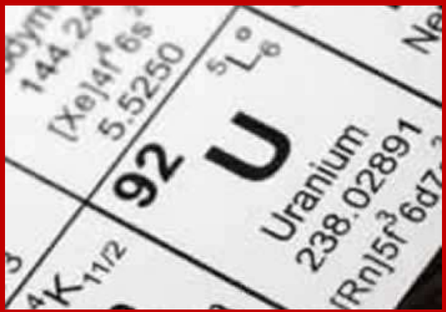
Uranium Resources and Wastes



"I began more carefully to look around me. A serious study of the soil was necessary to negate or confirm my hypothesis."

—Henry Lawson in "Journey to the Center of the Earth" by Jules Verne.

About Uranium (klaprothium?)

Uranium has an atomic number of 92, and was discovered by a German chemist named Martin Klaproth in 1789. He named it after the newly discovered planet Uranus.

There are currently 28 known isotopes of uranium yielding an atomic mass of 215 to 242.

About Uranium

Only three isotopes occur naturally:

Uranium-238 (99.284%)

Uranium-235 (0.72% and is fissile: capable of sustaining a nuclear chain reaction).

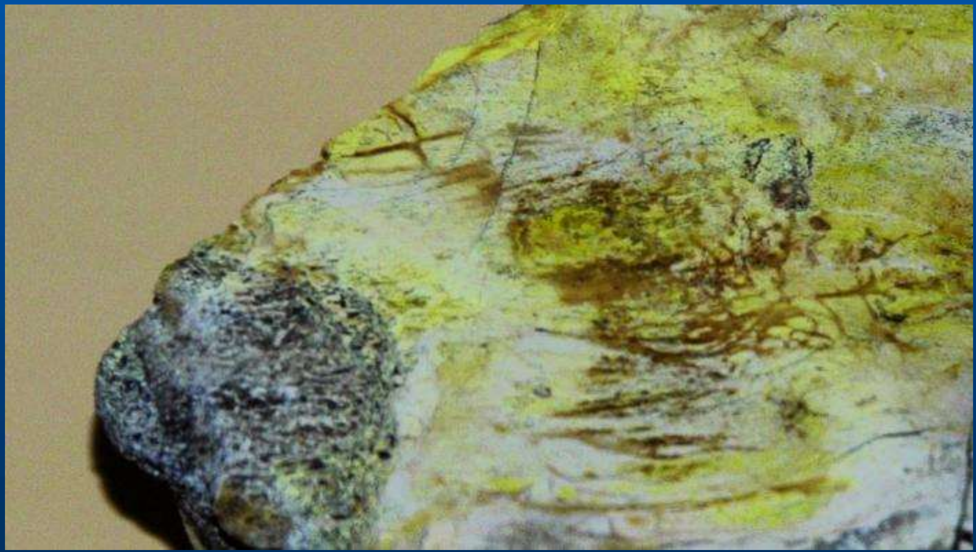
Uranium-234 (0.0055%)

Isotopes with masses 215 to 228 have short (≤ 9.1 minutes) and decay to thorium as

$$^{n}\mathrm{U} \rightarrow {}^{n-4}\mathrm{Th} + \alpha$$

About Uranium

Although a typical as-mined sample of uranium is mostly ^{238}U, and is radioactive because of alpha decay, the half-life of the reaction is comparable to the age of the Earth (circa 4.54 Ga).



Uranium ore versus waste

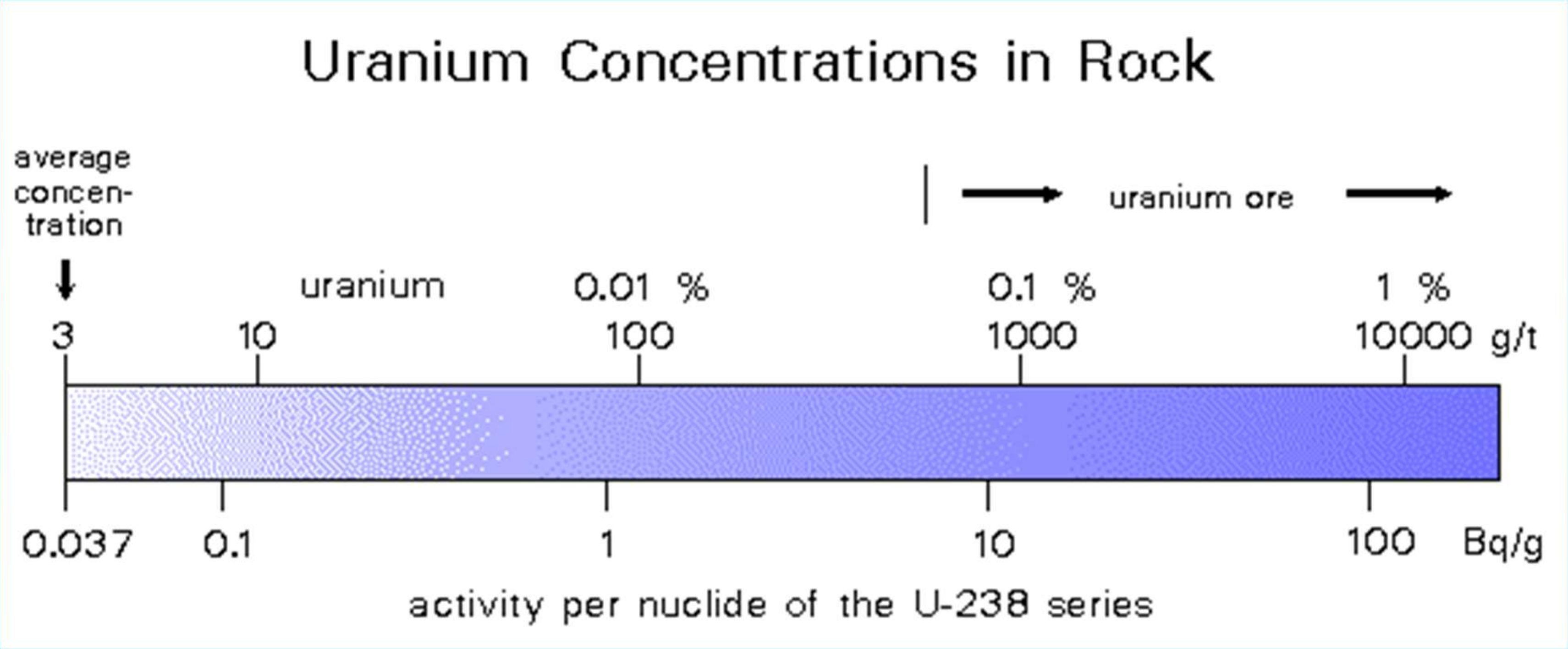


Table 1: Typical natural uranium concentrations

Very high-grade ore (Canada) – 20% U	200,000 ppm U
High-grade ore – 2% U	20,000 ppm U
Low-grade ore – 0.1% U	1000 ppm U
Very low-grade ore* (Namibia) – 0.01% U	100 ppm U
Granite	3-5 ppm U
Sedimentary rock	2-3 ppm U
Earth's continental crust (av)	2.8 ppm U
Seawater	0.003 ppm U

ppm = parts per million

Uranium Ores

Mineral	Chemical composition
Autunite	$Ca(UO_2)_2(PO_4)_2 \cdot 10\text{-}12H_2O$
Brannerite[1]	UTi_2O_6
Carnotite	$K_2(UO_2)_2(VO_4)_2 \cdot 1\text{-}3H_2O$
Torbernite	$Cu(UO_2)_2(PO_4)_2 \cdot 12H_2O$
Tyuyamunite	$Ca(UO_2)_2(VO_4)_2 \cdot 5\text{-}8H_2O$
Uranophane	$Ca(UO_2)_2(HSiO_4)_2 \cdot 5H_2O$

Uranium Resources

The World Nuclear Association (2020) estimated that the world's known resources of uranium are 6,147,800 tonnes U.

In 2020 Kazakhstan produced the largest share of uranium from mines (41% of world supply), followed by Australia (13%) and Canada (8%).

In 2019, the U.S. produced 6 tonnes of (0.01% of the world demand: 47,731 tonnes).

Figure 1.1. **Global distribution of identified resources**

Uranium Resources

Australia: Mined 6,203 tonnes of U in 2020. Has largest reserves on earth: about 28% of the earth's uranium (1,692,700 tonnes uranium)

Kazakhstan has 15% of the world's resources.
The U.S. has 47,900 tonnes of U (1%).

Why some areas have more uranium than others

Igneous rocks were/are close to the surface because of tectonic uplift (mountain building).

Areas of near-surface magma uplifts.

Once exposed at the surface, the igneous bedrock was eroded. Uranium concentrated.

Australia:

70% granitic breccia derived from uranium enriched granites and volcanic rocks.

19% unconformity-related deposits.

