[Template:About](/wiki/Template:About" \o "Template:About) [Template:Pp-semi-indef](/wiki/Template:Pp-semi-indef) [Template:Pp-move-indef](/wiki/Template:Pp-move-indef) [Template:Use dmy dates](/wiki/Template:Use_dmy_dates) [Template:Infobox uranium](/wiki/Template:Infobox_uranium) **Uranium** is a [chemical element](/wiki/Chemical_element) with symbol **U** and [atomic number](/wiki/Atomic_number) 92. It is a silvery-white [metal](/wiki/Metal) in the [actinide](/wiki/Actinide) series of the [periodic table](/wiki/Periodic_table). A uranium atom has 92 [protons](/wiki/Proton) and 92 [electrons](/wiki/Electron), of which 6 are [valence electrons](/wiki/Valence_electron). Uranium is weakly [radioactive](/wiki/Radioactive_decay) because all its [isotopes](/wiki/Isotope) are unstable (with half-lives of the six naturally known isotopes, uranium-233 to uranium-238, varying between 69 years and 4.5 billion years). The most common isotopes in [natural uranium](/wiki/Natural_uranium) are [uranium-238](/wiki/Uranium-238) (which has 146 [neutrons](/wiki/Neutron) and accounts for over 99%) and [uranium-235](/wiki/Uranium-235) (which has 143 neutrons). Uranium has the second highest [atomic weight](/wiki/Atomic_weight) of the [primordially](/wiki/Primordial_nuclide) occurring elements, lighter only than [plutonium](/wiki/Plutonium).[[1]](#cite_note-1) Its [density](/wiki/Density) is about 70% higher than that of [lead](/wiki/Lead), and slightly lower than that of [gold](/wiki/Gold) or [tungsten](/wiki/Tungsten). It occurs naturally in low concentrations of a few [parts per million](/wiki/Parts-per_notation#Parts-per_expressions) in soil, rock and water, and is commercially [extracted](/wiki/Uranium_mining) from uranium-bearing [minerals](/wiki/Mineral) such as [uraninite](/wiki/Uraninite).

In nature, uranium is found as uranium-238 (99.2739–99.2752%), uranium-235 (0.7198–0.7202%), and a very small amount of [uranium-234](/wiki/Uranium-234) (0.0050–0.0059%).[[2]](#cite_note-2) Uranium decays slowly by emitting an [alpha particle](/wiki/Alpha_particle). The [half-life](/wiki/Half-life) of uranium-238 is about 4.47 [billion](/wiki/1000000000_(number)) years and that of uranium-235 is 704 [million](/wiki/Million) years,[[3]](#cite_note-3) making them useful in dating the [age of the Earth](/wiki/Age_of_the_Earth).

Many contemporary uses of uranium exploit its unique [nuclear](/wiki/Atomic_nucleus) properties. Uranium-235 has the distinction of being the only naturally occurring [fissile](/wiki/Fissile) [isotope](/wiki/Isotope). Uranium-238 is fissionable by fast neutrons, and is [*fertile*](/wiki/Fertile_material), meaning it can be [transmuted](/wiki/Nuclear_transmutation) to fissile [plutonium-239](/wiki/Plutonium-239) in a [nuclear reactor](/wiki/Nuclear_reactor). Another fissile isotope, [uranium-233](/wiki/Uranium-233), can be produced from natural [thorium](/wiki/Thorium) and is also important in nuclear technology. Uranium-238 has a small probability for [spontaneous fission](/wiki/Spontaneous_fission) or even induced fission with fast neutrons; uranium-235 and to a lesser degree uranium-233 have a much higher fission cross-section for slow neutrons. In sufficient concentration, these isotopes maintain a sustained [nuclear chain reaction](/wiki/Nuclear_chain_reaction). This generates the heat in nuclear power reactors, and produces the fissile material for [nuclear weapons](/wiki/Nuclear_weapon). [Depleted uranium](/wiki/Depleted_uranium) (238U) is used in [kinetic energy penetrators](/wiki/Kinetic_energy_penetrator) and [armor plating](/wiki/Vehicle_armour).[[4]](#cite_note-4) Uranium is used as a colorant in [uranium glass](/wiki/Uranium_glass), producing lemon yellow to green colors. Uranium glass fluoresces green in ultraviolet light. It was also used for tinting and shading in early [photography](/wiki/Photography).

The 1789 [discovery](/wiki/Discovery_of_the_chemical_elements) of uranium in the mineral [pitchblende](/wiki/Uraninite) is credited to [Martin Heinrich Klaproth](/wiki/Martin_Heinrich_Klaproth), who named the new element after the planet [Uranus](/wiki/Uranus). [Eugène-Melchior Péligot](/wiki/Eugène-Melchior_Péligot) was the first person to isolate the metal and its radioactive properties were discovered in 1896 by [Henri Becquerel](/wiki/Henri_Becquerel). Research by [Otto Hahn](/wiki/Otto_Hahn), [Lise Meitner](/wiki/Lise_Meitner), [Enrico Fermi](/wiki/Enrico_Fermi) and others, such as [J. Robert Oppenheimer](/wiki/J._Robert_Oppenheimer) starting in 1934 led to its use as a fuel in the nuclear power industry and in [*Little Boy*](/wiki/Little_Boy), the [first nuclear weapon used in war](/wiki/Atomic_bombings_of_Hiroshima_and_Nagasaki). An ensuing [arms race](/wiki/Arms_race) during the [Cold War](/wiki/Cold_War) between the [United States](/wiki/United_States) and the [Soviet Union](/wiki/Soviet_Union) produced tens of thousands of nuclear weapons that used uranium metal and uranium-derived [plutonium-239](/wiki/Plutonium-239). The security of those weapons and their fissile material following the [breakup of the Soviet Union](/wiki/Collapse_of_the_Soviet_Union_(1985–1991)#Dissolution_of_the_USSR) in 1991 is an ongoing concern for public health and safety.[[5]](#cite_note-5) See [Nuclear proliferation](/wiki/Nuclear_proliferation).

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## Characteristics[[edit](/index.php?title=(none)&action=edit&section=1)]

[thumb|left|150px|A neutron-induced nuclear fission event involving uranium-235|alt=A diagram showing a chain transformation of uranium-235 to uranium-236 to barium-141 and krypton-92](/wiki/File:Nuclear_fission.svg) When [refined](/wiki/Refining_(metallurgy)), uranium is a silvery white, weakly radioactive [metal](/wiki/Metal). It has a [Mohs hardness](/wiki/Hardnesses_of_the_elements_(data_page)) of 6, sufficient to scratch glass and approximately equal to that of [titanium](/wiki/Titanium), [rhodium](/wiki/Rhodium), [manganese](/wiki/Manganese) and [niobium](/wiki/Niobium). It is [malleable](/wiki/Malleability), [ductile](/wiki/Ductility), slightly [paramagnetic](/wiki/Paramagnetism), strongly [electropositive](/wiki/Electronegativity) and a poor [electrical conductor](/wiki/Electrical_conductivity).[[6]](#cite_note-6)[[7]](#cite_note-7) Uranium metal has a very high [density](/wiki/Density) of 19.1 g/cm3,[[8]](#cite_note-8) denser than [lead](/wiki/Lead) (11.3 g/cm3),[[9]](#cite_note-9) but slightly less dense than [tungsten](/wiki/Tungsten) and [gold](/wiki/Gold) (19.3 g/cm3).[[10]](#cite_note-10)[[11]](#cite_note-11) Uranium metal reacts with almost all non-metal elements (with an exception of the [noble gases](/wiki/Noble_gas)) and their [compounds](/wiki/Chemical_compound), with reactivity increasing with temperature.[[12]](#cite_note-12) [Hydrochloric](/wiki/Hydrochloric_acid) and [nitric acids](/wiki/Nitric_acid) dissolve uranium, but non-oxidizing acids other than hydrochloric acid attack the element very slowly.[[6]](#cite_note-6) When finely divided, it can react with cold water; in air, uranium metal becomes coated with a dark layer of [uranium oxide](/wiki/Uranium_oxide).[[7]](#cite_note-7) Uranium in ores is extracted chemically and converted into [uranium dioxide](/wiki/Uranium_dioxide) or other chemical forms usable in industry.

Uranium-235 was the first isotope that was found to be [fissile](/wiki/Fissile). Other naturally occurring isotopes are fissionable, but not fissile. On bombardment with slow neutrons, its uranium-235 [isotope](/wiki/Isotope) will most of the time divide into two smaller [nuclei](/wiki/Atomic_nucleus), releasing nuclear [binding energy](/wiki/Binding_energy) and more neutrons. If too many of these neutrons are absorbed by other uranium-235 nuclei, a [nuclear chain reaction](/wiki/Nuclear_chain_reaction) occurs that results in a burst of heat or (in special circumstances) an explosion. In a nuclear reactor, such a chain reaction is slowed and controlled by a [neutron poison](/wiki/Neutron_poison), absorbing some of the free neutrons. Such neutron absorbent materials are often part of reactor [control rods](/wiki/Control_rod) (see [nuclear reactor physics](/wiki/Nuclear_reactor_physics) for a description of this process of reactor control).

As little as 15 lb (7 kg) of uranium-235 can be used to make an atomic bomb.[[13]](#cite_note-13) The first nuclear bomb used in war, [*Little Boy*](/wiki/Little_Boy), relied on uranium fission, but the very first nuclear explosive (the *Gadget* used at [Trinity](/wiki/Trinity_(nuclear_test))) and the bomb that destroyed Nagasaki ([*Fat Man*](/wiki/Fat_Man)) were both plutonium bombs.

