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NUCLEAR FUEL CYCLE

Uranium and Depleted Uranium

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The basic fuel for a nuclear power reactor is uranium – a heavy metal able to release abundant concentrated energy.

Uranium occurs naturally in the Earth's crust and is mildly radioactive. It is the only element with a naturally-occurring fissile isotope.

Depleted uranium is a by-product from enriching natural uranium to use in nuclear power reactors.

Most of the uranium used in nuclear reactors can be recycled.

The health hazards associated with uranium are much the same as those for lead.

The Earth's uranium (chemical symbol U) was apparently formed in supernovae up to about 6.6 billion years ago (see information page on The Cosmic Origins of Uranium). Its radioactive decay provides the main source of heat inside the Earth, causing convection and continental drift. As decay proceeds, the final product, lead, increases in relative abundance.

Uranium was discovered by Martin Klaproth, a German chemist, in 1789 in the mineral pitchblende, and was named after the planet Uranus. It occurs in most rocks in concentrations of 2 to 4 parts per million and is as common in the Earth's crust as tin, tungsten and molybdenum and about 40 times as common as silver. Being relatively soluble (in contrast to thorium), it is also found in the oceans, at an average concentration of 3 parts per billion. There are a number of locations in different parts of the world where it occurs in economically-recoverable concentrations. When mined, it yields a mixed uranium oxide product, U_3O_8. Uraninite, or pitchblende, is the most common uranium mineral.

Natural uranium is a mixture of isotopes, including a small proportion of one that is fissile – readily able to fission (split) to yield vastly more energy than any combustion process.

In the past, uranium was also used to colour glass (from as early as 79 AD) and deposits were once mined in order to obtain its decay product, radium. This element was used in luminous paint, particularly on the dials of watches and aircraft instruments up to the 1950s, and in medicine for the treatment of disease.

For many years from the 1940s, virtually all of the uranium that was mined was used in the production of nuclear weapons, but this ceased to be the case in the 1970s. Today the only substantial use for uranium is as fuel in nuclear reactors, mostly for electricity generation. Uranium-235 is the only naturally-occurring material which can sustain a fission chain reaction, releasing large amounts of energy.

While nuclear power is the predominant use of uranium, heat from nuclear fission can be used for industrial processes. It is also used for marine propulsion (mostly naval). And small nuclear reactors are important for making radioisotopes.

The uranium atom

Uranium is one of the heaviest of all the naturally-occurring elements and has a specific gravity of 18.7. Its melting point is 1132°C.

Like other elements, uranium occurs in slightly differing forms known as isotopes. These isotopes differ from each other in the number of neutron particles in the nucleus. Natural uranium (Unat) as found in the Earth's crust is a mixture of three isotopes: uranium-238 (U-238), accounting for 99.275%; U-235 – 0.720%; and traces of U-234 – 0.005%.

The isotope U-235 is important because under certain conditions it can readily be split, yielding a lot of energy. It is therefore said to be 'fissile'. Meanwhile, like all radioactive isotopes, it decays. U-238 decays very slowly, its half-life[a] being about the same as the age of the Earth. This means that it is barely radioactive, less so than many other radioisotopes in rocks and sand. Uranium-238 has a specific radioactivity of 12.4 kBq/g, and U-235 80 kBq/g, but the smaller amount of U-234 is very active (231 MBq/g) so the specific radioactivity of natural uranium (25 kBq/g) is about double that of U-238 despite it consisting of over 99% U-238.[b] In decay it generates 0.1 watts/tonne and this is enough to warm the Earth's mantle.

Uranium fission

The nucleus of the U-235 isotope comprises 92 protons and 143 neutrons (92 + 143 = 235). When the nucleus of a U-235 atom is split in two by a neutron[c], some energy is released in the form of heat, and two or three additional neutrons are thrown off. If enough of these expelled neutrons split the nuclei of other U-235 atoms, releasing further neutrons, a chain reaction can be achieved. When this happens over and over again, many millions of times, a very large amount of heat is produced from a relatively small amount of uranium.

It is this process, in effect 'burning' uranium, which occurs in a nuclear reactor. In a nuclear reactor the uranium fuel is assembled in such a way that a controlled fission chain reaction can be achieved. The heat created by splitting the U-235 atoms is then used to make steam which spins a turbine to drive a generator, producing electricity.

