Uranium Mining – Overview

Peter Diehl
Stockholm, April 27, 2007

Uranium Mines and Mills

Uranium deposits located near the surface are mined in *open pit mines*. An example is the Rössing uranium mine in Namibia (length: 2 km., width: 400 m., depth: 230 m.). The ore there has a very low average grade of 0.029% U. More than one billion t of material have been extracted from this mine so far, approximately one-third of which was processed in the uranium mill. The remainder was deposited on waste rock and low grade ore piles. Deep deposits are mined in *underground mines*.

As is the case with all conventional mining, the amount of waste rock is several times higher than the amount of ore mined. Waste rock piles release radioactive dust and radon gas into the environment.

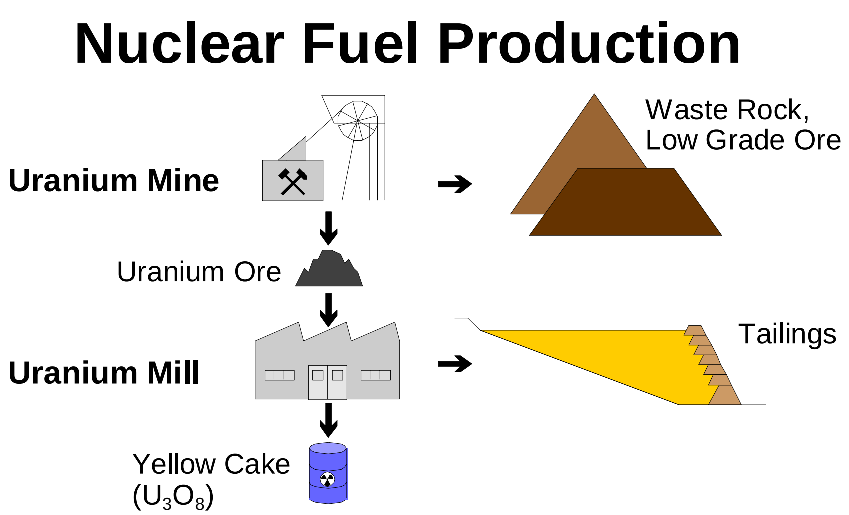
Ores with grades too low for milling are in some cases treated by *heap leaching* whereby a leaching agent, such as sulfuric acid, is percolated through the ore pile and the uranium-bearing liquid is collected at the bottom of the pile.

Example: Heap leaching in Pécs, Hungary (terminated after 1990). This large heap leaching operation with a total content of 7.2 million t of low grade ore was located adjacent to residential areas.

In *uranium mills*, ore is crushed and ground. Using a hydrometallurgical process, uranium is leached from the ore (with sulfuric acid or carbonate) and is then separated from other constituents contained in the solution.

The wastes generated from the milling process are called *uranium mill tailings*. Since the uranium represents only a minor fraction of the ore (for example 0.1%), the amount of mill tailings is nearly identical to that of the ore mined.

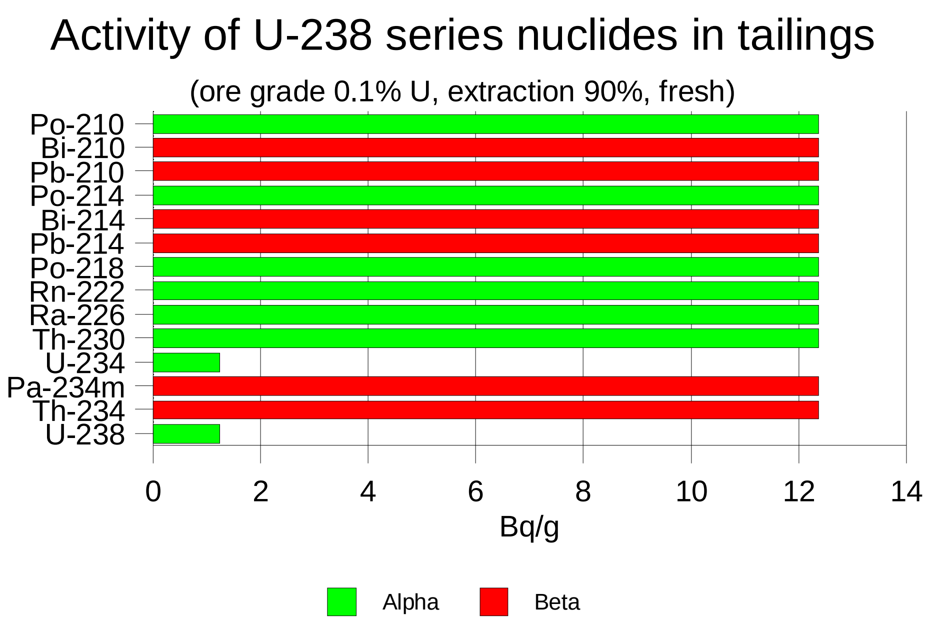
Example of a uranium mill: Ambrosia Lake, New Mexico, USA. This mill used the acid leach process and had a capacity of 6,350 metric tonnes of ore per day. From 1958 to 1985, it produced a total of 50,000 t of uranium. The mill generated 30 million t of tailings, covering an area of 142 ha. A total 18 evaporation ponds covered another 162 ha.



