# Mining of uranium ore

Uranium can be found all over the World, but in different concentrations. In the soil, its mean concentration is 3-5 g/ton, in the water of seas and oceans there are 5 g uranium in each 1 m3. But there are several places on the Earth, where the concentration is much higher, than average. The mining of uranium ore is economical, if the concentration of U is 0.5-5 g/kg ore.

Uranium ore can be mined in two ways: by deep mining (a kind of cave is dug in soil) or, if the rocks rich in uranium are close to the surface, by open-cast method (in this case they reach the ore simply by taking away the top soil).

The mined uranium containing rock is ground in special mills and the powder is dissolved in sulphuric acid. Next, the solution is filtered and the uranium content is precipitated in the form of uranium oxide ($U_3O_8$). This yellow powder is compacted into cakes (hence the nickname "yellow cake").

Uranium mining does not end when the ore deposits are exhausted. The environment has to be reset to a state similar to the situation before mining started. This process is called recultivation. In the upper picture an operating open-cast mine is shown, while the same area after recultivation can be seen in the lower picture.


Uranium ore was mined in Hungary in the Mecsek Hills, at Kővágószőlős. The yellow cake was manufactured on site. This was transported to the former Soviet Union, where further steps leading to the fabrication of fuel were made. The mine was closed in 1997 because the mining conditions were very hard, the miners had to work very deep under the ground and at very high temperature, moreover it cost more than buying uranium ore from abroad.

Kővágószőlős, 1,100 m below ground level

# Conversion

The nickname of this compound is hex, which means witch in German. Although from a technological viewpoint this material is difficult to handle, it is practical to use it: during the enrichment methods such a gas is required whose molecule mass only depends on the mass of the uranium atom. This is why fluor has been chosen: it has only one naturally occurring isotope; thus hex is the mixture of only two molecules: the molar mass of the one that contains $^{235}U$ is 349 g/mol, while the other that contains $^{238}U$ is 352 g/mol. ($^{235}U+6*^{19}F$, mass: 235+6*19=349; $^{238}U+6*^{19}F$, mass: 238+6*19=352).

$UF_6$ tank in an enrichment plant

# Enrichment

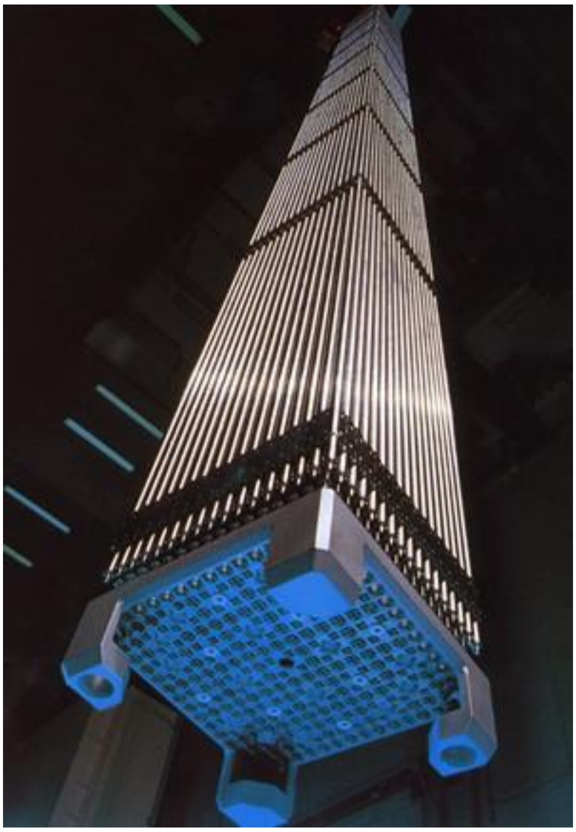
Natural uranium mainly consists of $^{238}U$ and only 0.72% is fissile $^{235}U$, in which fission reactions can be induced by thermal neutrons. Using natural uranium, the self-sustaining chain reaction can only be achieved with the application of heavy-water or graphite as moderator, since the hydrogen present in light water absorbs too many neutrons. The solution is enrichment, which means that the fraction of uranium atoms with mass number 235 is increased. The fuel of the most widespread, light water moderated nuclear power plants contains slightly enriched (2–4 % $^{235}U$) uranium.

