NUCLEAR WORDS

AND TERMS

By Miles Goldstick

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Please send any suggestions for improvements to:
Miles Goldstick, Box 1633, S-742 00 Östhammar, Sweden.
Tel. 46-173-70271. Email: pns:milesg

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Properties Of Selected Isotopes, Listed Alphabetically *

Nuclide	Symbol-Atomic Weight	Half-life	Specific Activity (Ci/g)	(Bq/g)	Type Of Decay
americium	Am-241	432.7 y	3.428	1.2684E+11	alpha/gamma
barium	Ba-140	12.746 d	73,170	2.7073E+15	beta-/gamma
carbon	C-14	5,730 y	4.46	1.6502E+11	beta-
cerium	Ce-141	32.5 d	28,495	1.0543E+15	beta-/gamma
cerium	Ce-144	284.9 d	3,182.8	1.1776E+14	beta-/gamma
cesium	Cs-134	2.062 y	1,294	4.7878E+13	beta-/gamma
cesium	Cs-135	3E+6 y	0.0009	33,300,000	beta-
cesium	Cs-137	30.04 y	87.0	3.219E+12	beta-/gamma
cobalt	Co-60	5.271 y	1,130.36	4.1823E+13	beta/gamma
curium	Cm-242	162.94 d	3,311.4	1.2252E+14	alpha/gamma
curium	Cm-244	18.11 y	80.9	2.9933E+12	alpha/gamma
iodine	I-131	8.04 d	123,974	4.587E+15	beta-/gamma
krypton	Kr-85	10.72 y	392.3	1.4515E+13	beta-/gamma
lead	Pb-210	22.3 y	76.3	2.8231E+12	alpha/beta-/gamma
molybdenum	Mo-99	2.7477 d	480,010	1.776E+16	beta-/gamma
neptunium	Np-239	2.355 d	232,000	8.584E+15	beta-/gamma
plutonium	Pu-238	87.74 y	17.119	6.334E+11	alpha/gamma
plutonium	Pu-239	24,110 y	0.06204	2.29E+09	alpha/gamma
plutonium	Pu-240	6,563 y	0.22696	8.3975E+09	alpha/gamma
plutonium	Pu-241	14.4 y	103.0	3.811E+12	alpha/beta-/gamma
plutonium	Pu-242	376,300 y	0.003926	1.4526E+08	alpha
potassium	K-40	1.277E+9 y	5.65E-6	209,050	beta-/beta+/gamma
radium	Ra-226	1,600 y	0.989	3.6593E+10	alpha/gamma
radon	Rn-222	3.825 d	153,770	5.6895E+15	alpha
ruthinium	Ru-103	39.25 d	32,295	1.1949E+15	beta-/gamma
ruthinium	Ru-106	1.02 y	3,306	1.2232E+14	beta-
strontium	Sr-89	50.55 d	29,020	1.0737E+15	beta-/gamma
strontium	Sr-90	28.5 y	139.4	5.1578E+12	beta-
technetium	Tc-99	213,000 y	0.0170	6.29E+08	beta-/gamma
thorium	Th-230	75,400 y	0.02062	7.6294E+08	alpha/gamma
thorium	Th-232	1.405E+10 y	1.0974E-7	4060.5	alpha/gamma
thorium	Th-234	24.1 d	23,150	8.5655E+14	beta-/gamma
tritium	H-3	12.33 y	9,664	3.5757E+14	beta-
uranium	U-234	245,400 y	0.006225	2.3033E+08	alpha/gamma
uranium	U-235	7.037E+8 y	1.922E-6	71,114	alpha/gamma
uranium	U-238	4.468E+9 y	3.3639E-7	12,447	alpha/gamma
xenon	Xe-133	5.245 d	187,180	6.9257E+15	beta-/gamma

*

Half-lives are listed in years (y), days (d), and seconds (s). Note: other sources may list different half-lives and thus specific activities, depending on the original source of information.

E-notation is a form of expressing numbers that originates from the computer language FORTRAN, developed in the 1950's. The use of E-notation avoids the use of superscripts when expressing powers of ten. For example 3.7×10^{10} becomes +0.37E+11, or more simply 3.7 E10. The uppercase "E" represents "times ten to the". The number 3.7 E10 is read "three point seven E ten", not "three point seven E to the tenth" as that would mean $3.7 \times e^{10}$ not 3.7×10^{10}.

Sources: Specific activities of Co-60, Th-234 and U-235 have been calculated independently. Halflives, types of decay, and all other specific activities are taken from: Browne, Edgardo and Firestone, Richard B.; Shirley, Virginia S. (ed). 1986. "Table Of Radioactive Isotopes." About six cm thick. John Wiley and Sons. ISBN: 0-471-84909-X.