Uranium Mill Tailings: Hazards and Management

Uranium mill tailings are pumped out of uranium mills in the form of a slurry.

Radiation hazard from uranium mill tailings
The ore contains all members of the uranium-238 decay series with 14 nuclides (in addition, the ore contains the uranium-235 decay series at much lower activity levels). Only the uranium nuclides are extracted by the milling process. Therefore 85% of the radioactivity originally present in the ore remains in the tailings. After half a year, the activities of the nuclides thorium-234 and protactinium-234 m decay to the level of the residual uranium-238. The activities remain at this level for tens of thousands of years (due to the 80,000 year half-life of thorium-230).



Uranium mill tailings constitute the most serious long-term hazard generated from uranium mining, and therefore require particularly careful management. However, during the early years of uranium mining (1940s-1950s), tailings were in several cases simply released into the environment. The French company Cogéma continued this practice even into the 1970s at its Mounana uranium mine in Gabon. During its first 15 years of operation, from 1961 to 1975, Cogéma's subsidiary COMUF simply released over 2 million tonnes of uranium mill tailings into a nearby creek. These tailings formed deposits downstream in the valley. After the mine was shut down, the contaminated material was covered in place with neutral soil rather than collecting it for safe disposal.

Usually, the slurries are sent to a tailings impoundment where the solids settle. These tailings impoundments present a number of specific hazards. In the first place, there are physical hazards. For cost reasons, tailings deposits are often unstable constructions. The following are two examples of catastrophic uranium mill tailings dam failures:

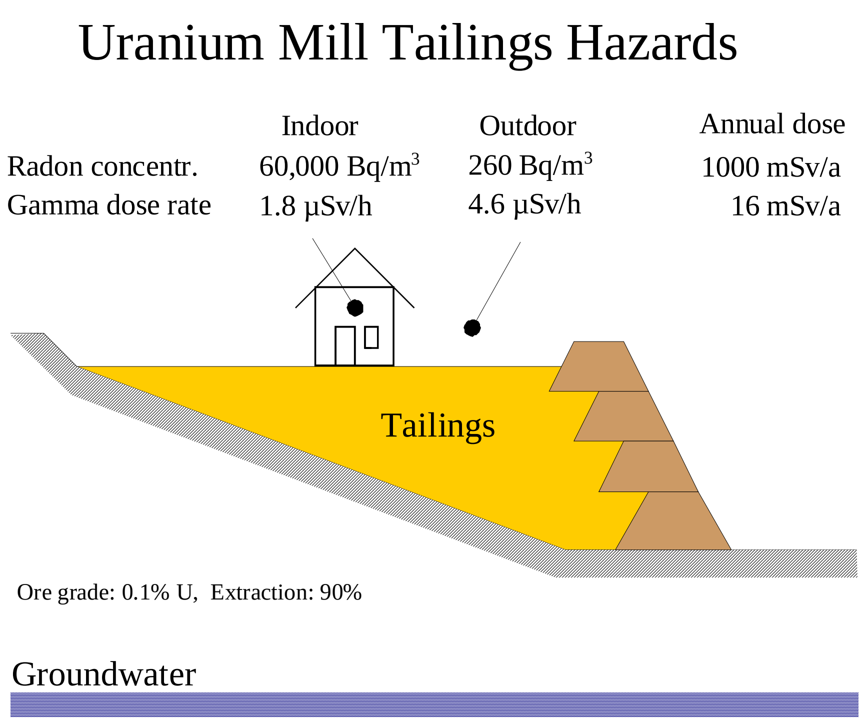
- Dam failure of Mailuu-Suu Tailing #7, Fergana Valley, Kyrgyzstan, April 1958:
The dam failed after an earthquake and heavy rain. A tailings volume of 600,000 m^3 was released. Many houses in the town were destroyed, people were killed, and the tailings were spread over 40 km down river, contaminating flood plains.