Whereas the U-235 atom is 'fissile', the U-238 atom is said to be 'fertile'. This means that it can capture a neutron and become (indirectly) plutonium-239, which is fissile. Pu-239 is very much like U-235, in that it can fission following neutron capture, also yielding a lot of energy[d]. Because there is so much U-238 in a reactor core (most of the fuel), these reactions occur frequently, and in fact about one-third of the energy yield typically comes from burning bred Pu-239*. A very small amount of U-238 also fissions from fast neutrons, contributing about 7% of the energy in a reactor.

* In certain reactors fuelled with natural uranium, bred plutonium provides about 60% of the energy.

Both uranium and plutonium were used to make bombs before they became important for making electricity and radioisotopes. But the type of uranium and plutonium for bombs is different from that in a nuclear power plant. Bomb-grade uranium is highly enriched (>90% U-235, instead of about 3.5-5.0% in a power plant); bomb-grade plutonium is fairly pure (>90%) Pu-239 and is made in special reactors.

Uranium as a fuel for nuclear power

About 10% of the world's electricity is generated from uranium in nuclear reactors[1]. This amounts to over 2600 billion kWh, as much as from all sources worldwide a few decades ago. It comes from about 440 nuclear reactors with a total output capacity of about 390,000 MWe operating in 32 countries plus Taiwan. Over 50 more reactors are under construction and about another 100 are planned[2]. A typical 1000 megawatt (MWe) reactor can provide enough electricity for a modern city of close to one million people, about 8 billion kWh per year.

A dozen countries get 25% or more of their electricity from nuclear reactors. Germany and Japan have derived a similar amount of their electricity from uranium in the past. The USA has over 90 reactors operating, supplying 20% of its electricity[3]. France generates about 70% of its electricity from nuclear power.

Nuclear power stations and fossil-fuelled power stations of similar capacity have many features in common. Both require heat to produce steam to drive turbines and generators. In a nuclear power station, however, the fissioning of uranium atoms replaces the burning of coal or gas. The chain reaction that takes place in the core of a nuclear reactor is controlled by rods which absorb neutrons. They are inserted or withdrawn to set the reactor at the required power level. The fuel elements are surrounded by a substance called a moderator to slow the speed of the emitted neutrons and thus enable the chain reaction to continue[e]. Water, graphite and heavy water are used as moderators in different types of reactors.

Sources of uranium

Uranium is widespread in many rocks, and even in seawater. However, like other metals, it is seldom sufficiently concentrated to be economically recoverable. Where it is, we speak of an orebody. Uranium is fairly soluble and uranium oxide precipitates from uranium-bearing groundwaters when they enter a reducing environment. It can be mobilized (re-dissolved) *in situ* from such placer deposits by oxygenated leach solution.

In defining what is ore, assumptions are made about the cost of mining and the market price of the metal. Known uranium resources are therefore calculated as tonnes recoverable up to a certain cost.

Australia's uranium resources are over 25% of the world's total, and Kazakhstan is the world's leading source, contributing more than one-third of world production. Other countries with significant known resources include Russian Federation, Canada South Africa, Namibia, and Niger. Many more countries have smaller deposits which could be mined. (See information page on Supply of Uranium).

Uranium is sold only to countries which are signatories of the Nuclear Non-Proliferation Treaty, and which allow international inspection to verify that it is used only for peaceful purposes. (See information page on Safeguards.)

From uranium ore to reactor fuel

Uranium ore can be mined by underground or open-cut methods, depending on its depth. After mining, the ore is crushed and ground up. Then it is treated with acid to dissolve the uranium, which is then recovered from solution. Uranium may also be mined by *in situ* leaching (ISL), where it is dissolved from the orebody *in situ* and pumped to the surface.

The end product of the mining and milling stages, or ISL, is uranium oxide concentrate (U_3O_8)*. Before it can be used in a reactor for electricity generation, however, it must undergo a series of processes to produce a useable fuel.

* U_3O_8 is a stable complex oxide: $U_2O_5.UO_3$.

