SAND2010-0514C

General Properties of Uranium

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
for the United States Department of Energy's National Nuclear Security Administration
under contract DE-AC04-94AL85000.

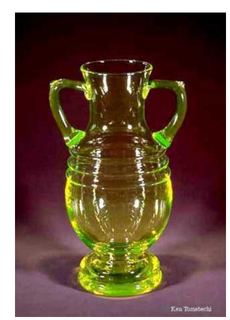
Topics

- Discovery and Early History of Uranium
- Overview of Uranium Cycle
- Physical and Chemical Properties of Uranium
- Radiological Properties of Uranium
- Properties of Depleted Uranium (DU)

Discovery and Early History of Uranium

- Discovered in 1789 by Martin Klaproth while analyzing mineral samples from Joachimsal silver mines in present day Czech Republic
- Only significant use throughout the 1800s was to color glass and ceramics

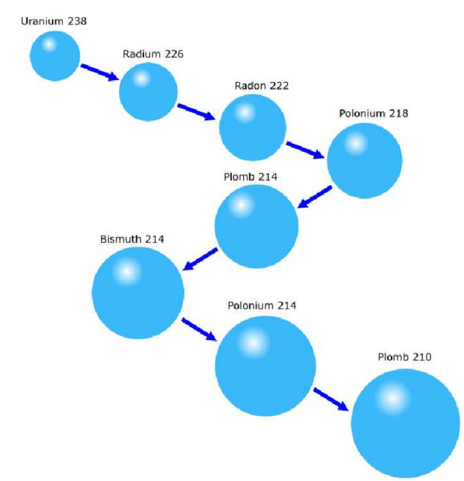
- Uranium compounds used to give vases and decorative glassware a yellow-green color
- Ceramic glazes (orange to bright red) used on various items (e.g., household crockery, architectural decorations)



Discovery and Early History of Uranium

- Uranium's radioactive properties discovered by Henri Becquerel in 1896
- Marie Curie, Becquerel's student, correctly interpreted his results and chose the name "radioactivity" for the new phenomenon
- Working with her husband Pierre, Marie Curie went on to discover another new element, Radium, in 1898
  - Radium was felt to be a miracle cure for cancer
  - Demand for radium led to a rapid expansion in the mining of uranium ore in the early 1900s

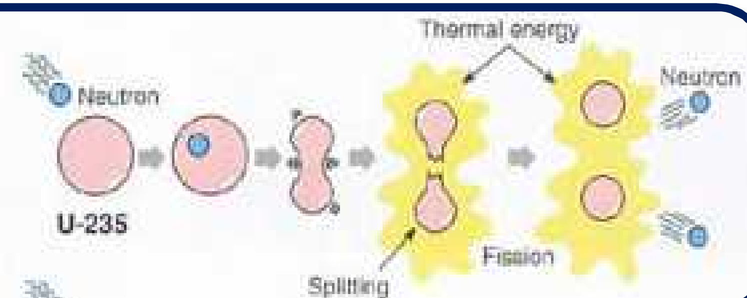
Antoine Henri Becquerel discovered the phenomenon of radioactivity by exposing a photographic plate to uranium (1896).



Discovery and Early History of Uranium

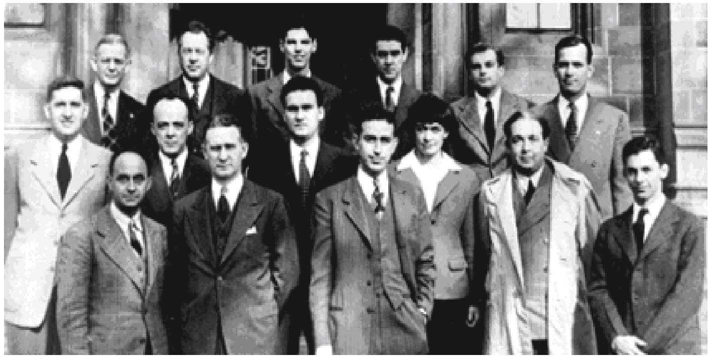
- After the Curies' first work with radioactive materials, scientists around the world began to study Uranium, trying to discover its atomic secrets
- In 1939, the first proven nuclear fission was performed by Otto Hahn in Germany
- This was when the world was on the edge of war and military secrecy quickly surrounded the work of atomic scientists