There are still 23 unsecured uranium mill tailings deposits from the Soviet era in Kyrgyzstan, located on steep valley slopes threatened by landslides. The possibility of a further disaster is not improbable.

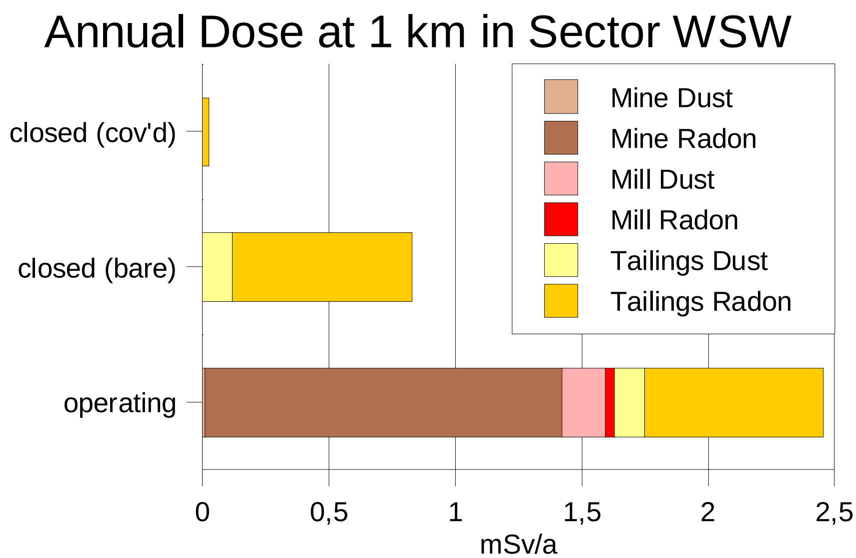
- UNC Church Rock uranium mill tailings dam failure, New Mexico, USA, July 16, 1979:
Spill of more than 1000 tons of slurry and 400,000 m^3 of contaminated water into the Rio Puerco River.

There have also been tailings dam failures in Sweden or in mines operated by Swedish companies. Examples include the following:
- Aitik copper tailings dam failure, near Gällivare, Sweden, September 8, 2000:
On September 8, 2000, the tailings dam of Boliden's Aitik copper mine near Gällivare in northern Sweden failed over a length of 120 meters. This resulted in the spill of 2.5 million cubic meters of liquid into an adjacent settling pond. Boliden subsequently released 1.5 million cubic meters of water from the settling pond into the environment to secure the stability of the settling pond. Together with this water, a certain amount of slurries were released. Seven to 8 km. of the Vassara river bed was covered with the white slurry.
- A much more serious toxic spill had occurred at Boliden's Los Frailes lead-zinc mine at Aznalcóllar in Spain. On April 25, 1998, a tailings dam failure released 4-5 million cubic meters of toxic tailings slurries and liquid into nearby Río Agrio, a tributary of the Río Guadiamar. The slurry wave covered several thousand hectares of farmland, and it threatened the Doñana National Park, a UN World Heritage Area. Nine years later, the involved parties are still struggling in courts about who is responsible for the clean-up costs.

The following hazards from tailings persist after termination of mining activities:
- gamma (and beta-) radiation is only of concern right on the deposit.
- dust blown to the surrounding areas contains radioactive and toxic constituents, such as radium-226 and arsenic.
- radon gas travels over large distances. New radon is continuously formed by the decay of radium-226. A certain fraction of the radon is released and dispersed over large areas.