For most of the world's reactors, the next step in making a useable fuel is to convert the uranium oxide into a gas, uranium hexafluoride (UF_6), which enables it to be enriched[f]. Enrichment increases the proportion of the U-235 isotope from its natural level of 0.7% to 3-

5% (see information page on Uranium Enrichment). This enables greater technical efficiency in reactor design and operation, particularly in larger reactors, and allows the use of ordinary water as a moderator. A by-product (sometimes considered a waste product) of enrichment is depleted uranium (about 86% of the original feed). This, largely U-238, has potential use in fast neutron reactors.

After enrichment, the UF_6 gas is converted to uranium dioxide (UO_2) which is formed into fuel pellets. These fuel pellets are placed inside thin metal tubes which are assembled in bundles to become the fuel elements for the core of the reactor. UO_2 has a very high melting point – 2865°C (compared with uranium metal – 1132°C).

Used reactor fuel is removed from the reactor and stored, either to be reprocessed or disposed of in deep geological repositories.

The uranium orebody contains both U-235 and (mostly) U-238. About 95% of the radioactivity in the ore is from the U-238 decay series. This has 14 radioactive isotopes in secular equilibrium, thus each represents 7% of the total. (In the case of Ranger ore - with 0.3% U_3O_8 it has about 450 kBq/kg, so irrespective of the mass proportion, 32 kBq/kg per nuclide in that decay series.) When the ore is processed, the U-238 and the very much smaller masses of U-234 (and the U-235) are removed. The balance becomes tailings, and at this point has about 86% of its original intrinsic radioactivity. However, with the removal of most U-238, the following two short-lived decay products (Th-234 & Pa-234) soon disappear, leaving the tailings with a little over 70% of the radio-activity of the original ore after several months. The controlling long-lived isotope then becomes Th-230 which decays with a half life of 77,000 years to radium-226 followed by radon-222.

Recycled (reprocessed) uranium

Uranium comprises about 96% of used fuel. When used fuel is reprocessed, both plutonium and uranium are usually recovered separately.

Uranium recovered from reprocessing used nuclear fuel (RepU) is mostly U-238 with about 1% U-235, so it needs to be converted and re-enriched for recycling into most reactors. This is complicated by the presence of impurities[g] and two isotopes in particular, U-232 and U-236, which are formed by or following neutron capture in the reactor, and increase with higher burn-up levels[h].

U-232 here is largely a decay product of Pu-236, and increases with storage time in used fuel, peaking at about ten years. Both U-232 and U-236 decay much more rapidly than U-235 and U-238, and one of the daughter products of U-232 emits very strong gamma radiation, which means that shielding is necessary in any plant handling material with more than very small traces of it. U-236, comprising about 0.5% of recovered uranium, is a neutron absorber which impedes the chain reaction, and means that a higher level of U-235 enrichment is required in the product to compensate.

Because they are lighter than U-238, both U-232 and U-236 tend to concentrate in the enriched (rather than depleted) output, so reprocessed uranium (RepU) that is re-enriched for fuel must be segregated from enriched fresh uranium. Enriched RepU has an activity of over 250 kBq/g, which compares with 82 kBq/g (most of this being from U-234) for enriched fresh uranium. The presence of U-236 in particular means that the U-235 enrichment level needs to be a bit higher than for fresh uranium, and most reprocessed uranium can normally be recycled only once. In the future, laser enrichment techniques may be able to remove these difficult isotopes.

High-enriched uranium

In October 2015 the Institute for Science and International Security (ISIS) reported that there was about 134 tonnes of civilian stocks of high-enriched uranium (HEU) worldwide at the end of 2014. The number of countries holding stocks of 1 kg or more of HEU stood at 29 then, but this has since fallen to 26. About 16.5 tonnes of HEU exist in the non-nuclear weapon states (NNWS), almost all of which resides in ten of them. The nuclear weapon states (NWS) possess a combined estimated total of 115-120 tonnes. Most civil HEU is used in research reactors.

ISIS reported that at the peak of HEU use, almost 60 countries used HEU fuels and tonnes of HEU were in international commerce. Since the late 1970s, the USA and other countries have converted many research reactors from HEU to low enriched uranium (LEU) fuels and discouraged the construction of new reactors that require HEU fuel. Both the USA and Russia also launched 'take-back' programmes to retrieve HEU they provided to these countries for use in their nuclear programmes. As a result the number of countries possessing HEU has more than halved. The number of countries with a kilogram or more of HEU is expected to decrease further as Russia is set to take back more of the HEU that it provided and to reprocess and blend down the recovered HEU. The USA also seeks to repatriate US-origin HEU and accept other priority stocks during the next several years. HEU production for civil purposes largely stopped years ago. However, Russia decided to resume producing HEU for a Chinese fast reactor that reached criticality in 2010.

