

## Depleted Uranium

*(This complements the general fact sheet for uranium.)*

**What Is Depleted Uranium?** Depleted uranium is created as a byproduct during the processing of natural uranium to make it suitable for use as fuel in nuclear power plants or as a component in nuclear weapons. In natural uranium, 99.27% of the mass consists of atoms of uranium-238. About 0.72% of the mass consists of atoms of uranium-235, and a very small amount (0.0055% by mass) is uranium-234. Although uranium-235 is the rarer of the two major uranium isotopes, it is the one that most readily undergoes nuclear fission and is thus the most useful for common nuclear applications. For most of these applications, the proportion of the uranium-235 isotope found in natural uranium must be increased through a process called enrichment.

The uranium enrichment process results in the production of “enriched” uranium (containing >0.72% uranium-235) and “depleted” uranium (containing <0.72% uranium-235). The uranium enrichment process also removes much of the uranium-234 from the depleted uranium. Most depleted uranium in the United States contains between 0.2 and 0.4% uranium-235, with the remainder being uranium-238 and a slight amount of uranium-234. Depleted uranium is less radioactive than natural uranium because some of the uranium-235 and most of the uranium-234 have been removed. Depleted uranium will not undergo a nuclear chain reaction.

### Specific Activity of Enriched and Depleted Uranium (For additional information, see the Uranium fact sheet.)

The specific activity (SA) of a uranium compound depends on its isotopic composition. The SA of natural uranium (containing 0.72% uranium-235) is  $6.77 \times 10^{-7}$  curies per gram (Ci/g). The SA for other mixtures of uranium-238, uranium-235, and uranium-234 can be estimated using the approach developed by the U.S. Nuclear Regulatory Commission (see 10 CFR 20):

For depleted uranium (uranium-235 containing less than 0.72%):  
 $SA = 3.6 \times 10^{-7}$  Ci/g

For enriched uranium (uranium-235 containing more than 0.72%):  
 $SA = \{0.4 + 0.38(\text{enrichment}) + 0.0034(\text{enrichment})^2\} \times 10^{-6}$  Ci/g,  
 where enrichment is the percent uranium-235.

Thus, the SA of depleted uranium is approximately half that of natural uranium. (To express SA in standard international units, multiply the value in Ci/g by  $3.7 \times 10^{10}$  becquerels [Bq]/Ci.)

**How Is It Produced?** In the United States, uranium is enriched by the gaseous diffusion process in which the compound uranium hexafluoride (UF<sub>6</sub>) is heated and converted from a solid to a gas. The UF<sub>6</sub> gas is forced through a long series of compressors and converters with porous barriers. Because uranium-235 has a slightly lighter isotopic mass than uranium-238, UF<sub>6</sub> molecules made with uranium-235 diffuse through the barriers at a slightly higher rate than do the molecules containing uranium-238 (the uranium-234 molecules diffuse through the barriers at a rate even higher than that of the uranium-235 molecules).

At the end of the process there are two UF<sub>6</sub> streams, with one having a higher concentration of uranium-235 than the other. The stream with the higher uranium-235 concentration is referred to as enriched UF<sub>6</sub>, while the stream that is reduced in its concentration of uranium-235 is referred to as depleted UF<sub>6</sub>. The depleted UF<sub>6</sub> can be converted to other chemical forms, such as depleted uranium oxide or depleted uranium metal. Other methods can be used to enrich uranium, and they too produce depleted uranium as a byproduct. The most common enrichment process used outside of the United States is gas centrifuge enrichment. Laser-based enrichment processes have also been investigated but not commercially developed.

**How Is It Used?** Although the vast majority of depleted uranium is stored as a byproduct of the enrichment process at the gaseous diffusion plant sites, several current and potential uses exist. Because of its high density, depleted uranium is currently used for radiation shielding. Depleted uranium metal was previously used on large commercial aircraft as counterweights in the wings. Military applications of depleted uranium include use as tank armor, armor-piercing projectiles (antitank weapons), and counterweights in missiles and high-performance aircraft. In a potential future use, depleted uranium could be mixed with highly enriched uranium from retired nuclear weapons to produce nuclear reactor fuel. This process is called blending, and to date only natural or slightly enriched uranium has been considered for this application. Limited amounts of depleted uranium can also be used for the fabrication of mixed uranium and plutonium oxide (MOX) fuel, which is currently being evaluated for use in commercial nuclear power plants.