Uranium metal has three [allotropic](/wiki/Allotropy) forms:[[14]](#cite_note-14)\* α ([orthorhombic](/wiki/Orthorhombic)) stable up to 668 °C. [Orthorhombic](/wiki/Orthorhombic), [space group](/wiki/Space_group) No. 63, *Cmcm*, [lattice parameters](/wiki/Lattice_parameter) *a* = 285.4 pm, *b* = 587 pm, *c* = 495.5 pm.<ref name=Grenthe>[Template:Cite book](/wiki/Template:Cite_book)</ref>

* β ([tetragonal](/wiki/Tetragonal)) stable from 668 °C to 775 °C. [Tetragonal](/wiki/Tetragonal), space group *P*42/*mnm*, *P*42*nm*, or *P*4*n*2, lattice parameters *a* = 565.6 pm, *b* = *c* = 1075.9 pm.<ref name=Grenthe/>
* γ ([body-centered cubic](/wiki/Body-centered_cubic)) from 775 °C to melting point—this is the most malleable and ductile state. [Body-centered cubic](/wiki/Body-centered_cubic), lattice parameter *a* = 352.4 pm.<ref name=Grenthe/>

## Applications[[edit](/index.php?title=(none)&action=edit&section=2)]

### Military[[edit](/index.php?title=(none)&action=edit&section=3)]

[thumb|left|Various militaries use](/wiki/File:30mm_DU_slug.jpg) [depleted uranium](/wiki/Depleted_uranium) as high-density penetrators.|alt=Shiny metallic cylinder with a sharpened tip. The overall length is 9 cm and diameter about 2 cm.

The major application of uranium in the military sector is in high-density penetrators. This ammunition consists of [depleted uranium](/wiki/Depleted_uranium) (DU) alloyed with 1–2% other elements, such as [titanium](/wiki/Titanium) or [molybdenum](/wiki/Molybdenum).[[15]](#cite_note-15) At high impact speed, the density, hardness, and [pyrophoricity](/wiki/Pyrophoricity) of the projectile enable the destruction of heavily armored targets. Tank armor and other removable [vehicle armor](/wiki/Vehicle_armor) can also be hardened with depleted uranium plates. The use of depleted uranium became politically and environmentally contentious after the use of such munitions by the US, UK and other countries during wars in the Persian Gulf and the Balkans raised questions concerning uranium compounds left in the soil (see [Gulf War Syndrome](/wiki/Gulf_War_Syndrome)).[[13]](#cite_note-13) Depleted uranium is also used as a shielding material in some containers used to store and transport radioactive materials. While the metal itself is radioactive, its high density makes it more effective than [lead](/wiki/Lead) in halting radiation from strong sources such as [radium](/wiki/Radium).[[6]](#cite_note-6) Other uses of depleted uranium include counterweights for aircraft control surfaces, as ballast for missile [re-entry vehicles](/wiki/Atmospheric_reentry) and as a shielding material.[[7]](#cite_note-7) Due to its high density, this material is found in [inertial guidance systems](/wiki/Inertial_guidance_system) and in [gyroscopic](/wiki/Gyroscope) [compasses](/wiki/Compass).[[7]](#cite_note-7) Depleted uranium is preferred over similarly dense metals due to its ability to be easily machined and cast as well as its relatively low cost.[[16]](#cite_note-16) The main risk of exposure to depleted uranium is chemical poisoning by [uranium oxide](/wiki/Uranium_oxide) rather than radioactivity (uranium being only a weak [alpha emitter](/wiki/Alpha_decay)).

During the later stages of [World War II](/wiki/World_War_II), the entire [Cold War](/wiki/Cold_War), and to a lesser extent afterwards, uranium-235 has been used as the fissile explosive material to produce nuclear weapons. Initially, two major types of fission bombs were built: a relatively simple device that uses uranium-235 and a more complicated mechanism that uses [plutonium-239](/wiki/Plutonium-239) derived from uranium-238. Later, a much more complicated and far more powerful type of fission/fusion bomb ([thermonuclear weapon](/wiki/Thermonuclear_weapon)) was built, that uses a plutonium-based device to cause a mixture of [tritium](/wiki/Tritium) and [deuterium](/wiki/Deuterium) to undergo [nuclear fusion](/wiki/Nuclear_fusion). Such bombs are jacketed in a non-fissile (unenriched) uranium case, and they derive more than half their power from the fission of this material by [fast neutrons](/wiki/Fast_neutron) from the nuclear fusion process.[[17]](#cite_note-17)

### Civilian[[edit](/index.php?title=(none)&action=edit&section=4)]

[thumb|The most visible civilian use of uranium is as the thermal power source used in](/wiki/File:Nuclear_Power_Plant_2.jpg) [nuclear power plants](/wiki/Nuclear_power_plant)|alt=Photograph featuring sunflowers in front and a plant on the back. The plant has a wide smoking chimney with diameter comparable to its height.

The main use of uranium in the civilian sector is to fuel [nuclear power plants](/wiki/Nuclear_power_plant). One kilogram of uranium-235 can theoretically produce about [20 terajoules](/wiki/Orders_of_magnitude_(energy)) of energy (2[Template:E](/wiki/Template:E) [joules](/wiki/Joule)), assuming complete fission; as much [energy](/wiki/Energy) as 1500 [tonnes](/wiki/Tonne) of [coal](/wiki/Coal).[[4]](#cite_note-4) Commercial [nuclear power](/wiki/Nuclear_power) plants use fuel that is typically enriched to around 3% uranium-235.[[4]](#cite_note-4) The [CANDU](/wiki/CANDU_reactor) and [Magnox](/wiki/Magnox) designs are the only commercial reactors capable of using unenriched uranium fuel. Fuel used for [United States Navy](/wiki/United_States_Navy) reactors is typically highly enriched in [uranium-235](/wiki/Uranium-235) (the exact values are [classified](/wiki/Classified_information)). In a [breeder reactor](/wiki/Breeder_reactor), uranium-238 can also be converted into [plutonium](/wiki/Plutonium) through the following reaction:[[7]](#cite_note-7)

[Template:Nuclide2](/wiki/Template:Nuclide2) + n [Template:Bigmath](/wiki/Template:Bigmath) [Template:Nuclide2](/wiki/Template:Nuclide2) + [Template:Mvar](/wiki/Template:Mvar) [Template:Overunderset](/wiki/Template:Overunderset) [Template:Nuclide2](/wiki/Template:Nuclide2) [Template:Overunderset](/wiki/Template:Overunderset) [Template:Nuclide2](/wiki/Template:Nuclide2)

[thumb|left|Uranium glass glowing under](/wiki/File:U_glass_with_black_light.jpg) [UV light](/wiki/Ultraviolet)|alt=A glass place on a glass stand. The plate is glowing green while the stand is colorless. Before (and, occasionally, after) the discovery of radioactivity, uranium was primarily used in small amounts for yellow glass and pottery glazes, such as [uranium glass](/wiki/Uranium_glass) and in [Fiestaware](/wiki/Fiesta_(dinnerware)).[[18]](#cite_note-18) The discovery and isolation of [radium](/wiki/Radium) in uranium ore (pitchblende) by [Marie Curie](/wiki/Marie_Curie) sparked the development of uranium mining to extract the radium, which was used to make glow-in-the-dark paints for clock and aircraft dials.[[19]](#cite_note-19) This left a prodigious quantity of uranium as a waste product, since it takes three tonnes of uranium to extract one [gram](/wiki/Gram) of radium. This waste product was diverted to the glazing industry, making uranium glazes very inexpensive and abundant. Besides the pottery glazes, [uranium tile](/wiki/Uranium_tile) glazes accounted for the bulk of the use, including common bathroom and kitchen tiles which can be produced in green, yellow, mauve, black, blue, red and other colors.

[thumb|Uranium glass used as lead-in seals in a vacuum](/wiki/File:Vacuum_capacitor_with_uranium_glass.jpg) [capacitor](/wiki/Capacitor)|alt=A glass cylinder capped on both ends with metal electrodes. Inside the glass bulb there is a metal cylinder connected to the electrodes. Uranium was also used in [photographic](/wiki/Photography) chemicals (especially [uranium nitrate](/wiki/Uranium_nitrate) as a [toner](/wiki/Toner)),[[7]](#cite_note-7) in lamp filaments for [stage lighting](/wiki/Stage_lighting) bulbs,[[20]](#cite_note-20) to improve the appearance of [dentures](/wiki/Dentures),[[21]](#cite_note-21) and in the leather and wood industries for stains and dyes. Uranium salts are [mordants](/wiki/Mordant) of silk or wool. Uranyl acetate and uranyl formate are used as electron-dense "stains" in [transmission electron microscopy](/wiki/Transmission_electron_microscopy), to increase the contrast of biological specimens in ultrathin sections and in [negative staining](/wiki/Negative_staining) of [viruses](/wiki/Virus), isolated [cell organelles](/wiki/Cell_organelle) and [macromolecules](/wiki/Macromolecule).

The discovery of the radioactivity of uranium ushered in additional scientific and practical uses of the element. The long [half-life](/wiki/Half-life) of the isotope uranium-238 (4.51[Template:E](/wiki/Template:E) years) makes it well-suited for use in estimating the age of the earliest [igneous rocks](/wiki/Igneous_rock) and for other types of [radiometric dating](/wiki/Radiometric_dating), including [uranium-thorium dating](/wiki/Uranium-thorium_dating), [uranium-lead dating](/wiki/Uranium-lead_dating) and [uranium-uranium dating](/wiki/Uranium-uranium_dating). Uranium metal is used for [X-ray](/wiki/X-ray) targets in the making of high-energy X-rays.[[7]](#cite_note-7)

## History[[edit](/index.php?title=(none)&action=edit&section=5)]

### Pre-discovery use[[edit](/index.php?title=(none)&action=edit&section=6)]

[thumb|right|200px|The planet](/wiki/File:Uranus_as_seen_by_NASA's_Voyager_2.tif) [Uranus](/wiki/Uranus), which uranium is named after The use of uranium in its natural [oxide](/wiki/Oxide) form dates back to at least the year 79 [CE](/wiki/Common_Era), when it was used to add a yellow color to [ceramic](/wiki/Ceramic) glazes.[[7]](#cite_note-7) Yellow glass with 1% uranium oxide was found in a [Roman](/wiki/Roman_Empire) villa on Cape [Posillipo](/wiki/Posillipo) in the [Bay of Naples](/wiki/Gulf_of_Naples), Italy, by R. T. Gunther of the [University of Oxford](/wiki/University_of_Oxford) in 1912.[[22]](#cite_note-22) Starting in the late [Middle Ages](/wiki/Middle_Ages), pitchblende was extracted from the [Habsburg](/wiki/Habsburg) silver mines in [Joachimsthal](/wiki/Jáchymov), [Bohemia](/wiki/Bohemia) (now Jáchymov in the Czech Republic), and was used as a coloring agent in the local [glassmaking](/wiki/Glass) industry.[[23]](#cite_note-23) In the early 19th century, the world's only known sources of uranium ore were these mines.