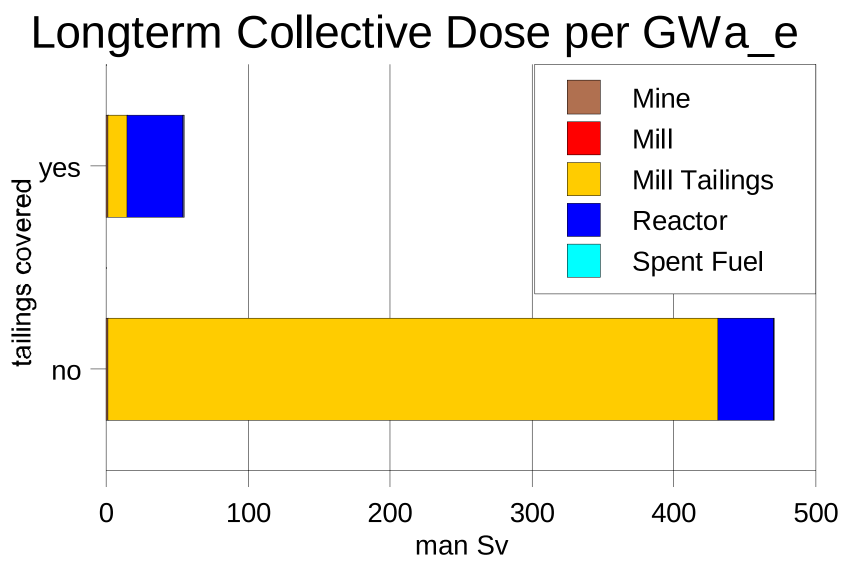
Settlements on top of tailings deposits must be prevented (in the long term!) due to the serious radiation hazard they present. However, radiation exposure is also an issue for nearby residents. Annual dose modeling for residents living near a model mine and mill are as follows:



The inhalation dose from radon and decay products to a person living 1 km downwind from a typical 1970s uranium mine and mill in the Western U.S. (annual production 1000 t U) varies according to whether the mine and mill are in operation or not. During operation the annual dose is approx 2.5 mSv, one third of which comes from the tailings. After shutdown of the mine, if the tailings remain uncovered, the annual dose is 1/3 of that during operation. If
the tailings are covered according to U.S. EPA standards, whereby dust release is stopped, then radon emanation is reduced to 0.74 Bq/m^2s (corresponding to a radon retention of 97% in this case).

To assess the long-term health hazards for future generations, global long-term collective dose modeling is used. This type of modeling takes into account the front and rear ends of the nuclear fuel cycle and the nuclear power plant. A linear no-threshold dose effect is assumed for these calculations. It shows the global long-term collective dose per GWa_e (= 8.76 TWh_e) produced; this is the approximate annual electricity production of a large 1300 MW_e nuclear power reactor.

With the tailings left uncovered after shutdown, 91% of the global collective dose comes from the abandoned tailings. Each year of reactor operation causes 23 deaths from cancer in the long-term. With a tailings cover that limits the radon-222 emission rate after mill shutdown to the U.S. EPA standard of 0.74 Bq/m^2s, the global collective dose is reduced by a factor of nine, given that the tailings cover stays intact for thousands of years. In this case each year of reactor operation is causes 3 deaths from cancer in the long-term, and 72% of the dose is caused by the reactor operation, mainly from the release of carbon-14.



The largest uranium mill tailings deposit in Europe is the Culmitzsch deposit in Thuringia, Germany, containing 90 million t, covering a surface area of 2.5 km^2. Installation of a preliminary cover started after 1990.

In the U.S., a multilayer soil/rock cover scheme was developed for the long-term management of uranium mill tailings deposits designed to meet the following requirements:
- stop radon emanation,
- stop infiltration of precipitation,
- minimize susceptibility to intrusion and erosion, and
- provide protection for 200 - 1000 years without active maintenance.

Such covers were applied at a number of legacy sites that were reclaimed by the government, as well as at sites that were reclaimed by their former operators, such as Rio Algom's Ambrosia Lake site in New Mexico, where 30 million t of tailings are now confined in one large disposal cell.

In Canada, such soil/rock covers are considered too expensive. There, water covers were applied in some cases as a low-cost alternative; for example at the Rio Algom Quirke Tailings in Elliot Lake, Ontario, containing 46 million t and covering a surface area of 192 ha. Several intermediate dykes were installed on the surface of the tailings to maintain the water cover in spite of the top slope.

In fact, a water layer of 2 metres limits radon emission effectively (unless it becomes ice), but it is difficult to maintain in the long-term, it causes continual seepage, and it provides no physical protection.

