Nuclear Fuel Cycle

Resources, Mining, Milling

SYE 4503

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Abundance of select elements

CRUSTAL ABUNDANCE OF SELECTED ELEMENTS*

Element	Abundance (g/ton)
Gold	0.004
Silver	0.07
Tungsten	1.5
Molybdenum	1.5
Uranium	1.8
Thorium	7
Lead	13
Copper	55
Zinc	70
Iron	50,000
Aluminum	81,300

B. Mason, *Principles of Geochemistry,* 3rd ed., John Wiley & Sons, New York (1966).

Uranium deposits

Uranium is a fairly common metal in rocks and seawater at various concentrations:	
Very high-grade ore (Canada) - 20%	200,000 ppm U
High-grade ore - 2% U,	20,000 ppm U
Low-grade ore - 0.1% U,	1,000 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

Uranium Exploration Techniques

- Seawater:
  - Small concentration of 0.003ppm and 1ppm in marine mud
  - Total deposits of 4,000 Mt
  - Not economical at low uranium prices
- Other sources:
  - Phosphate byproduct (in mid 90's about 20% of US uranium came from Florida phosphate deposits as a byproduct
  - Coal and Lignite (1-10 ppm)
  - Copper mining byproducts (2-20 ppm)

Uranium World Reserves

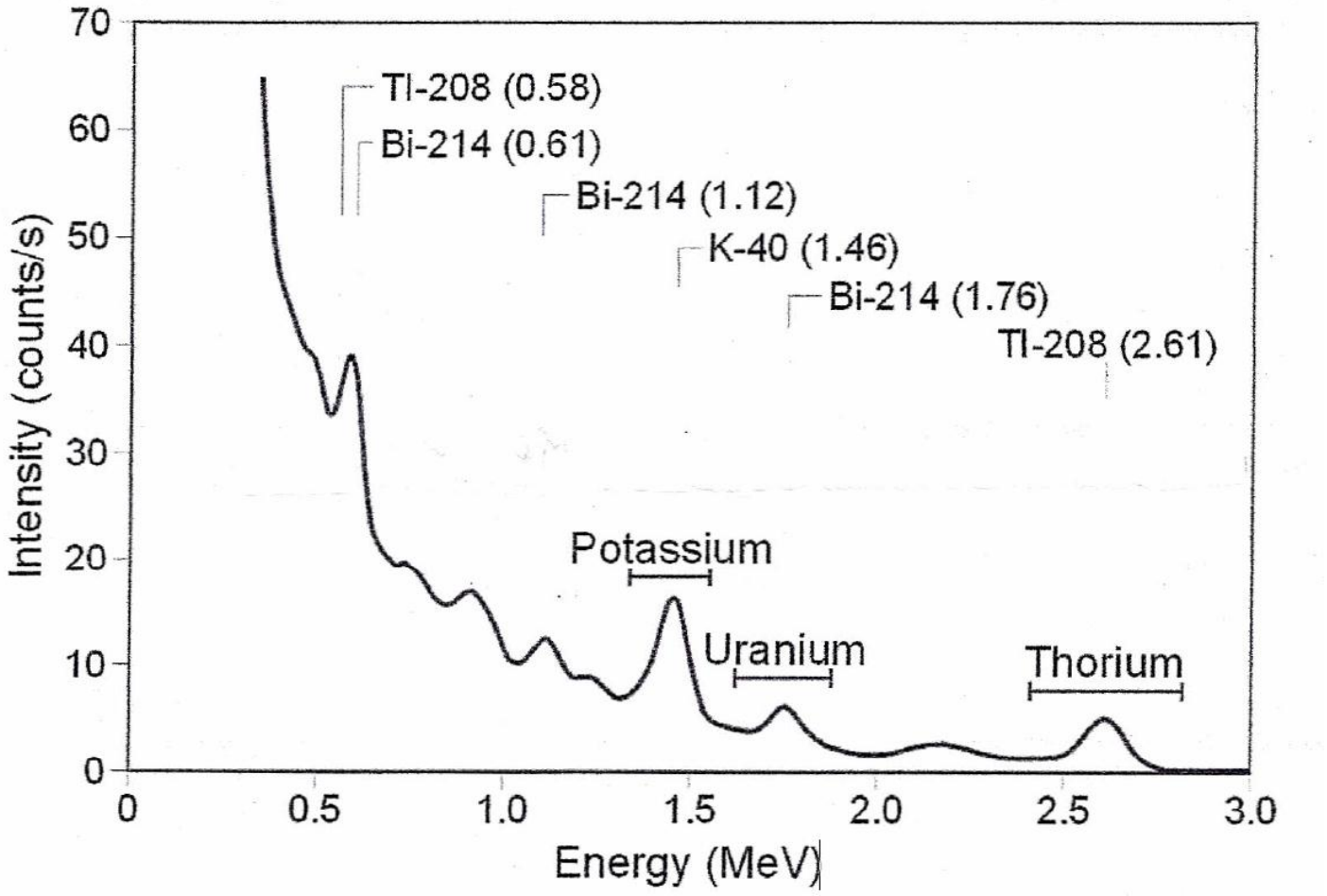
Known recoverable Uranium Resources as of 2011 at $130/Kg Uranium. At $260/Kg the reserves exceed 7,000,000 tons. Current use is about 68,000 tons/year. Latest estimates (2012) predict 100 year supply (NEA/IAEA).