Background Levels

Ore-forming processes

Leaching of U(VI) then precipitation as U(IV)

U-enriched igneous rocks (granite)

Hydrothermal deposits

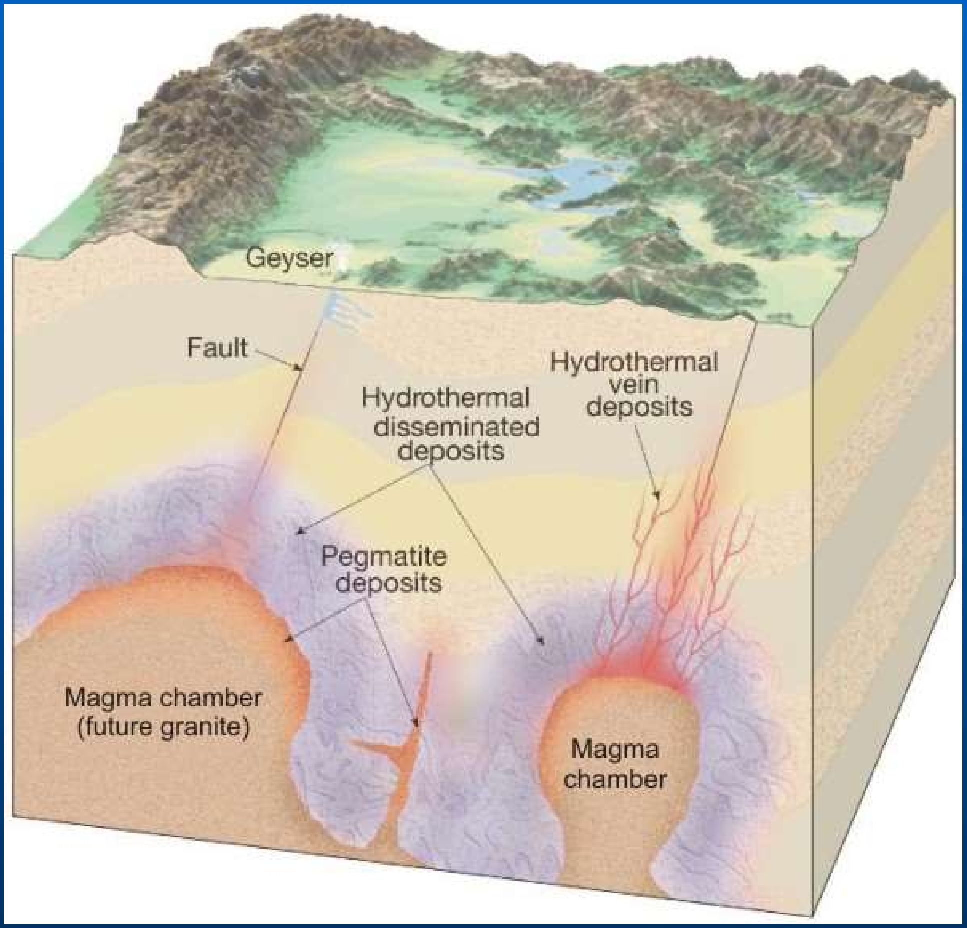
Geological processes that redistribute concentrated U

Erosion/ transport

Sandstone with U

Stratigraphic unconformities (weathering that leaves breccia or conglomerates or precipitation of dissolved U)

Hydrothermal deposits

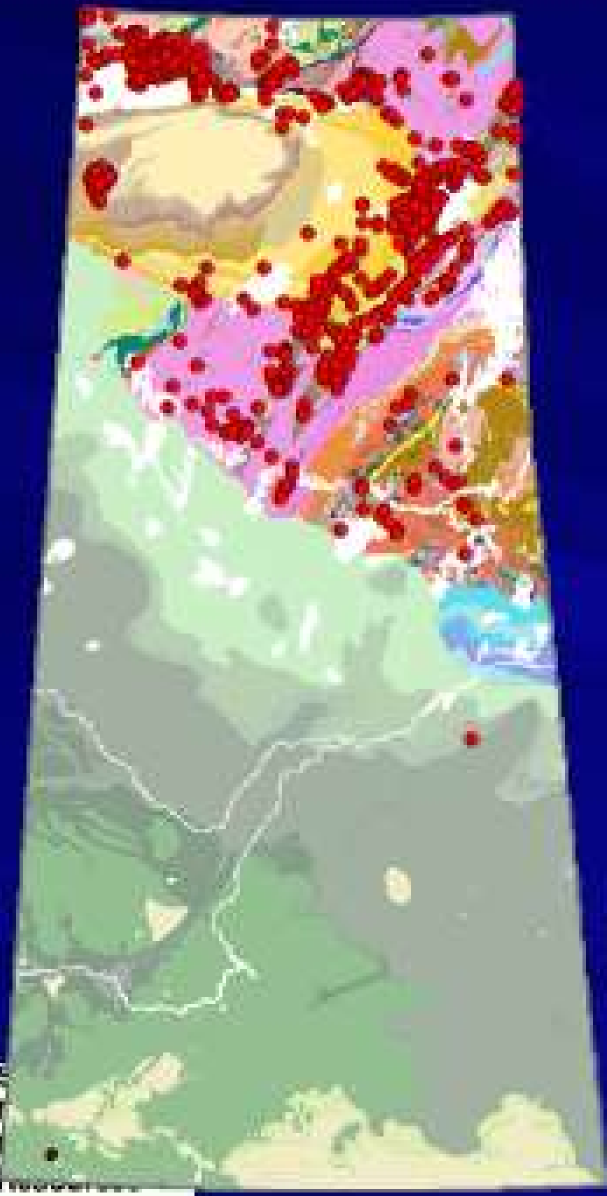


Metallic minerals formed by the precipitation from hot mineral-laden water (hydrothermal solution). The solutions arise in most cases from the deep groundwater heated by magma.

Unconformity

An unconformity is a buried erosional or non-depositional surface separating two rock masses or strata of different ages. Uranium-rich breccia may be present at the contact.

Saskatchewan Uranium



- Variety of Types:
  - Unconformity
  - Vein
  - Pegmatite
  - Shale
  - Sandstone/Lignite

www.er.gov.sk.ca

Uranium Production Terms

Mines/Extraction

In-Situ Leaching/Recovery

Yellow cake

Underground

Mills

Open-surface

pits

Waste rock

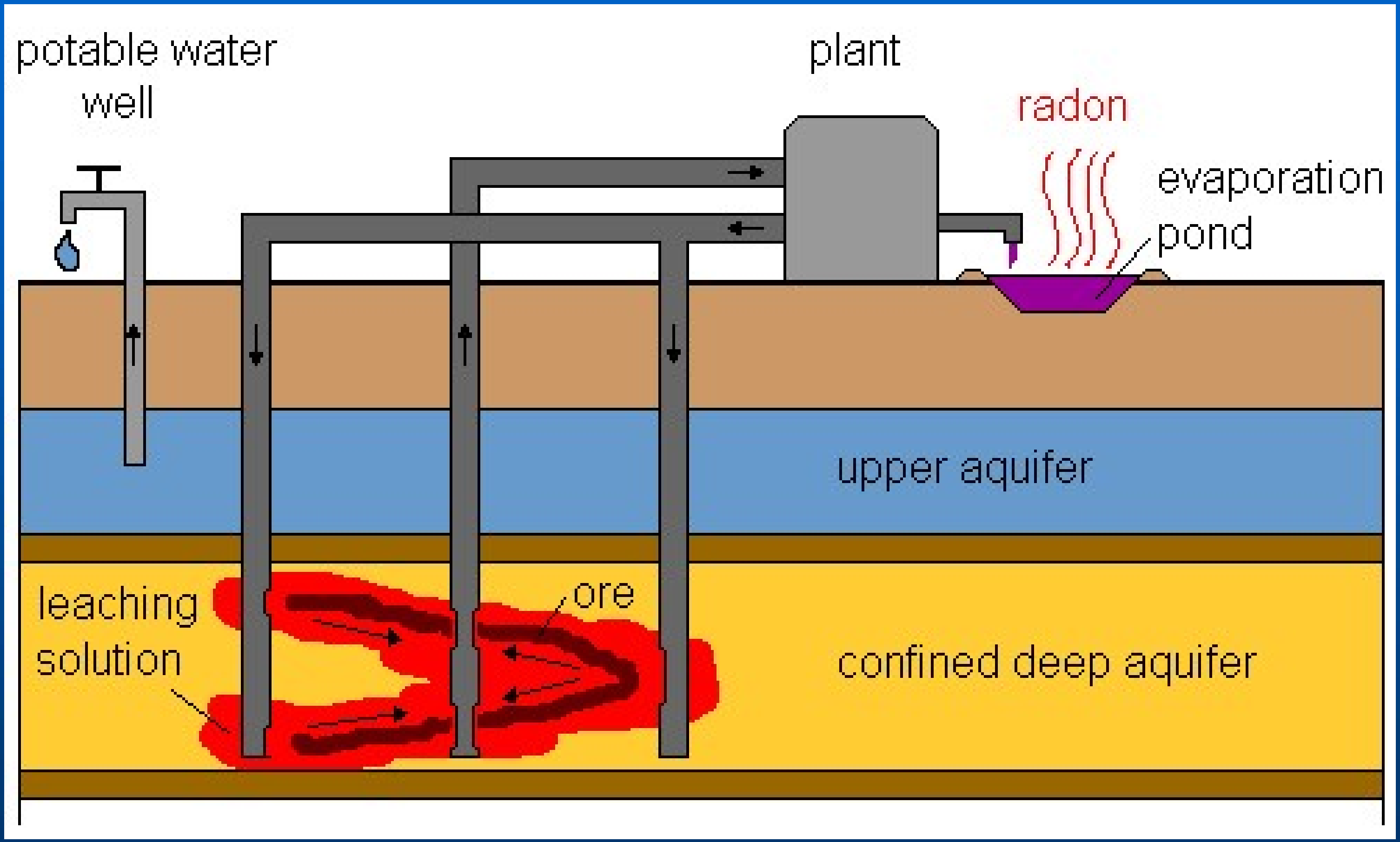
Tailings (Residual Radioactive Material)

Uranium Extraction (Global)

In-Situ Leaching 55%

Underground mines and open pits 38%

In-Situ Leaching



http://www.youtube.com/watch?v=1tnvg6wx6U8 (1:47)

Uranium Mines

The largest active mine in the world:
Cigar Lake Mine in Saskatchewan, Canada.
480-m deep underground mine.
U as pitchblende/uraninite
Commissioned in 2014
Ore quality: 16.2% U_3O_8
Produced 8,165 tonnes of U_3O_8 in 2019

Uranium Mines

Olympic Dam Mine in South Australia.