Some Types Of Nuclear Reactors

AGR: advanced gas-cooled graphite-moderated reactor
BLWR: same as BWR
BHWR: boiling-heavy-water-cooled and -moderated reactor
BWR: boiling light-water-cooled and -moderated reactor
FBR: fast breeder reactor
GCFBR: gas-cooled fast breeder reactor
GCHWR: gas-cooled, heavy-water-moderated reactor
GCR: gas-cooled, graphite-moderated reactor
HTGR: high-temperature gas-cooled, graphite-moderated reactor
HTR: high-temperature reactor
HWGCR: heavy-water-moderated, gas-cooled reactor
HWLWR: heavy-water-moderated, light-water-cooled reactor
LMFBR: liquid-metal-cooled fast breeder reactor
LWBR: light-water breeder reactor
LWCHWR: light-water-cooled heavy-water-moderated reactor
LWGR: light-water-cooled, graphite-moderated reactor
MTR: material test reactor
LWR: light-water-cooled and -moderated reactor
OMR: organic-moderated and -cooled reactor
PHWR: pressurized heavy-water-moderated and -cooled reactor
PWR: pressurized light-water-moderated and -cooled reactor
RR: research reactor
SGHWR: steam-generated heavy-water reactor
SGR: sodium-cooled, graphite-moderated reactor
SZR: sodium-cooled, zirconium-hydride-moderated reactor
THTR: thorium high-temperature reactor

SI Mathematical Prefixes And Multiples

Word	Prefix	Symbol	Factor	Number
quintillion	exa	E	10^{18}	1,000,000,000,000,000,000
	peta	P	10^{15}	1,000,000,000,000,000
trillion	tera	T	10^{12}	1,000,000,000,000
billion	giga	G	10^{9}	1,000,000,000
million	mega	M	10^{6}	1,000,000
thousand	kilo	k	10^{3}	1,000
hundred	hecto	h	10^{2}	100
ten	deka	da	10^{1}	10
tenth	deci	d	10^{-1}	0.1
hundredth	centi	c	10^{-2}	0.01
thousandth	milli	m	10^{-3}	0.001
millionth	micro	μ	10^{-6}	0.000,001
billionth	nano	n	10^{-9}	0.000,000,001
trillionth	pico	p	10^{-12}	0.000,000,000,001
	femto	f	10^{-15}	0.000,000,000,000,001
quintillionth	atto	a	10^{-18}	0.000,000,000,000,000,001

Isotopes of the same element have the same atomic number. In scientific writing the atomic number is written to the lower left of the element symbol, as the 92 below for the uranium-238 and -234 isotopes.

atomic weight $^{238}_{92}U$ element
atomic number

$^{234}_{92}U$

atomic weight - The number used to express the mass of an individual isotope of an element. It is the sum of protons and neutrons in the nucleus. In scientific writing the atomic weight is written to the upper left of the element symbol, as the 238 and 234 above for the uranium-238 and -234 isotopes. Also referred to as atomic mass.

B

becquerel (Bq) - The SI measure of the rate of spontaneous nuclear transformation of a radioactive nuclide. One becquerel is equal to one radioactive disintegration per second, written as $1\ Bq = 1\ s^{-1}$. The unit is named after the French physicist Henri Becquerel (1852-1908) who discovered radioactivity in 1896. It was approved as the SI unit of radioactivity in 1975 and replaces the curie.

becquerel per gram (Bq/g) - The number of radioactive disintegrations per second taking place in a gram of material. This is the most common way of expressing concentration of radioactivity.

beryllium oxide - An oxide of the element beryllium. It is used as a neutron reflector in an atomic bomb and has a health hazard similar to asbestos.

beta-emitter - A nuclide which releases beta radiation.

beta particle - The fragment emitted in beta decay. It is either an electron, which is negatively charged and referred to as beta-minus decay; or a positron which is positively charged, and called beta-plus. It can cause ionization. See also "radiation, ionizing".

Biological Effects of Ionizing Radiation (BEIR) Committee - A committee established by the U.S. government to study the effects of radiation. The BEIR Committee's findings have consistently been disputed by independent scientists.

body burden - The activity of radioactive material present in the body of a human or other animal.

bone seeker - A radioactive isotope that tends to accumulate in the bones, such as strontium-90.

Conversion Factors For Chemical Forms Of Uranium

	KILOGRAMS						
1 kg	NU	U3O8	NUO2	NUF6	3% LEUF6 (+kg DUF6)	3% LEUO2 (+kg DUF6)	DU
NU	1	1.179	1.134	1.479	0.269 (1.21)	0.206 (1.21)	0.818
U3O8	0.848	1	0.962	1.255	0.228 (0.278)	0.175 (0.278)	0.694
NUO2	0.882	1.04	1	1.304	---	---	0.721
NUF6	0.676	0.797	0.767	1	0.182 (0.818)	0.139 (0.818)	0.553
3% LEUF6 (+kg DUF6)	3.718 (3.042)	4.384 (3.586)	--- ---	5.5 (4.5)	1 (4.5)	0.767 (4.5)	3.042
3% LEUO2	4.85	5.72	---	7.17	1.304 (5.868)	1 (5.868)	3.976
DU	1.222	1.441	1.386	1.808	0.329	0.252	1

ADDITIONAL CONVERSION FACTORS

1 kg NU = 2.600 lb U3O8 | 1 lb U3O8 = 0.385 kg NU
1 STU3O8 = 0.769 MTNU | 1 MTNU = 1.3 STU3O8

5.5 kg NU (= 8.1 kg NUF6) + 4.3 kg-SWU =
1 kg 3% LEU + 4.5 kg DU (containing 0.20% uranium-235)