Certain isotopes of some elements can absorb a neutron and split into two lighter atoms, produce additional neutrons and release some of their energy. ***<u>This process is called fission.</u>***



Discovery and Early History of Uranium

- A team led by Enrico Fermi built the first nuclear reactor (known as an “atomic pile”) in great secrecy at the University of Chicago
  - Achieved the first controlled nuclear reaction in 1942
- The U.S., racing against Germany, developed the first atomic weapon under the Manhattan Project
  - First nuclear explosion occurred at the Trinity Test Site in New Mexico in July 1945
- A month later, two nuclear weapons were dropped on the cities of Hiroshima and Nagasaki



Enrico Fermi (bottom left) and the rest of the team that initiated the first artificial nuclear chain reaction (1942).

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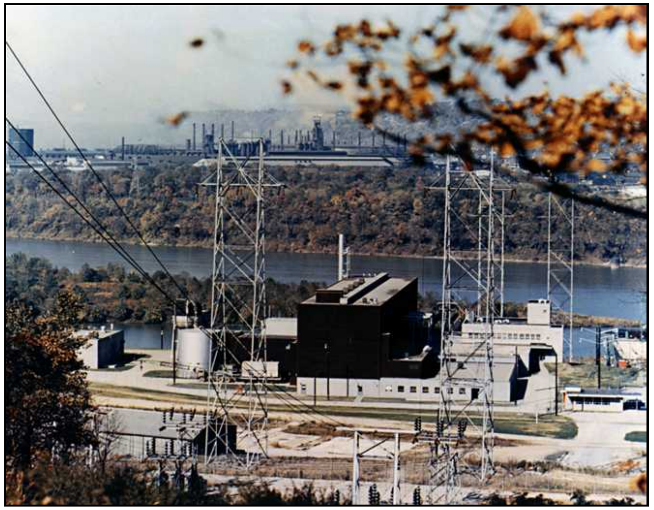
Discovery and Early History of Uranium

- After the war, attention quickly turned to developing the peaceful uses of nuclear energy
- First practical use of nuclear power was in 1951, when an experimental reactor at a U.S. research center in Idaho Falls lit four ordinary light bulbs
- In 1957, the first full-scale U.S. nuclear power plant went into service in Shippingport, Pennsylvania (60 MW-electrical)



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Discovery and Early History of Uranium

- Other countries were also building reactors:
  - Russia (1954 - world's 1st commercial reactor)
  - Great Britain (1956)
  - France (1956)
  - Canada (1962)
  - Sweden (1964)
- Nuclear industries of these countries grew rapidly during the 1960s and 1970s
- First export orders for nuclear power reactors, awarded by Italy in 1958

Discovery and Early History of Uranium

- Many other countries (e.g., West Germany, Switzerland, Spain, Belgium, Finland, Japan) constructed nuclear reactors
- Demand for Uranium increased; world's major source of uranium until the early 1950s was in the Belgian Congo
- Later, to meet the demand, Uranium mining was expanded in the U.S., Canada, France, Australia, and Africa
- Today, Canada produces the largest share of Uranium from mines (about one-third of world supply), followed by Australia (one-fifth)

Overview of Uranium Cycle

How is Uranium produced and prepared for use?