Uranium from thorium

Thorium, as well as uranium, can be used as a nuclear fuel. Although not fissile itself, Th-232 will absorb slow neutrons to produce uranium-233 (U-233)[i], which is fissile (and long-lived). The irradiated fuel can then be unloaded from the reactor, the U-233 separated from the thorium, and fed back into another reactor as part of a closed fuel cycle. Alternatively, thorium can be incorporated into the fuel salt of a molten salt reactor (MSR) and the U-233 burned as it is bred. (See information page on MSRs.)

U-233 has higher neutron yield per neutron absorbed than U-235 or Pu-239. Given a start with some other fissile material (U-233, U-235 or Pu-239) as a driver, a breeding cycle similar to but more efficient than that with U-238 and plutonium (in conventional thermal neutron reactors) can be set up. U-233 has a 95% probability of fission when struck by a neutron of any energy level (a higher probability than Pu-239), though some U-234 is formed. The driver fuels provide all the neutrons initially, but are progressively supplemented by U-233 as it forms from the thorium. However, the intermediate product protactinium-233 (Pa-233) is a neutron absorber which diminishes U-233 yield. (See information page on Thorium).

Specifically: Th-232 gains a neutron to form Th-233, which soon beta decays (half-life 22 minutes) to protactinium-233. The Pa-233 (half-life of 27 days) decays into U-233. Some U-232 is also formed along with Th-233, and a decay product of this is very gamma active. Chemical separation of the protactinium from irradiated thorium would minimize U-232 contamination of the ultimate U-233. The chemical separation is not as straightforward as the Purex process used to separate U & Pu from used power reactor uranium fuel, and it has not been demonstrated beyond bench scale. (Incidentally, more than about 50 ppm U-232 in U-233 renders it unsuitable for weapons.)

Other uses of uranium-fuelled reactors

There are also other uses for uranium-fuelled nuclear reactors. Over 200 small nuclear reactors power more than 150 ships, mostly submarines, but ranging from icebreakers to aircraft carriers. These can stay at sea for very long periods without having to make refuelling stops. In most such vessels the steam drives a turbine directly geared to propulsion.

The heat produced by nuclear reactors can also be used directly rather than for generating electricity. In Russia, for example, it is used to heat buildings and elsewhere it provides heat for a variety of industrial processes such as water desalination. In the future, high-temperature reactors could be used for industrial processes such as thermochemical production of hydrogen. (See information page on Hydrogen Production and Uses).

Radioisotope production in uranium fuelled reactors

Radioactive materials (radioisotopes) play a key role in the technologies that provide us with food, water and good health and have become a vital part of modern life. They are produced by bombarding small amounts of particular elements with neutrons. Using relatively small special purpose nuclear reactors (usually called research reactors), a wide range of radioisotopes can be made at low cost. The use of radioisotopes has become widespread since the early 1950s, and there are now some 280 research reactors in 56 countries producing them.

In medicine, radioisotopes are widely used for diagnosis, and also for treatment and research. Radioactive chemical tracers emit gamma radiation which provides diagnostic information about a person's anatomy and the functioning of specific organs. Radiotherapy also employs radioisotopes in the treatment of some illnesses, such as cancer. More powerful gamma sources are used to sterilize syringes, bandages and other medical equipment. About one in two people in Western countries is likely to experience the benefits of nuclear medicine in their lifetime, and gamma sterilisation of equipment is almost universal. (See information page on Radioisotopes in Medicine.)

In the preservation of food, radioisotopes are used to inhibit the sprouting of root crops after harvesting, to kill parasites and pests, and to control the ripening of stored fruit and vegetables. Irradiated foodstuffs are accepted by world and national health authorities for human consumption in an increasing number of countries. They include potatoes, onions, dried and fresh fruits, grain and grain products, poultry and some fish. Some prepacked foods can also be irradiated.

