ENVIRONMENTAL CONTAMINANTS ENCYCLOPEDIA

URANIUM ENTRY

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Like a library or many large databases (such as EPA's national STORET water quality database), this document contains information of variable quality from very diverse sources. In compiling this document, mistakes were found in peer reviewed journal articles, as well as in databases with relatively elaborate quality control mechanisms [366,649,940]. A few of these were caught and marked with a "[sic]" notation, but undoubtedly others slipped through. The [sic] notation was inserted by the editors to indicate information or spelling that seemed wrong or misleading, but which was nevertheless cited verbatim rather than arbitrarily changing what the author said.

Most likely additional transcription errors and typos have been added in some of our efforts. Furthermore, with such complex subject matter, it is not always easy to determine what is correct and what is incorrect, especially with the "experts" often disagreeing. It is not uncommon in scientific research for two different researchers to come up with different results which lead them to different conclusions. In compiling the Encyclopedia, the editors did not try to resolve such conflicts, but rather simply reported it all.

It should be kept in mind that data comparability is a major problem in environmental toxicology since laboratory and field methods are constantly changing and since there are so many different "standard methods" published by EPA, other federal agencies, state agencies, and various private groups. What some laboratory and field investigators actually do for standard operating practice is often a unique combination of various standard protocols and impromptu "improvements." In fact, the interagency task force on water methods concluded that [1014]:

> It is the exception rather than the rule that water-quality monitoring data from different programs or time periods can be compared on a scientifically sound basis, and that...
>
> No nationally accepted standard definitions exist for water quality parameters. The different organizations may collect data using identical or standard methods, but identify them by different names, or use the same names for data collected by different methods [1014].

Differences in field and laboratory methods are also major issues related to (the lack of) data comparability from media other than water: soil, sediments, tissues, and air.

In spite of numerous problems and complexities, knowledge is often power in decisions related to chemical contamination. It is therefore often helpful to be aware of a broad universe of conflicting results or conflicting expert opinions rather than having a portion of this information arbitrarily censored by someone else. Frequently one wants to know of the existence of information, even if one later decides not to use it for a particular application. Many would like to see a high percentage of the information available and decide for themselves what to throw out, partly because they don't want to seem uniformed or be caught by surprise by potentially important information. They are in a better position if they can say: "I knew about that data, assessed it based on the following quality assurance criteria, and decided not to use it for this application." This is especially true for users near the end of long decision processes, such as hazardous site cleanups, lengthy ecological risk assessments, or complex natural resource damage assessments.

For some categories, the editors found no information and inserted the phrase "no information found." This does not necessarily mean that no information exists; it simply means that during our efforts, the editors found none. For many topics, there is probably information "out there" that is not in the Encyclopedia. The more time that passes without encyclopedia updates (none are planned at the moment), the more true this statement will become. Still, the Encyclopedia is unique in that it contains broad ecotoxicology information from more sources than many other reference documents. No updates of this document are currently planned. However, it is hoped that most of the information in the encyclopedia will be useful for some time to come even without updates, just as one can still find information in the 1972 EPA Blue Book [12] that does not seem well summarized anywhere else.

Although the editors of this document have done their best in the limited time available to insure accuracy of quotes or summaries as being "what the original author said," the proposed interagency funding of a bigger project with more elaborate peer review and quality control steps never materialized.

> The bottom line: The editors hope users find this document useful, but don't expect or depend on perfection herein. Neither the U.S. Government nor the National Park Service make any claims that this document is free of mistakes.

The following is one chemical topic entry (one file among 118). Before utilizing this entry, the reader is strongly encouraged to read the README file (in this subdirectory) for an introduction, an explanation of how to use this document in general, an explanation of how to search for power key section headings, an explanation of the organization of each entry, an information quality discussion, a discussion of copyright issues, and a listing of other entries (other topics) covered.

See the separate file entitled REFERENC for the identity of numbered references in brackets.

HOW TO CITE THIS DOCUMENT: As mentioned above, for critical applications it is better to obtain and cite the original publication after first verifying various data quality assurance concerns. For more routine applications, this document may be cited as:

> **Irwin, R.J., M. VanMouwerik, L. Stevens, M.D. Seese**, and **W. Basham.** 1997. Environmental Contaminants Encyclopedia. National Park Service, Water Resources Division, Fort Collins, Colorado. Distributed within the Federal Government as an Electronic Document (Projected public availability

on the internet or NTIS: 1998).

Uranium (U, Uranium Metal, Uranium 238, Natural Uranium, CAS number 7440-61-1)

Brief Introduction:

Br.Class: General Introduction and Classification Information:

Natural uranium is a silver-colored metal that is radioactive. Small amounts of uranium are present in rocks, soil, water, plants, and animals and contribute to the weak background radiation from these sources. Soil commonly contains variable amounts, but the average is about 2 parts uranium per million parts of soil (2 ppm). This is equivalent to a tablespoon of uranium in a truckload of dirt. Fertilizers made from phosphate rocks contain higher amounts of uranium than natural soils. Some rocks and minerals in underground and open pit mines also contain uranium in a more concentrated form. After these rocks are mined, uranium is extracted and chemically converted into uranium dioxide or other usable forms [948].

Natural uranium is composed of three forms (called isotopes) of uranium: uranium-234, uranium-235, and uranium-238. The amount of uranium-238 in natural uranium is more than 99%. Uranium-235 is present at just 0.72% in natural uranium, but it is more radioactive per unit mass than uranium-238. Uranium-235 is used in nuclear bombs and nuclear reactors. An industrial process by which the percent of uranium-235 is concentrated is called enrichment, and the uranium obtained this way is called enriched uranium [948].

In natural uranium, the isotope U-234 is even less abundant, on a mass basis, than uranium-235; however, because of its relatively short half life, U-234 contributes a substantial fraction (about one half) of the total amount of radiation emitted in a gram of natural uranium. The radiological half-life of U-234 is 244,500 years; for U-235 it is 700 million years, and for U-238 it is 4.5 billion years (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997).

Units/Conversions: To reduce the probability of introducing errors, the units in this entry are reported as given by the original authors rather than being converted to standard units. Conversion Factors for Radiological Units:

For activity:

Ci = Curie = A unit of radioactivity, the amount of any nuclide that undergoes exactly 3.7E+10 radioactive disintegrations per second (dps) [492]. One curie (Ci), the old unit, equals 3.7E+10 becquerels (Bq), the new unit; 1 Bq = 1 dps [674].

Levels and criteria of various radioisotopes and gross alpha radiation are sometimes expressed in pCi/L = picoCuries per liter. The same is true for natural uranium, although data reviewers should be aware that uranium has some normal chemical toxicity in addition to its potential as a source of radiation (Roy Irwin, National Park Service, Personal Communication, 1996).

pCi/L = picoCuries per liter = 0.037 disintegrations per second [483]. A picoCurie is one trillionth of a curie. Therefore, one picoCurie per liter (pCi/L), equals 0.037 becquerels per liter (Bq/L).