Underground mine.

Discovered in 1975

Ore quality: 0.2% U_3O_8

Produced 43,565 tonnes of U_3O_8 in 2018-19. Also produced copper, silver and gold.

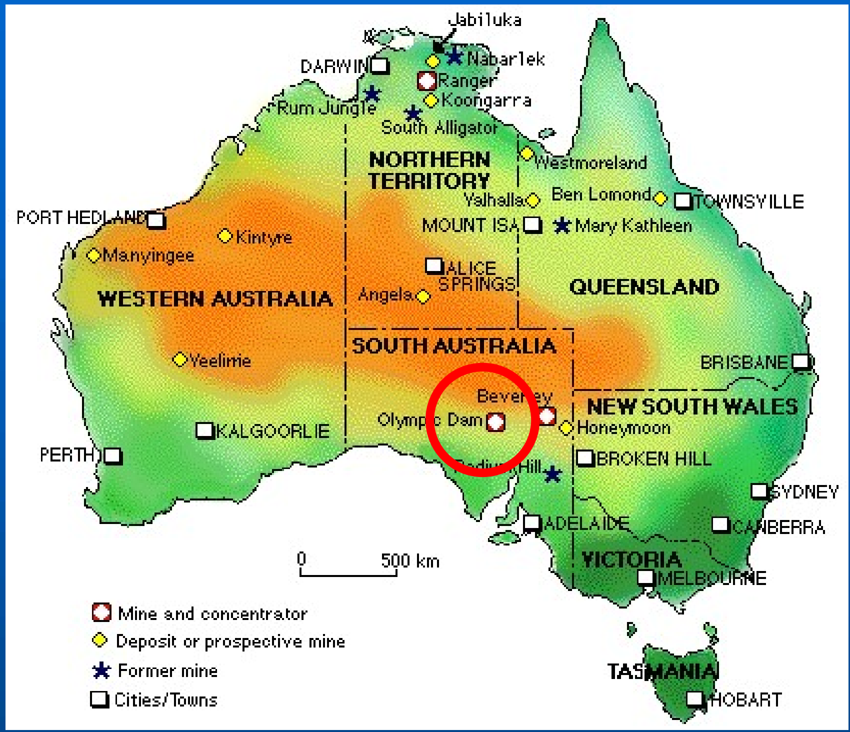


Figure 1.5. **Uranium production in 2018**

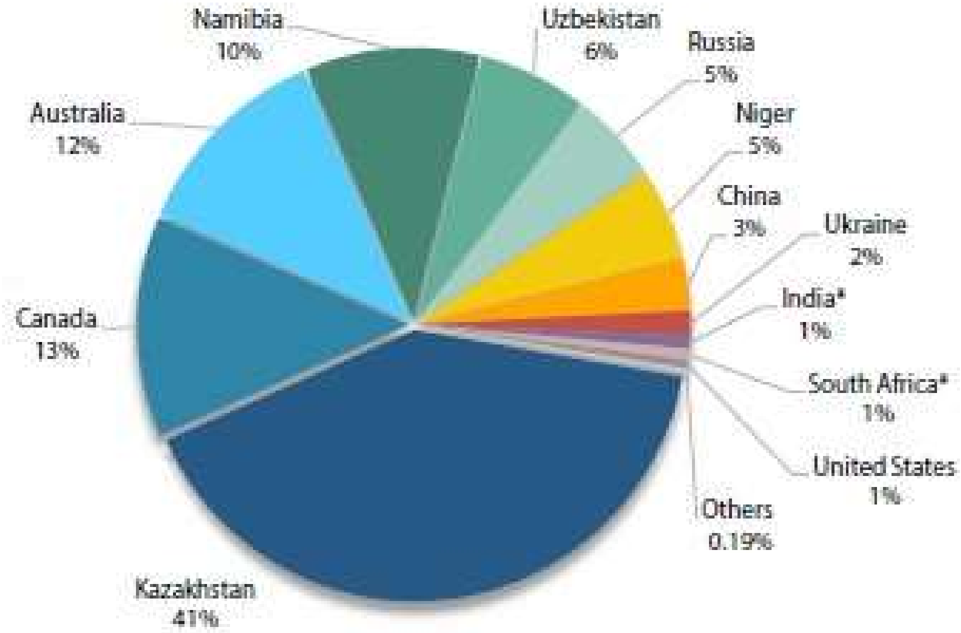
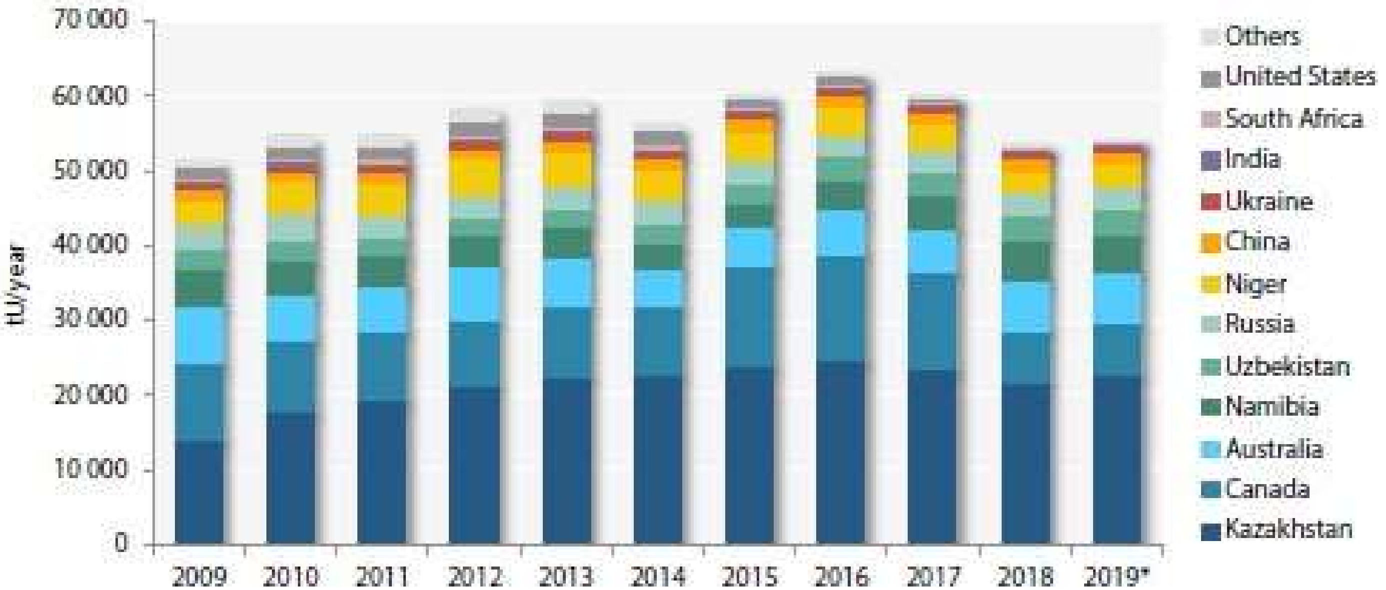
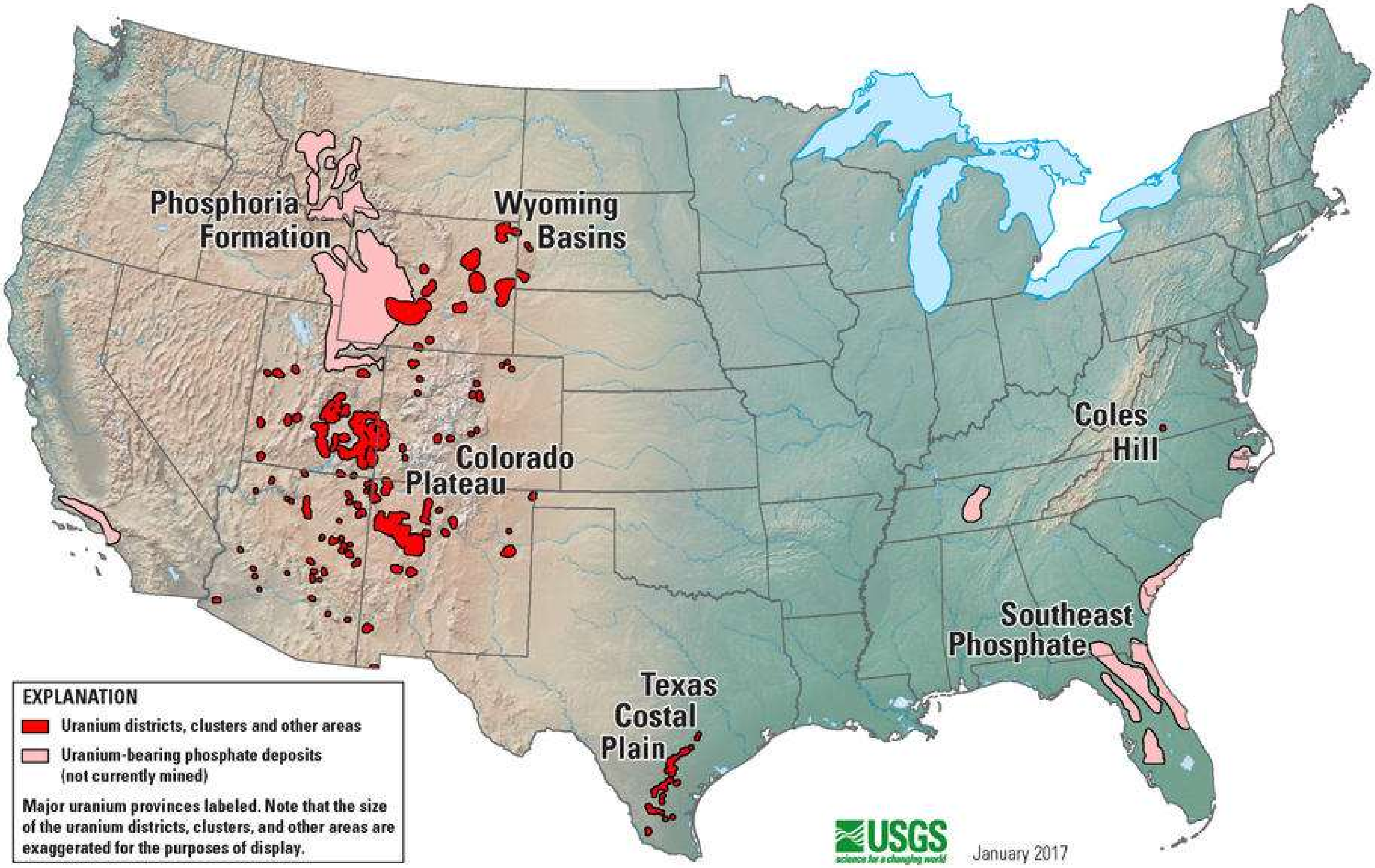


