Canadian Nuclear Society

Uranium decay fact sheet (there's Po-210 in me?)

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$^{238}_{92}\mathrm{U}$ $^{235}_{92}\mathrm{U}$

Uranium is a heavy, silvery-white metal that is a little softer than steel. While all fourteen isotopes of uranium are radioactive, only 3 are found in nature: ^{238}U at 99.283%, ^{235}U at 0.711%, and ^{234}U at 0.0054% (by weight). Uranium has the highest atomic mass of the natural elements found on earth, and is relatively abundant – about 2.8 parts per million on average in the earth's crust, similar to the abundances of molybdenum or arsenic.

Source

Uranium is present in the soil and rocks at low concentrations almost everywhere on earth and is dissolved in the oceans. It has been concentrated in ore formations by natural processes that make mining it practical. The Athabasca Basin in Saskatchewan has deposits with exceptionally high concentrations of uranium (averaging 15-20% U_3O_8, ~100 times the global average). Canadian mines supply 1/3 of the present world demand.

Hazards

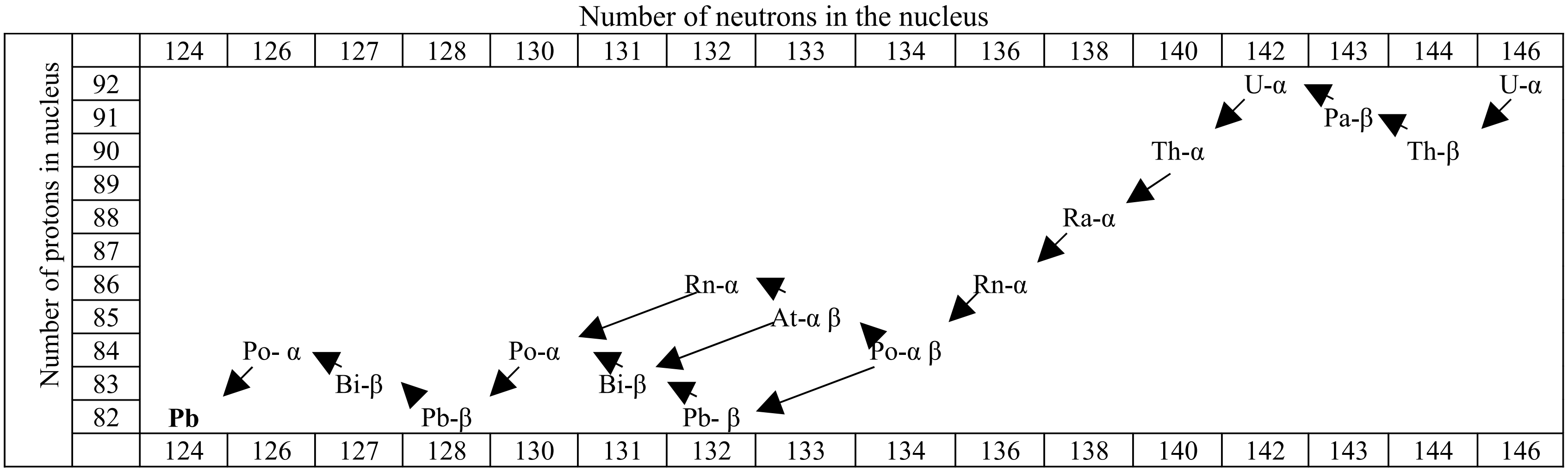
Uranium is a highly toxic heavy metal (but is less toxic than lead). Water-soluble chemical compounds containing uranium pass rapidly through the human body, with relatively large amounts being absorbed if ingested. Soluble uranium compounds may also be absorbed through the skin. A body burden of soluble uranium compounds leads to irreversible kidney damage. Insoluble compounds present a hazard to the lungs if particles are inhaled, leading to fibrosis and/or cancer.

The radioactive decay chain for each isotope of uranium is different. ^{238}U has a half-life of 4.47×10^9 years (about the age of the earth – there was twice as much ^{238}U when the earth was young). The first step in the decay chain is an alpha (α) decay to thorium, ^{234}Th. An α particle has 2 neutrons and 2 protons: it is the nucleus of a helium atom. Very rarely a ^{238}U atom undergoes spontaneous fission. A subset of the steps in the decay chain is listed below with the half-lives and nominal energies for the emitted particles as well as the total energy difference between the two isotope ground states ("Q value").