Each type of radiological contaminant has a different conversion between ug/L and pCi/L; in the case of natural uranium (only) to convert the uranium concentration from ug/L to pCi/L, one multiplies the ug/L figure by 0.692. The 0.692 pCi/micro gram is a generic number for natural uranium, which has some small percentage of U-234 and U-235 mixed in with the U-238. If the percentages of U-234 or U-235 are much different than the generic standard, a slightly different conversion would be necessary (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997).

For exposure:

One roentgen (R), the old unit, equals 2.58E-4 Coulomb/kg (C/kg), the new unit [674].

For absorbed dose:

One Rad (100 erg/g), the old unit, equals 0.01 Gray (Gy), the new unit [674]. Gray = 1 J/kg [674].

For dose equivalent:

One rem (same as damage effects of 1 roentgen), the old unit, equals 0.01 Sievert (Sv), the new unit [674]. Sievert = 1 J/kg [674].

Comment: A Sievert = 1 J/kg multiplied by a series of modifying and weighting factors that account for the biological effectiveness of different radiation types (alpha particles and neutrons versus beta particles, x-rays, and gamma-rays) and, for the effective dose to the whole body, the relative radiosensitivity of different tissues (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997).

Br.Haz: General Hazard/Toxicity Summary:

Summary of Potential Hazards to Fish, Wildlife, Invertebrates, Plants, and other non-human biota:

Uranium, as a chemical (rather than a radiological) substance tends to be highly toxic (soluble uranyl ions) on an acute basis [669]. Thus, the concerns about uranium include not only radiation, Uranium is also chemically toxic to the same degree as, for example, arsenic (Kirk-Othmer Encyclopedia of Chemical Technology. 3rd ed., Volumes 1-26. New York, NY: John Wiley and Sons, 1978-1984.,p. 23(83) 542) [940]. Uranium's toxic hazard resides not in its radiation effects but in its chemical effects on the renal tubules (Hamilton, A., and H. L. Hardy. Industrial Toxicology. 3rd ed. Acton, Mass.: Publishing Sciences Group, Inc., 1974. 397) [940].

Downstream of uranium mine tailings, the ecological concerns for natural uranium are minimal; they should predominantly relate to chemical toxicity and additional toxicity and acidification associated with co-contaminants in mill and mine tailings (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997)

Ecological concerns associated with radiation exposure of biota to natural uranium are minimal. Instead, environmental concerns about radiation exposure are primarily associated with an increased chance of cancer induction in humans due to inhalation of uranium in dusts and ingestion of soluble forms of uranium in water and food. Exposures to very high background sources of radiation have not been demonstrated to affect the overall abundance and distribution of organisms in nature (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997).

Concern levels for aquatic biota related to radiation and radionuclides have not been well defined. Until they are, it has been suggested that one Rad per day be the basic benchmark, regardless of the radioactive source. For radionuclides in the environment, standards for protection of human health have generally been assumed to protect other species, a thought which often seems to be true but may also need additional confirmation in certain situations [674]. It is most true in risk assessment if you assume that humans are consuming the fish whether they are or not (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997). The view that if one protects man (through limits on the amount of radioactivity in fish that man eats for example) has been criticized as an over simplification by some [563].

No (other) radiological criteria now exist for the protection of fish, wildlife or sensitive natural resources [674].

Mosquito fish exposed to 1,150 rad/year at the sediment/water interface successfully survived for 50 generations (18 years), apparently adapting to high radiation levels in a radioactive waste pond through an increase in genetic diversity (B.G. Blaylock, SENES Oak Ridge, Personal Communication, 1997, based on his manuscript "Biological Effects of Ionizing Radiation," International Symposium on Ionizing Radiation. Stockholm Sweden, May 20-24, 1996. The Swedish Radiation Protection Institute, In Press as of February, 1997).

One reason that higher animals and man seem to be more impacted by radiation than are simpler life forms:

> Direct radiation damage and indirect free radical damage (free radicals are produced by radiation in the water in an organism's body) to the longer, information-packed chromosomes are especially damaging to higher organisms; in damaging big chromosomes, much critical information is lost (Ward Whicker, Colorado State University, Personal Communication, 1996).

Symptoms of chronic toxicity & results of chronic toxicity studies become confused with radiation toxicity of uranium (Venugopal, B. and T.D. Luckey. Metal Toxicity in Mammals, 2. New York: Plenum Press, 1978. 164) [940].

In studies of subsurface agricultural irrigation drainage waters of the San Joaquin Valley of

California, uranium was determined to be a "substance of concern, additional data needed" [445].

Colorado has a water quality standard for aquatic life based on toxicity rather than just radioactivity [659]. The uranyl ion is the soluble uranium compound which is rapidly absorbed from the gastrointestinal (GI) tract [494].

Overview notes related to Uranium (Gerald Eddlemon, Oak Ridge National Lab, Personal Communication 1997):

> "By far, most of the radiation dose incurred by aquatic organisms as a result of natural uranium isotopes (and certain of their daughters such as Po-210) in aquatic habitat is acquired internally due to bioaccumulation of the isotopes in the organisms and to the inability of alpha particles from isotopes in the water outside the organism to penetrate the integument or cell wall. Note: These uranium and daughter isotopes are for the most part alpha emitters.
>
> Some of the uranium daughters (such as Po 210) can have bioconcentration potential much higher than uranium, depending on the type of organism; this in turn can result in a much greater internal dose absorbed by an organism than from an equivalent aqueous concentration of the parent uranium 238. Published bioconcentration factors vary widely, e.g., reported U BCFs range from 10 to 1000, while Po BCFs range from 50 to 20,000, again depending in part on the type of organism). Thus, for the same radionuclide concentration in water, the internal dose absorbed by an organism from Po-210 will likely be greater than the internal dose absorbed from uranium.
>
> Managers are often not so concerned about radiological effects in fish unless population effects are seen. Such effects are usually not seen in fish and other aquatic biota below the consensus benchmark of less than one rad per day. However, if people were getting one rad per day, we would all be quite concerned, since for people we are concerned with individual effects and not just population effects [Information Source: National Research Council of Canada, 1983. Radioactivity in the Canadian Aquatic Environment, Report Number

> NRCC No. 19250 of the Environmental Secretariat, available from Publications NRCC / CNRC Ottawa, CA K1A OR6, original quotes from Thompson, SE., et. al, 1972, Concentration Factors of Chemical Elements in edible aquatic organisms. Lawrence Livermore Lab, University of California, Report Number UCRL-50564]."

To date, no extinction of any animal population has been linked to high background levels of radioactivity [674].

In amphibians, radiation causes sterility, chromosomal aberrations, and many other problems [674].