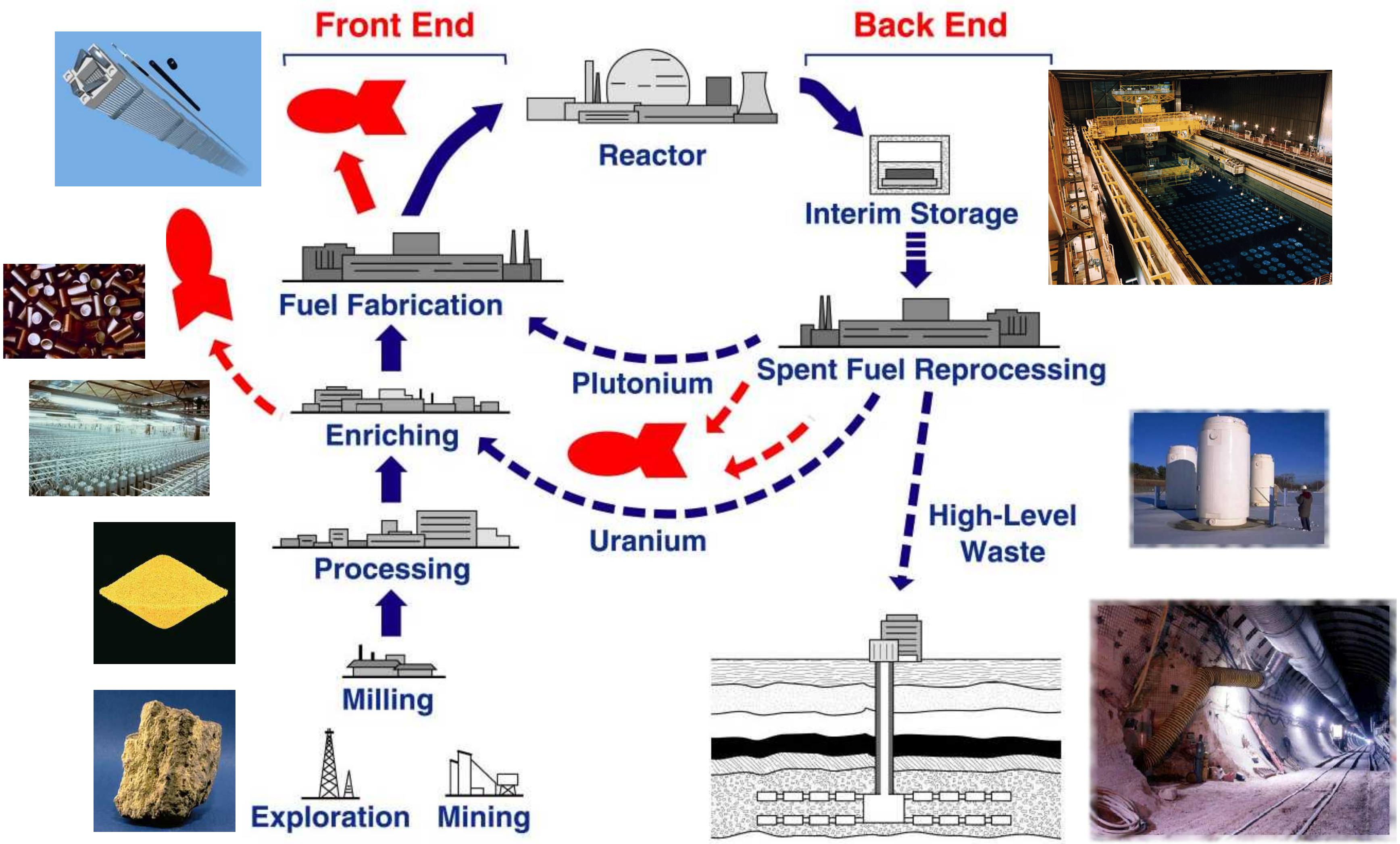
- *Exploration* to identify the compositions and amounts of Uranium available at various locations
- *Mining and milling* to bring the Uranium ore to the earth's surface to be processes and refined
- *Processing (or Refining)* to convert the ore into a purified form
- *Enrichment* to prepare a suitable composition of Uranium for use in a nuclear reactor