### Discovery[[edit](/index.php?title=(none)&action=edit&section=7)]

[thumb|](/wiki/File:Becquerel_plate.jpg)[Antoine Henri Becquerel](/wiki/Henri_Becquerel) discovered the phenomenon of [radioactivity](/wiki/Radioactivity) by exposing a [photographic plate](/wiki/Photographic_plate) to uranium in 1896|alt=Two fuzzy black features on a fuzzy white paper-like background. There is a handwriting at the top of the picture. The [discovery](/wiki/Discovery_of_the_chemical_elements) of the element is credited to the German chemist [Martin Heinrich Klaproth](/wiki/Martin_Heinrich_Klaproth). While he was working in his experimental laboratory in [Berlin](/wiki/Berlin) in 1789, Klaproth was able to precipitate a yellow compound (likely [sodium diuranate](/wiki/Sodium_diuranate)) by dissolving [pitchblende](/wiki/Pitchblende) in [nitric acid](/wiki/Nitric_acid) and neutralizing the solution with [sodium hydroxide](/wiki/Sodium_hydroxide).[[23]](#cite_note-23) Klaproth assumed the yellow substance was the oxide of a yet-undiscovered element and heated it with [charcoal](/wiki/Charcoal) to obtain a black powder, which he thought was the newly discovered metal itself (in fact, that powder was an oxide of uranium).[[23]](#cite_note-23)[[24]](#cite_note-24) He named the newly discovered element after the planet [Uranus](/wiki/Uranus), (named after the primordial [Greek god of the sky](/wiki/Uranus_(mythology))), which had been discovered eight years earlier by [William Herschel](/wiki/William_Herschel).[[25]](#cite_note-25) In 1841, [Eugène-Melchior Péligot](/wiki/Eugène-Melchior_Péligot), Professor of Analytical Chemistry at the [Conservatoire National des Arts et Métiers](/wiki/Conservatoire_National_des_Arts_et_Métiers) (Central School of Arts and Manufactures) in [Paris](/wiki/Paris), isolated the first sample of uranium metal by heating [uranium tetrachloride](/wiki/Uranium_tetrachloride) with [potassium](/wiki/Potassium).[[23]](#cite_note-23)[[26]](#cite_note-26) [Henri Becquerel](/wiki/Henri_Becquerel) discovered [radioactivity](/wiki/Radioactive_decay) by using uranium in 1896.[[12]](#cite_note-12) Becquerel made the discovery in Paris by leaving a sample of a uranium salt, K2UO2(SO<Sub>4</sub>)2 (potassium uranyl sulfate), on top of an unexposed [photographic plate](/wiki/Photographic_plate) in a drawer and noting that the plate had become "fogged".[[27]](#cite_note-27) He determined that a form of invisible light or rays emitted by uranium had exposed the plate.

### Fission research[[edit](/index.php?title=(none)&action=edit&section=8)]

[thumb|Cubes and cuboids of uranium produced during the Manhattan project](/wiki/File:UraniumCubesLarge.jpg) A team led by [Enrico Fermi](/wiki/Enrico_Fermi) in 1934 observed that bombarding uranium with neutrons produces the emission of [beta rays](/wiki/Beta_decay) ([electrons](/wiki/Electron) or [positrons](/wiki/Positron) from the elements produced; see [beta particle](/wiki/Beta_particle)).[[28]](#cite_note-28) The fission products were at first mistaken for new elements of atomic numbers 93 and 94, which the Dean of the Faculty of Rome, Orso Mario Corbino, christened [*ausonium*](/wiki/Ausonium) and [*hesperium*](/wiki/Hesperium), respectively.[[29]](#cite_note-29)[[30]](#cite_note-30)[[31]](#cite_note-31)[[32]](#cite_note-32) The experiments leading to the discovery of uranium's ability to fission (break apart) into lighter elements and release [binding energy](/wiki/Binding_energy) were conducted by [Otto Hahn](/wiki/Otto_Hahn) and [Fritz Strassmann](/wiki/Fritz_Strassmann)[[28]](#cite_note-28) in Hahn's laboratory in Berlin. [Lise Meitner](/wiki/Lise_Meitner) and her nephew, the physicist [Otto Robert Frisch](/wiki/Otto_Robert_Frisch), published the physical explanation in February 1939 and named the process "[nuclear fission](/wiki/Nuclear_fission)".[[33]](#cite_note-33) Soon after, Fermi hypothesized that the fission of uranium might release enough neutrons to sustain a fission reaction. Confirmation of this hypothesis came in 1939, and later work found that on average about 2.5 neutrons are released by each fission of the rare uranium isotope uranium-235.[[28]](#cite_note-28) Further work found that the far more common uranium-238 isotope can be [transmuted](/wiki/Nuclear_transmutation) into plutonium, which, like uranium-235, is also fissile by thermal neutrons. These discoveries led numerous countries to begin working on the development of nuclear weapons and [nuclear power](/wiki/Nuclear_power).

On 2 December 1942, as part of the [Manhattan Project](/wiki/Manhattan_Project), another team led by Enrico Fermi was able to initiate the first artificial self-sustained [nuclear chain reaction](/wiki/Nuclear_chain_reaction), [Chicago Pile-1](/wiki/Chicago_Pile-1). Working in a lab below the stands of [Stagg Field](/wiki/Stagg_Field) at the [University of Chicago](/wiki/University_of_Chicago), the team created the conditions needed for such a reaction by piling together 400 short tons (360 metric tons) of [graphite](/wiki/Graphite), 58 short tons (53 metric tons) of [uranium oxide](/wiki/Uranium_oxide), and six short tons (5.5 metric tons) of uranium metal, a majority of which was supplied by [Westinghouse Lamp Plant](/wiki/Westinghouse_Lamp_Plant) in a makeshift production process.[[28]](#cite_note-28)[[34]](#cite_note-34)

### Nuclear weaponry[[edit](/index.php?title=(none)&action=edit&section=9)]

[thumb|The](/wiki/File:Atomic_cloud_over_Hiroshima.jpg) [mushroom cloud](/wiki/Mushroom_cloud) over [Hiroshima](/wiki/Hiroshima) after the dropping of the uranium-based atomic bomb nicknamed '[Little Boy'](/wiki/Little_Boy)|alt=White fragmentred mushroom-like smoke cloud evolving from the ground. Two major types of atomic bombs were developed by the United States during [World War II](/wiki/World_War_II): a uranium-based device (codenamed "[Little Boy](/wiki/Little_Boy)") whose fissile material was highly [enriched uranium](/wiki/Enriched_uranium), and a plutonium-based device (see [Trinity test](/wiki/Trinity_test) and "[Fat Man](/wiki/Fat_Man)") whose plutonium was derived from uranium-238. The uranium-based Little Boy device became the first nuclear weapon used in war when it was detonated over the [Japanese](/wiki/Japan) city of [Hiroshima](/wiki/Hiroshima) on 6 August 1945. Exploding with a yield equivalent to 12,500 tonnes of [TNT](/wiki/Trinitrotoluene), the blast and thermal wave of the bomb destroyed nearly 50,000 buildings and killed approximately 75,000 people (see [Atomic bombings of Hiroshima and Nagasaki](/wiki/Atomic_bombings_of_Hiroshima_and_Nagasaki)).[[27]](#cite_note-27) Initially it was believed that uranium was relatively rare, and that [nuclear proliferation](/wiki/Nuclear_proliferation) could be avoided by simply buying up all known uranium stocks, but within a decade large deposits of it were discovered in many places around the world.[[35]](#cite_note-35)

### Reactors[[edit](/index.php?title=(none)&action=edit&section=10)]

[thumb|Four light bulbs lit with electricity generated from the first artificial electricity-producing nuclear reactor,](/wiki/File:First_four_nuclear_lit_bulbs.jpeg) [EBR-I](/wiki/Experimental_Breeder_Reactor_I) (1951)|alt=An industrial room with four large illuminated light bulbs hanging down from a bar. The [X-10 Graphite Reactor](/wiki/X-10_Graphite_Reactor) at [Oak Ridge National Laboratory](/wiki/Oak_Ridge_National_Laboratory) (ORNL) in Oak Ridge, Tennessee, formerly known as the Clinton Pile and X-10 Pile, was the world's second artificial nuclear reactor (after Enrico Fermi's Chicago Pile) and was the first reactor designed and built for continuous operation. [Argonne National Laboratory's](/wiki/Argonne_National_Laboratory) [Experimental Breeder Reactor I](/wiki/Experimental_Breeder_Reactor_I), located at the Atomic Energy Commission's National Reactor Testing Station near [Arco, Idaho](/wiki/Arco,_Idaho), became the first nuclear reactor to create electricity on 20 December 1951.[[36]](#cite_note-36) Initially, four 150-watt light bulbs were lit by the reactor, but improvements eventually enabled it to power the whole facility (later, the town of Arco became the first in the world to have all its [electricity](/wiki/Electricity) come from nuclear power generated by [BORAX-III](/wiki/BORAX-III), another reactor designed and operated by [Argonne National Laboratory](/wiki/Argonne_National_Laboratory)).[[37]](#cite_note-37)[[38]](#cite_note-38) The world's first commercial scale nuclear power station, [Obninsk](/wiki/Obninsk_Nuclear_Power_Plant) in the [Soviet Union](/wiki/Soviet_Union), began generation with its reactor AM-1 on 27 June 1954. Other early nuclear power plants were [Calder Hall](/wiki/Sellafield) in [England](/wiki/England), which began generation on 17 October 1956,[[39]](#cite_note-39) and the [Shippingport Atomic Power Station](/wiki/Shippingport_Atomic_Power_Station) in [Pennsylvania](/wiki/Pennsylvania), which began on 26 May 1958. Nuclear power was used for the first time for propulsion by a [submarine](/wiki/Submarine), the [USS *Nautilus*](/wiki/USS_Nautilus_(SSN-571)), in 1954.[[28]](#cite_note-28)[[40]](#cite_note-40)

