Uranium

The element and its properties

Uranium was discovered in 1789 by M. H. Klaproth while analysing the mineral petchblenda (believed to be an oxide mix of iron, zinc and tungsten) to which he gave the name Uranium to celebrate the discovery of the new planet in the solar system, discovered in those years. In 1789 Zirconium was discovered as well, an element of fundamental importance for nuclear reactor technology.
Uranium, in standard conditions, is a hard radioactive metal, silver-white in colour, malleable and ductile. It is quite common in nature but it is difficult to find it in high concentrations and on average it is present in the terrestrial crust in a proportion of about 3 grams of uranium per ton of crust (also called part per million, ppm): since the terrestrial crust is estimated to be $3X10^{19}$ tons, about 10^{13} tons of uranium are available (10000 billion tons), a greater quantity than silver, gold or molybdenum.
Uranium is constituted by various isotopes (atoms of the same chemical element, with the same atomic number but different mass number) present in different percentages in the terrestrial crust:

- 238U 99.2745%
- 235U 0.72%
- 234U 0.0055%

In nature about 200 minerals exist containing uranium, rarely found in isolation and more commonly present in various types of rocks, among which in particular granites (acid rocks) and siliceous rocks; smaller concentrations are present in basaltic and sedimentary rocks.
Uses of uranium
Uranium, before nuclear energy was discovered, was used primarily to stain glass. Today uranium is used primarily as a fuel in nuclear plants where the fissile material is constituted by isotope 235U.
An endless reservoir?
After having individuated an uranium presence in the terrestrial crust, it is necessary to evaluate a reservoir, that is individuate how many tons of uranium it contains. The reservoir has to be considered exploitable, otherwise we could say that the crust is an "enormous reservoir" since it contains 3 grams/ton of uranium, but we do not have a technology that allows its low cost extraction.
An uranium reservoir is defined as exploitable once an economic limit has been defined, that is a threshold that allows a classification: reservoir evaluation is a problem of international norm.

Uranium resources

When you talk of "retrievable" uranium, it means that it is possible to extract the mineral from a reservoir and make it available for a fuel element, at a specific price that is expressed in dollars. Analysing the world map of reservoirs and knowing their nature it is possible to assess the exploitable quantity of uranium by forming cost ranges: up to 40 $, between 40 $ and 80 $ and between 80 $ and 130 $. Obviously the most economical are the ones that are exploited first.
All areas where there is an attested presence of uranium are denominated **Reasonably Assured Resources** (RAR).
One the reasonably safe reservoirs are known, through analyses coupled with adeguate radioactive measures, similar areas in geomorphologic terms can be individuated in order to obtain information on reservoirs similar to the ones being exploited. These reservoirs are considered esteemed and are part of the **Estimated Additional Resources** (EAR, also known as Inferred Resources, IR).
These extra resources are classified in two categories: EAR-I and EAR-II; the EAR II are less certain than the first ones. There is also another category called Speculative Resources (SR), which derive from another extrapolation of the

geomorphologic characteristics of land that could easily obtain uranium.
The RAR resource types are the easier ones to exploit, thus cheaper; they are available in quantities that go between 507,400 t and 4,587,200 t in relation to how much money is available for the extraction.
The data relating to the Estimated Additional Resources of the second group (EAR-II) are much more precise in comparison with those on Speculative Resources and the estimates are of a quantity of uranium equal to about 2,200,000 tons at a price between 80 $ and 130 $.
The Speculative Resources also include uranium in phosphates and it can be estimated in about 22,000,000 tons of uranium. If we add the uranium container in the oceans' water we reach a quantity of uranium equal to about 4 billion tons!
The technology of uranium extraction from phosphates is essentially developed: it is already used in Belgium and the United States. However it has a limited diffusion because it is not economically convenient: it is estimated that an extraction project of 100 tU/year would have a cost in the range 60-100 $/kgU (inclusive of investment costs).
For what concerns the extraction of uranium from the sea, encouraging research has been undertaken in Japan: however, it is still a technology tested at laboratory level with very high costs, estimated around 300 $/kgU.