NOTES

The factors can not be used to make exact calculations in practical situations. All the numbers except the 3% LEUF6, 3% LEUO2, and DU equivalents are theoretical maximums based only on atomic weight.[1] The 3% LEUF6 and 3% LEUO2 are based on about an 80% enrichment efficiency. The DU conversion factors are based on production from 3% enriched UF6. In practice, most of the numbers are between 10 and 20% smaller depending on process efficiency, economic considerations, and other complications.[2] Still, accurate estimates can be made.[3]

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[1] For example, the UF6 equivalent of NU is calculated as follows: the atomic weight of NU = 238 and that of F = 19; thus the atomic weight of UF6 = 238 + 6 X 19 = 352; NU/UF6 = (238/352 = 1/x) = 352/238 = 1.479.

[2] For example, an individual fuel rod for a LWR or BWR may contain fuel pellets with a range of from 0.5% to 5% enrichment. Further, not included is the few percent U3O8 often mixed with NUO2 and LEUO2 (source: personal communication 18 April 1990 from Bengt-Åke Andersson, Information Department, Asea Brown-Bouveri, S-721 63 Västerås, Sweden).

[3] To calculate quantities of solid waste per kilo NU produced at an uranium mill to make

core to soak up neutrons and regulate the fission reaction rate. To increase the power output of the reactor, the rods are gradually moved out of the core. To decrease power output the rods are gradually moved further into the core.

core - The region of a reactor containing the fuel and moderator (if any) within which the fission reaction is occurring.

cosmic radiation - Radiation that comes from outer space.

critical mass - The smallest mass or amount of a fissionable material that will sustain a nuclear chain reaction. An amount of a fissionable material that is less than a critical mass is known as "subcritical" and an amount greater than a critical mass is called "supercritical".

cross-section - A hypothetical "target area" measuring the probability of a nuclear collision. The unit of cross-section is "barn".

curie (Ci) - The old unit of activity, replaced in the SI with becquerel (Bq). One curie equals 37 billion (3.7×10^{10}) radioactive disintegrations per second of any radionuclide. The unit was originally adopted in 1910 and defined as the radioactivity associated with the quantity of radon in equilibrium with one gram of radium-226. The present definition was agreed upon at the July 1953 meeting of the International Commission of Radiological Units. It is named after Pierre Curie (1859-1906), one of the discoverers of radium. He, his wife Marie (1867-1934), as well as their daughter, died from exposure to radiation.

collective dose - The average radiation dose times the number of people receiving that dose. It is expressed in the unit "man sievert".

D

daughter product - A nuclide resulting from the radioactive decay of another nuclide, called a "parent product". For example, radon-222 is the daughter product of radium-226. A daughter product may be either radioactive or stable.

decay - The gradual disintegration of radioactive material over time.

decay constant - The fraction of the amount of a radioactive nuclide that undergoes transition per unit time.

dose-effect curve - A graph showing the consequence of exposure to different amounts of a substance, for example the risk of leukemia from various radiation doses. The dose is normally put on the x-axis and response on the y-axis. For exposure to radiation, a straight line dose-effect curve means that the incidence of cancer is proportional to dose down to zero dose. This is called the linear dose-effect hypothesis. The infra-linear

(LEUF6), highly (HEUF6) or very highly enriched (VHEUF6). The quantity of uranium-235 in UF6 can not be determined visually; isotope composition must be checked by chemical analysis. The different types are used in different parts of the fuel chain, and differ greatly in economic value.

The physical and chemical properties of UF6 set it apart from the vast majority of radioactive materials. UF6 is both radiologically and chemically toxic, as are all compounds of uranium. But, the chemical hazard of UF6 is much greater than the chemical hazard of uranium alone. The most important difference between UF6 and other compounds of uranium is that UF6 will form a highly toxic cloud on contact with air or water. If UF6 comes into contact with air, a rapid reaction with the moisture in the air takes place forming the highly corrosive chemical hydrogen fluoride (HF-hydrofluoric acid) in a gaseous form, and uranyl fluoride (UO2F2). This is the main reason UF6 is stored and transported in specially made steel cylinders. UF6 vapor can cause kidney damage. Inhalation of as little as 15 mg hydrofluoric acid will kill within a short period of time and fluorine gas can burn skin on contact. The reaction with water vapor in the air is thus the greatest concern in a UF6 accident.

uranium milling - The removal of uranium from ore, accomplished by crushing the rock, grinding it down to a fine sand, and mixing it with large amounts of water and chemicals. The chemicals are either acids or bases, depending on the pH of the ore. Both of the processes are able to remove about 90% of the uranium and only a few percent of the other radionuclei. Uranium mills are usually located close to uranium mines to avoid ore transport costs. The final product of an uranium mill is a uranium concentrate commonly called yellowcake. See also "uranium mill tailings".

uranium mining - The process of removing uranium from its natural place. The most common types of uranium mines are open pit and underground. Other forms of mining include solution or leach mining, which is a technique of injecting highly acidic solutions into an ore body and then extracting the uranium from the solution; and separation of uranium from sea water. Uranium is often mined in conjunction with other minerals such as gold and phosphates.

uranium tetrafluoride (UF4, green salt) - An intermediate product in the production of UF6 and uranium metal. Natural UF4 is made into natural UF6 at a uranium conversion plant, where it is formed by the hydrofluorination of UO2. Highly enriched UF4 and depleted UF4 are made respectively from highly enriched UF6 and depleted UF6. Highly enriched UF4 is the feed material for production of highly enriched uranium metal used in nuclear weapons. Depleted UF4 is the feed material for production of depleted uranium ammunition.

uranium trioxide (UO3, orange oxide) - An intermediate product in uranium conversion and treatment of uranium recovered from fuel reprocessing operations.

a group of people.