Another hazard caused by uranium mill tailings is the release of seepage containing radioactive and toxic constituents. An example of tailings seepage is the contamination of shallow groundwater at the Pécs uranium mill tailings in Hungary. There are two basins both measuring 1 km^2. One basin is only partly filled and contains 20.4 million t. There is no liner installed beneath the tailings. The high Total Dissolved Solids (TDS) values of 20 g/l and more result from insufficient neutralization of the acidic tailings, causing seepage of process chemicals, such as $MgSO_4$, NaCl, etc. The groundwater contaminant plume is migrating towards the drinking water wells of the city of Pécs (170,000 inhabitants). Since 2001, the contaminant plume has been intercepted by a pump-and-treat scheme.

Another example of tailings seepage is the Atlas tailings pile in Moab, Utah, USA. It contains 10.8 million t and is located on the banks of the Colorado River which supplies drinking water to millions of Americans downstream. There is permanent seepage into the Colorado River, and in addition, a hazard from flooding. After years of discussion, a decision to relocate over a distance of 50 km. to a safer disposal site was taken in 2005.

Site owner Atlas Corp. had set aside approx. US$10 million for onsite reclamation, but relocation will cost more than US$300 million – to be paid by tax payers. Due to budget constraints, the relocation of the tailings will now take five times longer than initially projected, potentially dragging on through 2028.

Tailings disposal in open pits has the advantage of fewer problems from erosion, but groundwater contamination remains an issue. Three examples follow.

Example 1: tailings disposal in Bellezane open pit mine (France). Tailings disposal above groundwater level in a former open pit mine - drainage water has to be treated before release , in the long term.

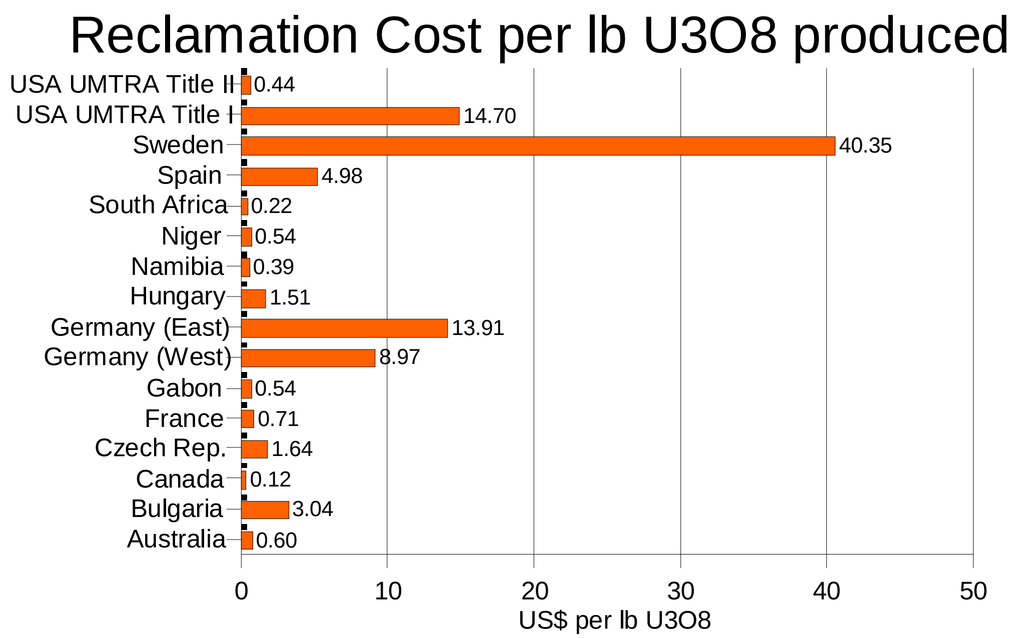
Example 2: tailings disposal in Deilmann open pit, Key Lake, Saskatchewan, Canada (Cameco). The Canadian low-cost alternative is tailings disposal *in* groundwater in a former open pit mine, so-called pervious surround disposal. The pit was lined with high-permeability material prior to disposal. No groundwater contamination is anticipated by the proponents, since the permeability of the tailings material is lower than that of the surrounding layer.

Example 3: tailings disposal in JEB open pit, McClean Lake, Saskatchewan, Canada (Areva, formerly Cogéma). This even lower-cost version of pervious surround disposal was established by Areva/Cogéma in the former JEB open pit. There is no artificial pervious layer at all. The surrounding rock is to serve as pervious surround.