Radiation hazards to fish, wildlife and invertebrates were summarized by Eisler in 1994 [674]; not all of the highlights from the Eisler summary have yet been summarized herein:

For additional information on the effects of radiation on plants and animals, see: IAEA (International Atomic Energy Agency). 1992. Effects of Ionizing Radiation on Plants and Animals at Levels Implied by Current Radiation Protection Standards. IAEA Technical Report Series 332. Vienna, Austria. This report is recommended by radiation risk expert Owen Hoffman, but due to a lack of time none of the information therein was included in this Uranium entry. (NOTE: Participants in a 1995 Dept. of Energy workshop reviewing the validity of the data in this report agreed with the IAEA that dose limits designed to protect humans generally protect biota as well, except when: 1) human access is restricted without restricting access by biota; 2) unique exposure pathways exist; 3) rare or endangered species are present; or 4) other stresses are significant. The participants also agreed that to deal with these exceptions, site-specific exposures should be considered in developing secondary standards.)

Potential Hazards to humans:

EPA and NRC have allegedly had some public disagreements on how to regulate radiation hazards to humans (see Soil.Human section below for details).

Miners who work underground in uranium mines had excessive incidence of diseases of the respiratory system including lung cancer [940]. Lung cancer has been a rare disease among the Indians of the southwestern USA. The advent of uranium mining in the area had been associated with an increased incidence of lung cancer among Navaho uranium miners [940].

A comprehensive toxicological profile for uranium, especially as they relate to human health, is available from ATSDR [948]. Due to lack of time, not all the highlights from this ATSDR document have been completely incorporated into this entry.

To date, human epidemiological studies have been unsuccessful in demonstrating a dose/response relationship for human populations exposed to high levels of naturally occurring radionuclides, with the exception of the relationship between lung cancer and the exposure of uranium miners to radon and it's decay products (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997).

Uranium is an industrial health hazard both chemically & radiologically; the chief hazard in mining is from radiation, the emission of alpha particles from uranium, radon gas, & its particulate daughters, RaA, & RaC. The chemical toxicity of uranium is mainly owing to contaminants such as lead, thorium, & vanadium (Venugopal, B. and T.D. Luckey. Metal Toxicity in Mammals, 2. New York: Plenum Press, 1978. 162) [940].

> Note: Epidemiological studies on residential exposures of humans to radon have produced mixed results, mostly due to low statistical power brought about by the limited number of individuals in the study, the high incidence of lung cancer in the general population, the inability to properly account for the uncertainty in individual radon exposures, and the confounding effect of cigarette smoking (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997).

The isotope most dangerous from the point of view of radiation, (235)uranium, comprises less than 1% of natural uranium, but is enriched during the production of nuclear fuels. Higher fractions of (235) uranium increase the irradiation risk (Friberg, L., Nordberg, G.F., Kessler, E. and Vouk, V.B., eds,. Handbook of the Toxicology of Metals. 2nd ed. Vols I, II.: Amsterdam: Elsevier Science Publishers B.V., 1986.,p. V2 632) [940].

For the purposes of radiation protection, it is currently assumed by most regulatory bodies, that any exposure to any radioactive source, including exposure to naturally occurring radioactive materials, will have some finite probability of increasing the lifetime risk of cancer in humans. For this reason, federal, state and international radiation dose limits for humans are based on the concept of keeping risks to any individual in the exposed population as low as is reasonably achievable [see National Council on Radiation Protection and Measurements. 1993. Limitation of Exposure to Ionizing Radiation, NCRP Report No. 116; Bethesda, Maryland] (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997).

Target organs in humans include: Respiratory system, blood, liver, lymphatics, kidneys, skin, bone marrow (NIOSH. Pocket Guide to Chemical Hazards. 2nd Printing. DHHS (NIOSH) Publ. No. 85-114. Washington, D.C.: U.S. Dept. of Health and Human Services, NIOSH/Supt.of Documents, GPO, February 1987. 235) [940].

Comparison of risks and benchmarks used for humans to those used for other living things.

Regulations designed for the protection of human health are associated with radiological dose rates markedly lower than those proposed as benchmarks for terrestrial and aquatic biota. The regulatory range of effective doses to the whole body for the protection of human health against the effects of ionizing radiation are 40 micro Sv to 1 milli Sv per year. This range would translate to an absorbed dose rate for uranium of 0.0055 micro Gy per day (0.55 micro rad per day) to 0.14 micro Gy per day (14 micro rad per day). The differences between the estimates of effective dose in Sv and the absorbed dose Gy is due to the large relative biological effectiveness of the high linear energy transfer associated with the alpha radiation emitted during the decay of natural uranium. RBE = 20 (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997).

This apparent large discrepancy is explained as follows: standards for humans are developed to protect for the quality of life of an individual, whereas benchmark values suggested for protection of other organisms [i.e., 0.1 and 1 cGy per day (0.1 and 1 rad per day) are intended to protect the viability of the population, not the individual. The possible impact on the longevity of a single or even a few individuals in an exposed population of biota is usually not considered ecologically significant Suggested ecological radiation benchmark values are not applicable to rare and endangered species, in which the survival of the population may indeed depend on the survival of a single organism (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997). For more detailed explanations, see:

IAEA (International Atomic Energy Agency). 1992. Effects of Ionizing Radiation on Plants and Animals at Levels Implied by Current Radiation Protection Standards. IAEA Technical Report Series 332. Vienna, Austria.

Barnthouse, L.W. 1995. Effects of ionizing radiation on terrestrial plants and animals, a workshop report. Oakridge National Lab Environmental Sciences Division Publication 4494. ORNL/TL-13141, 22 pages.

Blaylock, B.G. and Trabalka, J.R. 1978. "Evaluating the effects of ionizing radiation on aquatic organisms." 7:103-152. In: J.T. Lett and H. Alder (eds.), Advances in Radiation Biology. Academic Press, New York.

IAEA (International Atomic Energy Agency). 1976 Effects of Ionizing Radiation on Aquatic Organisms and Ecosystems. IAEA Technical Report Series 172. Vienna, Austria.

NCRP (National Council on Radiation Protection and Measurements. 1991. Effects of Ionizing Radiation on Aquatic Organisms. NCRP Report No. 109; National Council on Radiation Protection and Measurements, Bethesda, Maryland.]

Br.Car: Brief Summary of Carcinogenicity/Cancer Information:

Among humans, there is always a concern about getting cancer from any radioactive material. Natural uranium has very low levels of radioactivity. Nevertheless, it is possible that cancer could be induced from swallowing or breathing large amounts of natural uranium because the greater the exposure to a radioactive material, the greater the chance of developing cancer. This is particularly true for enriched uranium that has been made more radioactive. Cancer may develop many years after swallowing or breathing a radioactive material. Just being near natural uranium is of very little danger to health because most of the (alpha) radiation given off by uranium cannot go through human skin [948].

Further details:

> Contact of the skin with uranium is not usually very harmful, since the alpha radiation emitted from natural uranium cannot penetrate the skin. The highest exposures and doses usually come from dust inhalation. The other main route of concern for human exposure is ingestion of soluble forms of uranium. In humans, the prevailing assumption is that below 0.2 Gy (20 rad) the probability (risk) that radiation exposure causes cancer is linear with dose and that there is no threshold dose below which the risk of induction of cancer is zero. Based on this assumption, the health risks associated with current radiation protection standards for members of the public vary from a chance of an excess cancer of about a few in 10,000 (above that expected in an unexposed population) during a human lifetime to about a one in a thousand chance of cancer. These risk estimates are associated with effective whole body doses ranging from the EPA dose limits for drinking water of 40 micro Sv per year (4 mrem per year) to the primary international radiation protection standard of 1 milli Sv per year, same as 100 mrem per year (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997).