F

fallout - Radioactive materials which descend from the atmosphere onto the surface of the earth. The origin of fallout may be from nuclear explosions, radioactive substances released after a nuclear accident, and routine operation of nuclear facilities.

fertile material - A material that can be transformed into a fissionable material. The two main fertile nuclides are uranium-238 and thorium-232 which respectively form plutonium-239 and uranium-233 (both fissionable by thermal neutrons). The transformation of fertile material into fissionable material occurs in breeder reactors and fission-fusion-fission nuclear bombs.

film badge - A type of personal dosimeter in the form of a badge containing photographic films that are shielded by different materials, permitting discrimination between beta and gamma exposure. Since radiation darkens the film it provides a record of radiation exposure. They are normally issued for a period of one month.

fissile material - A material made up of heavy atoms that can be split into pieces emitting energy. A material may be fissile by one of either fast neutrons or thermal neutrons (also called slow neutrons). Thorium-232 and uranium-238 are fissile by fast neutrons and uranium-235 and -233 and plutonium-239 are fissile by slow neutrons.

fission - The splitting of a nucleus into two lighter fragments, accompanied by the release of energy and generally one or more neutrons. Fission can occur either spontaneously or as the consequence of absorption of a neutron. The main fissionable nuclides are uranium-235, plutonium-239, and uranium-233. The intensity of the fission reaction depends on many factors, including the degree of enrichment of the fuel, its mass, and physical arrangement in a given volume. The discovery of nuclear fission was made in January 1939 and was based on work by two German chemists.

fission product - Any of the primary fragments, and their decay products, resulting from the fission of heavy nuclei. Over 200 different stable and radioactive nuclides of over 34 different elements have been identified as fission products. They account for most of the radioactivity in spent fuel when it leaves the reactor and for almost all the radioactivity present in wastes from spent reactor fuel reprocessing. They also account for most of the radioactivity associated with radioactive fallout from nuclear weapons tests.

free radical - A chemistry term for an atom or compound in which there is an unpaired electron. Also, a bomb throwing nut who is not in jail.

to the U.S. Department of Defence (DOD) the new armour is two-and-a-half times "tighter" than steal.

uranium dioxide (UO2, brown oxide) - The form of uranium commonly used as fuel in nuclear power reactors. It is also an intermediate product in the production of uranium tetrafluoride (UF4) from uranium trioxide (UO3) (see "uranium conversion").

uranium, enriched - Uranium in which the proportion of uranium-235 has been artificially increased, or "enriched", above the .72% found in natural uranium. Definitions of the different levels of enrichment are:

low-enriched uranium (LEU) - Uranium containing less than 20% uranium-235 but greater than .72%. Commercial nuclear reactors use LEU as fuel that typically contains about 3% uranium-235.

highly-enriched uranium (HEU) - Uranium containing over 20% uranium-235. HEU is one of the explosive components of nuclear bombs and is also used in nuclear submarine reactors, research reactors, and plutonium production reactors. Fresh HEU for these purposes typically contains 93% or more uranium-235. HEU is not used in commercial electricity producing reactors. Because of its military applications, HEU is classified as a "highly strategic material".

very highly-enriched uranium (VHEU) - Uranium containing approximately 97.35% uranium-235. The remaining part may be 1.2% uranium-234 and 1.45% uranium-238. The fill limit for a VHEUF6 cylinder is 25 kg. VHEU is a military material with a high security classification.

uranium enrichment - A process, also called isotope separation, by which the percentage of the isotope uranium-235 is increased above that in naturally occurring uranium. The concentration of uranium-235 in natural uranium is too low to be used in nuclear bombs or to sustain a chain reaction in a reactor. Thus, the proportion of uranium-235 must be increased.

All enrichment technology is highly secret to discourage proliferation of nuclear weapons. There are three methods of uranium enrichment: gaseous diffusion, gas centrifuge, and laser separation, each describe below. Uranium arrives at gaseous diffusion and gas centrifuge enrichment plants in the form of solid NUF6. The feed for laser separation enrichment is U3O8.

All enrichment plants produce enriched UF6 at various levels of enrichment and depleted UF6 at various levels of depletion. The same type of transport containers may be used for depleted UF6 and enriched UF6 as natural UF6. However, stronger containers are generally used for transport than for storage.

Uranium enters an enrichment facility containing .72% uranium-235; almost all the remaining part is uranium-238. The final product may contain anywhere from a few percent to more than 90% uranium-235. Other final products include uranium metal and intermediate chemicals in the production of enriched UF6.

chains or cycles. However, even the so-called cycles are not true cycles in the sense that the original material does not itself recycle and that in the process wastes are produced that are not part of the cycle.

