material

- Plutonium and depleted uranium oxides are mixed into MOX pellets, sintered, ground and loaded into metal tubes (Zircaloy)
- Loaded metal tubes are assembled into "bundles" or "assemblies" of various size ready to be fed in reactors





The Back End Stages – After Reactor Irradiation – 2/2

Interim Storage of Spent Fuel

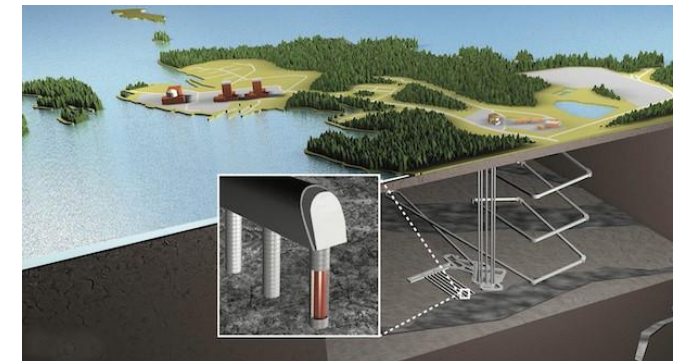
- Spent fuel whether it is reprocessed or not will eventually be stored temporarily for future use or for future recovery and transfer to the next management step
 - Fuel ponds/pools (wet storage)
 - Silos/containers (dry storage)

Interim Storage of High Level Waste

- Conditioned HLW for which no further use is envisaged may be kept in interim storage waiting for availability of a long term management solution

