



**U.S. Department of Energy Office of Environmental Management  
Depleted Uranium Hexafluoride Management Program**



**Characteristics of Uranium and Its Compounds**

*Uranium*

Uranium is a radioactive element that occurs naturally in varying but small amounts in soil, rocks, water, plants, animals, and all human beings. It is the heaviest naturally occurring element, with an atomic number of 92. In its pure form, uranium is a silver-colored heavy metal that is nearly twice as dense as lead. In nature, uranium atoms exist as several isotopes, which are identified by the total number of protons and neutrons in the nucleus: uranium-238, uranium-235, and uranium-234. (Isotopes of an element have the same number of protons in the nucleus, but a different number of neutrons.) In a typical sample of natural uranium, most of the weight (99.27%) consists of atoms of uranium-238. About 0.72% of the weight consists of atoms of uranium-235, and a very small amount (0.0055% by weight) is uranium-234.

**Symbol:** U

**Atomic Number:** 92  
(protons in nucleus)

**Atomic Weight:** 238  
(naturally occurring)

The three naturally occurring isotopes of uranium are each radioactive, which means the nuclei spontaneously disintegrate or “decay.” Radioactivity emitted from uranium isotopes consists of alpha particles (a collection of two protons and two neutrons) and gamma rays (an electromagnetic energy wave similar to visible light except with higher energy and more penetrating power). The rate at which the nuclei in an isotope sample decay is called activity, which is the number of disintegrations that occur per second. The activity of an isotope sample decreases with time as the atoms disintegrate. Each isotope has its own half-life, which is the time it takes for half of the atoms in a sample of the isotope to decay and the activity of the sample to be proportionately reduced.

<b>Radioactive Properties of Key Uranium Isotopes</b>				
<b>Isotope</b>	<b>Half-Life</b>	<b>Natural Abundance (%)</b>	<b>Specific Activity (Ci/g)</b>	<b>Decay Energy (MeV)</b>
U-234	248,000 yr	0.0055	$6.2 \times 10^{-3}$	4.8 $\alpha$
U-235	700 million yr	0.72	$2.2 \times 10^{-6}$	4.4 $\alpha$ 0.21 $\gamma$
U-238	4.5 billion yr	99.27	$3.3 \times 10^{-7}$	4.2 $\alpha$

Specific activity is the activity in curies (Ci) or becquerels (Bq) per gram of material. For reference, 1 Ci is  $3.7 \times 10^{10}$  disintegrations per second, and the specific activity of radium-226 is about 1 Ci/g. To convert specific activity expressed in curies to standard international units, multiply by  $3.7 \times 10^{10}$  Bq/Ci. The decay energy represents the average energy associated with the dominant decay modes, which is essentially the kinetic energy of the alpha ( $\alpha$ ) and beta ( $\beta$ ) particles and the electromagnetic energy of the gamma ( $\gamma$ ) rays. One million electron volts (MeV) is 0.16 trillionth of a joule.

In addition to being naturally radioactive, the uranium-235 isotope of uranium is capable of fission, the splitting of the nucleus into two parts, triggered by absorption of a neutron. When this splitting occurs, considerable energy is released, which makes uranium-235 valuable as a fuel in nuclear reactors used to generate electricity and for use in U.S. national defense.

## ***Depleted Uranium***

Over the last four decades, large quantities of uranium were processed by gaseous diffusion to produce uranium having a higher concentration of uranium-235 than the 0.72% that occurs naturally (called “enriched” uranium) for use in U.S. national defense and civilian applications. “Depleted” uranium is also a product of the enrichment process. However, depleted uranium has been stripped of some of its natural uranium-235 content. Most of the U.S. Department of Energy’s (DOE’s) depleted uranium inventory contains between 0.2 to 0.4 % (by weight) uranium-235, well below levels necessary to create a nuclear chain reaction.

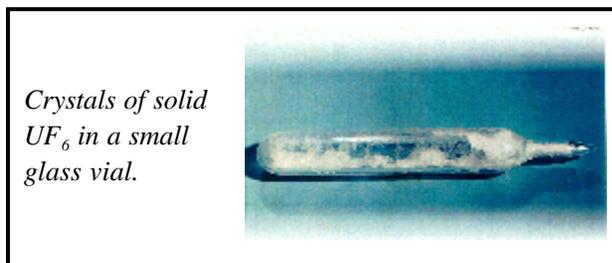
Depleted uranium is not a significant health hazard unless it is taken into the body. External exposure to radiation from depleted uranium is generally not a major concern because the alpha particles emitted by its isotopes travel only a few centimeters in air or can be stopped by a sheet of paper. Also, the uranium-235 that remains in depleted uranium emits only a small amount of low-energy gamma radiation. However, if allowed to enter the body, depleted uranium, like natural uranium, has the potential for both chemical and radiological toxicity, with the two important target organs being the kidneys and the lungs. The most likely pathways by which uranium could enter the body are ingestion and inhalation. The relative contribution of each pathway to the total uptake into the body depends on the physical and chemical nature of the uranium, as well as the level and duration of exposure.

## ***Chemical Forms of Uranium***

Uranium can take many chemical forms. In nature, uranium is generally found as an oxide, such as in the olive-green-colored mineral pitchblende, which contains triuranium octaoxide ( $U_3O_8$ ). Uranium dioxide ( $UO_2$ ) is the chemical form most often used for nuclear reactor fuel. Uranium-fluorine compounds are also common in uranium processing, with uranium hexafluoride ( $UF_6$ ) being the form used in the gaseous diffusion enrichment process. Uranium tetrafluoride ( $UF_4$ ) is frequently produced as an intermediate in the processing of uranium. As noted above, in its pure form, uranium is a silver-colored metal. Because several of these compounds might be used or produced during the conversion process, a brief description of the physical and chemical properties of each is provided below.