The cycles are: uranium-233 - thorium-232 - uranium-233 (in thermal breeder reactors), and plutonium-239 - uranium-238 - plutonium-239 (in fast breeder reactors). In both cases a fertile material is exposed to irradiation by a fissile material, causing the fertile material to transform into more of the fissile.material. The chains involve the substitution of uranium-235 for uranium-233 and plutonium-239.

The most commonly used fuel system is the uranium-235 - uranium-238 - plutonium-239 chain. There are also combination chains such as uranium-235 - uranium-238/thorium-232 - plutonium-239/uranium-233, and plutonium-239/uranium-235 - uranium-238 - plutonium-239 (the latter using MOX-fuel). The use of plutonium-enriched fuels avoid dependence on uranium enrichment facilities.

fuel fabrication - The part of the fuel chain where yellowcake or enriched uranium hexafluoride is converted to uranium dioxide, fashioned into fuel pellets and loaded into fuel rods. Fuel pellets may also be made of thorium or a mixture of uranium and plutonium called mixed oxide fuel (MOX). Uranium dioxide and MOX fuel fabrication can not take place at the same plant. Fuel fabricated for one reactor generally can not be used by another.

fuel reprocessing - The technique of breaking down spent reactor fuel by chopping it up and putting it through a series of chemical baths that allow extraction of uranium, plutonium-239 and -238, and other isotopes (such as krypton). At the same time large quantities of liquid high-level radioactive waste are produced. Plutonium-238 is used as a heat source in space satellites. Krypton is a radioactive gas valued for its use in leak and penetration testing of electronic assemblies. The plutonium-239 and uranium can be used for new reactor fuel or nuclear bombs. When the uranium by itself is used in new fuel it is first sent to a conversion then enrichment plant. The plutonium alone or plutonium mixed with uranium to be used in new fuel must be sent to a special MOX fuel fabrication plant, bypassing the enrichment stage. The new MOX or low-enriched uranium fuel can be used in reactors of the same basic type that was fueled with the non-reprocessed original uranium. Spent fuel reprocessed from fast breeder reactors must go through a unique fuel fabrication process to be used again in a fast breeder reactor.

Fuel reprocessing is not essential to commercial nuclear electricity generation, but is fundamental to producing plutonium for nuclear weapons. The high cost of reprocessing and its waste management problems, combined with the relative low cost of uranium, make it much cheaper to mine uranium than to make non-military reactor fuel from reprocessed uranium and plutonium.

fuel rod - A single tube of cladding filled with uranium, thorium, or MOX fuel pellets. Bundles of fuel rods called fuel assemblies or fuel elements are fuel because it is a neutron absorber, and because upon neutron capture it converts to uranium-237 (a short-lived gamma emitter that must be allowed to decay before the irradiated fuel can be reprocessed). As much as one-sixth of the uranium-235 consumed in a thermal power reactor fueled with low-enriched uranium may be converted to uranium-236. The half-life of uranium-236 is 23.9 million years and that of uranium-237 is 6.75 days.

uranium-238 - Also an indispensable isotope to the nuclear industry as it is one of the two fertile materials that can be used for production of fissionable material. It has a half-life of 4.468 billion years. Uranium-238 yields the primary fissionable material plutonium-239. Another important characteristic of uranium-238 is that it will fission under fast-neutron bombardment.

uranium concentrate (U3O8, yellowcake) - The marketable product from a uranium mill. It is a fine, sand-like material that is insoluble in water. The material, commonly referred to as "yellowcake", consists of between 70-90% uranium oxide (U3O8), the rest being uranium decay products and heavy metals. It is usually produced from uranium ore by putting the ore through a uranium mill using the following process: crushing, grinding, leaching with sulfuric acid or sodium carbonate-bicarbonate, separation by filtration, decantation or centrifugation, further separation by a solvent extraction or ion exchange process and finally precipitation by neutralization with ammonia, magnesia or caustic soda. After this process the resulting product is a solid usually canary yellow in color (but it may be dark brown or black) and ranging in consistency from granular to powder. A full 2,000 liter barrel weighs about 500 kg and contains about 200 millicuries of total radioactivity. Surface dose rate of such a barrel is about 1.5 mrem/hr and dose rate at one meter about 0.5 mrem/hr. Most yellowcake is sent to a uranium conversion plant for transformation to UF6, the feed for enrichment plants, or to UO2.

uranium conversion - The complex chemical process of purifying and converting new or recycled uranium to forms suitable for use as feed to uranium enrichment facilities, natural uranium fuel fabrication plants, or uranium metal processing plants. It is also called uranium refining, but since the chemical form of the feed is changed, or converted, the process is more accurately called conversion than refining.

The dominant activity of conversion plants is transformation of U3O8 or equivalent to UF6 for feed to enrichment plants. A conversion plant may transform depleted and highly enriched UF6 (produced at enrichment plants) to respectively depleted and highly enriched UF4.

