Uranium: Its Uses and Hazards

Some of the terms used in this factsheet are defined in IEER's on-line glossary.

First discovered in the 18th century, uranium is an element found everywhere on Earth, but mainly in trace quantities. In 1938, German physicists Otto Hahn and Fritz Strassmann showed that uranium could be split into parts to yield energy. Uranium is the principal fuel for nuclear reactors and the main raw material for nuclear weapons.

Natural uranium consists of three isotopes: uranium-238, uranium-235, and uranium-234. Uranium isotopes are radioactive. The nuclei of radioactive elements are unstable, meaning they are transformed into other elements, typically by emitting particles (and sometimes by absorbing particles). This process, known as radioactive decay, generally results in the emission of alpha or beta particles from the nucleus. It is often also accompanied by emission of gamma radiation, which is electromagnetic radiation, like X-rays. These three kinds of radiation have very different properties in some respects but are all ionizing radiation–each is energetic enough to break chemical bonds, thereby possessing the ability to damage or destroy living cells.

Summary of Uranium Isotopes

Isotope	Percent in natural uranium	No. of Protons	No. of Neutrons	Half-Life (in years)
Uranium-238	99.284	92	146	4.46 billion
Uranium-235	0.711	92	143	704 million
Uranium-234	0.0055	92	142	245,000

Uranium-238, the most prevalent isotope in uranium ore, has a half-life of about 4.5 billion years; that is, half the atoms in any sample will decay in that amount of time. Uranium-238 decays by alpha emission into thorium-234, which itself decays by beta emission to protactinium-234, which decays by beta emission to uranium-234, and so on. The various decay products, (sometimes referred to as "progeny" or "daughters") form a series starting at uranium-238. After several more alpha and beta decays, the series ends with the stable isotope lead-206.

URANIUM DECAY CHAIN — Main Branch
Read from left to right. Arrows indicate decay.

Uranium-238 ==>	Thorium-234 ==>	Protactinium-234m ==>
(half-life: 4.46 billion years)	(half-life: 24.1 days)	(half-life: 1.17 minutes)
alpha decay	beta decay	beta decay
Uranium-234 ==>	Thorium-230 ==>	Radium-226 ==>
(half-life: 245,000 years)	(half-life: 75,400 years)	(half-life: 1,600 years)
alpha decay	alpha decay	alpha decay
Radon-222 ==>	Polonium-218 ==>	Lead-214 ==>
(half-life: 3.82 days)	(half-life: 3.11 minutes)	(half-life: 26.8 minutes)
alpha decay	alpha decay	beta decay
Bismuth-214 ==>	Polonium-214 ==>	Lead-210 ==>

(half-life: 19.9 minutes)	(half-life: 163 microseconds)	(half-life: 22.3 years)
beta decay	alpha decay	beta decay
Bismuth-210 ==>	Polonium-210 ==>	Lead-206
(half-life: 5.01 days)	(half-life: 138 days)	(stable)
beta decay	alpha decay	

Uranium-238 emits alpha particles which are less penetrating than other forms of radiation, and weak gamma rays As long as it remains outside the body, uranium poses little health hazard (mainly from the gamma-rays). If inhaled or ingested, however, its radioactivity poses increased risks of lung cancer and bone cancer. Uranium is also chemically toxic at high concentrations and can cause damage to internal organs, notably the kidneys. Animal studies suggest that uranium may affect reproduction, the developing fetus, [3] and increase the risk of leukemia and soft tissue cancers. [4]

The property of uranium important for nuclear weapons and nuclear power is its ability to fission, or split into two lighter fragments when bombarded with neutrons releasing energy in the process. Of the naturally-occuring uranium isotopes, only uranium-235 can sustain a chain reaction– a reaction in which each fission produces enough neutrons to trigger another, so that the fission process is maintained without any external source of neutrons. [5] In contrast, uranium-238 cannot sustain a chain reaction, but it can be converted to plutonium-239, which can. [6] Plutonium-239, virtually non-existent in nature, was used in the first atomic bomb tested July 16, 1945 and the one dropped on Nagasaki on August 9, 1945.