Agriculturally, in the growing crops and breeding livestock, radioisotopes also play an important role. They are used to produce high-yielding, disease- and weather-resistant varieties of crops, to study how fertilizers and insecticides work, and to improve the productivity and health of domestic animals. Industrially, and in mining, they are used to examine welds, to detect leaks, to study the rate of wear of metals, and for on-stream analysis of a wide range of minerals and fuels. (See information page on Radioisotopes in Industry.)

Environmentally, radioisotopes are used to trace and analyse pollutants, to study the movement of surface water, and to measure water runoffs from rain and snow, as well as the flow rates of streams and rivers.

Most household smoke detectors use a radioisotope (americium-241) derived from the plutonium formed in nuclear reactors. These alarms save many lives.

Depleted uranium

Every tonne of natural uranium produced and enriched for use in a nuclear reactor gives about 130 kg of enriched fuel (3.5% or more U-235). The balance is depleted uranium tails (U-238, typically with 0.22% U-235 if from Western enrichment plants, 0.10% from Russian ones). This major portion has been depleted in its fissile U-235 isotope (and, incidentally, U-234) by the enrichment process. It is commonly known as DU if the focus is on the actual material, or enrichment tails if the focus is on its place in the fuel cycle and its U-235 assay.

DU tails are either stored as UF_6 or (especially in France and now also Russia and the USA) deconverted back to U_3O_8, which is more benign chemically and thus more suited for long-term storage. It is also less chemically toxic. Every year over 50,000 tonnes of depleted uranium joins already substantial stockpiles in the USA, Europe and Russia. World stock is about 1.6 million tonnes.

Some DU is drawn from these stockpiles to dilute high-enriched (>90%) uranium released from weapons programs, particularly in Russia, and destined for use in civil reactors (see information page on Military Warheads as a Source of Nuclear Fuel). This weapons-grade material is diluted about 25:1 with depleted uranium, or 29:1 with depleted uranium that has been enriched slightly (to 1.5% U-235) to minimize levels of (natural) U-234 in the product.

Some, assaying 0.25-0.40% U-235 from historic enrichment, has been sent to Russia for re-enrichment, using surplus plant capacity there to produce either natural uranium equivalent or low-enriched uranium (4-5% U-235).

The main current use for DU is used in mixed oxide (MOX) fuel, by mixing with plutonium (see information page on Mixed Oxide (MOX) Fuel).

Potentially DU can be used as fuel in future generations of fast neutron reactors. In the long-term perspective it thus needs to be seen as a resource.

Other uses depend on the metal's very high density (1.7 times that of lead). Hence, where maximum mass must fit in minimum space, such as aircraft control surface and helicopter counterweights, yacht keels, etc, it is often well suited. Until the mid 1970s it was used in dental porcelains. In addition it is used for radiation shielding in hospital and industrial radiography, being some five times more effective than lead in this role (in Australia some 6 tonnes is used thus, in about 60 items of equipment).

Also because of its density, it is used as solid slugs or penetrators in armour-piercing projectiles, alloyed with abut 0.75% titanium. DU is pyrophoric, so that upon impact about 30% of the projectile atomizes and burns to uranium oxide dust. It was widely used in the 1990/91 Gulf War (300 tonnes) and less so in the 1998/99 Kosovo War (11 tonnes). As well as ground-based artillery, the A-10 'Warthog' aircraft can fire 30mm DU armour-piercing rounds.

Health aspects of DU

Depleted uranium is not classified as a dangerous substance radiologically, though it is a potential hazard in large quantities, beyond what could conceivably be breathed. Its emissions are very low, since the half-life of U-238 is the same as the age of the Earth (4.5 billion years). There are no reputable reports of cancer or other negative health effects from radiation exposure to ingested or inhaled natural or depleted uranium, despite much study.

However, uranium does have a chemical toxicity about the same as that of lead, so inhaled fume or ingested oxide is considered a health hazard. Most uranium actually absorbed into the body is excreted within days, the balance being laid down in bone and kidneys. Its biological effect is principally kidney damage. The World Health Organization (WHO) has set a tolerable daily intake level for uranium of 0.6 microgram/kg body weight, orally. (This is about eight times our normal background intake from natural sources.) Standards for drinking water and concentrations in air are set accordingly.