Exposure to insoluble uranium compounds has been reported to cause an increase in cancer of the lymphatic & blood forming tissues in man [940]. Radiation hazard from inhalation of fine particles of approx 1 u. insoluble particles in lung may be long-term carcinogenic hazard [940].

Some uranium miners have developed lung cancer. This cancer is not from the uranium itself, but from the high levels of radioactive radon gas, which is formed when uranium decays [948].

EPA 1996 IRIS Carcinogenicity Assessment: Withdrawn 07/01/93 [893] for natural uranium, empty of uranium soluble salts.

It is interesting to note that this compound (Uranium, CAS 7440611) has not (sic) been treated as a carcinogen for model calculation purposes in some EPA risk-based (RBC and PRG) models [868,903]. However, this tentative distinction was made for the purpose of choosing a modeling scenario based on current (often inadequate) knowledge rather than for the purpose of strongly stating that this compound is definitely not a carcinogen; the non-carcinogenic benchmarks are sometimes nearly as low as the carcinogenic benchmarks (Stan Smucker, Personal Communication, EPA, 1996).

However, EPA officially recognizes that uranium is carcinogenic: the drinking water Maximum Contaminant Level Goal is 0 pCi/L; The proposed MCLG for both natural uranium (CAS number 7440-61-1) and for Uranium, soluble salts (no CAS number) is zero based on evidence of carcinogenic potential (Group A) [893].

Sarcomas resulted in rats injected with metallic uranium in the femoral marrow & in the chest wall; it is unknown whether the sarcomas were due to metallocarcinogenic or radiocarcinogenic action (Clayton, G. D. and F. E. Clayton, eds.,. Patty's Industrial Hygiene and Toxicology: Volume 2A, 2B, 2C: Toxicology. 3rd ed. New York: John Wiley Sons, 1981-1982. 2003) [940].

Injections of natural uranium in concentrations as high as 1 mg/kg induced no malignant bone tumors, whereas (233)uranium doses of 1 mg/kg proved to be a maximally effective bone carcinogen, comparable to (232)uranium at 5X10-4 mg/kg [940].

Br.Dev: Brief Summary of Developmental, Reproductive, Endocrine, and Genotoxicity Information:

No evidence was found to indicate that uranium crosses the placental barrier in humans but, since it does cross the placental barrier in animals, it is probable that exposure to high levels of uranium may cause human birth defects. It is not known whether environmental levels of uranium will cause developmental effects in humans [948].

The reproductive effects of uranium in humans are unknown [948]. The majority of animal studies show no histological damage to the gonads, but testicular damage in rats has been associated with large amounts of uranyl nitrate in the diet. The relevance of these data to humans is unknown, but it is likely that uranium exposure could have adverse effects on reproduction in humans [948].

One sensitive indicator of irradiation is the frequency of chromosomal aberrations in human lymphocytes. Uranium miners have shown such effects, but they are thought to be due to radon or its decay products. Other genotoxic effects of uranium have not been tested sufficiently in humans or animals, and it is difficult to predict the effects of uranium [948].

Br.Fate: Brief Summary of Key Bioconcentration, Fate, Transport, Persistence, Pathway, and Chemical/Physical Information:

Uranium-238 is not stable but breaks down into two parts. This process of breaking down is called decay. The decay of uranium-238 produces a small part called "alpha" radiation and a large part called the decay product. The break down of uranium-238 to its decay products happens very slowly [948]. In fact, it takes about 4.5 billion years for one-half of the uranium-238 to break down (4.5 billion years is the half-life of uranium-238; the age of the earth is estimated to be 3.6 billion years) [751]. Thorium, the decay product of uranium, is also not stable, and it continues to decay until stable lead is formed. During the decay processes, the parent uranium-238, its decay products, and their subsequent decay products release a series of new elements and radiation, including such elements as radium and radon, alpha and beta particles, and gamma radiation. Alpha particles cannot pass through human skin, whereas, gamma radiation passes through more easily [948].

Because of the slow rate of decay, the total amount of natural uranium in the earth stays almost the same, but it can be moved from place to place through natural processes or by human activities. When rocks are broken up by water or wind, uranium becomes a part of the soil. When it rains, the soil containing uranium can go into rivers and lakes. Mining, milling, manufacturing and other human activities also move uranium around natural environments [948].

Uranium has a complex radioactive decay scheme resulting in the emission of different radiations and the production of several radioactive daughter products (National Research Council. Drinking Water & Health. Volume 5. Washington, D.C.: National Academy Press, 1983. 90) [940].

Aquatic fate: Uranium, thorium, radium, radon, lead, and polonium radionuclide concentrations in ground waters from the Hanford Site indicate that uranium, thorium, and radium are highly sorbed [940]. In general, the levels of uranium in groundwater are higher than in surface waters [948].

For more information on the fate of radionuclides in various environmental compartments (like soil, sediment, foods and biota such as plants, fish, animals, etc.) see: IAEA (International Atomic Energy Agency). 1994. Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments. IAEA Technical Report Series 364. Vienna, Austria. This report is recommended by radiation risk expert Owen Hoffman, but due to a lack of time none of the information therein was included in this Uranium entry.

See also: Br.Haz section above and Bio.Detail section below for more detailed information on bioconcentration.

Synonyms/Substance Identification:

URANIUM I (238U) [940]
Uranium metal [617]

Molecular Formula [940]: U

Associated Chemicals or Topics (Includes Transformation Products):

Associated chemicals:

Lead (214, 210). Note: Lead 210 has a long half life, 22 years.

(234) Uranium = Uranium-234 [940]
(235) Uranium [940]
Radon gas (including RaA and RaC) [940]
Radium 226
Thorium [940]. Includes Thorium 234 and 235.
Polonium isotopes 208, 209, 210, 214, 218

As a daughter of U-238, Po-210 can be expected to occur in uranium mill tailings and their leachates still to be found in the western U.S. (Gerald K. Eddlemon, Oak Ridge National Labs, Personal Communication, 1997).

In fact, all of the above radionuclides should be present in tailings leachate; lead is often analyzed since it is a breakdown products of some of these contaminants (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997).

Relationships between this metal versus indicator plants, other metals, and various rock types was summarized by Brooks in 1972 [951].

Uranium deposits in the Colorado plateau contain appreciable quantities of selenium [951]. The yellow cat area of grand county, Utah tends to have a lot of vanadium, sulfur, selenium, arsenic, and molybdenum concentrated in uranium ores [951]. Certain plants, including some selenium tolerant plants of genus Astragalus are used as uranium indicators

[951]. Sometimes uranium turns flowers bluish [951], and bryophytes (such as mosses and liverworts) and ferns tend to be better at uptake of uranium than higher plants [951]. Certain contaminants, such as selenium, thorium 230, and vanadium, tend to leach out of uranium mining tailing piles in the U.S.; thorium is quite dangerous and is often leached out of acid process uranium piles (Ward Whicker, Colorado State University, Personal Communication, 1996).