Overview of Uranium Cycle

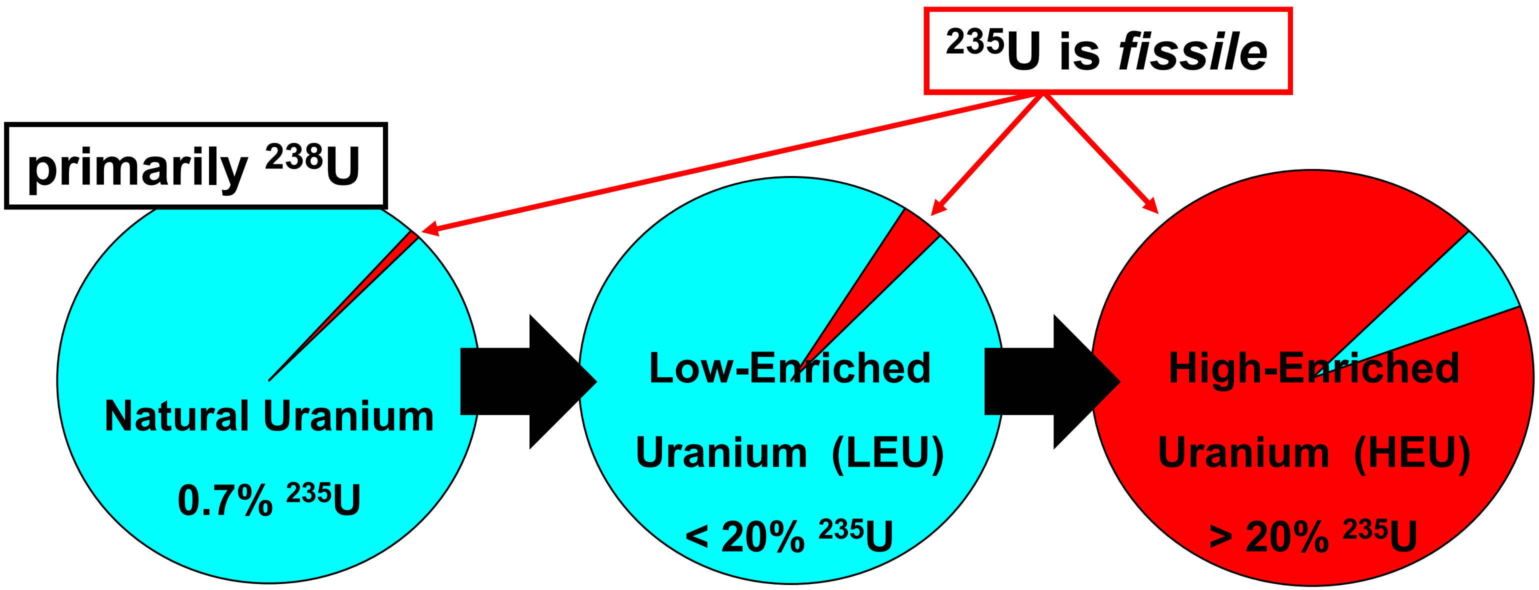
How is Uranium produced and prepared for use?

- *Fuel Fabrication* to fabricate fuel pellets, fuel rods, and fuel assemblies
- *Consumption* (burn) of the fuel for energy production in nuclear reactor
- *Disposal* of burnt fuel known as "Spent Fuel" from reactor operation
- *Reprocessing* - extraction of un-used enriched Uranium from Spent Fuel

Overview of Uranium Cycle



Overview of Uranium Cycle



- Natural Uranium, Low-Enriched Uranium (LEU) and High-Enriched Uranium (HEU) are all useful in reactors
- Depleted Uranium (<0.7% ^{235}U) is a by-product of enrichment