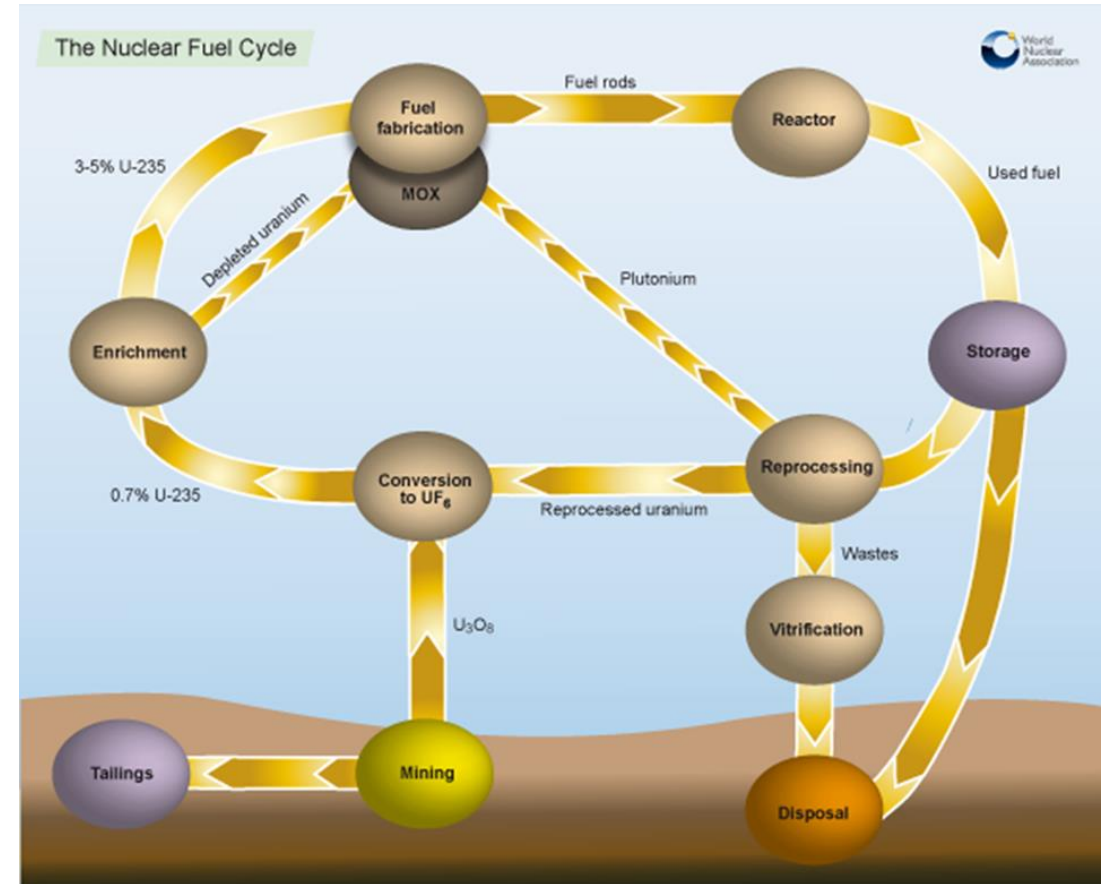
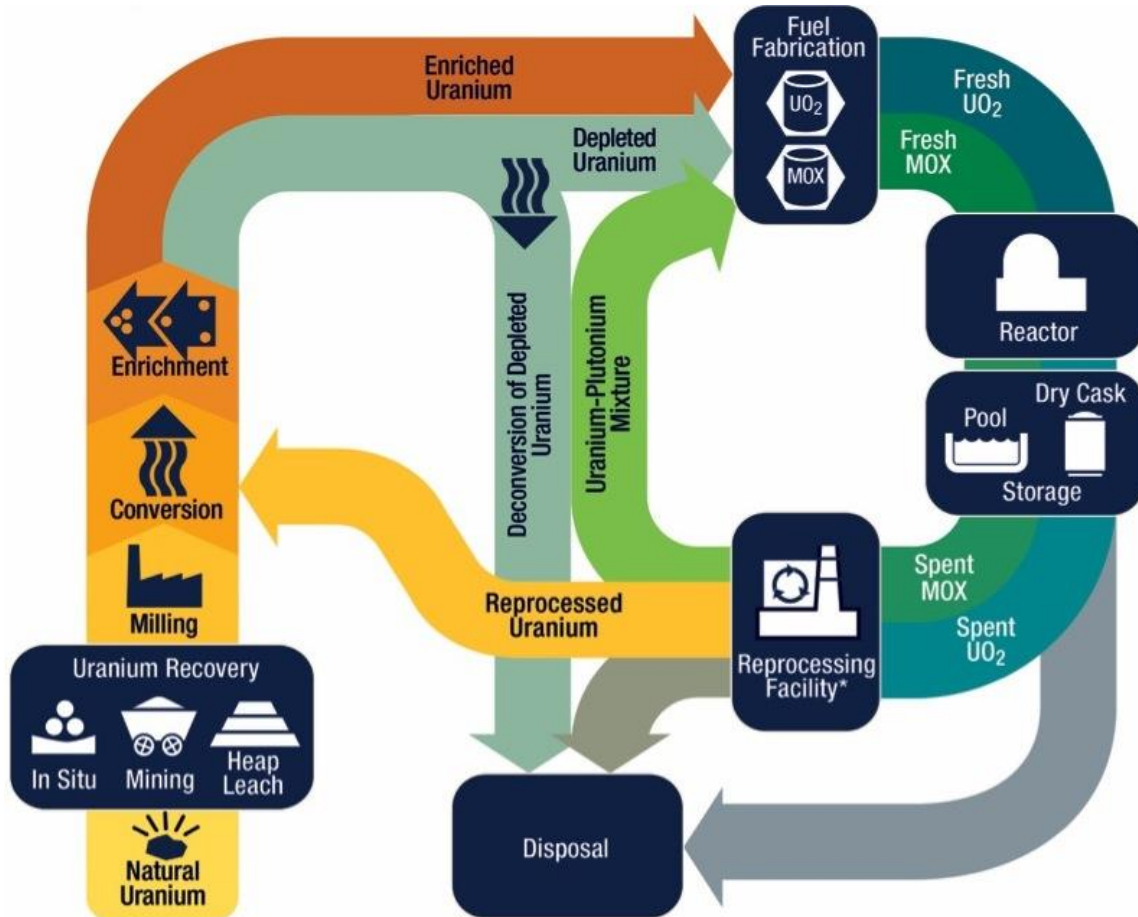
Deep Geological Disposal

- Currently the reference solution for the long term management of HLW
- Deep geological disposal are designed to isolate waste from the environment and contain the hazardous substances for very long time periods (several 10^5 to 10^6 of years)





Examples of Representation of the Fuel Cycle



An Example of an Operational Fuel Cycle – The French Nuclear Fuel Industry

The fully operational fuel cycle is distributed on several locations. Efficient transport is an essential tool for any operational fuel cycle.



France aims to reach 25% Uranium gain through reprocessing and multi-recycling.

Facilities are linked and have technical interfaces

- National energy programs provide industrial visibility

The fuel cycle activities, including reprocessing, are commercial activities answering industrial needs and welcoming foreign customers.