**What Are Depleted Uranium Munitions?** Research, tests, and evaluations were conducted during the 1970s to develop improved armor-penetrating munitions capable of defeating a heavily armored target. High-density materials such as tungsten and depleted uranium were considered candidates for this type of munitions; depleted uranium was ultimately selected because of its very high density, availability, noncompetitive uses, and pyrophoricity (spontaneous combustion upon exposure to air).

The two main antitank weapons made of depleted uranium are the 120-millimeter (mm) cannon shell used by the Army's M1 Abrams tank, and the 30-mm munitions used by A-10 antitank aircraft. Depleted uranium weapons are also used in Britain's Challenger tank, and the U.S. and British Navy Phalanx gun systems. The M1 Abrams tank fires a 120-mm shell that contains a kinetic energy penetrator, a solid rod with a pointed tip. The penetrator is made from about 5 kilograms (kg) (11 pounds [lb]) of depleted uranium metal alloyed with less than 1% titanium. The shell is a sabot round, meaning that the penetrator is contained within a carrier as it is fired from the barrel. The carrier separates from the penetrator after exiting the gun barrel. In addition, many M1 Abrams tanks incorporate depleted uranium metal as part of the external armor.

*120-mm antitank kinetic energy rounds fired by the M1 Abrams tank*



Depleted uranium rounds are also fired by a 30-mm, seven-barrel gatling gun mounted in the nose of the A-10 Thunderbolt aircraft, the only U.S. military plane that employs depleted uranium rounds. Depleted uranium is the primary munition for the A-10 Thunderbolt for combat. Each 30-mm depleted uranium projectile contains approximately 0.3 kg (0.66 lb) of extruded depleted uranium metal alloyed with 0.75% titanium. The projectile is encased in a 0.8-mm-thick aluminum shell as the final depleted uranium round.

Depleted uranium penetrators have a “sharpening effect” upon impact that allows greater penetration through armor. Weapon testing shows that when a depleted uranium round penetrates an armored vehicle, it may pass completely through the vehicle or ricochet around and fragment inside the vehicle. Metal fragments from the penetrator and the vehicle’s hull can scatter inside the vehicle, killing and injuring personnel, destroying equipment, and causing secondary explosions and fires. As much as 70% of a depleted uranium penetrator can be aerosolized when it strikes a tank. Aerosols containing uranium oxides may contaminate the area downwind. Uranium metal and oxide fragments may also contaminate the soil around the struck vehicle. Tests of depleted uranium penetrators striking depleted uranium armored vehicles have shown that most of the contamination will occur within 5 to 7 meters (16 to 23 feet) of the vehicle.

**For Whom Is Exposure a Concern?** Soldiers can be exposed to depleted uranium when intact rounds are in storage or uploaded in armored vehicles, or on the battlefield following the use of depleted uranium munitions. Studies have shown that exposure to intact depleted uranium weapons systems, both munitions and armor, pose very little risk from external radiation. Uranium and its decay products are primarily alpha emitters, emitting only very low levels of gamma radiation. However, individuals involved in handling or processing depleted uranium generally wear heavy gloves to protect against the high-energy beta particle from protactinium-234m, which is only a concern for skin exposure.

On the battlefield, exposure to depleted uranium can occur several ways. After impact with an armored vehicle, depleted uranium in the form of oxide and metal fragments will contaminate the struck vehicle and the surrounding area, especially if an explosion or fire occurs. Depleted uranium oxide can be aerosolized, presenting an inhalation hazard to soldiers in the vicinity or downwind of the struck vehicle. In addition, depleted uranium dust can be resuspended in the air from soil contamination around the vehicle. Soil contamination also can be ingested inadvertently from hand to mouth contact. In another example of battlefield exposure, at least 36 soldiers in Operation Desert Storm were reported to have wounds involving imbedded depleted uranium fragments. (Many of these fragments were not removed because the risk of

surgery was judged to be too great.) Following combat, maintenance and recovery personnel can be exposed to equipment contaminated with depleted uranium. Dust containing depleted uranium can be resuspended during recovery operations, posing an inhalation hazard. Spent depleted uranium rounds and penetrators that were fired but missed their targets may be scattered on the battlefield and can thus potentially lead to additional exposures.