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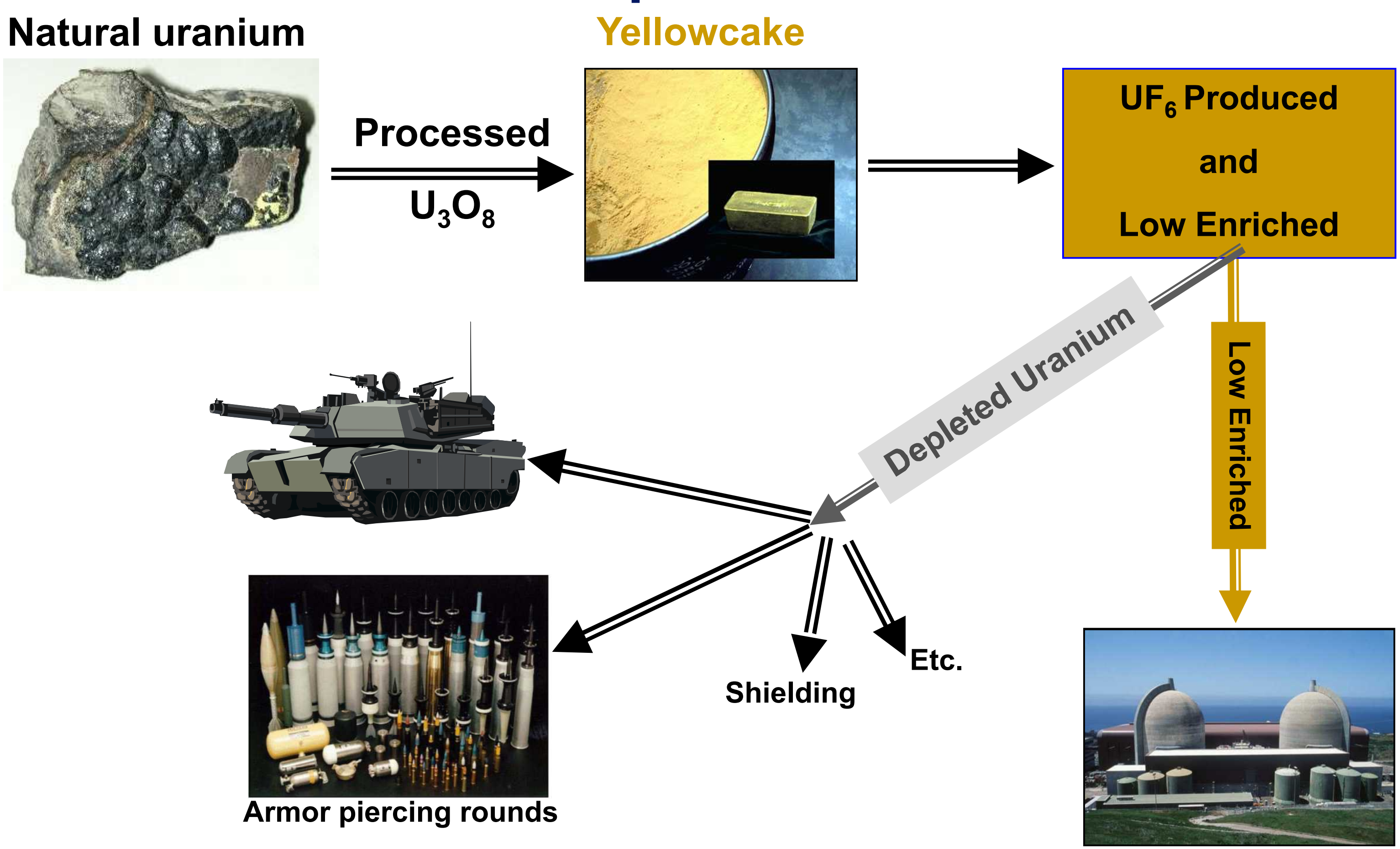
Overview of Uranium Cycle

Depleted Uranium (DU) is a by-product of the Uranium enrichment process:



Physical and Chemical Properties of Uranium

- Primary Uranium bearing ores:
  - Uraninite, autunite, carnotite, samarskite (some varieties of samarskite contain up to 23% uranium) and torbernite
  - Annual world wide production: ~35,000 tons
  - Primary mining areas: Canada, Zaire, Czech Republic, and USA

Compound	Appearance†	Properties/Handling
Ammonium, magnesium, or sodium diuranite; "yellow-cake"	Bright yellow solid	Packaged and shipped in steel drums with a polyethylene liner
Uranyl nitrate ($UO_2(NO_3)_2$)	Yellow crystalline solid	m.p. 118°C††
Uranium trioxide (UO_3)	Orange solid	Stable in air up to 450 - 600°C
Uranium dioxide (UO_2)	Dark brown cinnamon-colored powder	m.p. 2827°C
Uranium tetrafluoride (UF_4) "green salt"	Emerald-green solid	m.p. 1036°C; insoluble in water
Uranium hexafluoride (UF_6)	Colorless crystalline solid	m.p. 64°C; reacts violently with water and oils; corrosive to many metals; sublimates at 56.4°C; shipped as a solid in specially designed cylinders
Uranium tetrachloride (UCl_4)	Dark green solid	m.p. 590°C; soluble in water
Uranium trihydride (UH_3)	Black powder	Highly reactive, pyrophoric
Uranium carbide (UC)	Gray-black solid	m.p. 2525°C; reactive with moist air, steam, or water
Uranium nitride (UN)	Gray-black solid	m.p. 2805°C; reactive with moist air, steam, or water

† At ambient temperature and atmospheric pressure.
†† m.p. = melting point.