### Prehistoric naturally occurring fission[[edit](/index.php?title=(none)&action=edit&section=11)]

[Template:Main article](/wiki/Template:Main_article) In 1972, the French physicist [Francis Perrin](/wiki/Francis_Perrin) discovered fifteen ancient and no longer active natural nuclear fission reactors in three separate ore deposits at the [Oklo](/wiki/Oklo) mine in [Gabon](/wiki/Gabon), [West Africa](/wiki/West_Africa), collectively known as the [Oklo Fossil Reactors](/wiki/Natural_nuclear_fission_reactor). The ore deposit is 1.7 billion years old; then, uranium-235 constituted about 3% of the total uranium on Earth.[[41]](#cite_note-41) This is high enough to permit a sustained nuclear fission chain reaction to occur, provided other supporting conditions exist. The capacity of the surrounding sediment to contain the [nuclear waste](/wiki/Nuclear_waste) products has been cited by the U.S. federal government as supporting evidence for the feasibility to store spent nuclear fuel at the [Yucca Mountain nuclear waste repository](/wiki/Yucca_Mountain_nuclear_waste_repository).[[41]](#cite_note-41)

### Contamination and the Cold War legacy[[edit](/index.php?title=(none)&action=edit&section=12)]

[thumb|U.S. and USSR/Russian nuclear weapons stockpiles, 1945–2005|alt=A graph showing evolution of number of nuclear weapons in the US and USSR and in the period 1945–2005. US dominates early and USSR later years with and crossover around 1978.](/wiki/File:US_and_USSR_nuclear_stockpiles.svg) Above-ground [nuclear tests](/wiki/Nuclear_testing) by the Soviet Union and the United States in the 1950s and early 1960s and by [France](/wiki/France) into the 1970s and 1980s[[16]](#cite_note-16) spread a significant amount of [fallout](/wiki/Nuclear_fallout) from uranium daughter isotopes around the world.[[42]](#cite_note-42) Additional fallout and pollution occurred from several [nuclear accidents](/wiki/Nuclear_and_radiation_accidents).[[43]](#cite_note-43) Uranium miners have a higher incidence of [cancer](/wiki/Cancer). An excess risk of lung cancer among [Navajo](/wiki/Navajo_people) uranium miners, for example, has been documented and linked to their occupation.[[44]](#cite_note-44) The [Radiation Exposure Compensation Act](/wiki/Radiation_Exposure_Compensation_Act), a 1990 law in the USA, required $100,000 in "compassion payments" to uranium miners diagnosed with cancer or other respiratory ailments.[[45]](#cite_note-45) During the [Cold War](/wiki/Cold_War) between the Soviet Union and the United States, huge stockpiles of uranium were amassed and tens of thousands of nuclear weapons were created using enriched uranium and plutonium made from uranium. Since the [break-up of the Soviet Union](/wiki/Collapse_of_the_Soviet_Union_(1985–1991)#Dissolution_of_the_USSR) in 1991, an estimated 600 short tons (540 metric tons) of highly enriched weapons grade uranium (enough to make 40,000 nuclear warheads) have been stored in often inadequately guarded facilities in the [Russian Federation](/wiki/Russia) and several other former Soviet states.[[13]](#cite_note-13) Police in [Asia](/wiki/Asia), [Europe](/wiki/Europe), and [South America](/wiki/South_America) on at least 16 occasions from 1993 to 2005 have [intercepted shipments](/wiki/Nuclear_espionage) of smuggled bomb-grade uranium or plutonium, most of which was from ex-Soviet sources.[[13]](#cite_note-13) From 1993 to 2005 the Material Protection, Control, and Accounting Program, operated by the [federal government of the United States](/wiki/Federal_government_of_the_United_States), spent approximately [US $](/wiki/United_States_dollar)550 million to help safeguard uranium and plutonium stockpiles in Russia.[[13]](#cite_note-13) This money was used for improvements and security enhancements at research and storage facilities. *Scientific American* reported in February 2006 that in some of the facilities security consisted of chain link fences which were in severe states of disrepair. According to an interview from the article, one facility had been storing samples of enriched (weapons grade) uranium in a broom closet before the improvement project; another had been keeping track of its stock of nuclear warheads using index cards kept in a shoe box.[[46]](#cite_note-46)

## Occurrence[[edit](/index.php?title=(none)&action=edit&section=13)]

### Biotic and abiotic[[edit](/index.php?title=(none)&action=edit&section=14)]

[Template:Main article](/wiki/Template:Main_article) [thumb|Uraninite, also known as pitchblende, is the most common ore mined to extract uranium|alt=A shiny gray 5-centimeter piece of matter with a rough surface.](/wiki/File:Pichblende.jpg)

[thumb|right|The evolution of Earth's](/wiki/File:Evolution_of_Earth's_radiogenic_heat.jpg) [radiogenic heat](/wiki/Radiogenic_heat) flow over time: contribution from 235U in pink and from 238U in light blue

Uranium is a [naturally occurring](/wiki/Natural_abundance) element that can be found in low levels within all rock, soil, and water. Uranium is the 51st element in order of [abundance](/wiki/Abundance_of_elements_in_Earth's_crust) in the Earth's crust. Uranium is also the highest-numbered element to be found naturally in significant quantities on Earth and is almost always found combined with other elements.[[7]](#cite_note-7) Along with all elements having [atomic weights](/wiki/Atomic_weight) higher than that of [iron](/wiki/Iron), it is only naturally formed in [supernovae](/wiki/Supernova).[[47]](#cite_note-47) The decay of uranium, [thorium](/wiki/Thorium), and [potassium-40](/wiki/Potassium-40) in the Earth's [mantle](/wiki/Mantle_(geology)) is thought to be the main source of heat[[48]](#cite_note-48)[[49]](#cite_note-49) that keeps the [outer core](/wiki/Structure_of_the_Earth) liquid and drives [mantle convection](/wiki/Mantle_convection), which in turn drives [plate tectonics](/wiki/Plate_tectonics).

Uranium's average concentration in the [Earth's](/wiki/Earth) [crust](/wiki/Crust_(geology)) is (depending on the reference) 2 to 4 parts per million,[[6]](#cite_note-6)[[16]](#cite_note-16) or about 40 times as abundant as [silver](/wiki/Silver).[[12]](#cite_note-12) The Earth's crust from the surface to 25 km (15 mi) down is calculated to contain 1017 kg (2[Template:E](/wiki/Template:E) lb) of uranium while the [oceans](/wiki/Ocean) may contain 1013 kg (2[Template:E](/wiki/Template:E) lb).[[6]](#cite_note-6) The concentration of uranium in soil ranges from 0.7 to 11 parts per million (up to 15 parts per million in farmland soil due to use of phosphate [fertilizers](/wiki/Fertilizer)), and its concentration in sea water is 3 parts per billion.[[16]](#cite_note-16) Uranium is more plentiful than [antimony](/wiki/Antimony), [tin](/wiki/Tin), [cadmium](/wiki/Cadmium), [mercury](/wiki/Mercury_(element)), or silver, and it is about as abundant as [arsenic](/wiki/Arsenic) or [molybdenum](/wiki/Molybdenum).[[7]](#cite_note-7)[[16]](#cite_note-16) Uranium is found in hundreds of minerals, including uraninite (the most common uranium [ore](/wiki/Ore)), [carnotite](/wiki/Carnotite), [autunite](/wiki/Autunite), [uranophane](/wiki/Uranophane), [torbernite](/wiki/Torbernite), and [coffinite](/wiki/Coffinite).[[7]](#cite_note-7) Significant concentrations of uranium occur in some substances such as [phosphate](/wiki/Phosphate) rock deposits, and minerals such as [lignite](/wiki/Lignite), and [monazite](/wiki/Monazite) sands in uranium-rich ores[[7]](#cite_note-7) (it is recovered commercially from sources with as little as 0.1% uranium[[12]](#cite_note-12)).

[thumb|](/wiki/File:Citrobacter_freundii.jpg)[*Citrobacter*](/wiki/Citrobacter) species can have concentrations of uranium in their bodies 300 times the level of the surrounding environment|alt=Five cylinder-like bodies on a flat surface: four in a group and one separate. Some bacteria, such as [*Shewanella putrefaciens*](/wiki/Shewanella_putrefaciens), [*Geobacter metallireducens*](/wiki/Geobacter_metallireducens) and some strains of [*Burkholderia fungorum*](/wiki/Burkholderia_fungorum), use uranium for their growth and convert U(VI) to U(IV).[[50]](#cite_note-50)[[51]](#cite_note-51)Some organisms, such as the lichen *Trapelia involuta* or [microorganisms](/wiki/Microorganism) such as the [bacterium](/wiki/Bacterium) [*Citrobacter*](/wiki/Citrobacter), can absorb concentrations of uranium that are up to 300 times the level of their environment.[[52]](#cite_note-52) *Citrobacter* species absorb [uranyl](/wiki/Uranyl) ions when given [glycerol phosphate](/wiki/Glycerol_phosphate) (or other similar organic phosphates). After one day, one gram of bacteria can encrust themselves with nine grams of uranyl phosphate crystals; this creates the possibility that these organisms could be used in [bioremediation](/wiki/Bioremediation) to [decontaminate](/wiki/Radioactive_contamination) uranium-polluted water.[[23]](#cite_note-23)[[53]](#cite_note-53)The proteobacterium [*Geobacter*](/wiki/Geobacter) has also been shown to bioremediate uranium in ground water.[[54]](#cite_note-54) The mycorrhizal fungus [Glomus intraradices](/wiki/Glomus_intraradices) increases uranium content in the roots of its symbiotic plant.[[55]](#cite_note-55) In nature, uranium(VI) forms highly soluble carbonate complexes at alkaline pH. This leads to an increase in mobility and availability of uranium to groundwater and soil from nuclear wastes which leads to health hazards. However, it is difficult to precipitate uranium as phosphate in the presence of excess carbonate at alkaline pH. A *Sphingomonas* sp. strain BSAR-1 has been found to express a high activity alkaline phosphatase (PhoK) that has been applied for bioprecipitation of uranium as uranyl phosphate species from alkaline solutions. The precipitation ability was enhanced by overexpressing PhoK protein in *E. coli*.[[56]](#cite_note-56) [Plants](/wiki/Plant) absorb some uranium from soil. Dry weight concentrations of uranium in plants range from 5 to 60 parts per billion, and ash from burnt wood can have concentrations up to 4 parts per million.[[23]](#cite_note-23) Dry weight concentrations of uranium in [food](/wiki/Food) plants are typically lower with one to two micrograms per day ingested through the food people eat.[[23]](#cite_note-23)