from	by	to	Half-life	Mean α or β^- energy [MeV]	Q value [MeV]
U-238	α	Th-234	4.47 E9 year	4.2	4.27
Th-234	β^-	Pa-234	24.1 day	0.045	0.27
Pa-234	β^-	U-234	6.7 h	0.813	2.2
U-234	α	Th-230	2.45 E5 year	4.7	4.86
Th-230	α	Ra-226	7.5 E4 year	4.7	4.77
Ra-226	α	Rn-222	1.6 E3 year	4.8	4.87
Rn-222	α	Po-218	3.82 day	5.5	5.59
Po-218	α	Pb-214	3.1 min	6.0	6.1
Pb-214	β^-	Bi-214	26.8 min	0.218	1.02
Bi-214	β^-	Po-214	19.9 min	0.642	3.27
Po-214	α	Pb-210	164 µs	7.7	7.83
Pb-210	β^-	Bi-210	22.2 year	0.006	0.0635
Bi-210	β^-	Po-210	5.012 day	0.389	1.16
Po-210	α	**Pb-206**	138.4 day	5.3	5.4
			Total	45.01	51.67

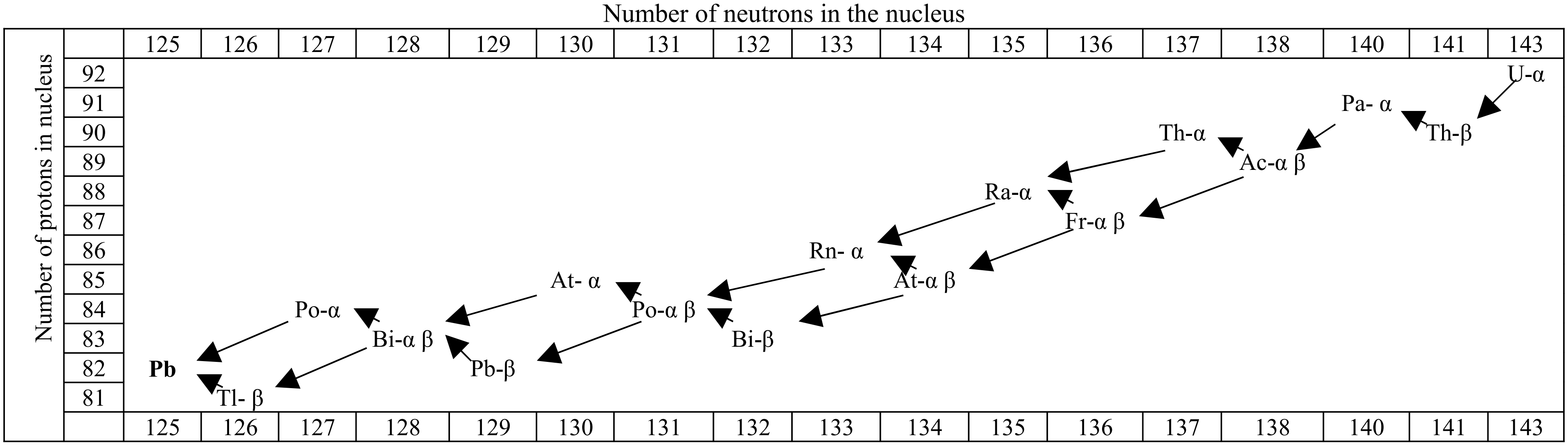
^{206}Pb is a stable isotope of lead. It does not decay.

The complete decay chain for ^{238}U, extracted from the Interactive Chart of the Nuclides is illustrated below:



(Note: some neutron numbers are skipped for brevity.)

The complete decay chain for ^{235}U, extracted from the Interactive Chart of the Nuclides is illustrated below:



(Note: some neutron numbers are skipped for brevity.)

from	by	to	Half-life	Mean α or β^- energy [MeV]	Q value [MeV]
U-235	α	Th-231	7.04 E8 year	4.4	4.7
Th-231	β^-	Pa-231	25.5 h	0.080	0.39
Pa-231	α	Ac-227	3.3 E4 year	5.0	5.15
Ac-227	β^-	Th-227	21.8 year	4.95	5.04
Th-227	α	Ra-223	18.7 day	6.0	6.14
Ra-223	α	Rn-219	11.43 day	5.7	5.98
Rn-219	α	Po-215	4 s	6.8	6.9
Po-215	α	Pb-211	1.8 ms	7.4	7.5
Pb-211	β^-	Bi-211	36.1 min	0.445	1.37
Bi-211	α	Tl-207	2.1 min	6.62	6.75
Tl-207	β^-	**Pb-207**	4.77 min	0.495	1.427
			Total	47.89	51.35

^{207}Pb is a stable isotope of lead.

The radioactivity of a sample of uranium depends on its history. A sample of uranium ore that has not been disturbed, crushed, or processed chemically will have reached an equilibrium where each of the decay products will be present at its respective equilibrium value. Alpha decays are detected only from isotopes near the surface of the sample since the α particles, despite their very high energies, travel a short distance before being stopped by scattering off other atoms in the sample. Beta decays produce high-energy electrons, and while these can penetrate further than alpha particles, again most are stopped within the sample. However, if you examine the β^--particle energies in the ^{238}U decay table and compare these with the respective “Q values”, you will notice that there is a substantial discrepancy. Most β^- decays are accompanied by gamma (γ) emissions. The γ have much greater penetration distances in matter and a large fraction emerge from the sample. These are much more easily detected than the α or β^-.