***What Happens to It in the Body?*** After it is ingested, most uranium is excreted from the body within a few days and never enters the bloodstream. The small fraction that is absorbed into the bloodstream (0.2 to 5%) is deposited preferentially in bone and kidneys. Most of what goes to the kidneys leaves within a few days (in urine), while that deposited in bone can remain for many years. After inhalation, generally only a small fraction penetrates to the lung's alveolar region, where it can remain for years and can also enter the bloodstream.

***What Are the Primary Health Effects?*** Uranium is a health hazard only if it is taken into the body. External gamma exposure is generally not a major concern because uranium emits only a small amount of low-energy gamma radiation, and beta exposure is only of concern for direct handling operations (due to potential skin effects). The main means of exposure are ingestion of food and water containing uranium isotopes and inhalation of uranium-contaminated dust. Ingestion is usually the exposure route of concern unless there is a nearby source of airborne dust. Because uranium is taken up in the body much more readily if inhaled than if ingested, both exposure routes can be important. The major health concern is kidney damage caused by the chemical toxicity of soluble uranium compounds; these effects can be reversible depending on the level of exposure. Uranium is not considered a chemical carcinogen. A second concern is for uranium deposited in bone, which can lead to bone cancer as a result of the ionizing radiation associated with the radioactive decay products. Uranium has caused reproductive problems in laboratory animals and developmental problems in young animals, but it is not known if these problems exist for humans.

***What Are the Risks?*** Lifetime cancer mortality risk coefficients have been calculated for nearly all radionuclides, including uranium (*see the companion fact sheet for Uranium*). On an activity (curie) basis, these risk coefficients are essentially the same for all three natural uranium isotopes. Hence, the risk is essentially independent of the ratio of the various isotopes in a uranium compound. For this reason, the risk of a fatal cancer from exposure to depleted uranium is essentially the same as for enriched uranium on an activity basis. However, because of the difference in specific activity, equal activities of enriched and depleted uranium have significantly different masses.

The decay of uranium isotopes in depleted uranium results in the generation of radioactive decay products. For example, thorium-234 and protactinium-234m (the "m" meaning metastable) are produced from the decay of uranium-238. The recycling of irradiated uranium may also result in some radioactive impurities in depleted uranium. Some of these decay products and impurities could potentially also exhibit chemical toxicity. The decay products and impurities contribute to the radiation emitted by depleted uranium; however, the concentrations are generally too small to be of significance when assessing the chemical health effects from exposures to depleted uranium.

The extent of chemical damage from exposure to a depleted uranium compound depends on its solubility and the route of exposure. In most assessments, only inhalation and ingestion are considered because although dermal absorption of some soluble compounds (e.g., uranyl nitrate) is possible, these exposures generally are not significant in association with industrial emissions or environmental exposures. When soluble or moderately soluble compounds such as uranyl fluoride ( $\text{UO}_2\text{F}_2$ ) or uranium tetrafluoride ( $\text{UF}_4$ ) are inhaled or ingested, some of the uranium enters the bloodstream and reaches the kidney and other internal organs; thus, chemical toxicity is of primary importance.

When insoluble compounds such as  $\text{UO}_2$  and  $\text{U}_3\text{O}_8$  are inhaled, the uranium is generally deposited in the lungs and can remain there for long periods of time (months or years). The main concern from exposure to these insoluble compounds is increased cancer risk from the internal exposure to radioactivity. Ingested insoluble compounds are poorly absorbed from the gastrointestinal tract, and so generally have low toxicity.

Available health effect criteria for acute and chronic uranium exposures are provided in Tables 1 and 2, respectively, derived from animal studies. Only limited data exist for human exposures.