Yellowcake is usually delivered to a conversion plant in 55 gallon drums. The yellowcake is dissolved in nitric acid and piped to tanks in which trace metals, sand, and other impurities are extracted. The solution is then piped to another set of tanks where it is heated to remove the nitric acid and to reconcentrate the uranium into orange colored beads of UO3. The UO3 may then be shipped to another facility or be further processed on site.

of an amount of a radionuclide by the normal process of elimination. It is influenced by health and diet. The main methods of elimination are via the urine, feces, exhalation and perspiration.

half-life, effective - The time required for a given amount of radioactivity in a living thing to decrease by half as a result of the combined action of radioactive decay and biological elimination. Effective half-life (T_{eff}) is defined as:

$$1/T_{eff} = 1/T_{biol} + 1/T_{rad}$$

where T_{biol} is equal to biological half-life and T_{rad} is equal to radioactive half-life. Effective half-life is of importance in determining the extent of tissue exposure from internal emitters.

half-life, physical or radioactive - The time it takes for half of any amount of a radioactive substance to undergo decay. The process of radioactive decay is independent of temperature, pressure, or chemical condition. Half-lives range from less than a millionth of a second to millions of years. It is a characteristic constant for each particular nuclide. An individual nuclide may decay before or after the half-life. The chemical resulting from the decay may be either radioactive or non-radioactive. Radiation is released every time a radioactive material changes to the next material in its decay series.

Radioactivity per unit weight is inversely proportional to the half-life. For example, a specified quantity of cesium-137 (half-life 30.04 years) is about 76,000 times more radioactive than the same quantity of cesium-135 (half-life 3 million years).

In traditional nuclear physics there is a rule of thumb that after ten half-lives a substance is considered to have decayed to a "safe" level. However, this rule does not consider the size of the original quantity of the radioactive nuclide, nor is there a universally accepted definition of "safe".

heavy water (deuterium oxide) - Water in which the hydrogen atoms are almost entirely replaced by heavy hydrogen (deuterium). Naturally occurring water, or "light water", contains virtually no heavy hydrogen.

hot cell - A room with heavily shielded walls where highly radioactive materials are handled by remote control. It may be used for small-scale separation of plutonium from spent fuel.

hot spot - A local geographic area where environmental contamination levels are higher than average for the surrounding area. Hot spots may be a tiny point containing only a few radioactive fragments or encompass many square kilometers, such as when an air mass or cloud containing a high concentration of radioactive dust becomes part of rain or snow. Areas of body tissue where a much higher than average concentration of radioactivity occurs are also referred to as hot spots.

I

sodium diuranate/ ammonium diuranate - An intermediate chemical compound in the production of UF_6 produced from UO_3 (which is made from yellowcake) then heated with hydrogen to produce UO_2.

somatic effects of radiation - Those experienced by the individual receiving the radiation; in contrast to genetic effects, which occur in offspring or future generations; and teratogenic effects, which occur in the embryo or fetus inside the mother's womb.

special nuclear material (SNM) - Plutonium, thorium, or uranium enriched in the isotope uranium-233 or uranium-235. In the U.S. a license is required to obtain and use such materials.

specific activity - The number of disintegrations over a given period of time (referred to as "activity") per unit mass of a pure radioisotope; or the activity of a radioisotope in a material per unit mass of that material. Specific activity is expressed in becquerels per gram (Bq/g) or curies per gram (Ci/g). For a list of specific activity of selected isotopes see the table "Properties Of Selected Isotopes". The formula to calculate specific activity can be expressed as:

$$\frac{4.1769 \times 10^{23}}{\text{half-life in seconds} \times \text{atomic weight}} = \text{Bq/g}$$

or

$$\frac{1.32355 \times 10^{16}}{\text{half-life in years} \times \text{atomic weight}} = \text{Bq/g}$$

strategic special nuclear material (SSNM) - Plutonium, uranium-233, or highly-enriched uranium (HEU).

T

tailings - The residue left over after a product is produced. See also "nuclear waste, uranium mill tailings".

teratogenic effects of radiation - Those experienced by the embryo or fetus inside the mother's womb; in contrast to genetic effects, which occur in children of the individual receiving the radiation or in later generations; and somatic effects, which occur in the individual receiving the radiation.

tonne - A unit of mass in the metric system equal to 1,000 kilograms or 2,205 pounds. An Imperial or American ton is 2,000 pounds or 909.1 kilograms.

milligram (mg) - A thousandth of a gram. One mg per liter (mg/l) is the same as one part per million (ppm).

mixed-oxide fuel (MOX) - Reactor fuel in which plutonium-239 is mixed with natural or depleted uranium. MOX fuel can be used in commercial light water reactors instead of low-enriched uranium fuel. In MOX fuel, the fissile nuclei are plutonium-239. See also "fuel fabrication" and "fuel reprocessing".

moderator - A material used in a reactor core to slow down fast neutrons released by fission. The neutrons must be slowed down in order to maintain a chain reaction. Moving at a slower speed, there is an increased probability that the neutrons will be absorbed in uranium-235 or plutonium-239 and cause further fission. The nuclei of moderators (e.g. light water, heavy water, or graphite) are predominantly of low atomic weight.