Natural uranium contains approximately 0.7% ^{235}U which has a half life of 7 x 10^8 years – about one-sixth that of ^{238}U (there was over sixty-four times as much ^{235}U when the earth was young). While a given mass of ^{235}U is therefore more radioactive than that of ^{238}U, it contributes a small fraction of the total radioactivity of an ore sample. When uranium ore is crushed, the radon isotopes can escape to the atmosphere, interrupting the decay chains. When the ore is processed chemically, the concentrations of other decay products may be reduced. By removing the short-half-life isotopes, the radioactivity of the processed uranium is reduced relative to that of natural uranium ore.

^{210}Po in me?

^{210}Po, the second-last member of the decay chain for ^{238}U, decays to ^{206}Pb, a stable isotope of lead. The ^{210}Po half life of 138.4 days makes it a convenient high-energy, high-intensity α source for industrial applications such as ionising air to control static electricity. To produce useful quantities a target material such as ^{209}Bi may be irradiated in a nuclear reactor to produce ^{210}Bi. ^{210}Bi has a 5-day half life for β^- decay to ^{210}Po. The poisoning of Alexander Litvinenko with ^{210}Po resulted in his death 2006 November 23. News of this apparent homicide sparked public interest in polonium (like uranium, all isotopes of polonium are radioactive).

The decay chain for ^{238}U always includes ^{210}Po. It is very unlikely that the tiny amount of ^{238}U that is present in a person will decay to ^{210}Po during the person’s lifetime. However, the decay chain includes radon, a noble gas, among the other isotopes that are “heavy metals”. Because radon may escape from the ore body or ground where it was formed, and subsequently decay to a metal (^{218}Po), it is highly probable that every human being who ever lived has inhaled or ingested dust carrying tiny amounts of radioactive polonium, including ^{210}Po.

Fission

The nucleus of an atom may fission spontaneously without an external cause, the fission may be induced by interaction with a slow (thermal) neutron (slow, but faster than a speeding bullet), or the fission may be induced by a fast neutron (relativistic, ~10% of the speed of light). A thermal neutron can induce a ^{235}U fission whereas a fast neutron, with an energy of at least 1.2 MeV, is needed to induce a ^{238}U fission. The fission process results in the heavy atom splitting into two lighter atoms and releasing a number of neutrons having high energies. The fission process produces many different pairs of atoms / nuclides.

Nuclear reactors that use ordinary (light) water to moderate (slow down) the neutrons to fission ^{235}U require an increased concentration of ^{235}U – say 3% to 5% to compensate for the absorption of neutrons by the hydrogen in water. Enrichment facilities perform this function by processing UF_6 – uranium hexafluoride gas. Enrichment produces "tailings" of depleted uranium which has a reduced ^{235}U concentration relative to natural uranium. This makes depleted-uranium metal slightly less radioactive than natural-uranium metal. Depleted-uranium metal is used as an absorber of radiation in some shielding applications. It has been used for dense ballast material such as sailboat keels. Depleted uranium is used in armour piercing projectiles because of the high density of uranium and the manner in which it burns in air.

Nuclear reactors that use heavy water (deuterium oxide) to moderate the neutrons can fission ^{235}U at natural concentrations. An enrichment facility is required to produce heavy water by increasing the concentration of the heavy hydrogen isotope ^{2}H to a value greater than 99.75% from its natural concentration (~0.016%).

Nuclear reactors that use fast neutrons cannot be cooled with water as this would moderate the neutrons. These fast reactors use liquid-metal or molten-salt coolants to remove heat from the fuel. Only a few prototype fast power reactors have been built.

The ~ 52 MeV produced by the ^{238}Udecay chain over more than 10^9 years can be compared with the ~183 MeV that results from an average ^{235}U fission event in much much less than 1 s (not including the energy from the decay of the fission product nuclides, and the neutrinos whose energy is not recoverable).

Cost

The cost of uranium in the form of "yellowcake" as it is produced from the mills near uranium mines has varied greatly over time: from $10.75 (US) per pound U_3O_8 in 2003 to $95 in 2007 for long term supply contracts. Presently the "spot" market price follows that of oil as the energy supply industries are ultimately coupled by users that can switch energy sources based on cost – and because of to the influence of commodities traders.

References

Via the internet: The Interactive Chart of the Nuclides, www.nndc.bnl.gov/chart
The Uranium Institute, London, UK
Uranium Information Centre Limited, Melbourne, Australia
US Department of Energy, WSRC-TR-2001-00331, Chemical and Radiological Toxicity of Uranium and its Compounds, http://sti.srs.gov/fulltext/tr2001331/tr2001331.html
CAMECO, www.cameco.com

Handbook of Chemistry and Physics, 60th Edition, Chemical Rubber Company, 1979.