### Production and mining[[edit](/index.php?title=(none)&action=edit&section=15)]

[Template:Main article](/wiki/Template:Main_article) [thumb|World uranium production (mines) and demand](/wiki/File:U_production-demand.png)[[57]](#cite_note-57) [thumb|](/wiki/File:Yellowcake.jpg)[Yellowcake](/wiki/Yellowcake) is a concentrated mixture of uranium oxides that is further refined to extract pure uranium|alt=A yellow sand-like rhombic mass on black background. Worldwide production of U3O8 (yellowcake) in 2013 amounted to 70,015 [tonnes](/wiki/Tonne), of which 22,451 t (32%) was mined in [Kazakhstan](/wiki/Kazakhstan). Other important uranium mining countries are [Canada](/wiki/Canada) (9,331 t), [Australia](/wiki/Australia) (6,350 t), [Niger](/wiki/Niger) (4,518 t), [Namibia](/wiki/Namibia) (4,323 t) and [Russia](/wiki/Russia) (3,135 t).[[57]](#cite_note-57) Uranium ore is mined in several ways: by [open pit](/wiki/Open-pit_mining), [underground](/wiki/Underground_mining_(soft_rock)), [in-situ leaching](/wiki/In-situ_leach), and [borehole mining](/wiki/Borehole_mining) (see [uranium mining](/wiki/Uranium_mining)).[[4]](#cite_note-4) Low-grade uranium ore mined typically contains 0.01 to 0.25% uranium oxides. Extensive measures must be employed to extract the metal from its ore.[[58]](#cite_note-58) High-grade ores found in [Athabasca Basin](/wiki/Athabasca_Basin) deposits in [Saskatchewan](/wiki/Saskatchewan), Canada can contain up to 23% uranium oxides on average.[[59]](#cite_note-59) Uranium ore is crushed and rendered into a fine powder and then leached with either an [acid](/wiki/Acid) or [alkali](/wiki/Alkali). The [leachate](/wiki/Leachate) is subjected to one of several sequences of precipitation, solvent extraction, and ion exchange. The resulting mixture, called [yellowcake](/wiki/Yellowcake), contains at least 75% uranium oxides U3O8. Yellowcake is then [calcined](/wiki/Calcined) to remove impurities from the milling process before refining and conversion.[[60]](#cite_note-60) Commercial-grade uranium can be produced through the [reduction](/wiki/Redox) of uranium [halides](/wiki/Halide) with [alkali](/wiki/Alkali_metal) or [alkaline earth metals](/wiki/Alkaline_earth_metal).[[7]](#cite_note-7) Uranium metal can also be prepared through [electrolysis](/wiki/Electrolysis) of [Template:Chem](/wiki/Template:Chem) or [Template:Chem](/wiki/Template:Chem), dissolved in molten [calcium chloride](/wiki/Calcium_chloride) ([Template:Chem](/wiki/Template:Chem)) and [sodium chloride](/wiki/Sodium_chloride) ([NaCl](/wiki/Sodium)) solution.[[7]](#cite_note-7) Very pure uranium is produced through the [thermal decomposition](/wiki/Thermal_decomposition) of uranium halides on a hot filament.[[7]](#cite_note-7)

### Resources and reserves[[edit](/index.php?title=(none)&action=edit&section=16)]

It is estimated that 5.5 million tonnes of uranium exists in ore reserves that are economically viable at US$59 per lb of uranium,[[61]](#cite_note-61) while 35 million tonnes are classed as mineral resources (reasonable prospects for eventual economic extraction).[[62]](#cite_note-62) Prices went from about $10/lb in May 2003 to $138/lb in July 2007. This has caused a big increase in spending on exploration,<ref name=autogenerated1/> with US$200 million being spent worldwide in 2005, a 54% increase on the previous year.[[62]](#cite_note-62) This trend continued through 2006, when expenditure on exploration rocketed to over $774 million, an increase of over 250% compared to 2004. The [OECD](/wiki/OECD) [Nuclear Energy Agency](/wiki/Nuclear_Energy_Agency) said exploration figures for 2007 would likely match those for 2006.[[61]](#cite_note-61) Australia has 31% of the world's known uranium ore reserves[[63]](#cite_note-63) and the world's largest single uranium deposit, located at the [Olympic Dam](/wiki/Olympic_Dam,_South_Australia) Mine in [South Australia](/wiki/South_Australia).[[64]](#cite_note-64) There is a significant reserve of uranium in [Bakouma](/wiki/Bakouma) a [sub-prefecture](/wiki/Sub-prefecture) in the [prefecture](/wiki/Prefecture) of [Mbomou](/wiki/Mbomou) in [Central African Republic](/wiki/Central_African_Republic).

Some nuclear fuel comes from nuclear weapons being dismantled,[[65]](#cite_note-65) such as from the [Megatons to Megawatts Program](/wiki/Megatons_to_Megawatts_Program).

An additional 4.6 billion tonnes of uranium are estimated to be in [sea water](/wiki/Sea_water) ([Japanese](/wiki/Japan) scientists in the 1980s showed that extraction of uranium from sea water using [ion exchangers](/wiki/Ion_exchange) was technically feasible).[[66]](#cite_note-66)[[67]](#cite_note-67) There have been experiments to extract uranium from sea water,[[68]](#cite_note-68) but the yield has been low due to the carbonate present in the water. In 2012, [ORNL](/wiki/ORNL) researchers announced the successful development of a new absorbent material dubbed HiCap which performs surface retention of solid or gas molecules, atoms or ions and also effectively removes toxic metals from water, according to results verified by researchers at Pacific Northwest National Laboratory.[[69]](#cite_note-69)[[70]](#cite_note-70)

### Supplies[[edit](/index.php?title=(none)&action=edit&section=17)]

[Template:Main article](/wiki/Template:Main_article) [thumb|right|Monthly uranium spot price in US$ per pound. The](/wiki/File:MonthlyUraniumSpot.png) [2007 price peak](/wiki/Uranium_bubble_of_2007) is clearly visible.<ref name=uraniumingo>[Template:Cite web](/wiki/Template:Cite_web)</ref> In 2005, seventeen countries produced concentrated uranium oxides, with [Canada](/wiki/Canada) (27.9% of world production) and [Australia](/wiki/Australia) (22.8%) being the largest producers and [Kazakhstan](/wiki/Kazakhstan) (10.5%), [Russia](/wiki/Russia) (8.0%), [Namibia](/wiki/Namibia) (7.5%), [Niger](/wiki/Niger) (7.4%), [Uzbekistan](/wiki/Uzbekistan) (5.5%), the [United States](/wiki/United_States) (2.5%), [Argentina](/wiki/Argentina) (2.1%), [Ukraine](/wiki/Ukraine) (1.9%) and [China](/wiki/People's_Republic_of_China) (1.7%) also producing significant amounts.[[71]](#cite_note-71) Kazakhstan continues to increase production and may have become the world's largest producer of uranium by 2009 with an expected production of 12,826 tonnes, compared to Canada with 11,100 t and Australia with 9,430 t.[[72]](#cite_note-72)[[73]](#cite_note-73) In the late 1960s, UN geologists also discovered major uranium deposits and other rare mineral reserves in [Somalia](/wiki/Somalia). The find was the largest of its kind, with industry experts estimating the deposits at over 25% of the world's then known uranium reserves of 800,000 tons.[[74]](#cite_note-74) The ultimate available supply is believed to be sufficient for at least the next 85 years,[[62]](#cite_note-62) although some studies indicate underinvestment in the late twentieth century may produce supply problems in the 21st century.[[75]](#cite_note-75)Uranium deposits seem to be log-normal distributed. There is a 300-fold increase in the amount of uranium recoverable for each tenfold decrease in ore grade.[[76]](#cite_note-76)In other words, there is little high grade ore and proportionately much more low grade ore available.

## Compounds[[edit](/index.php?title=(none)&action=edit&section=18)]

[thumb|350px|right|Reactions of uranium metal](/wiki/File:Uranium_reactions.png)

### Oxidation states and oxides[[edit](/index.php?title=(none)&action=edit&section=19)]

#### Oxides[[edit](/index.php?title=(none)&action=edit&section=20)]

[Template:Double image](/wiki/Template:Double_image)

Calcined uranium yellowcake, as produced in many large mills, contains a distribution of uranium oxidation species in various forms ranging from most oxidized to least oxidized. Particles with short residence times in a calciner will generally be less oxidized than those with long retention times or particles recovered in the stack scrubber. Uranium content is usually referenced to [Template:Chem](/wiki/Template:Chem), which dates to the days of the [Manhattan project](/wiki/Manhattan_project) when [Template:Chem](/wiki/Template:Chem) was used as an analytical chemistry reporting standard.

[Phase relationships](/wiki/Phase_(matter)) in the uranium-oxygen system are complex. The most important oxidation states of uranium are uranium(IV) and uranium(VI), and their two corresponding [oxides](/wiki/Oxide) are, respectively, [uranium dioxide](/wiki/Uranium_dioxide) ([Template:Chem](/wiki/Template:Chem)) and [uranium trioxide](/wiki/Uranium_trioxide) ([Template:Chem](/wiki/Template:Chem)).[[77]](#cite_note-77) Other [uranium oxides](/wiki/Uranium_oxide) such as uranium monoxide (UO), diuranium pentoxide ([Template:Chem](/wiki/Template:Chem)), and uranium peroxide ([Template:Chem](/wiki/Template:Chem)) also exist.