N

neutron - An uncharged particle and constituent of a nucleus that is ejected at high energy during atomic fission, and capable of being absorbed in another nucleus and bringing about further fission or radioactive behavior.

neutron, fast - Neutrons with an energy greater than 1.1 mega-electron-volts (Mev); capable of fissioning thorium-232 and uranium-238.

neutron, slow or thermal - Neutrons with an energy below 0.4 electron-volts; capable of fissioning uranium-235 and -233 and plutonium-239. Slow neutrons spend more time near a nucleus than fast neutrons, and thus have a greater chance of hitting a nucleus. The speed of slow neutrons is about 2,200 meters per second, much faster than a high-velocity bullet.

neutron capture - Neutron absorption.

nuclear bomb - A device in which energy is produced by nuclear fission, fusion, or both.

nuclear energy - The internal energy on an atom that is absorbed when it is formed from its constituent particles and released when it is broken down into its constituent particles. Energy contained in matter by virtue of its mass is given quantitatively by the relationship $E=mc^2$. Also called atomic energy.

nuclear power - A general term for all modes of release and use of nuclear energy on a large scale. Also referred to as atomic power. See also "nuclear energy".

nuclear power plant - A facility where the heat released during nuclear fission or fusion in a nuclear reactor is used to turn water to steam. The tunnels.

Less well known aspects of radon gas are its use as a means of measuring earthquake activity, and its influence on weather. Emissions of radon gas from natural cave systems are used to measure and predict earthquakes and earth tremors. When ground motion deep below the surface crushes rock, radon is released. Even the slightest tremor shows up as a burst of radon gas. The mouths of cave systems all over the planet are wired to "sniff" radon and warn of earthquake activity. An unexpected discovery during this research was that natural radon emissions occur all the time and play a role in the ionization of gas and water molecules in the air, creating lightning and effecting weather. The huge quantity of radon coming from uranium mine and mill wastes may have an effect on weather patterns.

raffinate - A liquid waste stream resulting from extraction of a liquid with a solvent.

relative biological effectiveness (RBE) factor - The ratio of the absorbed dose of a standard ionizing radiation that produces a particular biological effect to the absorbed dose of the radiation under consideration that produces the same effect under otherwise identical conditions.

rem (roentgen equivalent man) - The amount of ionizing radiation required to produce the same biological effect as one roentgen of x-rays. This old unit is replaced with the sievert (Sv) in the SI. One sievert is equal to 100 rem.

roentgen - The old unit of radiation exposure. It is named after W.C. Roentgen (1845-1923), the discoverer of x-rays. See also "rad".

Rutherford - An old unit of radioactivity defined as the quantity of radioactive material which undergoes one million disintegrations per second. One millicurie equals 37 rutherfords. The unit was named in 1946 after Lord Rutherford (1871-1937), the founder of nuclear physics.

S

separative work unit (SWU) - The unit usually used to state quantity of uranium enrichment services. An SWU is the measure of how much work must be done (in the thermodynamic sense) to enhance the concentration of the uranium-235 isotope in uranium. Generally, a large amount of UF6 enriched to a few percent requires the same quantity of separative work as a comparatively small amount of UF6 enriched to 90% or more.

sievert (Sv) - The SI unit for dose equivalent (in joules per kilogram), calculated by multiplying absorbed dose times a quality factor (which takes into account effectiveness in causing biological damage) for the particular type of radiation. One sievert equals 100 rem. In terms of the effect on humans, the sievert is a very large unit, thus the number is commonly

low-level waste - A catch-all kind of radioactive waste that is in a relatively diluted form, and does not fit into any other category. The term "low-level" is misleading because this type of waste often contains some of the same isotopes that are in high-level waste and spent fuel. Further, the total quantity of radioactivity may be quite large. They are produced in many ways, including research and medicine, though the bulk comes from nuclear power and weapons production. Included are slightly radioactive work clothes, gloves, containers, etc.

spent fuel - Nuclear reactor fuel once it has been exposed to a nuclear reaction; also called irradiated fuel. When not reprocessed, spent fuel is considered radioactive waste. In military programs, spent fuel is a highly valuable, strategic material that is reprocessed.

Spent fuel is intensely hot when the chain reaction in a reactor stops, and heat continues to be generated by the radioactive decay of fission products. Spent fuel contains the greatest concentration of radioactivity of any material on Earth. It must be isolated from living things for hundreds of thousands of years, forever. Low-level waste can be just as long lived but it has a lower concentration of radioactivity. Human contact with spent fuel rods means certain death.

When spent fuel rods are removed from a reactor they are so hot that they must be stored under constantly circulating water for a period of years, usually at the reactor site. The water must be specially treated with a neutron absorbing material such as boron to insure a chain reaction does not take place.

transuranic waste - Contains mostly transuranic elements or their compounds in sufficient concentrations, including plutonium. Most of these wastes are created in nuclear weapons production.

uranium mill tailings - The solid, fine sand that is left over after the milling process. Large volumes of tailings are produced in the uranium milling process over a short period of time. Hundreds of tonnes of waste are produced for every tonne of yellowcake.

Uranium tailings contain about 85% of the total radioactivity in the ore, including about 99% of the radium. In addition, the tailings contain almost 100% of the heavy metals in the ore.