	tons U	percentage of world
Australia	1,661,000	31%
Kazakhstan	629,000	12%
Russia	487,200	9%
Canada	468,700	9%
Niger	421,000	8%
South Africa	279,100	5%
Brazil	276,700	5%
Namibia	261,000	5%
USA	207,400	4%
China	166,100	3%
Ukraine	119,600	2%
Uzbekistan	96,200	2%
Mongolia	55,700	1%
Jordan	33,800	1%
other	164,000	3%
World total	**5,327,200**	

Uranium Exploration Techniques

- Rock and sediment studies
- Aerial surveys:
  - Satellites beams and bounce back
  - Radiometric using small planes and helicopters
    - Helicopters easier to maneuver
    - Altitudes of 200 to 3000 ft
    - Large NaI detectors (2x4x16 and larger)
    - HPGe detectors
    - Look for signals from Uranium daughters and K-40
      - K-40 at 1.46 MeV
      - Bi-214 at 1.76 MeV for Uranium
      - Tl-208 at 2.61 MeV for Thorium
      - Rn as evidenced by Pb-214 gamma rays
    - Can detect concentrations as low as 0.2% U3O8

Gamma spectrum of Uranium and Thorium



Uranium Exploration Techniques

- Surface surveys:
  - Simple GM counter
  - NaI or HPGe detectors
  - Look for K-40, Bi-214, Tl-208, Th-234, down to 50ppm
  - Can also use Kr-85 and Xe-133
- Radiochemistry of water samples:
  - Telltale signs of Uranium and other heavy metals
  - Can also use mass spectrometers or neutron activation techniques for sensitivities down to about 1ppm

Uranium Exploration Techniques

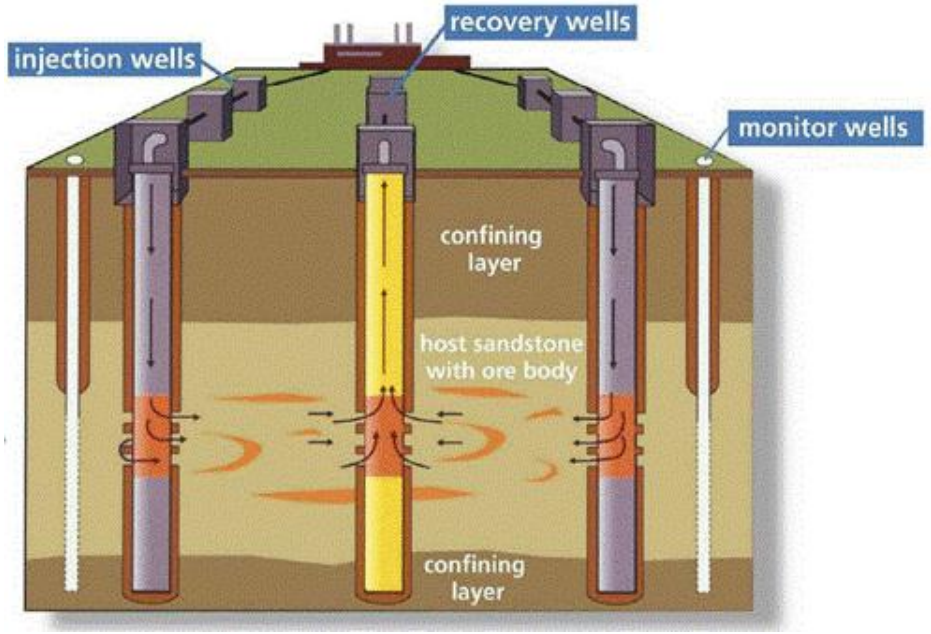
- Well logging:
  - To further explore and verify surface discoveries
  - Direct gamma counting:
    - NaI detectors
    - HPGe detectors
  - Delayed neutron counting
- Botanical method:
  - Selective concentration of certain elements in some plants with affinity to absorb some Uranium daughters

Uranium Mining Methods

- Open pit mining:
  - Remove top soil and replace later
  - Dig up the ore bed
- Underground mining:
  - Similar to coal mining, relatively lower environmental impact
  - Part of the mine left behind for support
  - More hazardous to miners
  - High concentration of radon gas

Solution (in Situ Leach) Mining

- Leaves the ore in the ground and recovers the uranium by dissolving and pumping the “pregnant” solution to the surface where the minerals can be recovered.
- In 2011, 45% of world uranium was mined using solution mining.



Solution (in Situ Leach) Mining

- Advantages:
  - No need for hauling of ore to mill
  - No need for grinding and milling operations
  - No need for large scale excavation
  - Lower costs
  - Risk reduction for workers
  - Small fraction of radioactivity reaches the surface
- Disadvantages:
  - Potential for ground water contamination
  - Lower recovery rate

Uranium Milling

- Sequence of physical and chemical treatment steps to extract the uranium from the ore
- Acid leach (sulfuric acid) or Alkali (bicarbonate) leach mills
- About 95% of the original uranium is recovered
- The end product is dried yellowcake powder (U_3O_8)

Uranium milling flow chart