Like most radionuclides, it is not known as a carcinogen, or to cause birth defects (from effects *in utero*) or to cause genetic mutations. Radiation from DU munitions depends on how long since the uranium has been separated from the lighter isotopes so that its decay products start to build up. Decay of U-238 gives rise to Th-234, Pa-234 (beta emitters) and U-234 (an alpha emitter)[k]. On this basis, in a few months, DU is weakly radioactive with an activity of around 40 kBq/g quoted. (If it is fresh from the enrichment plant and hence fairly pure, the activity is 15 kBq/g, compared with 25 kBq/g for pure natural uranium. Fresh DU from enriching reprocessed uranium has U-236 in it and more U-234 so is about 23 kBq/g.)

In 2001, the UN Environment Programme (UNEP) examined the effects of nine tonnes of DU munitions having been used in Kosovo, checking the sites targeted by it[4]. UNEP found no widespread contamination, no sign of contamination in water of the food chain and no correlation with reported ill-health in NATO peacekeepers. A two-year study[5] by Sandia National Laboratories in USA reported in 2005 that consistent with earlier studies[l], reports of serious health risks from DU exposure during the 1991 Gulf War are not supported by medical statistics or by analysis.

An editorial in the *Radiological Protection Bulletin* of the UK's National Radiation Protection Board stated: "DU is radioactive and doses from inhalation of dust or from handling bare spent rounds need to be assessed properly. However, the scientific consensus at present is that the risks are likely to be small and easily avoidable, especially compared with the other risks the armed forces have to take in war."[6]

Thus DU is clearly dangerous for military targets, but for anyone else – even in a war zone – there is little hazard. Ingestion or inhalation of uranium oxide dust resulting from the impact of DU munitions on their targets is the main possible exposure route.

Other forms of uranium, legacy materials

As well as natural uranium, enriched uranium, depleted uranium tails and reprocessed uranium, there are other forms of it, some as legacy materials arising from military processing.

Slightly irradiated uranium (SIU, 0.65% U-235 in Russia) arises from military plutonium production with low burn-up of natural uranium, after reprocessing to separate that plutonium (essentially Pu-239). If SIU is enriched, the product can readily be used in nuclear plants and the tails become DSIU, with lower content of even uranium isotopes (232, 234, 236) than normal RepU, hence more valuable.

Notes & references

Notes

a. The half-life is the time it takes for a radionuclide to lose half of its own radioactivity. [Back]

b. The becquerel (Bq) is a unit or measure of actual radioactivity in material (as distinct from the radiation it emits), with reference to the number of nuclear disintegrations per second (1 Bq = 1 disintegration/sec). For further information on units of radioactivity see the *Units of radiation and radioactivity* section in the information page on Nuclear Radiation and Health Effects [Back]

c. U-235 can fission following capture of a low-energy (or 'thermal') neutron to form a new compound nucleus, which then splits into two daughter fragments and two or three neutrons (average around 2.5), releasing energy in the process. (See also information page on Physics of Nuclear Energy) [Back]

d. Sometimes Pu-239 simply captures a neutron without splitting, and it becomes Pu-240. Because the Pu-239 is either progressively burned or becomes Pu-240, the longer the fuel stays in the reactor the more Pu-240 accumulates in it. The significance of this is that when the used fuel is removed after about three years, the plutonium in it is not suitable for making weapons – because Pu-240 has a relatively high rate of spontaneous fission – but can be recycled as fuel. (See also information page on Plutonium). [Back]

e. Neutrons released in fission are initially fast (velocity about 10^9 cm/s, or energy above 1 MeV), but fission in U-235 is most readily caused by slow (thermal) neutrons (velocity about 10^5 cm/s, or energy about 0.02 eV). A moderator material comprising light atoms thus surrounds the fuel rods in a reactor to slow down the neutrons in elastic collisions. (See also information page on Physics of Nuclear Energy) [Back]

f. For reactors which use natural uranium as their fuel (and which require graphite or heavy water as a moderator) the U_3O_8 concentrate simply needs to be refined and converted directly to uranium dioxide. [Back]

g. Recovered uranium (especially from earlier military reprocessing) may be contaminated with traces of fission products. Over 2002-06 USEC cleaned up 7400 tonnes of technetium-contaminated uranium from the US Department of Energy. [Back]