The most common forms of uranium oxide are [triuranium octoxide](/wiki/Triuranium_octoxide) ([Template:Chem](/wiki/Template:Chem)) and [Template:Chem](/wiki/Template:Chem).[[78]](#cite_note-78) Both oxide forms are solids that have low solubility in water and are relatively stable over a wide range of environmental conditions. Triuranium octoxide is (depending on conditions) the most stable compound of uranium and is the form most commonly found in nature. Uranium dioxide is the form in which uranium is most commonly used as a nuclear reactor fuel.[[78]](#cite_note-78) At ambient temperatures, [Template:Chem](/wiki/Template:Chem) will gradually convert to [Template:Chem](/wiki/Template:Chem). Because of their stability, uranium oxides are generally considered the preferred chemical form for storage or disposal.[[78]](#cite_note-78)

#### Aqueous chemistry[[edit](/index.php?title=(none)&action=edit&section=21)]

[thumb|left|150px|Uranium in its oxidation states III, IV, V, VI](/wiki/File:U_Oxstufen.jpg) Salts of many [oxidation states](/wiki/Oxidation_state) of uranium are water-[soluble](/wiki/Solubility) and may be studied in [aqueous solutions](/wiki/Aqueous_solution). The most common ionic forms are [Template:Chem](/wiki/Template:Chem) (brown-red), [Template:Chem](/wiki/Template:Chem) (green), [Template:Chem](/wiki/Template:Chem) (unstable), and [Template:Chem](/wiki/Template:Chem) (yellow), for U(III), U(IV), U(V), and U(VI), respectively.[[79]](#cite_note-79) A few [solid](/wiki/Solid) and semi-metallic compounds such as UO and US exist for the formal oxidation state uranium(II), but no simple ions are known to exist in solution for that state. Ions of [Template:Chem](/wiki/Template:Chem) liberate [hydrogen](/wiki/Hydrogen) from [water](/wiki/Water) and are therefore considered to be highly unstable. The [Template:Chem](/wiki/Template:Chem) ion represents the uranium(VI) state and is known to form compounds such as [uranyl carbonate](/wiki/Uranyl_carbonate), [uranyl chloride](/wiki/Uranyl_chloride) and [uranyl sulfate](/wiki/Uranyl_sulfate). [Template:Chem](/wiki/Template:Chem) also forms [complexes](/wiki/Complex_(chemistry)) with various [organic](/wiki/Organic_compound) [chelating](/wiki/Chelation) agents, the most commonly encountered of which is [uranyl acetate](/wiki/Uranyl_acetate).[[79]](#cite_note-79) Unlike the uranyl salts of uranium and [polyatomic ion](/wiki/Polyatomic_ion) uranium-oxide cationic forms, the [uranates](/wiki/Uranate), salts containing a polyatomic uranium-oxide anion, are generally not water-soluble.

#### Carbonates[[edit](/index.php?title=(none)&action=edit&section=22)]

The interactions of carbonate anions with uranium(VI) cause the [Pourbaix diagram](/wiki/Pourbaix_diagram) to change greatly when the medium is changed from water to a carbonate containing solution. While the vast majority of carbonates are insoluble in water (students are often taught that all carbonates other than those of alkali metals are insoluble in water), uranium carbonates are often soluble in water. This is because a U(VI) cation is able to bind two terminal oxides and three or more carbonates to form anionic complexes.

|  |  |
| --- | --- |
| [Pourbaix diagrams](/wiki/Pourbaix_diagram)[[80]](#cite_note-80) | |
| [thumb|center|180px|alt=A graph of potential vs. pH showing stability regions of various uranium compounds](/wiki/File:Uranium_pourdaix_diagram_in_water.png) | [center|thumb|180px|alt=A graph of potential vs. pH showing stability regions of various uranium compounds](/wiki/File:Uranium_pourdiax_diagram_in_carbonate_media.png) |
| Uranium in a non-complexing aqueous medium (e.g. [perchloric acid](/wiki/Perchloric_acid)/sodium hydroxide).[[80]](#cite_note-80) | Uranium in carbonate solution |
| [thumb|center|220px|alt=A graph of potential vs. pH showing stability regions of various uranium compounds](/wiki/File:Uranium_fraction_diagram_with_no_carbonate.png) | [thumb|center|230px|alt=A graph of potential vs. pH showing stability regions of various uranium compounds](/wiki/File:Uranium_fraction_diagram_with_carbonate_present.png) |
| Relative concentrations of the different chemical forms of uranium in a non-complexing aqueous medium (e.g. [perchloric acid](/wiki/Perchloric_acid)/sodium hydroxide).[[80]](#cite_note-80) | Relative concentrations of the different chemical forms of uranium in an aqueous carbonate solution.[[80]](#cite_note-80) |

#### Effects of pH[[edit](/index.php?title=(none)&action=edit&section=23)]

The uranium fraction diagrams in the presence of carbonate illustrate this further: when the pH of a uranium(VI) solution increases, the uranium is converted to a hydrated uranium oxide hydroxide and at high pHs it becomes an anionic hydroxide complex.

When carbonate is added, uranium is converted to a series of carbonate complexes if the pH is increased. One effect of these reactions is increased solubility of uranium in the pH range 6 to 8, a fact that has a direct bearing on the long term stability of spent uranium dioxide nuclear fuels.

### Hydrides, carbides and nitrides[[edit](/index.php?title=(none)&action=edit&section=24)]

Uranium metal heated to [Template:Convert](/wiki/Template:Convert) reacts with [hydrogen](/wiki/Hydrogen) to form [uranium hydride](/wiki/Uranium_hydride). Even higher temperatures will reversibly remove the hydrogen. This property makes uranium hydrides convenient starting materials to create reactive uranium powder along with various uranium [carbide](/wiki/Carbide), [nitride](/wiki/Nitride), and [halide](/wiki/Halide) compounds.[[81]](#cite_note-81) Two crystal modifications of uranium hydride exist: an α form that is obtained at low temperatures and a β form that is created when the formation temperature is above 250 °C.[[81]](#cite_note-81) [Uranium carbides](/wiki/Uranium_carbide) and [uranium nitrides](/wiki/Uranium_nitride) are both relatively [inert](/wiki/Inert) [semimetallic](/wiki/Semimetal) compounds that are minimally soluble in [acids](/wiki/Acid), react with water, and can ignite in [air](/wiki/Air) to form [Template:Chem](/wiki/Template:Chem).[[81]](#cite_note-81) Carbides of uranium include uranium monocarbide (U[C](/wiki/Carbon)), uranium dicarbide ([Template:Chem](/wiki/Template:Chem)), and diuranium tricarbide ([Template:Chem](/wiki/Template:Chem)). Both UC and [Template:Chem](/wiki/Template:Chem) are formed by adding carbon to molten uranium or by exposing the metal to [carbon monoxide](/wiki/Carbon_monoxide) at high temperatures. Stable below 1800 °C, [Template:Chem](/wiki/Template:Chem) is prepared by subjecting a heated mixture of UC and [Template:Chem](/wiki/Template:Chem) to mechanical stress.[[82]](#cite_note-82) Uranium nitrides obtained by direct exposure of the metal to [nitrogen](/wiki/Nitrogen) include uranium mononitride (UN), uranium dinitride ([Template:Chem](/wiki/Template:Chem)), and diuranium trinitride ([Template:Chem](/wiki/Template:Chem)).[[82]](#cite_note-82)

### Halides[[edit](/index.php?title=(none)&action=edit&section=25)]

[thumb|](/wiki/File:Uranium_hexafluoride_crystals_sealed_in_an_ampoule.jpg)[Uranium hexafluoride](/wiki/Uranium_hexafluoride) is the feedstock used to separate uranium-235 from natural uranium|alt=Snow-like substance in a sealed glass ampoule. All uranium fluorides are created using [uranium tetrafluoride](/wiki/Uranium_tetrafluoride) ([Template:Chem](/wiki/Template:Chem)); [Template:Chem](/wiki/Template:Chem) itself is prepared by hydrofluorination of uranium dioxide.[[81]](#cite_note-81) Reduction of [Template:Chem](/wiki/Template:Chem) with hydrogen at 1000 °C produces uranium trifluoride ([Template:Chem](/wiki/Template:Chem)). Under the right conditions of temperature and pressure, the reaction of solid [Template:Chem](/wiki/Template:Chem) with gaseous [uranium hexafluoride](/wiki/Uranium_hexafluoride) ([Template:Chem](/wiki/Template:Chem)) can form the intermediate fluorides of [Template:Chem](/wiki/Template:Chem), [Template:Chem](/wiki/Template:Chem), and [Template:Chem](/wiki/Template:Chem).[[81]](#cite_note-81) At room temperatures, [Template:Chem](/wiki/Template:Chem) has a high [vapor pressure](/wiki/Vapor_pressure), making it useful in the [gaseous diffusion](/wiki/Gaseous_diffusion) process to separate the rare uranium-235 from the common uranium-238 isotope. This compound can be prepared from uranium dioxide and uranium hydride by the following process:[[81]](#cite_note-81)

[Template:Chem](/wiki/Template:Chem) + 4 HF → [Template:Chem](/wiki/Template:Chem) + 2 [Template:Chem](/wiki/Template:Chem) (500 °C, endothermic)

[Template:Chem](/wiki/Template:Chem) + [Template:Chem](/wiki/Template:Chem) → [Template:Chem](/wiki/Template:Chem) (350 °C, endothermic)

The resulting [Template:Chem](/wiki/Template:Chem), a white solid, is highly [reactive](/wiki/Chemical_reaction) (by fluorination), easily [sublimes](/wiki/Sublimation_(chemistry)) (emitting a vapor that behaves as a nearly [ideal gas](/wiki/Ideal_gas)), and is the most volatile compound of uranium known to exist.[[81]](#cite_note-81) One method of preparing [uranium tetrachloride](/wiki/Uranium_tetrachloride) ([Template:Chem](/wiki/Template:Chem)) is to directly combine [chlorine](/wiki/Chlorine) with either uranium metal or uranium hydride. The reduction of [Template:Chem](/wiki/Template:Chem) by hydrogen produces uranium trichloride ([Template:Chem](/wiki/Template:Chem)) while the higher chlorides of uranium are prepared by reaction with additional chlorine.[[81]](#cite_note-81) All uranium chlorides react with water and air.