Physical and Chemical Properties of Uranium

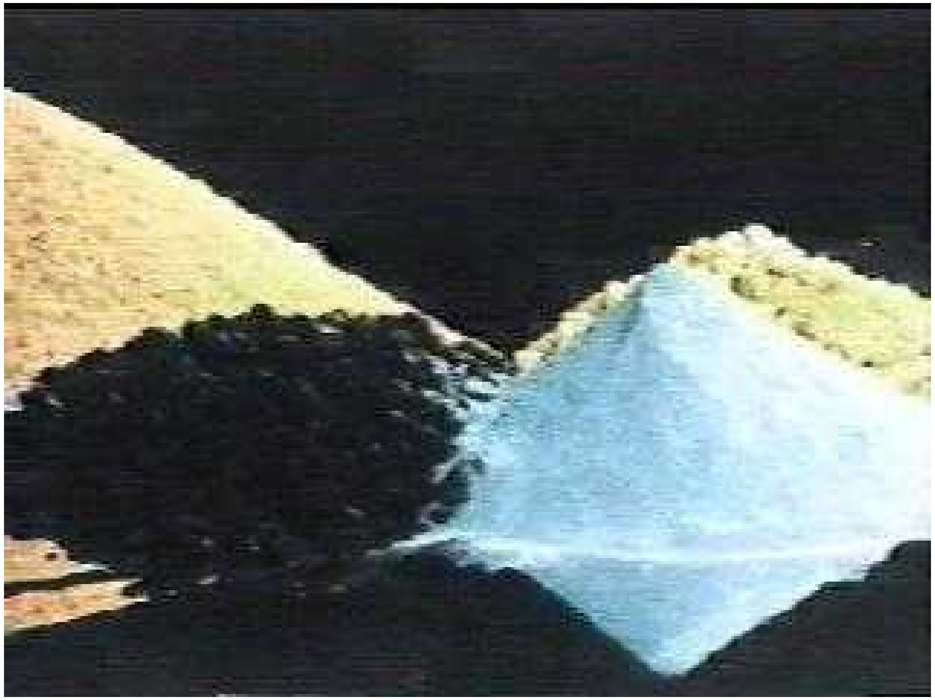
Torbernite, $Cu(UO_2)_2(PO_4)_2 x 12H_2O$

Uraninite, UO_2

Uranophane, $Ca(UO_2)_2(HSiO_4)_2$ x 5 H_2O

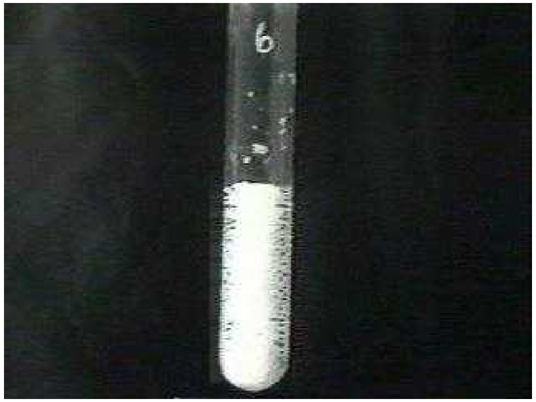
Carnotite, $K_2(UO_2)_2(VO_4)_2 x 1\text{-}3H_2O$

Physical and Chemical Properties of Uranium

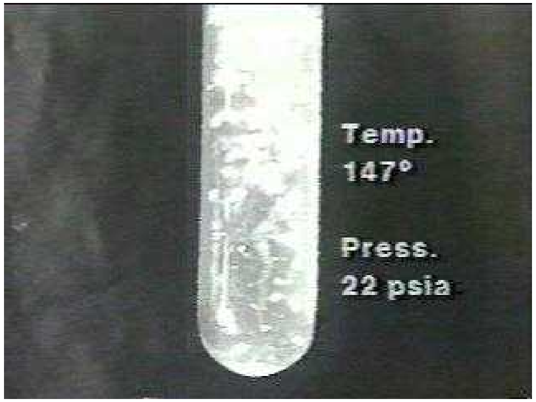


Various compounds of Uranium:

- U_3O_8 (yellowcake) - left background
- UO_2 (Brown Oxide) - left foreground
- $(NH_4)2U_2O_7$ (ADU) - right background
- UF_4 (green salt) - right foreground



Depleted Uranium Hexafluoride (UF_6) as a solid at room temperature



Creating liquid UF_6 by applying some heat

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Physical and Chemical Properties of Uranium

- Atomic Weight: 238.0289
- Density: 18.95g/cc @ 300° K
- Combines with non-metals (O, S, Cl, F, P, Br)
- Dissolves in acids
- Pyrophoric in finely divided particles
- Attacked by cold water in a finely divided state
- Resists Alkalis
- Forms many compounds with yellowish or greenish colors
- Poor electrical conductor
- Toxic to ~ same degree as arsenic

Pitchblende, U_3O_8

Autunite; $Ca(UO_2)_2(PO_4)_2$ x8-12H_2O

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Radiological Properties of Uranium

Heaviest naturally occurring radioactive element

Mass #	Abundance	Specific Activity	Half-life
U-234	0.005%	2.31×10^{8} Bq/gm	$2.48 \times 10^{+5}$ yrs
U-235	0.711%	80,011 Bq/gm	$7.04 \times 10^{+8}$ yrs
U-238	99.284%	12,445 Bq/gm	$4.5 \times 10^{+9}$ yrs

Note: U-234 has the smallest abundance, but has the highest Specific activity

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Question: What is the total activity of 1 gram of pure Natural Uranium?

Ans: (0.005%) x (2.31×10^{8}) + (0.711%) x (80,011) + (99.284%) x (12,445)

= (11,550) + (569) + (12,356) = 24,474 Bq = 0.7 µCi

	U-234	U-235	U-238
% of activity	47.2%	2.3%	50.5%

Relative Isotopic Ratios for Depleted Uranium

Relative mass abundances and isotopic ratios for Natural Uranium isotopes

Isotope	Abundance
^{238}U -	99.2745%
^{235}U -	0.7200%
^{234}U -	0.0054%
$^{235}U/^{238}U$	0.00725
$^{234}U/^{238}U$*	0.0000554

Highlighted ratios are used to distinguish the natural uranium from the enriched or Depleted Uranium.