The cycle of nuclear fuel

Nuclear fuel is subject to a cycle throughout its life. Obvious preliminaries are all the mining operations, which are followed by a long and complex series of various purification processes, with the primary aim of eliminating the elements that absorb neutrons. Neutrons are particles capable of starting the fission process by breaking the U-235 nucleus with subsequent release of energy: if there are elements that absorb neutrons, these cannot produce fission reactions ("neutron poisons"). The operations undertaken in this first part of the fuel cycle are mainly of a chemical nature and lead to the production of a gaseous compound of uranium (uranium hexafluoride, UF_6) that allows the enrichment process of the isotopeU-235. This phase is necessary since the majority of nuclear reactors uses fuel made of enriched uranium: on average the enrichment is around 3% of U-235, against 0.72% of U-235 in the uranium found in nature. If we send the gaseous compound of uranium hexafluoride to a centrifuge it is possible to discriminate the different mass of the isotope U-235 compared to the isotope U-238 and it is possible to concentrate an isotope compared to another. Gaseous ultracentrifuges constitute the enrichment plants: other enrichment processes are possible through the gaseous diffusion plants or the laser selective isotopic separation.
The enriched hexafluoride is successively converted in uranium dioxide (UO_2) powder, which is assembled in pellets that, appropriately canned, will constitute the fuel element.
Nuclear fuel is thus inserted in nuclear reactors and produces energy until the end of its life. At this stage the fuel element has become radioactive and it is put into pools, usually near the reactor, in order to reduce the radioactivity level. Exhausted fuel can have two different endings: the definitive deposit in areas with appropriate geological characteristics or reprocessing.
During its time inside the reactor not all U-235 is burned (about 1% is left) and in the meantime, because of nuclear reactions, other nuclids have been born that can produce a nuclear fission reaction: fissile nuclei such as plutonium, PU-239, born from U-238 through the "fertilisation" process. These can be used in turn as nuclear fuel, while the remaining fuel must be stocked in definitive deposits.
The reprocessing alternative, which is used by some countries like France and the UK, has some advantages: first of all it allows a more rational exploitation of fuel, allowing not only the recovery of the left over U-235 but also the newborn PU-239 that represents an extremely important resource because it descends through fertilisation fromU-238 and represents the great majority of the uranium found in nature.
Secondly, the reprocessing allows to substantially reduce the volume of highly radioactive products that require long term stocking. Finally reusing already irradiated reduces considerably the risk of proliferation by making material treated twice unsuitable for the production of nuclear weapons.

A look at the future

The current fuel cycle exploits, with current reactors, just a small part of the energy that can be extracted from uranium found in mines and leaves a legacy of waste that has to be confined for long periods of time. It is obvious that, to truly close the cycle and to fully exploit the potential of the nuclear fuel available in nature, it is necessary to have not only thermal reactors with high burning rates but also “fast” type reactors, where neutrons do not undergo a slowing process to kick-start the fission reaction. These reactors are capable of exploiting much better the fuel found in nature with a totally different production of waste, a lot less problematic compared to current reactors.
At the current rhythm of nuclear energy production uranium resources translate into a 65-year energy availability with current reactor consumption equal to 66.000 tons/year. However the exploitation of Estimated Additional Resources of the second group (EAR-II) would guarantee energy for another 260 years without any retreatment process. Considering also the Speculative Resources and neglecting the uranium contained in the oceans there would be another 360 years of energy production available.
Currently the supply of uranium is based for 50-60% of the total on extraction from mines, while the rest derives from:

- stock of natural uranium and/or enriched uranium of civil or military origin. In the previous years more uranium than necessary has been extracted: this has caused a build-up of the element, partly due to a limited development of nuclear energy
- production compared to what was expected;
- reprocessing of exhausted fuel;
- use of 235U of military origin, which derives from the dismantling of nuclear warheads.