The Mining and Milling Process

Traditionally, uranium has been extracted from open-pits and underground mines. In the past decade, alternative techniques such in-situ leach mining, in which solutions are injected into underground deposits to dissolve uranium, have become more widely used. Most mines in the U.S. have shut down and imports account for about three-fourths of the roughly 16 metric tons of refined uranium used domestically each year — Canada being the largest single supplier. [7]

The milling (refining) process extracts uranium oxide (U_3O_8) from ore to form yellowcake, a yellow or brown powder that contains about 90 percent uranium oxide. [8] Conventional mining techniques generate a substantial quantity of mill tailings waste during the milling phase, because the usable portion is generally less than one percent of the ore. (In-situ leach mining leaves the unusable portion in the ground, it does not generate this form of waste). The total volume of mill tailings generated in the U.S. is over 95 percent of the volume of all radioactive waste from all stages of the nuclear weapons and power production. [9] While the hazard per gram of mill tailings is low relative to most other radioactive wastes, the large volume and lack of regulations until 1980 have resulted in widespread environmental contamination. Moreover, the half-lives of the principal radioactive components of mill tailings, thorium-230 and radium-226 are long, being about 75,000 years and 1,600 years respectively.

The most serious health hazard associated with uranium mining is lung cancer due to inhaling uranium decay products. Uranium mill tailings contain radioactive materials, notably radium-226, and heavy metals (e.g., manganese and molybdenum) which can leach into groundwater. Near tailings piles, water samples have shown levels of some contaminants at hundreds of times the government’s acceptable level

for drinking water. [10]

Mining and milling operations in the U.S. have disproportionately affected indigenous populations around the globe. For example, nearly one third of all mill tailings from abandoned mill operations are on lands of the Navajo nation alone. [11] Many Native Americans have died of lung cancers linked to their work in uranium mines. Others continue to suffer the effects of land and water contamination due to seepage and spills from tailings piles. [12]

Conversion and Enrichment

Uranium is generally used in reactors in the form of uranium dioxide (UO_2) or uranium metal; nuclear weapons use the metallic form. Production of uranium dioxide or metal requires chemical processing of yellowcake. Further, most civilian and many military reactors require uranium that has a higher proportion of uranium-235 than present in natural uranium. The process used to increase the amount of uranium-235 relative to uranium-238 is known as uranium enrichment.

U.S. civilian power plants typically use 3 to 5 percent uranium-235. Weapons use “highly enriched uranium” (HEU) with over 90 percent uranium-235. Some research reactors and all U.S. naval reactors also use HEU.

To enrich uranium, it must first be put in the chemical form uranium hexafluoride (UF_6). After enrichment, UF6 is chemically converted to uranium dioxide or metal. A major hazard in both the uranium conversion and uranium enrichment processes comes from the handling of uranium hexafluoride, which is chemically toxic as well as radioactive. Moreover, it reacts readily with moisture, releasing highly toxic hydrofluoric acid. Conversion and enrichment facilities have had a number of accidents involving uranium hexafluoride. [13]

The bulk of waste from the enrichment process is depleted uranium–so-called because most of the uranium-235 has been extracted from it. Depleted uranium has been used by the U.S. military to fabricate armor-piercing conventional weapons and tank armor plating. It was incorporated into these conventional weapons without informing armed forces personnel that depleted uranium is a radioactive material and without procedures for measuring doses to operating personnel.

The enrichment process can also be reversed. Highly enriched uranium can be diluted, or “blended down” with depleted, natural, or very low-enriched uranium to produce 3 to 5 percent low-enriched reactor fuel. Uranium metal at various enrichments must be chemically processed so that it can be blended into a homogeneous material at one enrichment level. As a result, the health and environmental risks of blending are similar to those for uranium conversion and enrichment.

Regulations in the U.S.

In 1983 the federal government set standards for controlling pollution from active and abandoned mill tailings piles resulting from yellowcake production. The principal goals of federal regulations are to limit the seepage of radionuclides and heavy metals into groundwater and reduce emissions of radon-222 to the air.