Relative Isotopic Ratios for Natural Uranium

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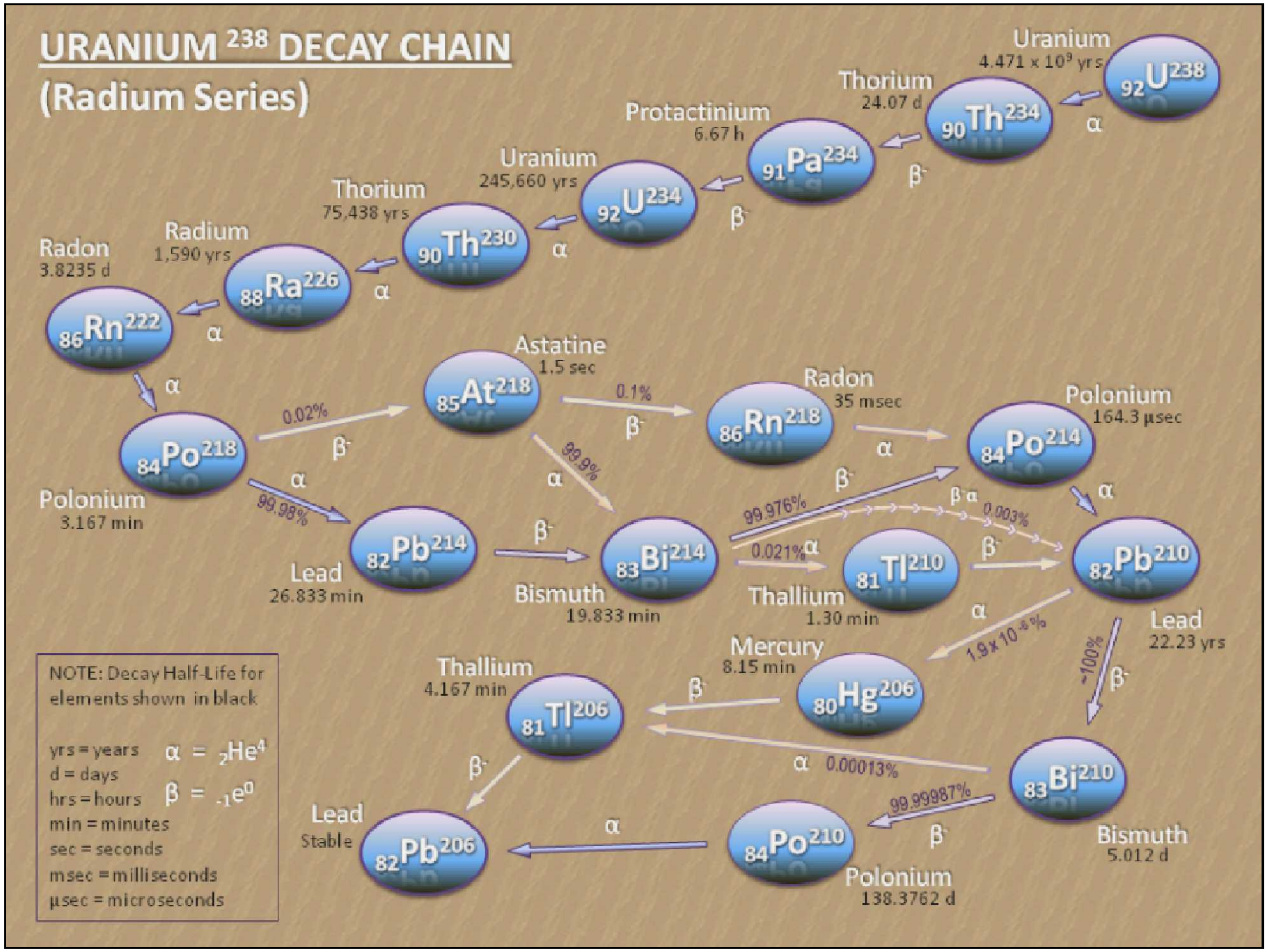
Radiological Properties of Uranium



$$^{238}_{92}U \longrightarrow {}^{206}_{82}Pb + 8He^{4}_{2} + 6\ {}_{-1}e^{0}$$

Radiological Properties of Uranium

Element	Emission	Energy (MeV)
Uranium-238	alpha	4.197, 4.147
Thorium-234	beta	0.188, 0.096
Protactinium-234m	beta	2.29
Uranium-234	alpha	4.776, 4.725
Thorium-230	alpha	4.688, 4.621
Radium-226	alpha	4.7844 4.602
Radon-222	alpha	5.4895
Polonium-218	alpha	6.0024
Lead-214	beta	0.67, 0.73
Bismuth-214	beta	1.54, 1.51, 3.27
Polonium-214	alpha	7.6869
Lead-210	beta	0.017, 0.061
Bismuth-210	beta	1.162
Polonium-210	alpha	5.3044
Lead-206		

Radiological Properties of Depleted Uranium

Heaviest naturally occurring radioactive element

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Questions:

1. What is the total activity of 1 gram of pure depleted natural uranium?
2. How does this compare to activity of 1 gram of pure natural uranium?
3. What are the U-234/U-238 and U-235/U-238 ratios for DU?

Closing Points

Uranium values in environmental matrices

Matrix	Typical concentration range	Reference
Soil	0.3–11.7 mg/kg	UNSCEAR, 1993
Air	2.5×10^{-8}–10^{-7} mg/m^3	NCRP, 1999
Surface water	3×10^{-2}–2.1 µg/l	WHO, 2001
Ground water	3×10^{-3}–2.0 µg/l	WHO, 2001

On a weight-by-weight basis the reduced proportion of U-235 and U-234, and the absence of radioactive progeny such as radium in DU, means that DU poses less of a radiological hazard than either pure processed uranium or naturally occurring uranium ores, respectively.