Uranium Processing: Site Assessment-Related Information Provided by Shineldecker (Potential Site-Specific Contaminants that May be Associated with a Property Based on Current or Historical Use of the Property) [490]:

Raw Materials, Intermediate Products, Final Products, and Waste Products Generated During Manufacture and Use:

- Fluorine
- Sulfuric acid

Water Data Interpretation, Concentrations and Toxicity (All Water Data Subsections Start with "W."):

Note: See Br.Class section at beginning of this entry for conversion factors for radiological and other units.

W.Low (Water Concentrations Considered Low):

No information found.

W.High (Water Concentrations Considered High):

The concentration of uranium in mine discharge water in New Mexico was 31,500 ug/L (22,680 pCi/L or 839 Bq/L, assuming natural uranium) [948].

In uranium ore areas, concentrations higher than 1.0 mg/l have been recorded [190].

One constituent analyzed in urban ground water of Denver, Colorado that might be related to human activities is uranium, a trace element that also occurs naturally. Uranium had elevated levels in the alluvial ground water of the Denver metropolitan area. The average uranium concentration for this study was 24 micrograms per liter, which is slightly higher than the proposed USEPA drinking-water maximum concentration level of 20 micrograms per liter. Uranium concentrations in ground water in the study area ranged from less than 1 to 80 micrograms per liter [690].

Uranium-234: Max. 0.093 Bq/L FW (sampled in 1977) vs. max 2.19 Bq/L FW (sampled in 1981) [674].

Uranium-235: Max. 0.0026 Bq/L FW (sampled in 1977) vs. max 0.027 Bq/L FW (sampled in 1981) [674].

Uranium-238: Max. 0.067 Bq/L FW (sampled in 1977) vs. max 0.562 Bq/L FW (sampled in 1981) [674].

Drinking water, United States, nationwide, 1988:

Uranium-234: Max. 0.090 Bq/L FW [674].

Uranium-235: Max. 0.007 Bq/L FW [674].

Uranium-238: Max. 0.183 Bq/L FW [674].

In Beaverlodge Lake, near a uranium mine near Saskatchewan, Canada, a study was done to assess the chronic effects of low-level uranium-series radionuclides on wild fish. Radionuclide levels in water, fish, and sediments were highly elevated [972]. Uranium concentrations in water (Total uranium = 180-390 ug/L) were 3 - 115 times higher than control levels [972]. For more information, see Tis.Fish section below.

W.Typical (Water Concentrations Considered Typical):

In a survey of about 35,000 surface waters and 55,000 groundwaters, the mean concentrations of uranium were 1.1 and 3.2 pCi/L (0.04 and 0.12 Bq/L), respectively [948]. These concentrations correspond roughly to 1.6 and 4.6 ug/L.

Freshwater Concentrations not Considered Elevated: USGS 1985: Levels between 0.1 and 10 ug/L can be commonly expected in river water [190].

A study of over 28,000 domestic water supplies by Oak Ridge National Laboratory indicated that the range of uranium concentrations was 0.07-653 pCi/L (0.003-24 Bq/L). The mean uranium concentration in these waters was 1.73 pCi/L (0.064 Bq/L) and the median concentration range was 0.1-0.2 pCi/L (0.004-0.007 Bq/L) [948]. Most drinking water supplies have concentrations of less than 1 pC/L [948].

The population-weighted average uranium concentrations from all 50 states in groundwaters that are sources of drinking water ranged from 0.05-4.6 pCi/L (0.02-0.17 Bq/L), with a mean value of 0.55 pCi/L (0.02 Bq/L) [948].

Uranium concentration in milk and tea and other human beverages were mostly below 6 ppb [948].

Precipitation, United States, nationwide:

Uranium-234: Max. 0.004 Bq/L fresh weight (1978) [674].

Uranium-235: Max. 0.0001 Bq/L fresh weight (1978) [674].

Uranium-238: Max. 0.003 Bq/L fresh weight (1978) [674].

Uranium-234: Max. 0.013 Bq/L fresh weight (1987) vs. max. 0.002 Bq/L fresh weight (1988) [674].

Uranium-235: Max. 0.0004 Bq/L fresh weight (1987) vs. max. 0.0003 Bq/L fresh weight (1988) [674].

Uranium-238: Max. 0.0026 Bq/L fresh weight (1987) vs. max. 0.002 Bq/L fresh weight (1988) [674].

Seawater (Natural radionuclides in surface seawater, typical concentrations):

Uranium-234: 0.048 Bq/L FW [674].

Uranium-235: <0.002 Bq/L FW [674].

Uranium-238: 0.044 Bq/L FW [674].

Information on uranium in water from ATSDR (see ATSDR for embedded references) [948].

In a survey of about 35,000 surface waters and 55,000 groundwaters, the mean concentrations of uranium were 1.1 and 3.2 pCi/L (0.04 and 0.12 Bq/L), respectively (NCRP 1984). In some surface waters contaminated by waste discharge and groundwaters from natural uranium-bearing aquifers, the concentrations of uranium may be considerably higher. Discharge of dewatering effluents from underground uranium mines and runoff from uranium mine tailings piles have contaminated surface waters and aquifers in New Mexico with elevated levels of gross alpha activity and uranium (NMHED 1989). The concentration of uranium in mine discharge water in New Mexico was 31,500 ug/L (22,680 pCi/L or 839 Bq/L, assuming natural uranium) (EPA 1985b). In the United States, the maximum concentrations of uranium in surface water and groundwater used for the abstraction of drinking water may be as high as 582 and 653 pCi/L (21.5 and 24.2 Bq/L), respectively (EPA 1985b). The concentration of uranium in creek waters that lead to the Ohio River near Paducah Gaseous Diffusion Plant in Kentucky, ranged from less than 1-700 ug/L (UCC 1980). Mono Lake, a natural alkaline and saline lake in California, contained 185 pCi/L (6.8 Bq/L) of uranium-238 and 222 pCi/L (8.2 Bq/L) of uranium-234 during 1978-1980 (Simpson et al. 1982). Analysis of the Colorado River and its tributaries in 1985-1986 indicated levels of total uranium (uranium-234 + uranium-235 + uranium-238) in the range of 3.4-60 pCi/L (0.13-2.22 Bq/L) (Stewert et al. 1988) [948].