The reclamation cost of uranium mill tailings per lb. U_3O_8 produced (after [BMWi 1995]) spans a very wide range and depends on the following:
- the protection standards applied,
- whether reclamation was performed continuously during mine operations, or whether an abandoned legacy site had to be managed,
- various other factors.

With their reclamation costs of US $40.35 per lb. U_3O_8 produced, Sweden is world champion by a wide margin! Nevertheless, the Ranstad tailings cover does not perform as anticipated, and seepage still has to be treated before being released.

A comparison of the reclamation costs to the historical price range for fresh uranium, from 7 to 113 US$ per lb. U_3O_8, shows that at certain points in time, in several cases, the cost of reclamation was higher than the value of the uranium mined.



Uranium in-situ leaching

An alternative to conventional mining is in situ leaching (ISL), or solution mining. ISL currently provides approx. 20% of world uranium production. With in-situ leaching, the ore remains in place underground, a leaching solution is injected into the deposit, and the uranium bearing liquid is pumped to the surface for further processing. Here are two examples:

Example 1: Stráz pod Ralskem, Czech Rep. in situ leaching (shut down after 1990), area 5.74 km^2, approx. 4 million t of sulfuric acid as well as other chemicals were injected.

Example 2: Large scale in-situ leaching facility in Zarafshan, Uzbekistan.

At present, Kazakhstan is making a big effort to increase its uranium in-situ leaching capacities for European customers.

The uranium is recovered from the solution pumped out of the deposit in a sorption plant. An example is the Alta Mesa ISL sorption plant, Texas, USA (Mesteña Uranium LLC) with a designed capacity of 385 t U/a, in operation since October 2005.

In-situ leaching only functions with deposits located in permeable sandstone that are not too deep below the surface (approx. 200 m). To prevent the spread of leaching solution, the ore zone must be confined by impervious layers. Waste solutions arising from the uranium recovery plant are either dumped in surface impoundments or in deep disposal wells. There are no conventional mining hazards from ISL, but there are environmental hazards such as the release of mining solution to aquifers used to supply potable water. At the Czech Stráz ISL site, for example, 28.7 million m^3 of groundwater were contaminated in the leaching zone, and another 235 million m^3 of groundwater were contaminated in the upper aquifer.

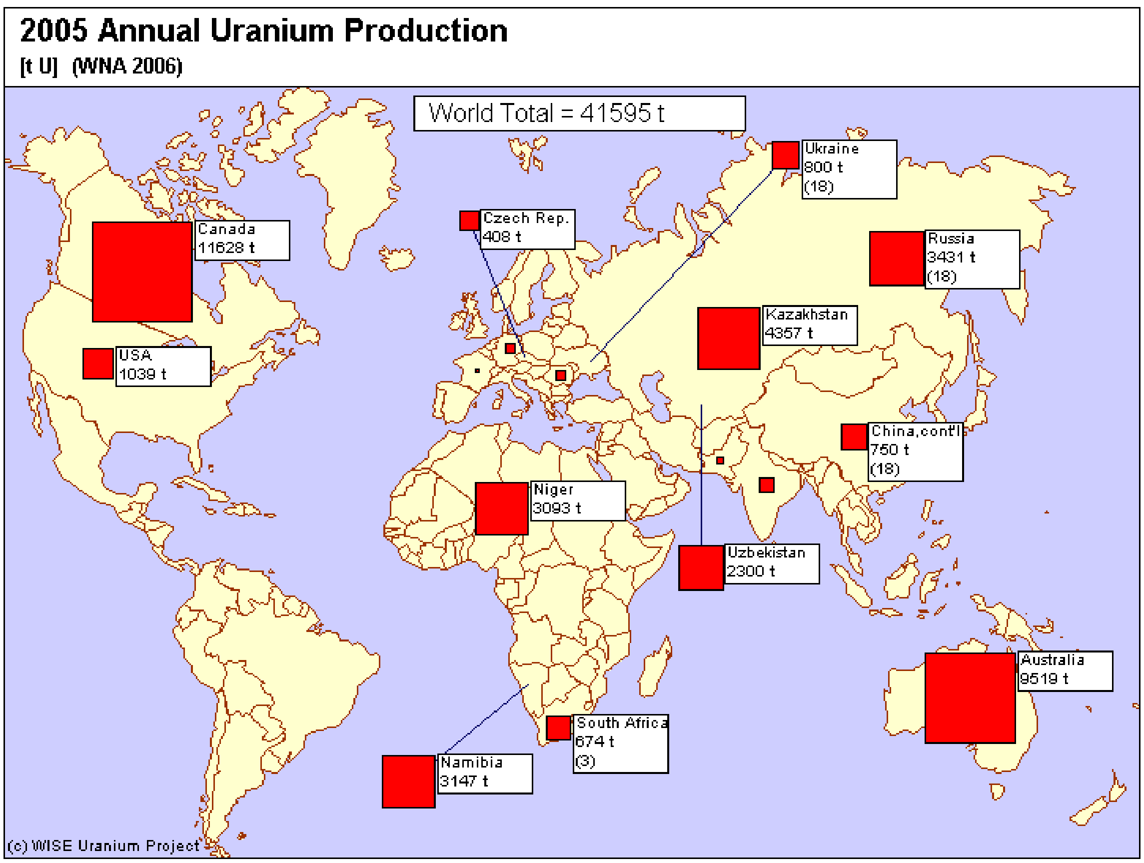
Experience with the decommissioning of various uranium in-situ leach sites in Wyoming and Texas (USA) shows that groundwater restoration to pre-mining conditions is virtually impossible, even after 10 or more years of groundwater pumping and treatment. Instead, the authorities in charge establish site-specific “alternate” groundwater standards. In Nov. 2006, an examination of 32 permits from closed South Texas in-situ leach mines showed that in each case, companies were permitted to leave behind minerals such as uranium, molybdenum and selenium at higher levels in groundwater than were listed in the original permit.