[Bromides](/wiki/Bromide) and [iodides](/wiki/Iodide) of uranium are formed by direct reaction of, respectively, [bromine](/wiki/Bromine) and [iodine](/wiki/Iodine) with uranium or by adding [Template:Chem](/wiki/Template:Chem) to those element's acids.[[81]](#cite_note-81) Known examples include: [Template:Chem](/wiki/Template:Chem), [Template:Chem](/wiki/Template:Chem), [Template:Chem](/wiki/Template:Chem), and [Template:Chem](/wiki/Template:Chem). Uranium oxyhalides are water-soluble and include [Template:Chem](/wiki/Template:Chem), [Template:Chem](/wiki/Template:Chem), [Template:Chem](/wiki/Template:Chem), and [Template:Chem](/wiki/Template:Chem). Stability of the oxyhalides decrease as the [atomic weight](/wiki/Atomic_weight) of the component halide increases.[[81]](#cite_note-81)

## Isotopes[[edit](/index.php?title=(none)&action=edit&section=26)]

### Natural concentrations[[edit](/index.php?title=(none)&action=edit&section=27)]

[Template:Main article](/wiki/Template:Main_article) [Natural uranium](/wiki/Natural_uranium) consists of three major [isotopes](/wiki/Isotope): [uranium-238](/wiki/Uranium-238) (99.28% [natural abundance](/wiki/Natural_abundance)), uranium-235 (0.71%), and [uranium-234](/wiki/Uranium-234) (0.0054%). All three are [radioactive](/wiki/Radioactive_decay), emitting [alpha particles](/wiki/Alpha_particle), with the exception that all three of these isotopes have small probabilities of undergoing [spontaneous fission](/wiki/Spontaneous_fission), rather than [alpha emission](/wiki/Alpha_emission). There are also five other trace isotopes: uranium-239, which is formed when 238U undergoes spontaneous fission, releasing neutrons that are captured by another 238U atom; uranium-237, which is formed when 238U captures a neutron but emits two more, which then decays to [neptunium-237](/wiki/Neptunium-237); uranium-233, which is formed in the [decay chain](/wiki/Decay_chain) of that neptunium-237; and finally, uranium-236 and -240, which appear in the decay chain of primordial [plutonium-244](/wiki/Plutonium-244). It is also expected that [thorium-232](/wiki/Thorium-232) should be able to undergo [double beta decay](/wiki/Double_beta_decay), which would produce uranium-232, but this has not yet been observed experimentally.<ref name=NUBASE>[Template:Cite journal](/wiki/Template:Cite_journal)</ref>

Uranium-238 is the most stable isotope of uranium, with a [half-life](/wiki/Half-life) of about 4.468[Template:E](/wiki/Template:E) years, roughly the [age of the Earth](/wiki/Age_of_the_Earth). Uranium-235 has a half-life of about 7.13[Template:E](/wiki/Template:E) years, and uranium-234 has a half-life of about 2.48[Template:E](/wiki/Template:E) years.[[83]](#cite_note-83)For natural uranium, about 49% of its alpha rays are emitted by each of 238U atom, and also 49% by 234U (since the latter is formed from the former) and about 2.0% of them by the 235U. When the Earth was young, probably about one-fifth of its uranium was uranium-235, but the percentage of 234U was probably much lower than this.

Uranium-238 is usually an α emitter (occasionally, it undergoes spontaneous fission), decaying through the ["Uranium Series" of nuclear decay](/wiki/Decay_series), which has 18 members, into [lead-206](/wiki/Lead#Isotopes), by a variety of different decay paths.[[12]](#cite_note-12) The [decay series of 235U](/wiki/Decay_series), which is called the [actinium series](/wiki/Decay_series), has 15 members and eventually decays into lead-207.[[12]](#cite_note-12) The constant rates of decay in these decay series makes the comparison of the ratios of parent to daughter elements useful in [radiometric dating](/wiki/Radiometric_dating).

Uranium-234, which is a member of the ["Uranium Series"](/wiki/Decay_series), decays to lead-206 through a series of relatively short-lived isotopes.

Uranium-233 is made from [thorium-232](/wiki/Thorium#Isotopes) by neutron bombardment, usually in a nuclear reactor, and 233U is also fissile.[[7]](#cite_note-7) Its decay series ends at [bismuth-209](/wiki/Bismuth-209) and [thallium](/wiki/Thallium)-205.

Uranium-235 is important for both [nuclear reactors](/wiki/Nuclear_reactor) and [nuclear weapons](/wiki/Nuclear_weapon), because it is the only uranium isotope existing in nature on Earth in any significant amount that is [fissile](/wiki/Fissile). This means that it can be split into two or three fragments ([fission products](/wiki/Fission_products)) by thermal neutrons.[[12]](#cite_note-12) Uranium-238 is not fissile, but is a fertile isotope, because after [neutron activation](/wiki/Neutron_activation) it can produce [plutonium-239](/wiki/Plutonium-239), another fissile isotope. Indeed, the 238U nucleus can absorb one neutron to produce the radioactive isotope [uranium-239](/wiki/Uranium-239). 239U decays by [beta emission](/wiki/Beta_emission) to [neptunium](/wiki/Neptunium)-239, also a beta-emitter, that decays in its turn, within a few days into plutonium-239. 239Pu was used as fissile material in the first [atomic bomb](/wiki/Atomic_bomb) detonated in the "[Trinity test](/wiki/Trinity_test)" on 15 July 1945 in [New Mexico](/wiki/New_Mexico).[[28]](#cite_note-28)

### Enrichment[[edit](/index.php?title=(none)&action=edit&section=28)]

[Template:Main article](/wiki/Template:Main_article) [thumb|Cascades of](/wiki/File:Gas_centrifuge_cascade.jpg) [gas centrifuges](/wiki/Gas_centrifuge) are used to enrich uranium ore to concentrate its fissionable isotopes|alt=A photo of a large hall filled with arrays of long white standing cylinders. In nature, uranium is found as uranium-238 (99.2742%) and uranium-235 (0.7204%). [Isotope separation](/wiki/Isotope_separation) concentrates (enriches) the fissionable uranium-235 for nuclear weapons and most nuclear power plants, except for [gas cooled reactors](/wiki/Gas_cooled_reactor) and [pressurised heavy water reactors](/wiki/Pressurised_heavy_water_reactor). Most neutrons released by a fissioning atom of uranium-235 must impact other uranium-235 atoms to sustain the [nuclear chain reaction](/wiki/Nuclear_chain_reaction). The concentration and amount of uranium-235 needed to achieve this is called a '[critical mass'](/wiki/Critical_mass).

To be considered 'enriched', the uranium-235 fraction should be between 3% and 5%.[[84]](#cite_note-84) This process produces huge quantities of uranium that is depleted of uranium-235 and with a correspondingly increased fraction of uranium-238, called depleted uranium or 'DU'. To be considered 'depleted', the uranium-235 isotope concentration should be no more than 0.3%.[[85]](#cite_note-85) The price of uranium has risen since 2001, so enrichment tailings containing more than 0.35% uranium-235 are being considered for re-enrichment, driving the price of depleted uranium hexafluoride above $130 per kilogram in July 2007 from $5 in 2001.[[85]](#cite_note-85) The [gas centrifuge](/wiki/Gas_centrifuge) process, where gaseous [uranium hexafluoride](/wiki/Uranium_hexafluoride) ([Template:Chem](/wiki/Template:Chem)) is separated by the difference in molecular weight between 235UF6 and 238UF6 using high-speed [centrifuges](/wiki/Centrifuge), is the cheapest and leading enrichment process.[[27]](#cite_note-27) The [gaseous diffusion](/wiki/Gaseous_diffusion) process had been the leading method for enrichment and was used in the [Manhattan Project](/wiki/Manhattan_Project). In this process, uranium hexafluoride is repeatedly [diffused](/wiki/Diffusion) through a [silver](/wiki/Silver)-[zinc](/wiki/Zinc) membrane, and the different isotopes of uranium are separated by diffusion rate (since uranium 238 is heavier it diffuses slightly slower than uranium-235).[[27]](#cite_note-27) The [molecular laser isotope separation](/wiki/Molecular_laser_isotope_separation) method employs a [laser](/wiki/Laser) beam of precise energy to sever the bond between uranium-235 and fluorine. This leaves uranium-238 bonded to fluorine and allows uranium-235 metal to precipitate from the solution.[[4]](#cite_note-4) An alternative laser method of enrichment is known as [atomic vapor laser isotope separation](/wiki/Atomic_vapor_laser_isotope_separation) (AVLIS) and employs visible [tunable lasers](/wiki/Tunable_laser) such as [dye lasers](/wiki/Dye_laser).[[86]](#cite_note-86) Another method used is liquid thermal diffusion.[[6]](#cite_note-6)

## Human exposure[[edit](/index.php?title=(none)&action=edit&section=29)]

A person can be exposed to uranium (or its radioactive daughters, such as [radon](/wiki/Radon)) by inhaling dust in air or by ingesting contaminated water and food. The amount of uranium in air is usually very small; however, people who work in factories that process [phosphate](/wiki/Phosphate) [fertilizers](/wiki/Fertilizer), live near government facilities that made or tested nuclear weapons, live or work near a modern battlefield where depleted uranium [weapons](/wiki/Weapons) have been used, or live or work near a [coal](/wiki/Coal)-fired power plant, facilities that mine or process uranium ore, or enrich uranium for reactor fuel, may have increased exposure to uranium.[[87]](#cite_note-87)[[88]](#cite_note-88) Houses or structures that are over uranium deposits (either natural or man-made slag deposits) may have an increased incidence of exposure to radon gas. The [Occupational Safety and Health Administration](/wiki/Occupational_Safety_and_Health_Administration) (OSHA) has set the [permissible exposure limit](/wiki/Permissible_exposure_limit) for uranium exposure in the workplace as 0.25 mg/m3 over an 8-hour workday. The [National Institute for Occupational Safety and Health](/wiki/National_Institute_for_Occupational_Safety_and_Health) (NIOSH) has set a [recommended exposure limit](/wiki/Recommended_exposure_limit) (REL) of 0.2 mg/m3 over an 8-hour workday and a short-term limit of 0.6 mg/m3. At levels of 10 mg/m3, uranium is [immediately dangerous to life and health](/wiki/IDLH).[[89]](#cite_note-89) Most ingested uranium is excreted during [digestion](/wiki/Digestion). Only 0.5% is absorbed when insoluble forms of uranium, such as its oxide, are ingested, whereas absorption of the more soluble [uranyl](/wiki/Uranyl) ion can be up to 5%.[[23]](#cite_note-23) However, soluble uranium compounds tend to quickly pass through the body, whereas insoluble uranium compounds, especially when inhaled by way of dust into the [lungs](/wiki/Lung), pose a more serious exposure hazard. After entering the bloodstream, the absorbed uranium tends to [bioaccumulate](/wiki/Bioaccumulation) and stay for many years in [bone](/wiki/Bone) tissue because of uranium's affinity for phosphates.[[23]](#cite_note-23) Uranium is not absorbed through the skin, and [alpha particles](/wiki/Alpha_particle) released by uranium cannot penetrate the skin.