The combined dissolved concentrations of uranium-234 and uranium-238 in groundwater from Cambrian-Ordovician sandstone aquifers in Illinois ranged from less than 0.1-8.0 pCi/L (0.005-0.3 Bq/L). The uranium-234 to uranium-238 activity ratio ranged from 2.0 to greater than 40. The lowest ratios were found in unconfined aquifers in primary recharge zones and ratios greater than 20 were found in confined zones of the aquifer. It was suggested that glacial recharge in unconfined zones might be responsible for the high uranium-234 to uranium-238 ratios (Gilkeson and Cowart 1987). Fifty-five groundwaters from the Lockatong and Passaic Formation in the Newark Basin, New Jersey, analyzed during 1985-1987, contained 0.1-40 pCi/L (0.004-1.5 Bq/L) uranium, with a median value of 2.1 pCi/L (0.078 Bq/L). Four of the 55 waters exceeded EPA's maximum contaminant level (Szabo and Zepecza 1987). The concentrations of uranium in seven samples of groundwater from the Raymond Basin in California were 5.3-43.7 pCi/L (0.20-1.62 Bq/L) (Wiegand et al. 1987). The population-weighted average (sum of [concentration in water supply x population consuming that water]/total exposed population) uranium concentrations from all 50 states in groundwaters that are sources of drinking water ranged from 0.05-4.6 pCi/L (0.02-0.17 Bq/L), with a mean value of 0.55 pCi/L (0.02 Bq/L). The highest population-weighted average uranium concentrations occurred between the states of Montana and Texas, and California and Kansas (Longtin 1988). This mean is lower than the population-weighted value for finished waters of 0.8 pCi/L (0.03 Bq/L) (NCRP 1984). Water from a private well in Maine was reported to contain as much as 403 ug/L (about 260 pCi/L or 9.6 Bq/L) of uranium, probably of geological origin (Lowry et al. 1987). Elevated levels of uranium (up to 110 pCi/L) in waters of private wells located in northern and northeastern Nebraska are thought to be due to upward migration of uranium from bedrock and heavy use of phosphate fertilizers (NEDH 1989) [948].

The concentrations of uranium in selected drinking water supplies in the United States were analyzed by EPA and a concentration as high as 113 pCi/L (4.2 Bq/L) was detected in a water from Lathrop, CA, but the concentrations usually were less than 1 pCi/L (0.04 Bq/L) (EPA 1985b). A study of over 28,000 domestic water supplies by Oak Ridge National Laboratory indicated that the range of uranium concentrations was 0.07-653 pCi/L (0.003-24 Bq/L). The mean uranium concentration in these waters was 1.73 pCi/L (0.064 Bq/L) and the median concentration range was 0.1-0.2 pCi/L (0.004-0.007 Bq/L). States in which average uranium concentrations in drinking water exceeded 2 pCi/L (0.07 Bq/L) were South Dakota, Nevada, New Mexico, California, Wyoming, Texas, Arizona, and Oklahoma. States in which average uranium concentrations exceeded 1 pCi/L (0.04 Bq/L) are shown in Figure 5-3. Of a total of 28,239 surface and groundwater supplies that were used to abstract drinking water in the United States, the level of uranium in 2228 water supplies was 10 pCi/L or more (0.37 Bq/L or more), and in 979 water supplies, the concentrations were 20 pCi/L or more (0.74 Bq/L or more). Most of these water supplies were in small towns and served less than a few thousand persons (Cothern and Lappenbusch 1983; EPA 1985b). The average population-weighted uranium concentrations in United States community water supplies range from 0.3-2.0 pCi/L (0.01-0.07 Bq/L) (Cothern 1987).

W.Concern Levels, Water Quality Criteria, LC50 Values, Water Quality Standards, Screening Levels, Dose/Response Data, and Other Water Benchmarks:

W.General (General Water Quality Standards, Criteria, and Benchmarks Related to Protection of Aquatic Biota in General; Includes Water Concentrations Versus Mixed or General Aquatic Biota):

Oak Ridge National Lab, 1994: Ecological Risk Assessment Freshwater Screening Benchmarks for concentrations of contaminants in water [649]. To be considered unlikely to represent an ecological risk, field concentrations should be below all of the following benchmarks [649]:

For Uranium, CAS 7440-61-1, the benchmarks in ug/L are:

NATIONAL AMBIENT WATER QUALITY CRITERION - ACUTE: No information found.

NATIONAL AMBIENT WATER QUALITY CRITERION - CHRONIC: No information found.

SECONDARY ACUTE VALUE: 33.5

SECONDARY CHRONIC VALUE: 1.87

ESTIMATED LOWEST CHRONIC VALUE - FISH: 142

LOWEST CHRONIC VALUE - DAPHNIDS: No information found.

LOWEST CHRONIC VALUE - NON-DAPHNID INVERTEBRATES: No information found.

LOWEST CHRONIC VALUE - AQUATIC PLANTS: No information found.

ESTIMATED LOWEST TEST EC20 - FISH: 455

LOWEST TEST EC20 - DAPHNIDS: No information found.

SENSITIVE SPECIES TEST EC20: No information found.

POPULATION EC2O: 27

Because of the screening nature of benchmark values, concentrations below these benchmark values indicate with high probability that significant ecological effects should not occur. However, concentrations above these benchmark values will not necessarily be associated with ecological impacts either. The literature documenting the ecological effects of different concentrations of contaminants is still poorly developed and research is ongoing to improve the usefulness of the suggested benchmark values produced initially at Oak Ridge National Laboratory (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997).

Among aquatic organisms, the developing eggs and young of freshwater fish are among the most sensitive tested organisms; death was observed at acute doses of 0.3 to 0.6 Gy and adverse physiological and metabolism effects were associated with daily exposure rates of 0.01 Gy [674].

At least one state, Colorado, has water quality standards for uranium based on chemical toxicity (rather than radioactive) concerns [659]:

Colorado specified a hardness dependent equation as the acute aquatic life water quality standard for uranium in 1991; at a hardness of 100 mg/L, the standard is 2.4 mg/L [659].

> NOTE: The above is a hardness-dependent criteria (100 mg/L CaCO3 was used to calculate the above concentration). For sites with different water hardness, site-specific criteria should be calculated with the following formula:
>
> Acute = e(1.1021[ln(hardness)]+2.7088) where "e" = exponential [659]. Further clarification:
>
>> e is the base of natural logarithms and numerically equals 2.72 (rounded), and In(hardness) equals the natural logarithm of the measured hardness (Gary Rosenlieb, National Park Service, Personal Communication, 1997).
>>
>> For many metals, alkalinity is sometimes a more important co-factor for toxicity than hardness (Pat Davies, Colorado Division of Wildlife, personal communication, 1997).

Colorado specified a hardness dependent equation as the chronic aquatic life water quality standard for uranium in 1991; at a hardness of 100 mg/L, the standard is 1.5 mg/L [659].

> NOTE: The above is a hardness-dependent criteria (100 mg/L CaCO3 was used to calculate the above concentration). For sites with different water hardness, site-specific criteria should be calculated with the following formula:
>
>> Chronic = e(1.1021[ln(hardness)]+2.2382) where "e" = exponential [659]. Further clarification:
>>
>>> e is the base of natural logarithms and numerically equals 2.72 (rounded), and In(hardness) equals the natural

logarithm of the measured hardness (Gary Rosenlieb, National Park Service, Personal Communication, 1997).

For many metals, alkalinity is sometimes a more important co-factor for toxicity than hardness (Pat Davies, Colorado Division of Wildlife, personal communication, 1997).