Figure 1.6. **Recent world uranium production (tU/year)**



Uranium Resources of the United States



Active U.S. Mines (2020)

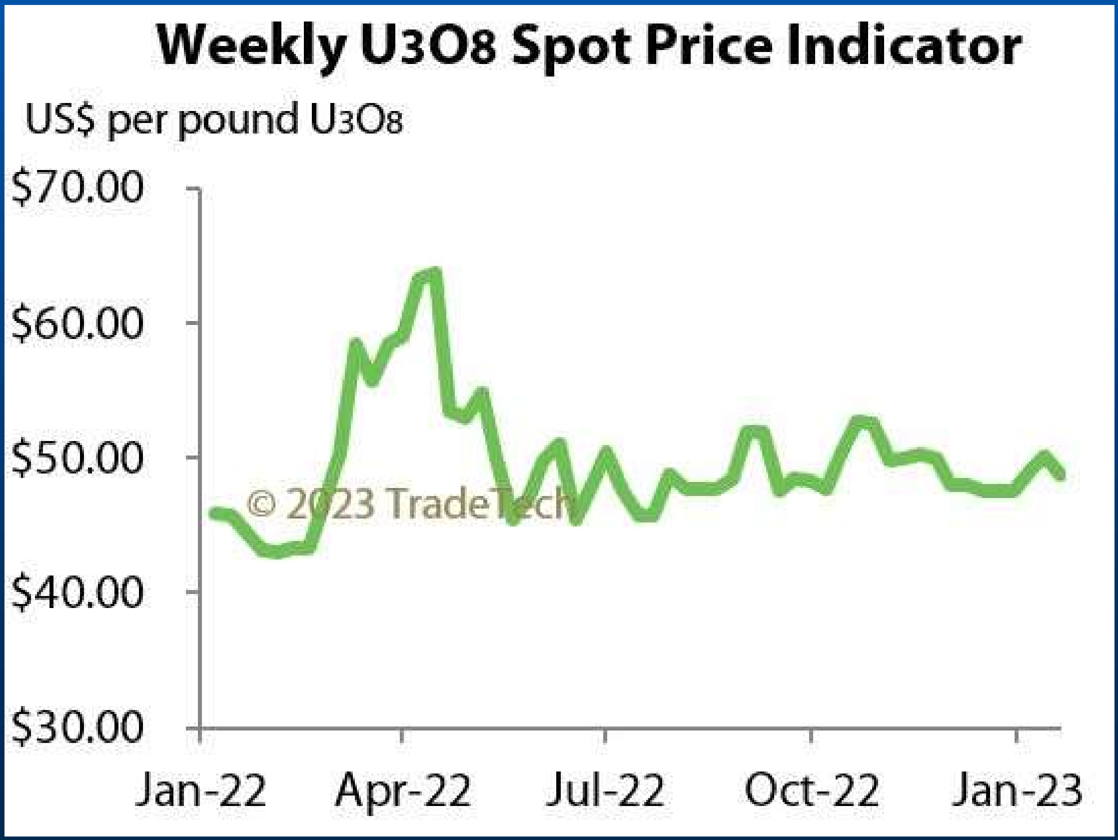
No update available for 2023

State	Mine (ISL)	Details
Wyoming	Lost Creek	20 tonnes
	Lance	21 tonnes
	Nichols Ranch	27 tonnes
Utah	White Mesa Mill	86 tonnes

Uranium Prices

Jan. 15, 2022 $46.50/pound as U_3O_8

Feb. 6, 2023 $47.68/pound as U_3O_8



Uranium prices increased

"Political unrest and violent protests in Kazakhstan, responsible for 40% of global uranium supply, sparked fears that production could be jeopardized. Hence, fears of nuclear fuel shortages spurred physical uranium funds to ramp up their stocks."

Uranium prices increased

"Market Dynamics
The industry at large remains in a state of oversupply and producers continue to feel pressure to reduce costs and preserve margins."

However . . .

U.S. uranium production could increase!

"Could Russia's invasion of Ukraine revive U.S. uranium mining?"

"Russia's role in world's nuclear energy industry prompts calls to up U.S. uranium production."

How long will the supply of uranium last?

Not an easy question. We are not sure how much is available, and the answer will depend on how we use it in the future.

Some previous assessments have been completely wrong!

How long will the supply of uranium last?

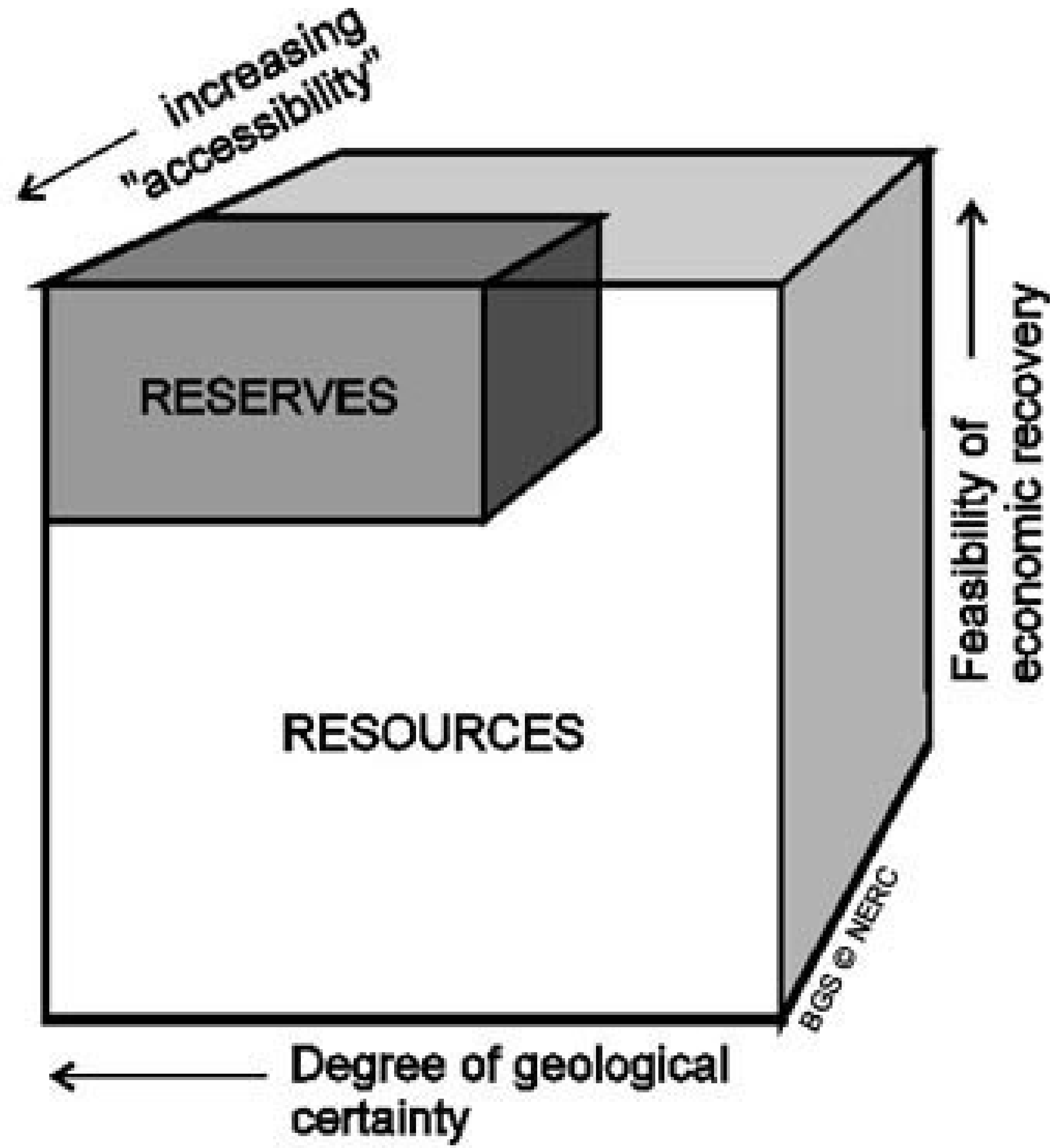
Terms to know first:

Reserves: known volume and concentration of uranium (ore); economical to mine.