**TABLE 1. Reference Levels for Chemical Effects of Acute Uranium Exposures**

| Health Endpoint                        | Estimated Intake      | Source                             | Air Concentration of Various Compounds <sup>a</sup>   |
|--|-----------------------|------------------------------------|---|
| Potential irreversible adverse effects | 30 mg soluble uranium | NRC (1994)<br>Fisher et al. (1994) | UO <sub>2</sub> F <sub>2</sub> , UF <sub>4</sub> : 26 mg/m <sup>3</sup><br>U <sub>3</sub> O <sub>8</sub> : 590 mg/m <sup>3</sup><br>UO <sub>2</sub> : 570 mg/m <sup>3</sup> |
| Potential adverse effects              | 10 mg soluble uranium | McGuire (1991)                     | UO <sub>2</sub> F <sub>2</sub> , UF <sub>4</sub> : 9 mg/m <sup>3</sup><br>U <sub>3</sub> O <sub>8</sub> : 200 mg/m <sup>3</sup><br>UO <sub>2</sub> : 190 mg/m <sup>3</sup>  |

<sup>a</sup> Assumes 1-hour exposure at an inhalation rate of 1.5 m<sup>3</sup> per hour; assuming a higher inhalation rate for a shorter exposure duration may be appropriate (ICRP 1994) and will result in lower air concentrations. A factor of 25 decrease in systemic absorption of insoluble compounds (i.e., U<sub>3</sub>O<sub>8</sub> and UO<sub>2</sub>) was also assumed. These concentrations may not be protective against the adverse radiological effects of insoluble uranium compounds.

**TABLE 2. Reference Levels for Chemical Effects of Chronic Uranium Exposures**

| Route      | Reference Level <sup>a</sup>                              | Source                               | Notes  |
|------------|---|--------------------------------------|--|
| Ingestion  | <u>Soluble compounds</u><br>(1) 0.003 mg/kg/d             | EPA (2004); Maynard and Hodge (1949) | Based on a lowest observed adverse effect level (LOAEL) of 3 mg/kg-day and an uncertainty factor of 1,000.               |
|            | (2) 0.002 mg/kg/d   | ATSDR, 1999;<br>Gilman et al., 1998  | Based on an intermediate-duration (91 days) oral exposure of rabbits to a soluble uranium compound.                      |
|            | <u>Insoluble compounds</u><br>(1) 0.003 mg/kg/d           | EPA (2004); Maynard and Hodge (1949) | Same as for soluble compounds; no correction for decreased absorption.   |
|            | (2) Compound-specific based on absorption data            | ATSDR, 1999;<br>Gilman et al., 1998  |  |
| Inhalation | <u>Soluble compounds</u><br>(1) 0.011 mg/m <sup>3</sup>   | Derived                              | Based on route-to-route extrapolation of ingestion value (EPA 1996).   |
|            | (2) 0.0012 mg/m <sup>3</sup>                              | Derived                              | Based on adjustments to occupational exposure limit (EPA 1992).  |
|            | (3) 0.0004 or 0.0003 mg/m <sup>3</sup>                    | ATSDR (1999)                         | Based on intermediate duration (5 weeks) and chronic (1 year) inhalation exposures of dogs to soluble uranium compounds. |
|            | <u>Insoluble compounds</u><br>(1) 0.011 mg/m <sup>3</sup> | Derived                              | Same as for soluble compounds; no correction for decreased absorption.   |
|            | (2) 0.28 mg/m <sup>3</sup>                                | Derived                              | Assume absorption is decreased by a factor of 25 (ICRP 1979).  |
|            | (3) 0.008 mg/m <sup>3</sup>                               | ATSDR (1999)                         | Based on intermediate duration (5 weeks) inhalation exposures of dogs to insoluble uranium dioxide.                      |
|            | (4) 0.006 mg/m <sup>3</sup>                               | Derived                              | Based on adjustments made to occupational exposure limit (EPA 1992).   |

<sup>a</sup> Soluble compounds include uranyl fluoride (UO<sub>2</sub>F<sub>2</sub>), uranyl nitrate hexahydrate (UO<sub>2</sub>[NO<sub>3</sub>]<sub>2</sub>·6H<sub>2</sub>O), and uranium tetrachloride (UCl<sub>4</sub>). Some insoluble compounds are uranium metal, uranium dioxide (UO<sub>2</sub>), uranium trioxide (UO<sub>3</sub>), and triuranium octaoxide (U<sub>3</sub>O<sub>8</sub>). Uranium hexafluoride (UF<sub>6</sub>) decomposes to UO<sub>2</sub>F<sub>2</sub> and hydrogen fluoride (HF) in the presence of moisture. Uranium tetrafluoride (UF<sub>4</sub>) is very slightly soluble. Source: ATSDR (1999).