DOE order 5400.5 and proposed 10 CFR 834 include limits on absorbed dose to native animal aquatic organisms of 1 rad (10 Mgy, same as 10 mGy) per day from liquid discharges of radioactive materials.

Note: The one rad per day will protect populations but perhaps be inadequate for individual fish considerations, for example the protection of endangered fish where one is trying to protect individuals. Either one rad per day or a similar recommendation is made in: IAEA (International Atomic Energy Agency). 1992. Effects of Ionizing Radiation on Plants and Animals at Levels Implied by Current Radiation Protection Standards. IAEA Technical Report Series 332. Vienna, Austria; and in: NCRP (National Council on Radiation Protection and Measurements. 1991. Effects of Ionizing Radiation on Aquatic Organisms. NCRP Report No. 109; National Council on Radiation Protection and Measurements, Bethesda, Maryland. Non-human exposures of 1 cGy (rad) per day (aquatic organisms) and 0.1 cGy (rad) per day for (terrestrial organisms) are much higher than would normally be expected for any reasonable scenario involving radiation exposure of biota from natural sources of uranium (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997) [For Details see: Barnthouse, L.W. 1995. Effects of ionizing radiation on terrestrial plants and animals, a workshop report. Oakridge National Lab Environmental Sciences Division Publication 4494. ORNL/TL-13141, 22 pages].

For radionuclides in the environment, standards for protection of human health have generally been assumed to protect other species. For certain non-radiological hazardous chemicals there are more stringent standards for the protection of other species, (Roy Irwin, Personal Communication, 1997).

No (other) radiological criteria now exist for the protection of fish, wildlife or sensitive natural resources [674]. For radionuclides in the environment, standards for protection of human health have generally been assumed to protect other species, a thought which often seems to be true but may also need additional confirmation in certain situations [674].

See also: NCRP (National Council on Radiation Protection and Measurements. 1991. Effects of Ionizing Radiation on Aquatic Organisms. NCRP Report No. 109. National Council on Radiation Protection and Measurements, Bethesda, Maryland. This summary document is recommended by radiation risk expert Owen Hoffman, but due to a lack of time none of the information therein was included in this Uranium entry.

W.Plants (Water Concentrations vs. Plants):

Shallow Groundwater Ecological Risk Assessment Screening Benchmark for Terrestrial Plants Listed by Oak Ridge National Lab, 1994 [651]:

To be considered unlikely to represent an ecological risk, field concentrations in shallow groundwater or porewater should be below the following benchmark for any aqueous solution in contact with terrestrial plants. Toxicity of groundwater to plants may be affected by many variables such as pH, Eh, cation exchange capacity, moisture content, organic content of soil, clay content of soil, differing sensitivities of various plants, and various other factors. Thus, the following solution benchmark is a rough screening benchmark only, and site specific tests would be necessary to develop a more rigorous benchmark for various combinations of specific soils and plant species [651]:

For CAS 7440-61-1, URANIUM, the benchmark is 40 mg/L (groundwater or porewater) [651].

W.Invertebrates (Water Concentrations vs. Invertebrates):

For the protection of terrestrial biota, the 1993 IAEA Report recommends a screening level dose limit of 1 mGy per day (0.1 rad per day) [National

Council on Radiation Protection and Measurements. 1993. Non-human exposures of 1 cGy (rad) per day (aquatic organisms) and 0.1 cGy (rad) per day for (terrestrial organisms) are much higher than would normally be expected for any reasonable scenario involving radiation exposure of biota from natural sources of uranium. Limitation of Exposure to Ionizing Radiation, NCRP Report No. 116; Bethesda, Maryland] (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997). For details, see also Barnthouse, L.W. 1995. Effects of ionizing radiation on terrestrial plants and animals, a workshop report. Oakridge National Lab Environmental Sciences Division Publication 4494. ORNL/TL-13141, 22 pages.

W.Fish (Water Concentrations vs. Fish):

No information found.

W.Wildlife (Water Concentrations vs. Wildlife or Domestic Animals):

For the protection of terrestrial biota, the 1993 IAEA Report recommends a screening level dose limit of 1 mGy per day (0.1 rad per day) [National Council on Radiation Protection and Measurements. 1993. Non-human exposures of 1 cGy (rad) per day (aquatic organisms) and 0.1 cGy (rad) per day for (terrestrial organisms) are much higher than would normally be expected for any reasonable scenario involving radiation exposure of biota from natural sources of uranium. Limitation of Exposure to Ionizing Radiation, NCRP Report No. 116; Bethesda, Maryland] (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997). For details, see also: Barnthouse, L.W. 1995. Effects of ionizing radiation on terrestrial plants and animals, a workshop report. Oakridge National Lab Environmental Sciences Division Publication 4494. ORNL/TL-13141, 22 pages.

Oak Ridge National Lab, 1994: Risk Assessment Screening Benchmarks for Wildlife derived from No-Observed-Adverse-Effect (NOAEL) levels (see Tis.Wildlife, B) for these). To be considered unlikely to represent an ecological risk, water concentrations should be below the following benchmarks for each species present at the site [650]:

CAS 7440-61-1, URANIUM (AS URANYL ACETATE)

SPECIES	WATER CONCENTRATION (ppm)
Mouse (test species)	0.0000
Short-tailed Shrew	17.1460
Little Brown Bat	29.6350
White-footed Mouse	11.0810
Meadow Vole	19.3940
Cottontail Rabbit	9.1900
Mink	9.5290
Red Fox	6.8010
Whitetail Deer	3.8050

Comment: the number of significant figures for a benchmark value should never be more than one; even if these values have been taken directly from another report, they should be rounded otherwise the impression is given of a level of accuracy that is simply unwarranted. Even after rounding, I would be very hard pressed to claim that the value of 4 for white tailed deer is any different than 10. The uncertainties are too large to justify such a fine distinction (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997).

W.Human (Drinking Water and Other Human Concern Levels):

EPA 1996 IRIS database information for natural uranium (CAS 7440-61-1) and for Uranium, soluble salts (no CAS number) [893]:

Maximum Contaminant Level Goal

Value: 0 pCi/L Uranium Status/Year: Proposed 1991. Reference: 56 FR 33050 (07/18/91)

Contact: Health and Ecological Criteria Division / (202)260-7571 Safe Drinking Water Hotline / (800)426-4791

Discussion: The proposed MCLG for uranium is zero based on evidence of carcinogenic potential (Group A).

Maximum Contaminant Level (MCL)

Value: 20 ug/L Uranium Status/Year: Proposed 1991 Econ/Tech?: Yes, does consider economic or technical feasibility Reference: 56 FR 33050 (07/18/91) [893].

Contact: Drinking Water Standards Division / OGWDW / (202)260-7575 Safe Drinking Water Hotline / (800)426-4791 [893].

Discussion: The proposed MCL of 20 ug/L (approx. 30 pCi/L) is equal to 6X the PQL and is associated with a maximum lifetime individual risk of 1E-5 [893].