Mandatory standards for decommissioning nuclear facilities including conversion and enrichment facilities are only now being developed by the U.S. Environmental Protection Agency and the U.S. Nuclear Regulatory Commission (NRC). So far, the NRC has been using guidelines developed by its staff in 1981 to oversee decommissioning efforts. [14]

The Future

Uranium and associated decay products thorium-230 and radium-226 will remain hazardous for thousands of years. Current U.S. regulations, however, cover a period of 1,000 years for mill tailings and at most 500 years for "low-level" radioactive waste. This means that future generations–far beyond those promised protection by these regulations–will likely face significant risks from uranium mining, milling, and processing activities.

Go to IEER's on-line glossary.

Notes:

1. The terms alpha, beta, and gamma radiation, and X-rays were coined because scientists did not know the nature of these kinds of radiation when they were first detected. ? Return
2. Nuclear fission can also be induced by bombardment of the nucleus by electrically charged particles, such as alpha particles. However, the nucleus is positively charged and alpha particles are also positively charged. Since positive charges repel each other, these types of fission reactions are more difficult to accomplish than reactions with neutrons. Fission can also be induced by bombarding the nucleus with energetic gamma rays (photons). This process is called photofission. ? Return
3. Agency for Toxic Substances and Disease Registry, ATSDR Public Health Statement: Uranium, Atlanta: ATSDR, December 1990. ? Return
4. Filippova, L. G., A. P. Nifatov, and E. R. Lyubchanskii, Some of the long-term sequelae of giving rats enriched uranium (in Russian), Radiobiologiya, v. 18, n. 3,, pp. 400-405. 1978. Translated in NTIS UB/D/120-03 (DOE-TR-4/9), National Technical Information Service, Springfield, Virginia. ? Return
5. Uranium-235 and plutonium-239 are called "fissile" isotopes–defined as materials that can be fissioned by low-energy (ideally zero energy) neutrons. ? Return
6. Uranium-238 is converted to plutonium-239 by bombarding it with neutrons: U-238 + neutron –>> U-239 U-239 ==> Np-239 + beta particle (electron) Np-239 ==> Pu-239 + beta particle (electron) ? Return
7. Energy Information Administration, Uranium Purchases Report 1992, DOE/EIA-0570(92), Washington, D.C., August 1993. The number of conventional mines operating in the U.S. has declined from a peak of hundreds to zero in 1993, seven "non-conventional" mining operations (e.g., in-situ leach) accounted for all domestic ore production for that year. (NUEXCO, NUEXCO Review: 1993 Annual, Denver, 1994). ? Return
8. Benedict, Manson, Thomas Pigford, and Hans Wolfgang Levi. Nuclear Chemical Engineering. 2 ed.. (New York: McGraw-Hill Book Company, 1981), p. 265. Note that pure U3O8 is black. Yellowcake gets its color from the presence of ammonium diuranate. ? Return
9. Based on the total volume of all radioactive waste (including spent fuel, high-level waste, transuranic waste, low-level waste and uranium mill tailings) from all sources (both commercial

and military) produced in the U.S. since the 1940s, as compiled in Scott Saleska, et al. Nuclear Legacy: An Overview of the Places, Politics, and Problems of Radioactive Waste in the United States (Washington, DC: Public Citizen, 1989), Appendix C. ? Return

10. U.S. Environmental Protection Agency, Final Environmental Impact Statement for Standards for the Control of Byproduct Materials from Uranium Ore Processing, Washington, D.C., 1983, v. 1, pp. D-12, D-13. ? Return
11. Gilles, Cate, Marti Reed, and Jacques Seronde, Our Uranium Legacy, 1990 [available from Southwest Research and Information Center, Albuquerque, NM]. ? Return
12. In 1979, a dam holding water in a mill tailings settling pond at the United Nuclear Fuels Corporation mill near Church Rock, New Mexico gave way and released about 100 million gallons of contaminated water into the Puerco River which cuts through Navajo grazing lands. ? Return
13. One such accident at the Sequoyah Fuels conversion plant in Gore, Oklahoma killed one worker, hospitalized 42 others, and approximately 100 residents. ? Return
14. For more information about cleanup standards, see Science for Democratic Action, (IEER, Takoma Park, MD), Vol. 3, No. 1, Winter 1994. ? Return

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