Resources: suspected uranium deposits based on geology; undiscovered; uneconomical to mine.

Secondary sources: Reprocessed uranium, depleted uranium, decommissioned nuclear weapons.

Unconventional resources: uranium-rich coal ash, oil shale, seawater.


increasing
"accessibility"
RESERVES
RESOURCES
Feasibility of
economic recovery
BGS © NERC
Degree of geological
certainty

How long will the supply of uranium last?

Source of estimate	Scenario	Year of depletion
European Commission	Light-water reactors (LWR), all known resources plus secondary sources	2043 2073
Australian Uranium Association	"Present measured resources"	2079
Organ. for Economic Co-op Devel. (OECD)	All known sources plus undiscovered With breeder reactors	2087 2273 10503
International Atomic Energy Commission. (IAEA)	Known reserves, once-through. Plus secondary, undiscovered, unconventional sources	2107 49007
Cohen (1983)	Fast breeder reactors plus extracting uranium from sea water.	5 billion years

Uranium in Sea Water

The average concentration of uranium in sea water is about 3.3 μg/L.

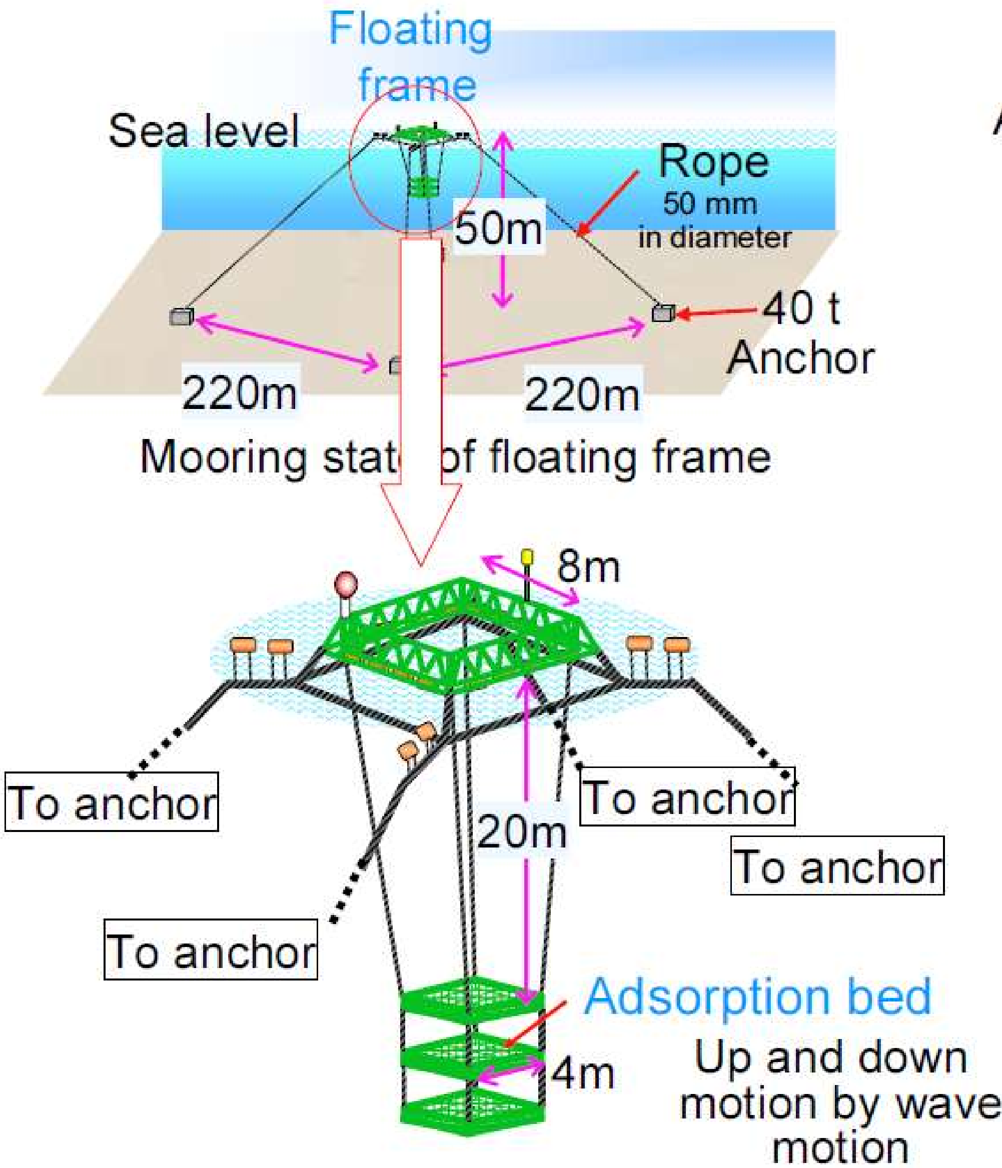
However, it is estimated that there are 4.5 billion metric tonnes of uranium in all the oceans.

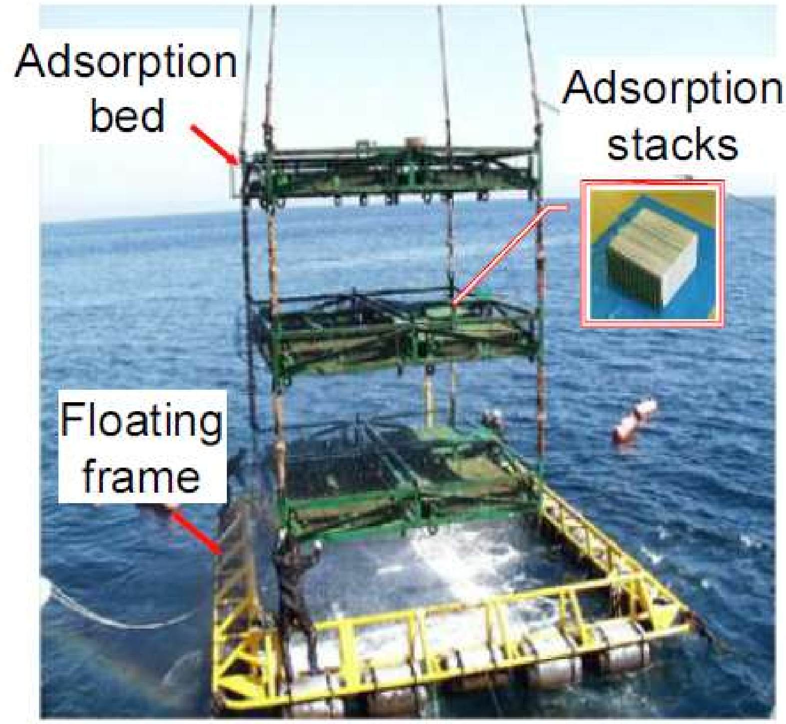
How to recover this uranium? Uranium-specific sorbents tested as fabric stacks and cages.

Dip, retrieve, then extract.

Not economical at present.

Marine equipment for uranium recovery





Drawing up of adsorption bed packed with adsorbent stacks at northern sea in Japan

(350 kg in three adsorbent beds)

Uranium Waste Rock

Most mines in the U.S. are in the west, and thus so are the wastes. Waste rock from mining. The non-ore rock that must be removed to access the ore.

In open pit mines, the ratio of waste-to-ore may be 40:1 or greater. That is, for each ton (0.91 tonne) of U ore, there will be 40 tons (36.3 tonnes) of waste rock.

Uranium Waste Rock

Example: an open pit at the Key Lake mine in Saskatchewan, Canada produced 3.67 tonnes of U ore (1.95% U) and 79.6 tonnes of waste rock. Now mined out.

The choice of pits or underground mines depends on depth of the ore.