Several methods have been developed for enrichment, of which the gas diffusion and the gas centrifugal techniques are the most important. In both of them uranium-hexafluoride is applied and the mass difference between the uranium isotopes is made use of. Since these methods separate the two isotopes at a low effectivity (due to the relatively low, 0.86 % mass difference), several units are connected in a series, in a so called cascade manner.

Enrichment plant

# Fuel fabrication

The uranium hexafluoride that has been enriched to the necessary extent is converted into uranium dioxide, which is then compacted to pellets using a powder metallurgical technique called agglomeration (or sintering). These pellets are filled into fuel rods and the rods are bundled into assemblies.



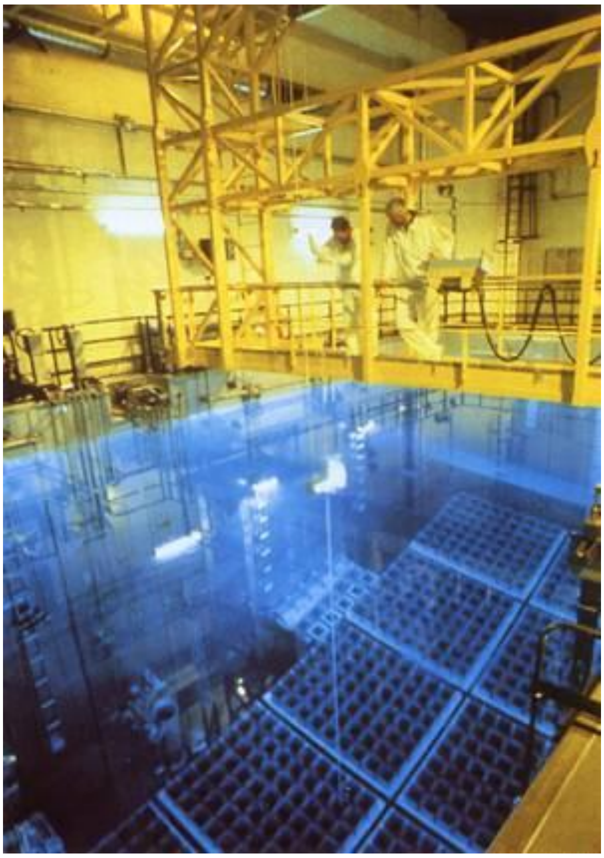
PWR fuel assembly

Head of hexagonal assets in Paks NPP

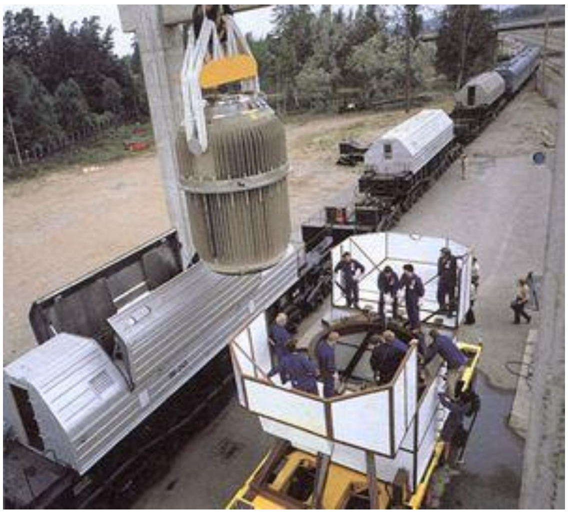
# Interim storage

During its stay in the reactor core, substantial changes take place in the fuel. In parallel with the decrease of the quantity of fissile material (235U), radioactive nuclei are produced. On the one hand, fission products are produced due to fission events; on the other hand, the nuclei present in fuel (235U, 238U) capture neutrons and transuranic isotopes evolve via series of decays.

The activity of the spent fuel is so high that it must be cooled; otherwise it may melt due to the heat released during radioactive decays. Moreover, the neighbourhood must be shielded from the very intense radiation. The two tasks are simultaneously performed by the cooling pond. The spent fuel is stored by Paks for 5 years.



Cooling pond in a French NPP



Spent fuel shipping cask

After a few years of storage (cooling) the activity of the fuel drops to such a low level that it can be transported and even air cooling is sufficient during the later storage. The interim storage is undertaken in special pits. Back transfer to Russia was cancelled in 1998, but the international contract between the two countries is still valid.