***Uranium Oxide.*** The most common forms of uranium oxide are  $U_3O_8$  and  $UO_2$ . Both oxide forms are solids that have a low solubility in water and are relatively stable over a wide range of environmental conditions.  $U_3O_8$  is the most stable form of uranium and is the form found in nature. The most common form of  $U_3O_8$  is “yellow cake,” a solid named for its characteristic color that is produced during the uranium mining and milling process.  $UO_2$  is a solid ceramic material and is the form in which uranium is most commonly used as a nuclear reactor fuel. At ambient temperatures,  $UO_2$  will gradually convert to  $U_3O_8$ . Uranium oxides are extremely stable in the environment and are thus generally considered the preferred chemical form for storage or disposal.

***Uranium Hexafluoride.***  $UF_6$  is the chemical form of uranium that is used during the uranium enrichment process. Within a reasonable range of temperature and pressure, it can be a solid, liquid, or gas. Solid  $UF_6$  is a white, dense, crystalline material that resembles rock salt.  $UF_6$  does not react with oxygen, nitrogen, carbon dioxide, or dry air, but it does react with water or water vapor (including humidity in the air). When  $UF_6$  comes into contact with water, such as water vapor in the air, the  $UF_6$  and water react, forming corrosive hydrogen fluoride (HF) and a uranium-fluoride compound called uranyl fluoride ( $UO_2F_2$ ). For this reason,



UF<sub>6</sub> is always handled in leak-tight containers and processing equipment. Although very convenient for processing, UF<sub>6</sub> is not considered a preferred form for long-term storage or disposal because of its relative instability.

**Uranium Tetrafluoride.** UF<sub>4</sub> is often called green salt because of its characteristic color. It is generally an intermediate in the conversion of UF<sub>6</sub> to U<sub>3</sub>O<sub>8</sub>, UO<sub>2</sub>, or uranium metal because it can be readily converted to any of these forms. UF<sub>4</sub> is a solid composed of agglomerating particles with a texture similar to baking soda. It is non-volatile, non-hygroscopic, but only slightly soluble in water. After exposure to water, UF<sub>4</sub> slowly dissolves and undergoes hydrolysis, forming any of several possible uranium compounds and hydrogen fluoride (HF). The time for hydrolysis can be lengthy. Although not as stable as the uranium oxides, several recent studies have indicated that UF<sub>4</sub> may be suitable for disposal.

**Uranium Metal.** Uranium metal is heavy, silvery white, malleable, ductile, and softer than steel. It is one of the densest materials known (19 g/cm<sup>3</sup>), being 1.6 times more dense than lead. Uranium metal is not as stable as U<sub>3</sub>O<sub>8</sub> or UO<sub>2</sub> because it is subject to surface oxidation. It tarnishes in air, with the oxide film preventing further oxidation of bulk metal at room temperature. Water attacks uranium metal slowly at room temperature and rapidly at higher temperatures. Uranium metal powder or chips will ignite spontaneously in air at ambient temperature.

Physical Characteristics of Uranium Compounds				
Compound	Melting Point (°C)	Density (g/cm <sup>3</sup> )		Solubility in Water at Ambient Temperature
		Crystal Particle	Bulk	
UF <sub>6</sub>	64.1	4.68	4.6	Decomposes to UO <sub>2</sub> F <sub>2</sub>
UF <sub>4</sub>	960 ± 5	6.7	2.0 - 4.5	Very slightly soluble
UO <sub>2</sub> F <sub>2</sub>	Decomposes to U <sub>3</sub> O <sub>8</sub> at 300	6.37	~2.6	Soluble
U <sub>3</sub> O <sub>8</sub>	Decomposes to UO <sub>2</sub> at 1,300	8.30	1.5 - 4.0	Insoluble
UO <sub>2</sub>	2,878 ± 20	10.96	2.0 - 5.0	Insoluble
Uranium metal	1,132	19.05	19	Insoluble

### ***For More Information***

Please direct comments or questions concerning the DOE DUF<sub>6</sub> Management Program to: Kevin Shaw, U.S. Department of Energy, Office of Environmental Management, Office of Site Closure Oak Ridge Office (EM-32), 19901 Germantown Road, Germantown, MD 2087; (301) 903-4232; fax (301) 903-3479.

Environmental and project-related materials are available for public review in the following reading rooms:

DOE Headquarters, Freedom of Information Reading Room, 1000 Independence Avenue, S.W., Room 1 E-190, Washington, DC 20585. Telephone: (202) 586-3142.

Oak Ridge/DOE, Public Reading Room, 230 Warehouse Road, Suite 300, Oak Ridge, Tennessee 37831. Telephone: (865) 241-4780 or 1-800-382-6938, option 6.

Paducah/DOE, Environmental Information Center, 115 Memorial Drive, Paducah, Kentucky 42001. Telephone: (270) 554-6967.

Portsmouth/DOE, Environmental Information Center, 3930 U.S. Route 23, Perimeter Road, Piketon, Ohio 45661. Telephone: (740) 289-3317.

Additional information is also available through the project web site at: <http://web.ead.anl.gov/uranium>, or at <http://www.tis.eh.doe.gov/nepa> .