Incorporated uranium becomes [uranyl](/wiki/Uranyl) ions, which accumulate in bone, liver, kidney, and reproductive tissues. Uranium can be decontaminated from steel surfaces<ref name=Francis>[Template:Cite journal](/wiki/Template:Cite_journal)</ref> and [aquifers](/wiki/Aquifer).<ref name=Wu>[Template:Cite journal](/wiki/Template:Cite_journal)</ref>

### Effects and precautions[[edit](/index.php?title=(none)&action=edit&section=30)]

Normal functioning of the [kidney](/wiki/Kidney), [brain](/wiki/Brain), [liver](/wiki/Liver), [heart](/wiki/Heart), and other systems can be affected by uranium exposure, because, besides being weakly radioactive, uranium is a [toxic metal](/wiki/Toxic_metal).[[23]](#cite_note-23)<ref name=Craft04>[Template:Cite journal](/wiki/Template:Cite_journal)</ref>[[90]](#cite_note-90) Uranium is also a reproductive toxicant.[[91]](#cite_note-91)[[92]](#cite_note-92) Radiological effects are generally local because alpha radiation, the primary form of 238U decay, has a very short range, and will not penetrate skin. [Uranyl](/wiki/Uranyl) ([Template:Chem](/wiki/Template:Chem)) ions, such as from [uranium trioxide](/wiki/Uranium_trioxide) or uranyl nitrate and other hexavalent uranium compounds, have been shown to cause birth defects and immune system damage in laboratory animals.[[93]](#cite_note-93) While the CDC has published one study that no human [cancer](/wiki/Cancer) has been seen as a result of exposure to natural or depleted uranium,[[94]](#cite_note-94) exposure to uranium and its decay products, especially [radon](/wiki/Radon), are widely known and significant health threats.[[16]](#cite_note-16) Exposure to [strontium-90](/wiki/Strontium-90), [iodine-131](/wiki/Iodine-131), and other fission products is unrelated to uranium exposure, but may result from medical procedures or exposure to spent reactor fuel or fallout from nuclear weapons.[[95]](#cite_note-95)Although accidental inhalation exposure to a high concentration of [uranium hexafluoride](/wiki/Uranium_hexafluoride) has resulted in human fatalities, those deaths were associated with the generation of highly toxic hydrofluoric acid and [uranyl fluoride](/wiki/Uranyl_fluoride) rather than with uranium itself.[[96]](#cite_note-96) Finely divided uranium metal presents a fire hazard because uranium is [pyrophoric](/wiki/Pyrophoricity); small grains will ignite spontaneously in air at room temperature.[[7]](#cite_note-7) Uranium metal is commonly handled with gloves as a sufficient precaution.[[97]](#cite_note-97) Uranium concentrate is handled and contained so as to ensure that people do not inhale or ingest it.[[97]](#cite_note-97)

|  |
| --- |
| +Compilation of 2004 review on uranium toxicity<ref name=Craft04/> |
| **Body system** | **Human studies** | **Animal studies** | ***In vitro*** |
| Renal | Elevated levels of protein excretion, urinary catalase and diuresis | Damage to proximal convoluted tubules, necrotic cells cast from tubular epithelium, glomerular changes ([renal failure](/wiki/Renal_failure)) | No studies |
| Brain/CNS | Decreased performance on neurocognitive tests | Acute cholinergic toxicity; Dose-dependent accumulation in cortex, midbrain, and vermis; Electrophysiological changes in hippocampus | No studies |
| DNA | Increased reports of cancers[[45]](#cite_note-45)[[98]](#cite_note-98)[[99]](#cite_note-99)[[100]](#cite_note-100)[[101]](#cite_note-101)[[102]](#cite_note-102) | Increased mutagenicity (in mice) and induction of tumors | Binucleated cells with micronuclei, Inhibition of cell cycle kinetics and proliferation; Sister chromatid induction, tumorigenic phenotype |
| Bone/muscle | No studies | Inhibition of periodontal bone formation; and alveolar wound healing | No studies |
| Reproductive | Uranium miners have more first born female children | Moderate to severe focal tubular atrophy; vacuolization of Leydig cells | No studies |
| Lungs/respiratory | No adverse health effects reported | Severe nasal congestion and hemorrhage, lung lesions and fibrosis, edema and swelling, lung cancer | No studies |
| Gastrointestinal | Vomiting, diarrhea, albuminuria | No studies | No studies |
| Liver | No effects seen at exposure dose | Fatty livers, focal necrosis | No studies |
| Skin | No exposure assessment data available | Swollen vacuolated epidermal cells, damage to hair follicles and sebaceous glands | No studies |
| Tissues surrounding embedded DU fragments | Elevated uranium urine concentrations | Elevated uranium urine concentrations, perturbations in biochemical and neuropsychological testing | No studies |
| Immune system | Chronic fatigue, rash, ear and eye infections, hair and weight loss, cough. May be due to combined chemical exposure rather than DU alone | No studies | No studies |
| Eyes | No studies | Conjunctivitis, irritation inflammation, edema, ulceration of conjunctival sacs | No studies |
| Blood | No studies | Decrease in RBC count and hemoglobin concentration | No studies |
| Cardiovascular | Myocarditis resulting from the uranium ingestion, which ended six months after ingestion | No effects | No studies |

## See also[[edit](/index.php?title=(none)&action=edit&section=31)]

[Template:Colbegin](/wiki/Template:Colbegin)

* [K-65 residues](/wiki/K-65_residues)
* [List of countries by uranium production](/wiki/List_of_countries_by_uranium_production)
* [List of countries by uranium reserves](/wiki/List_of_countries_by_uranium_reserves)
* [List of countries by uranium reserves](/wiki/List_of_countries_by_uranium_reserves)
* [List of uranium projects](/wiki/List_of_uranium_projects)
* [Lists of nuclear disasters and radioactive incidents](/wiki/Lists_of_nuclear_disasters_and_radioactive_incidents)
* [Nuclear and radiation accidents and incidents](/wiki/Nuclear_and_radiation_accidents_and_incidents)
* [Nuclear engineering](/wiki/Nuclear_engineering)
* [Nuclear fuel cycle](/wiki/Nuclear_fuel_cycle)
* [Nuclear physics](/wiki/Nuclear_physics)
* [Thorium fuel cycle](/wiki/Thorium_fuel_cycle)
* [Uranium bubble of 2007](/wiki/Uranium_bubble_of_2007)
* [Uranium nitride](/wiki/Uranium_nitride)
* [World Uranium Hearing](/wiki/World_Uranium_Hearing)

[Template:Colend](/wiki/Template:Colend)

## Notes[[edit](/index.php?title=(none)&action=edit&section=32)]

[Template:Reflist](/wiki/Template:Reflist)

## References[[edit](/index.php?title=(none)&action=edit&section=33)]

* [Template:Cite book](/wiki/Template:Cite_book)
* [Template:Cite book](/wiki/Template:Cite_book)

## External links[[edit](/index.php?title=(none)&action=edit&section=34)]

[Template:Commons category](/wiki/Template:Commons_category) [Template:Wiktionary](/wiki/Template:Wiktionary)

* [U.S. EPA: Radiation Information for Uranium](http://www.epa.gov/radiation/radionuclides/uranium.html)
* ["What is Uranium?" from World Nuclear Association](http://world-nuclear.org/education/uran.htm)
* [Nuclear fuel data and analysis from the U.S. Energy Information Administration](http://www.eia.gov/nuclear/)
* [Current market price of uranium](http://www.uxc.com)
* [World Uranium deposit maps](http://www.wise-uranium.org/umaps.html)
* [Annotated bibliography for uranium from the Alsos Digital Library](http://alsos.wlu.edu/qsearch.aspx?browse=science/Uranium)
* [NLM Hazardous Substances Databank—Uranium, Radioactive](http://toxnet.nlm.nih.gov/cgi-bin/sis/search/r?dbs+hsdb:@term+@na+@rel+uranium,+radioactive)
* [CDC - NIOSH Pocket Guide to Chemical Hazards](http://www.cdc.gov/niosh/npg/npgd0650.html)
* [Mining Uranium at Namibia's Langer Heinrich Mine](http://www.infomine.com/library/publications/docs/Mining.com/Feb2008e.pdf)
* [World Nuclear News](http://www.world-nuclear-news.org/)
* [ATSDR Case Studies in Environmental Medicine: Uranium Toxicity](http://www.atsdr.cdc.gov/csem/uranium/) U.S. [Department of Health and Human Services](/wiki/Department_of_Health_and_Human_Services)
* [Uranium](http://www.periodicvideos.com/videos/092.htm) at [*The Periodic Table of Videos*](/wiki/The_Periodic_Table_of_Videos) (University of Nottingham)

[Template:Compact periodic table](/wiki/Template:Compact_periodic_table) [Template:Uranium compounds](/wiki/Template:Uranium_compounds) [Template:Chemical elements named after places](/wiki/Template:Chemical_elements_named_after_places) [Template:Nuclear Technology](/wiki/Template:Nuclear_Technology) [Template:Nuclear and radiation accidents and incidents](/wiki/Template:Nuclear_and_radiation_accidents_and_incidents) [Template:Featured article](/wiki/Template:Featured_article)

[Template:Authority control](/wiki/Template:Authority_control)

[Category:Uranium](/wiki/Category:Uranium) [Category:Actinides](/wiki/Category:Actinides) [Category:Chemical elements](/wiki/Category:Chemical_elements) [Category:Nuclear fuels](/wiki/Category:Nuclear_fuels) [Category:Nuclear materials](/wiki/Category:Nuclear_materials) [Category:Suspected male-mediated teratogens](/wiki/Category:Suspected_male-mediated_teratogens) [Category:Manhattan Project](/wiki/Category:Manhattan_Project)