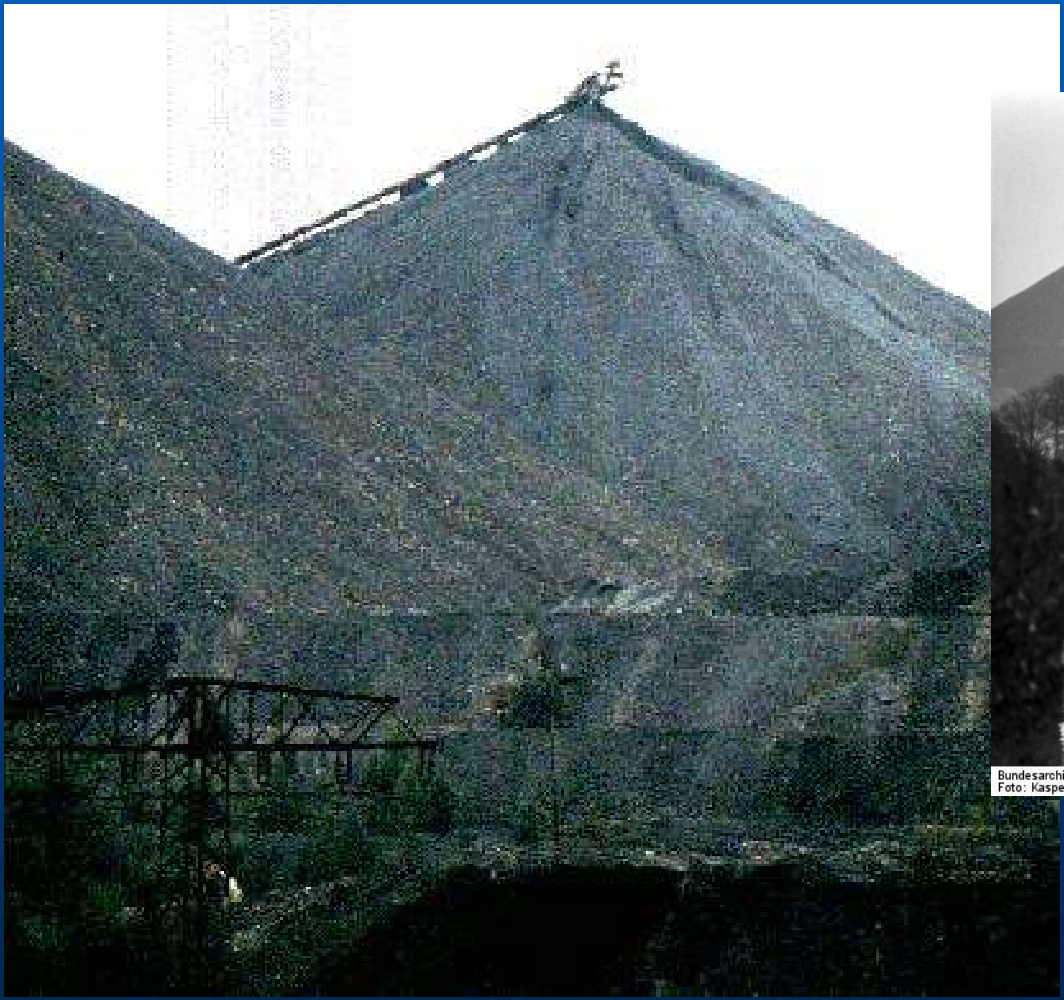
Underground mines are more expensive.

Uranium Waste Rock

Historically

The waste rock was abandoned on-site as piles on the surface (not unique to U mining). Some waste rock contained sulfide minerals which oxidized to form sulfuric acid. These piles are sources of heavy metals and threaten surface and groundwater quality.

The waste rock "pyramids" in former East Germany



Uranium Waste Rock

Today there are on-going efforts to remediate old piles. The waste rock is graded on the surface, covered with soil, and re-vegetated.

Sometimes placed in flooded, mined-out excavations.

Tailings from (milling)

Material left after removing the ore.

The ore is crushed, then leached with sulfuric acid. The remaining solids are then washed with water, and the slurry is pumped to a retention pond in which the water evaporates, and the solids settle in the pond or are stored as a pile.

The basics about milling

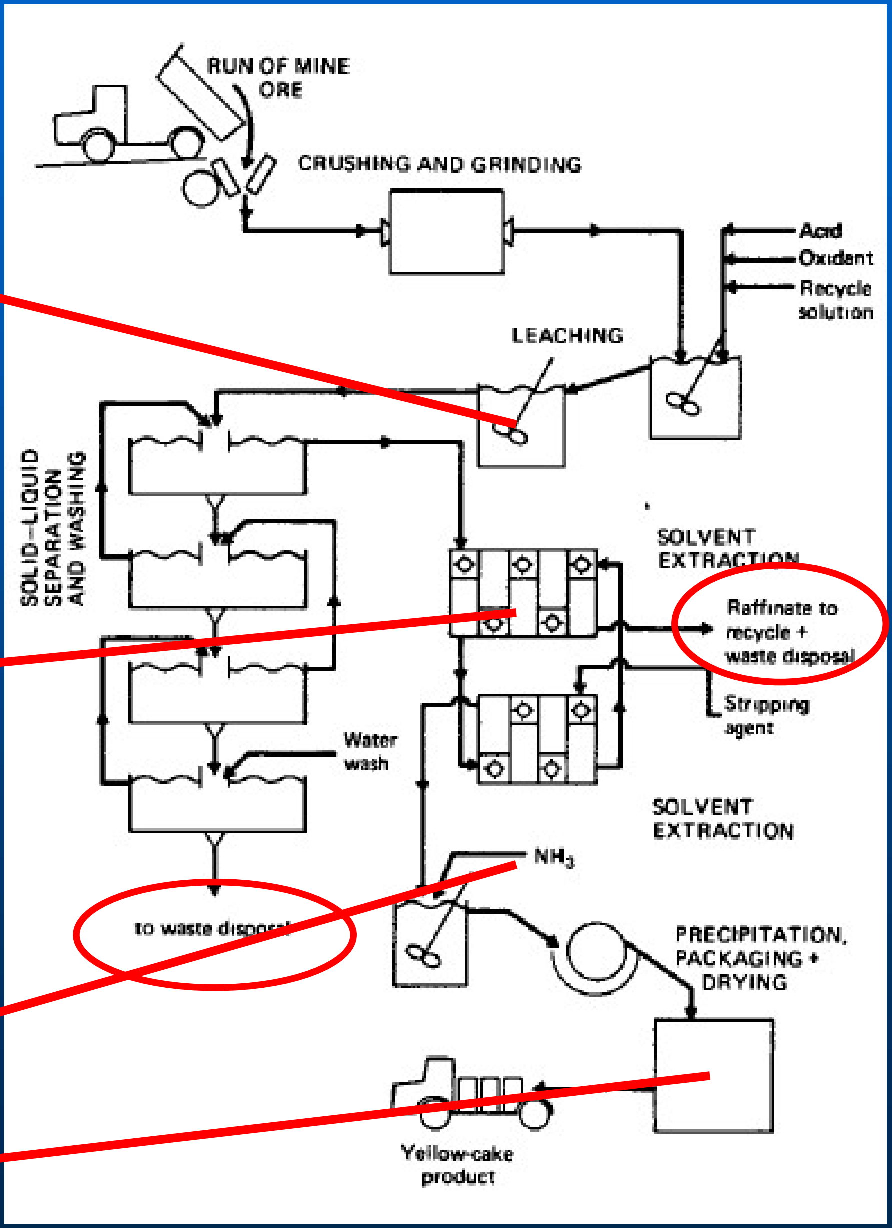
Leaching/extraction:

Solid $UO_3 + H_2SO_4$ yields $UO_2(SO_4)_3^{4-}$

Extraction into the organic phase by reacting with $(R_3NH)_2SO_4$.

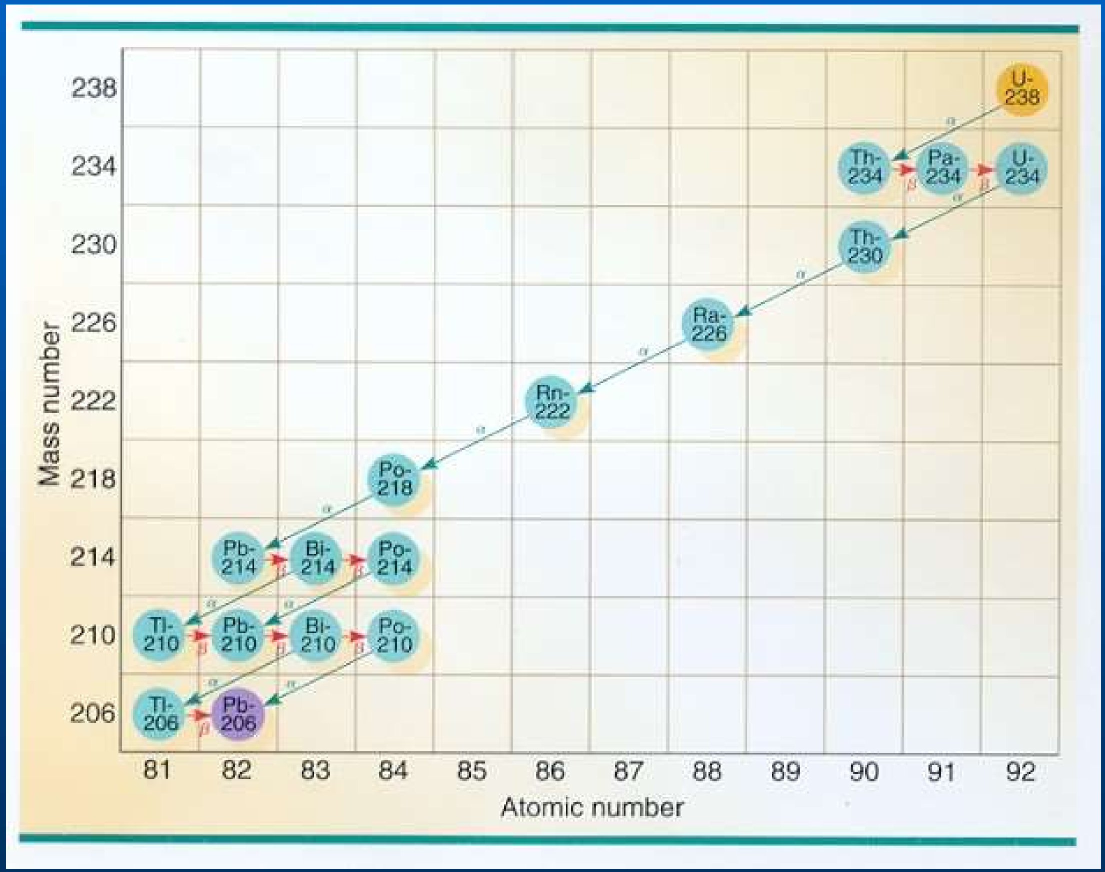
Evaporate solvent then *precipitate* $(NH_4)_2U_2O_7$ by adding ammonia.