h. Recovered uranium also contains a higher proportion of U-234 than fresh reactor fuel. As well as having a greater specific activity than both U-235 and U-238, the presence of U-234 alters the reactivity as it absorbs neutrons. [Back]

i. Neutron absorption by Th-232 produces Th-233, which has a half-life of about 22 minutes. This undergoes beta decay to form Pa-233 (half-life 27 days), most of which forms U-233 by further beta decay. Around 11% of the U-233 is converted by further neutron absorption to U-235, which is the fissile isotope of uranium used in conventional nuclear reactors. A small amount of the Pa-233 and U-233 forms U-232 in the reactor. Separated U-233 is therefore always contaminated with traces of U-232, which has a 69-year half-life but whose daughter products[j], particularly thallium-208, are strong gamma emitters with very short half-lives. This creates significant problems in handling the bred U-233 and makes it easy to detect, hence conferring proliferation resistance. [Back]

j. The decay chain of U-232 has six short-lived decay products before Tl-208, which precedes stable Pb-208. [Back]

k. U-238 (half-life 4.5 billion years) decays to thorium-234 (half-life 24 days), which beta decays to protactinium-234 (half-life one minute), which beta decays to U-234 (alpha emitter, half-life 246,000 years). [Back]

l. For example, a 2001 paper by the Australasian Radiation Protection Society (ARPS), which quotes several studies, concludes that health risks associated with the levels of DU exposure experienced during the Gulf War are essentially zero. A summary of the ARPS statement reads as follows:

Some military personnel involved in the 1991 Gulf War complained of continuing stress-like symptoms for which no obvious cause was found. These symptoms were at times attributed to the use of depleted uranium in shells and other missiles, which are said to have caused toxic effects. Similar complaints arose from later fighting in the Balkans (Kosovo). Because of the latency period for the induction of cancer by radiation, it is not credible that any cases of radiation-induced cancer could in the short term be attributed to the Kosovo conflict. Furthermore, extensive studies have concluded that no radiological health hazard should be expected from exposure to depleted uranium. The risk from external exposure is essentially zero, even when pure metal is handled. No detectable increases of cancer, leukaemia, birth defects or other negative health effects have ever been observed from radiation exposure to inhaled or ingested natural uranium concentrates, at levels far exceeding those likely in areas where DU munitions have been used. This is mainly because the low radioactivity per unit mass of uranium means that the mass needed for significant internal exposure would be virtually impossible to accumulate in the body – and DU is less than half as radioactive as natural uranium. [Back]

References

1. International Energy Agency, Data and Statistics [Back]

2. World Nuclear Association table of World Nuclear Power Reactors & Uranium Requirements [Back]

3. World Nuclear Association table of Nuclear share figures [Back]

4. Depleted Uranium in Kosovo: Post-Conflict Environmental Assessment, United Nations Environment Programme (2001) [Back]

5. Albert C. Marshall, An Analysis of Uranium Dispersal and Health Effects Using a Gulf War Case Study, Sandia National Laboratories, USA, SAND2005-4331 (July 2005) [Back]

6. Michael Clark, *Editorial*, Radiological Protection Bulletin No. 229, P3 (March 2001), National Radiological Protection Board [Back]

General sources

World Health Organization fact sheet on depleted uranium
Balkans Task Force Final Report, The Kosovo Conflict – Consequences for the Environment & Human Settlements, United Nations Environment Programme and United Nations Centre for Human Settlements (Habitat), ISBN 9280718011 (1999)
Management of Depleted Uranium, OECD Nuclear Energy Agency, OECD Publishing, ISBN 9789264195257 (Aug 2001)
Bulletin of the Atomic Scientists, Volume 55, Number 6, (November-December 1999)

Related information

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ADDRESS

York House,
23 Kingsway,
London,
WC2B 6UJ,
United Kingdom

GENERAL ENQUIRIES

t: +44 (0)20 7451 1520
f: +44 (0)20 7839 1501

MEMBERSHIP ENQUIRIES

Member support
members@world-nuclear.org

e: info@world-nuclear.org

Joining enquiries
enrolment@world-nuclear.org

MEDIA ENQUIRIES

Henry Preston
t: +44 (0)20 7451 1523
e: press@world-nuclear.org

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