At the ISL site of Tzarimir, Bulgaria, the low cost alternative for ISL decommissioning: was used: the entire wellfield was abandoned. No groundwater restoration was undertaken at all. Is this what we have to expect once the huge in-situ leaching facilities are shut down that are now under construction in Kazakhstan? Kazakhstan hasn't even started cleaning up the mess left behind from uranium mining during the Soviet era.

Uranium Resources and Supply

The final product from uranium milling is Yellow Cake: U_3O_8 in the chemical form of ammonium-diuranate, or sodium-diuranate, with impurities. This is the form in which uranium is traded worldwide and shipped to plants for further processing.

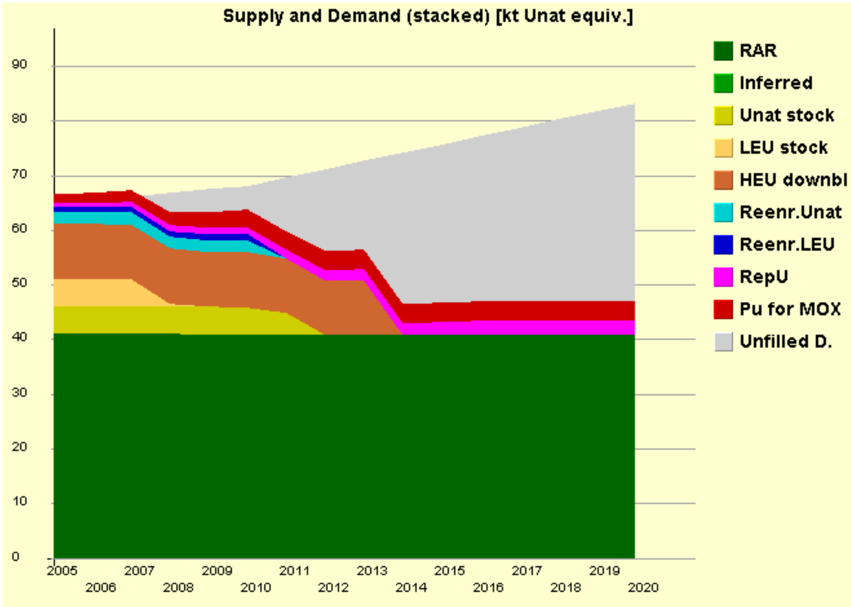
In 2005, world production from mines (41,595 t U) supplied only 62% of the demand (66,840 t U).



The downblending of highly enriched uranium (HEU) obtained from dismantled nuclear weapons is currently the main source filling the supply gap.. The current downblending contracts between the U.S. and Russia expire after 2013, so at that time the supply gap may worsen considerably.

With the depletion of secondary supplies, additional uranium mining would be required to fill the supply gap looming in the next decade. As development of a new uranium mine easily requires 10 or more years, time may be running short to attain the required production increase.