Heat to yield solid U_3O_8



Uranium tailings

Milling wastes may contain residual uranium because the extraction process is not 100% efficient, and decay products such as ^{230}Th, ^{226}Ra, and ^{222}Rn are present.



Uranium ore samples (Class demonstration)

Carnotite (bright yellow) $K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$

Uraninite (black crystal) UO_2

Pitchblende (jet black) UO_2

Uranophane (canary yellow) $Ca(UO_2)_2(SiO_3OH)_2 \cdot 5H_2O$

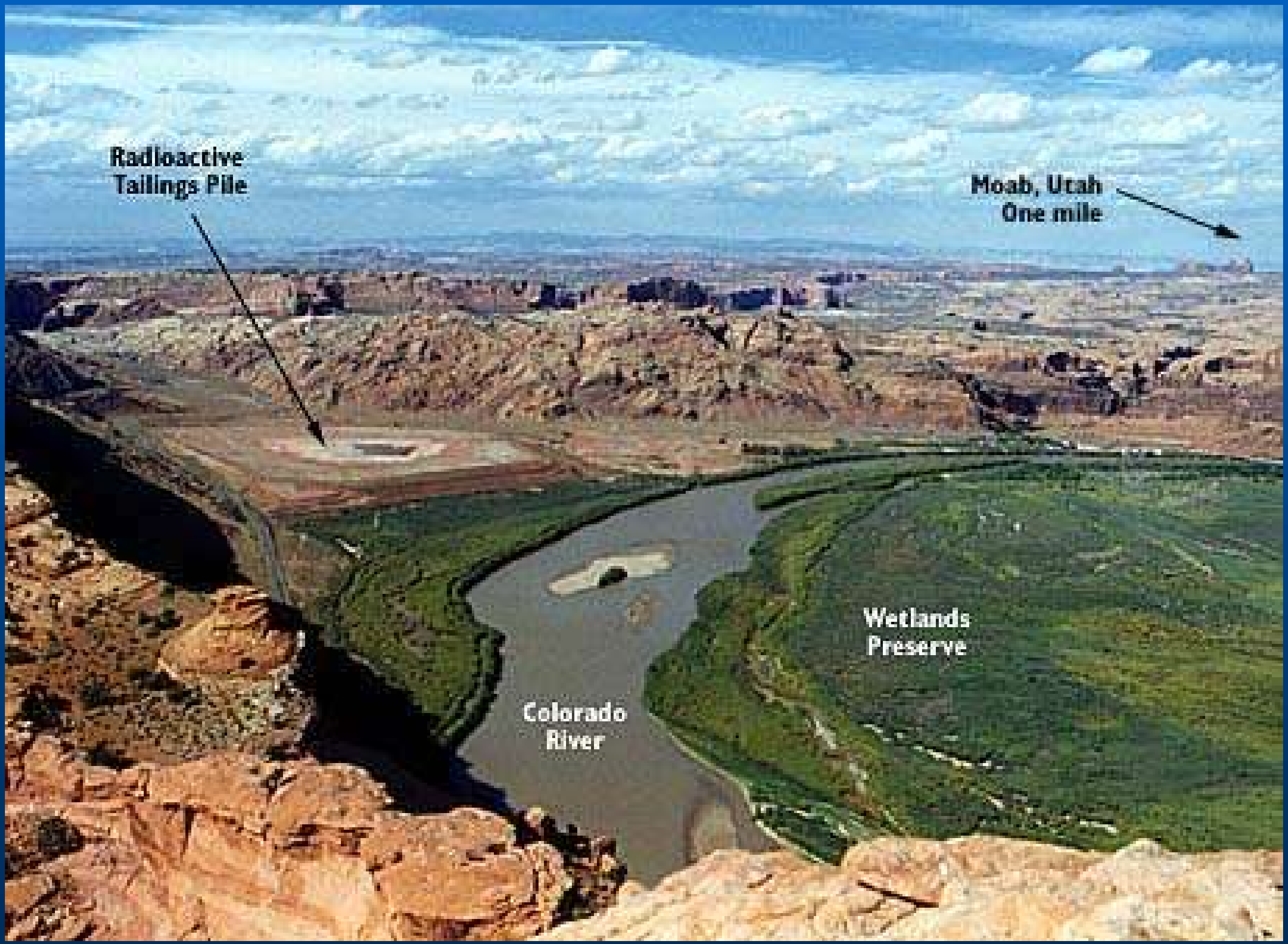
Gummite (maroon to rust brown)

Mixture of U oxides and silicates

Tyuyamunite (green to yellow)

$Ca(UO_2)_2V_2O_8 \cdot H_2O$

Atlas Co. uranium mill tailings, Moab, Utah,



Uranium Mill Tailings Radiation Control Act of 1978

The UMTRCA Title I program established a joint Federal/State-funded program for remedial action at abandoned mill tailings sites where tailings resulted largely from production of uranium for the Nuclear Weapons Complex. The Department of Energy (DOE) is responsible for cleaning up inactive milling sites.

UMTRA Remediation

Cover with compacted clays and rocks with vegetation on top of the clay: reduce gamma radiation, radon emissions, and blowing dust.

Groundwater monitoring: is there a plume of contaminated groundwater?

Groundwater remediation: Pump and treat (pump water to the surface, remove contaminants, then return the water to subsurface).

UMTRA remediation examples

The Moab Uranium Mill Tailings Remedial Action Project.

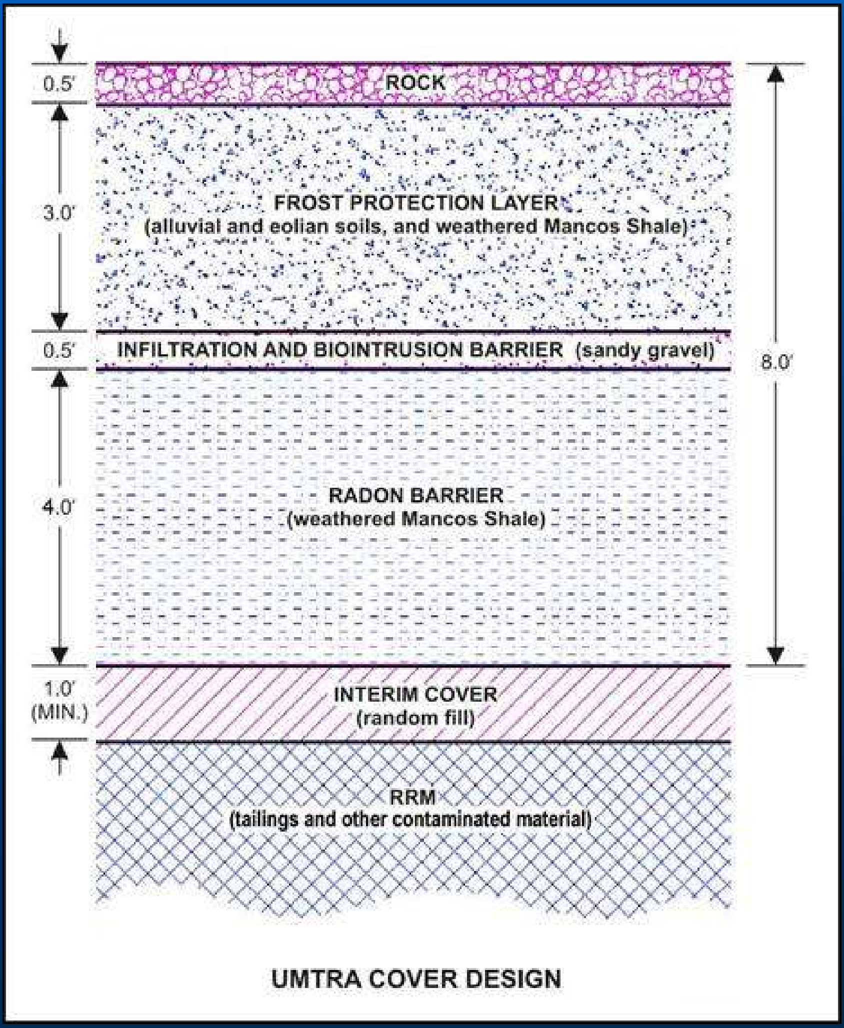
Uranium milling operations from 1956 to 1984. Before 1970, for the defense program, after 1970 for commercial power plants. Waste slurry was discharged into an unlined pond. Tailings pile about 90 feet (27 m) tall; volume of tailings and contaminated soil: 9.2 million m^3. Average activity: 665 pCi/g (24.6 Bq/g) of ^{226}Ra.

The Moab Uranium Mill Tailings Remedial Action Project.

Site remediation began in 2009. DOE (Energy*Solutions*) is hauling the tailings by rail to a disposal cell. One train/day, 4 days a week. Mid 2013, 6 million tons (5.4 tonnes) were moved (38% to the total). Completion planned for 2025.