There is usually at least twice as much liquid waste produced in the milling process as tailings. Liquid wastes have a greater impact on the surrounding environment than solid wastes as they can carry contamination great distances via streams, rivers and lakes.

nucleus - The center of an atom, which makes up almost the entire mass of the atom but only a minute part of its volume. The nucleus has a positive electric charge, and the electrons, which constitute the outer area of the atom, have a negative electrical charge. The positive and negative charge is usually equal, thus the normal stable atom is electrically neutral. The nucleus consists of protons and neutrons, together called nucleons. The plural is nuclei.

nukespeak - The language of the nuclear industry, both for nuclear particle accelerators, and mesons which are a component of cosmic rays. All forms of particle radiation have the ability to induce ionization, either directly or as a secondary effect.

radiation, ionizing - Radiation which can deliver energy in a form capable of knocking electrons off atoms, turning them into ions. On interaction with matter, high-intensity ionizing radiation creates excited states of atoms or molecules and thereby promotes chemical reactions which would otherwise occur very slowly or not at all.

Radioactive nuclides pose the greatest threat to human health when they are inhaled or ingested. However, radiation emitting fragments can be so small that they fasten in the many sweat pores and hair follicles all over the body. There are three main types of ionizing radiation, alpha, beta, and gamma. Alpha emitters are the most harmful to living cells if ingested or inhaled but the distance alpha particles can travel is only about a few centimeters in air and tens of microns in soft tissue. The distance beta particles can travel is up to about 80 cm in air and they can not go through thin steel or wood about one centimeter thick. The difference between alpha and beta particles is like a cannon-ball compared to a bullet. Alpha particles, like cannon-balls, have less penetrating power but more impact. For this reason the biological damage of alpha radiation is considered to be about 20 times that of the same absorbed dose of gamma or beta radiation.

Gamma rays are a type of electromagnetic radiation, not particle radiation as alpha and beta. Gamma radiation can be as harmful as beta radiation but can travel great distances. The majority of gamma radiation is stopped by a few centimeters of lead or about 30 centimeters of concrete.

When discussing the distance different forms of radiation are capable of travelling, it is important to distinguish between radioactive particles and radioactive emitters. Alpha and beta particles travel a very short distance due to radioactive decay. In contrast, minute dust fragments containing alpha, beta, and gamma emitters can be transported great distances by wind and water. Sometimes the false impression is given that locations only centimeters away from a radioactive source are isolated from exposure.

See also "alpha particle", "beta particle", and "gamma ray".

radiation, natural background - The total radiation from cosmic radiation and none man-made radioactive materials found on Earth. The latter category includes radon, uranium, potassium and other trace elements. Ground disturbing human activities such as uranium mining and milling increase "natural" background radiation by making uranium and its decay products more easily available to life forms via uptake in air, water, and food. Further, releases of man-made radiation from sources such as atomic bomb fallout and routine operation of nuclear reactors have changed natural background radiation levels.

radioactive equilibrium - When the amount of daughter radioactive products in a decay series remains constant. The loss due to decay of the used as a heat source in space satellites.

plutonium-239 - The most important plutonium isotope as it is one of the three primary fissionable materials (the other two being uranium-235 and uranium-233) and the most common one used in nuclear weapons. It is an alpha-emitter and has a half-life of 24,110 years. Plutonium-239 has the highest neutron yield of the three primary fissionable materials and hence is the best fissionable material for use in fast breeder reactors. It is formed by the following reaction and decay sequence: uranium-238 captures a neutron from fission (typically of uranium-235) and is changed to uranium-239 plus a gamma ray; uranium-239 has a half-life of 23.5 minutes and decays into neptunium-239 plus an electron; neptunium-239, with a half-life of 2.3 days, decays to plutonium-239 plus an electron.

plutonium-240 - The most significant plutonium isotope other than plutonium-239. It is non-fissionable, is an alpha-emitter, and has a half-life of 6,563 years. It is regarded as unsuitable for use in weapons and reactor fuel. Thus, in a reactor whose main purpose is plutonium production, the rate at which plutonium-240 is formed controls the length of time fuel is allowed to remain under irradiation.

Plutonium is categorized according to plutonium-240 content, as follows:

Category	% plutonium-240
super-grade	2-3
weapons-grade	less than 7
fuel-grade	7-19
reactor-grade	19 or greater

Super-grade plutonium is the purest form of plutonium, and is produced in the blanket surrounding the core of a breeder reactor and in military production reactors.

plutonium-241 - A fissionable alpha and beta-emitter with a half-life of 14.4 years.

proton - Positively charged particle and constituent of a nucleus.

PUREX - An acronym for the plutonium and uranium extraction method of reprocessing spent fuel. It is a series of chemical processes for extracting, separating, purifying and concentrating plutonium, uranium, and neptunium, from irradiated fuel. It uses nitric acid and tributyl-n-phosphate in a kerosene solvent. See also "fuel reprocessing".

Q

quality factor - The amount by which the absorbed dose of ionizing radiation is multiplied in order to determine the biological effects of the dose. Multiplication by the quality factor is necessary because the same dose of different types of ionizing radiation will result in different biological effects. The greater the quality factor the greater the ability of the radiation