The uranium spot market price, in response, started climbing from a low of US $7.10 per lb U_3O_8 at the end of 2000 to US $113 on April 6, 2007, making the exploitation of low grade deposits viable.



As a first reaction, several mine operators are now planning to extend the lifetime of mines that were supposed to be closed in the near future due to the depletion of the mineable mineral resources. One example is the planned extension of the Rössing open pit (Namibia) to mine low-grade material. Similar plans are being made for the Ranger uranium mine in Australia.
With the mining of lower grade material, the amount of tailings generated will increase disproportionately. The already gigantic Rössing tailings dam is therefore to be extended by 300 ha.

A first new uranium mine was licensed in Namibia at breath-taking speed in 2005: Paladin Resources' Langer Heinrich mine, located in the Namib Naukluft park. The environmental impacts of the project, however, were not adequately assessed during this record-breaking licensing process. Furthermore, mining companies are not required to pay into any reclamation bonds in Namibia, so the government will be left with the mess once the company goes bankrupt.

Paladin acquired the deposit some years ago at costs of US $15,000. Now, since the increase in the price of uranium has made the mining of the deposit viable, the uranium in the deposit is worth more than US $1 billion. The Langer Heinrich mine was officially opened in March 2007. Planned production is 933 t U/a for at least 10 years.
Paladin is now planning to open its next uranium mine in Malawi.

The next project in Namibia is Trekkopje (UraMin Inc.) The feasibility study for the project is to be completed by the end of 2007, with production planned to start at the end of 2008. Since local water resources are insufficient, a desalination plant will have to be built at the coast to supply water to the mine. Apparently, UraMin even wants to top Paladin's breath-taking speed-up of the licensing and construction processes.

At present, uranium exploration companies experience no problems raising funds for their projects. Investors, on the contrary, are queuing up wherever someone announces an opportunity to invest in a uranium project.

After a 20 year long decline of the uranium industry, uranium exploration activities are now booming, but it is unclear whether this will result in sufficient mine production in time. One point is however clear. With the economical viability of decreasing ore grades, the environmental impacts from future uranium mining are likely to increase.

With the increase in uranium prices, some famous large, but low-grade, uranium deposits are becoming attractive again - those located in black shales.

Table 1: Examples of black shale uranium deposits [IAEA 2001]

Location	**Area** [km^2]	**Uranium resource** [t U]	**Grade** [ppm U]
Ronneburg, Germany	164	169,230	850 – 1,700
Ranstad, Sweden	500	254,000	170 – 250
Chattanooga Shale, USA	80,000	4 – 5 million	57

In the case of Ranstad, more than 1 billion tonnes of tailings would result!

However, the International Atomic Energy Agency is skeptical that these deposits will ever be mined: "While the black shale deposits represent a large resource, they will require very high production costs, and their development would require huge mines, processing plants and mill tailings dams, which would certainly elicit strong environmental opposition. In addition, the Ronneburg area is currently the subject of the multibillion dollar Wismut reclamation project. Therefore the black shale deposits represent a long term resource that will require market prices in excess of US $130/kg U to be economically attractive, assuming environmental opposition could be overcome, which is by no means certain for any of the three deposits mentioned above." [IAEA 2001]

The economic criterion stated is fulfilled already: the spot market price (April 6, 2007) of US $113 per lb U_3O_8 corresponds to US $293.80 per kg U, more than twice the level stated. Therefore, it must be anticipated that the uranium companies won't simply give up even though the exploration licenses in Skaraborg were denied...

References

[IAEA 2001] Analysis of uranium supply to 2050, IAEA 2001, p.65

[BMWi 1995] Kosten der Stillegung und Sanierung von Urangewinnungsprojekten im internationalen Vergleich - Einflußgrößen und Abhängigkeiten - Auszug aus dem Abschlußbericht zum Forschungsauftrag Nr.37/93, im Auftrag des Bundesministeriums für Wirtschaft durchgeführt von Uranerzbergbau GmbH, BMWi Studienreihe Nr.90, Bundesministerium für Wirtschaft, Bonn 1995 [Comparison of Decommissioning and Cleanup Costs of Uranium Producing Projects on an International Basis; with summaries in English, French, Spanish, and Russian]

For details, see also:

WISE Uranium Project
http://www.wise-uranium.org/