Crescent Junction Disposal Cell

When completed, the cell will cover an area of 287 acres (116 ha), and will be 25 feet (7.6 m) tall/deep. It will be capped with a 9-foot (2.7 m) cover.

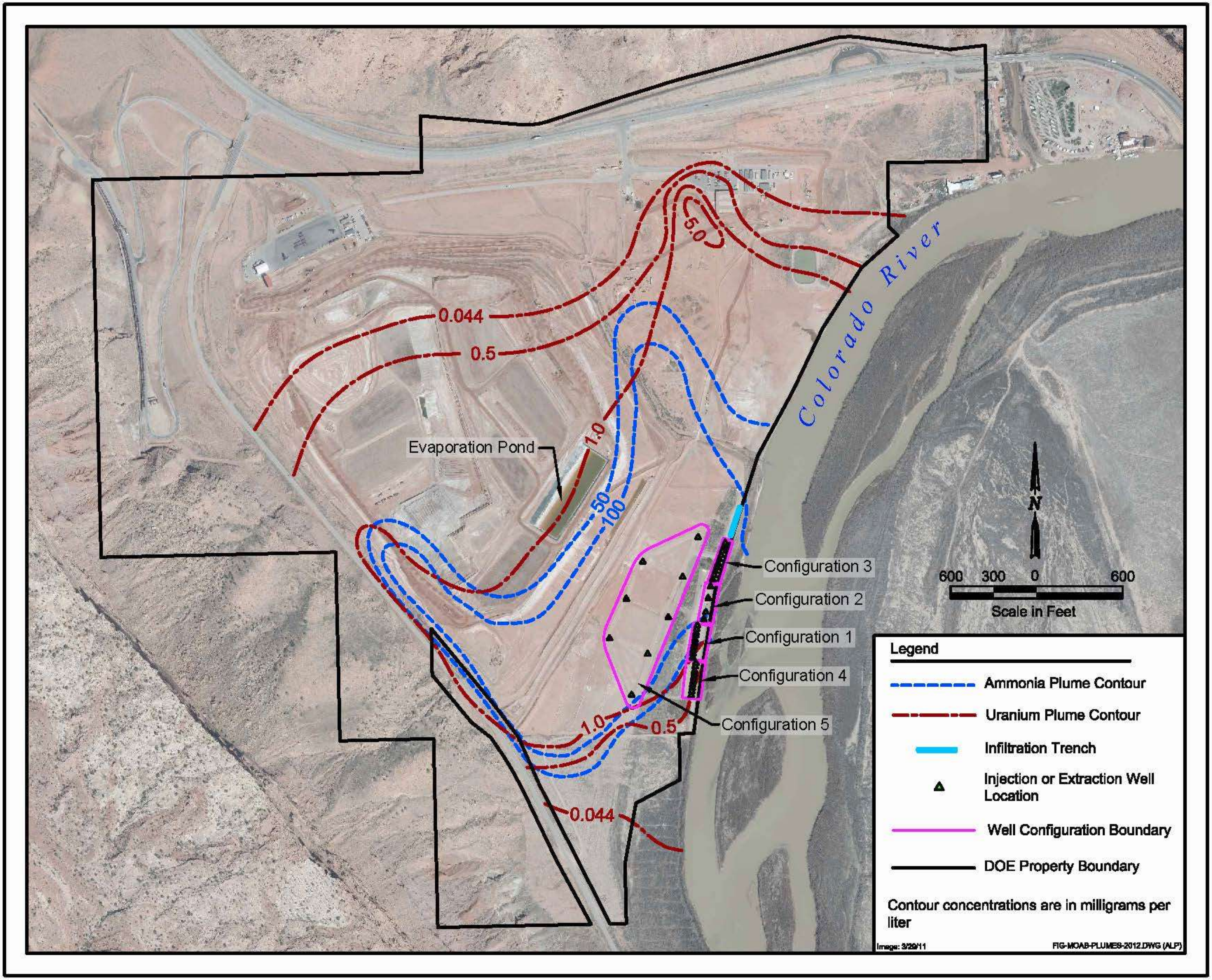


Groundwater contamination

The groundwater at the Moab site is contaminated with uranium and ammonia (and ammonium). Ten extraction wells are currently removing contaminated groundwater which is pumped into a lined-evaporation pond.

Groundwater contamination

32 injection wells are being used to pump diverted river water into the groundwater dilute and displace the plumes. The overall goal is to recover uranium and ammonia before they migrate to the Colorado River.


Colorado River
Evaporation Pond
0.044
0.5
1.0
5.0
50
100
Configuration 3
Configuration 2
Configuration 1
Configuration 4
Configuration 5
N
600 300 0 600
Scale in Feet
Legend
Ammonia Plume Contour
Uranium Plume Contour
Infiltration Trench
Injection or Extraction Well Location
Well Configuration Boundary
DOE Property Boundary
Contour concentrations are in milligrams per liter
Image: 3/29/11
FIG-MOAB-PLUMES-2012.DWG (ALP)

Depleted Uranium (DU)

DU is a by-product of the process used to enrich natural U to make reactor fuel.

Depleted with respect to ^{235}U

	Natural U (%)	DU (%)
^{234}U	0.006	0.001
^{235}U	0.72	0.2
^{238}U	99.28	99.80

Is DU a "waste?"

DU was listed a Class A waste in the draft Part 61 in 1981, and then it vanished.

However, NRC does not currently classify DU as Class A explicitly: only by default.

"These wastes did not exist in large quantities and were not analyzed when the current rules were put in place."

DU disposal

Depleted uranium is primarily stored at the enrichment facilities in the form of uranium hexafluoride (UF_6). Depleted uranium can be disposed at commercial facilities of as low-level radioactive waste if it is converted to chemically stable uranium oxide compounds, such as U_3O_8 or uranium dioxide (UO_2), which are similar to the chemical form of natural uranium.

DU stored as UF_6 in Portsmouth, Ohio (25,000 cylinders) and Paducah, Kentucky (39,000)

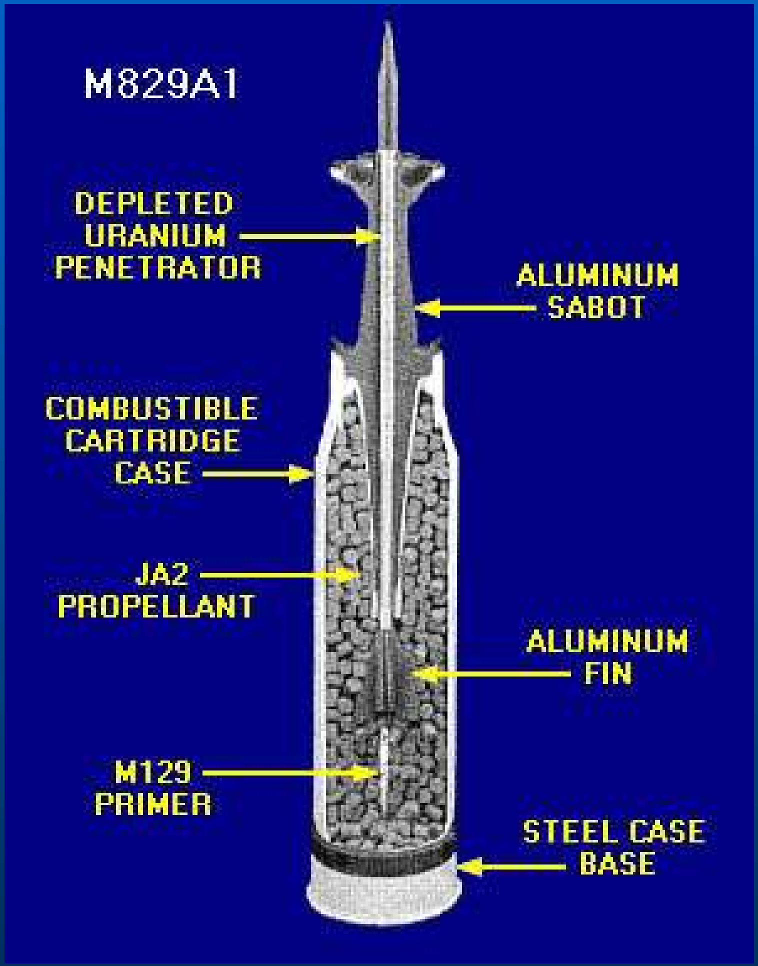
DU as a useful product

Because of its great density—(19.1 g/cm^3)--the main civilian uses of DU include counterweights in aircraft, radiation shields in medical radiation therapy machines and containers for the transport of radioactive materials.

DU as a useful product

The military uses DU for defensive armor plate and armor-piercing military shells because of its great density, and also because DU can ignite on impact if the temperature exceeds 600° C.

DU ammunition



DU inhalation after use in weapons

DU ammunition was first used in the Gulf War by U.S. forces, and then in the Bosnia and Kosovo conflict by NATO forces.

Like U, DU is an alpha source. Major route of exposure to DU is inhalation of small particles. DU residues were reported in battlefields in Iraq.

The depleted uranium mystery on campus

Storage area for radioactive wastes for GCOE

What is it?

Assessing the radioactivity

Chase to the rescue!

But what are in these boxes?

Depleted uranium

Depleted uranium

Depleted uranium

There was no paperwork in any of the boxes. No information was available.

It appeared that when the sections were assembled, they would form cylinders. Perhaps this was an abandoned project to make some type of radiation shields.

All of the boxes were sent to Idaho National Laboratory.