EPA Region 9 Preliminary remediation goals (PRGs) for tap water [868]: 1.1E+02 (0.0092) ug/L = about 0.00636 pCi/L.

In the United States, the maximum concentrations of uranium in surface water and groundwater used for the abstraction of drinking water may be as high as 582 and 653 pCi/L (21.5 and 24.2 Bq/L), respectively [948]. These correspond to about 403 to 452 ug/L.

Federal Drinking Water Standards [940]:

EPA 20 ug/l [USEPA/Office of Water; Federal-State Toxicology and Risk Analysis Committee (FSTRAC). Summary of State and Federal Drinking Water Standards and Guidelines (11/93)].

State Drinking Water Standards [940]:

(CA) CALIFORNIA 20 ug/l [USEPA/Office of Water; Federal-State Toxicology and Risk Analysis Committee (FSTRAC). Summary of State and Federal Drinking Water Standards and Guidelines (11/93)].

State Drinking Water Guidelines [940]:

(AZ) ARIZONA 35 ug/l [USEPA/Office of Water; Federal-State Toxicology and Risk Analysis Committee (FSTRAC). Summary of State and Federal Drinking Water Standards and Guidelines (11/93)].

(CA) CALIFORNIA 30 ug/l [USEPA/Office of Water; Federal-State Toxicology and Risk Analysis Committee (FSTRAC). Summary of State and Federal Drinking Water Standards and Guidelines (11/93)].

(MA) MASSACHUSETTS 10 ug/l [USEPA/Office of Water; Federal-State Toxicology and Risk Analysis Committee (FSTRAC). Summary of State and Federal Drinking Water Standards and Guidelines (11/93)].

Acceptable Daily Intake:

In 1983, a chronic exposure SNARL (Suggested No Adverse Response Level) was calculated as 0.035 mg/l, or 35 ug/l, assuming an uncertainty factor of 100, and also assuming that a 70 kg adult consumes 2 l of water daily, and that 10% of the uranium intake is provided by water (National Research Council. Drinking Water & Health. Volume 5. Washington, D.C.: National Academy Press, 1983. 96) [940].

Comment: This calculation was made solely on the basis of the chemical toxicity of natural uranium (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997).

Newsmedia Reports on Radiation Standards, From Greenwire May 9, 1997 --- Vol. 7 --- No. 7, THE ENVIRONMENTAL NEWS DAILY, 3129 Mount Vernon Avenue, Alexandria, VA (703) 518-4600:

EPA AND NRC CLASH OVER RADIOACTIVITY LIMITS: The US EPA and the Nuclear Regulatory Commission "are on a collision course" over the issue of setting limits on how much radioactivity can be left at sites that use nuclear materials and may eventually be clean up for other uses.

The conflict between the two agencies has escalated in the last few weeks as the EPA has taken "strong and public exception" to the level of cancer risk considered acceptable by the NRC at deactiviated power plants and research facilities. NRC officials set the level at about 25 millirem per year, while the EPA backs an earlier proposal to set the limit at 15 millirem. The EPA claims the level settled on by the NRC would treat radiation as a "privileged pollutant" compared with other materials subject to cleanup under the Superfund program. EPA Office of Radiation and Indoor Air Director Ramona Trovato claims the NRC proposal would also reduce groundwater protection and diminish public input into cleanup decision-making processes.

But NRC officials say their proposal is "reasonably achievable," citing some researchers who believe people receive up to 350 millirem of natural background radiation in some parts of the country.

Technically, the EPA is supposed to set the cleanup standards, with the NRC responsible for implementation and enforcement, but the two agencies "are supposed to work together" in this case. Meanwhile, the EPA "took a whack" at setting its own standard, which the NRC "dismissed as too stringent and costly." Nuclear industry officials back the NRC proposal and say the EPA standard would "put in place a duplicative set of rules" (Cindy Skrzycki, WASH. POST, 5/9/97).

RADIATION II: LETTERS RESPOND TO CONTROVERSIAL ARTICLE Two letters-to-the-editor in the WASH. POST today attack a 4/97 article in the newspaper saying that several recent studies suggest low-level radiation may be less dangerous than commonly believed (GREENWIRE, 4/14). Marvin Resnikoff, an associate at a New York radioactivity consulting firm, writes that instead of "devoting an article to dubious claims of pro-nuclear groups," the newspaper "should instead have focused on mainstream scientific opinion," which he says supports the "linear no-threshold theory" which says the more radiation one receives, the more likely cancer will occur.

Meanwhile, Arlie Schardt, executive director of nonprofit public-relations firm Environmental Media Services, writes that the article misrepresented the strictness of federal radiation regulations, made use of a "widely discredited" study on radon and "overstate[d]" opposition to existing radiation regs within the Health Physics Society (WASH. POST, 5/9/97).

W.Misc. (Other Non-concentration Water Information):

Fertilizers made from phosphate rocks contain higher amounts of uranium than natural soils, and highly fertilized areas of the midwest (Mississippi River) tend to contain more dissolved uranium (especially during spring runoff) than other areas of the Missippi River system [912].

The levels of uranium in surface water and groundwater have been measured more frequently than its concentrations in drinking water. In general, the levels of uranium in groundwater are higher than in surface waters [948].

Phytoremediation [1023]:

Rafts with sunflowers growing on them float on a small pond at the Chernobyl nuclear accident site in the Ukraine [1023]. No, its not some touching monument to the 1986 disaster [1023]. The plants are helping to clean the pond; their roots dangle in the water to suck up the radionuclides cesium 137 and strontium 90 [1023]. The plants preferentially absorb cesium and strontium from a mixture of metals, he notes [1023]. The plants don't metabolize the radionuclides, but the cesium stays in the roots and most of the strontium moves to the shoots [1023]. The company disposes of the plants as radioactive waste after about 3 weeks on the pond [1023]. This summer, Phytotech and DOE researchers began a project using sunflowers to remove uranium from contaminated springs at the Oak Ridge (Tenn.) National Laboratory [1023]. "I've heard of uranium contamination at DOE sites of 100 parts per million [ppm], and we couldn't clean that up [1023]. We could go up to 2,000 ppb," Ensley says [1023].

Sediment Data Interpretation, Concentrations and Toxicity (All Sediment Data Subsections Start with "Sed."):

Note: See Br.Class section at beginning of this entry for conversion factors for radiological and other units.

Sed.Low (Sediment Concentrations Considered Low):

No information found.

Sed.High (Sediment Concentrations Considered High):

No information found.

Sed.Typical (Sediment Concentrations Considered Typical):

Unconsolidated beach sands contain an average concentration of 3.0 ug/g of uranium [948].

Radionuclide concentrations in field collections of selected materials. Concentrations are in becquerels per kilogram fresh weight (FW) or dry weight (DW) [674]:

Shale, limestone, sandstone, basalt:

Uranium-238: 6-44 Bq/kg DW [674].

Granite vs. beach sands:

Uranium-238: 62 Bq/kg DW vs. 37 Bq/kg DW [674].

Sediments, deep ocean:

Uranium-238: 5-37 Bq/kg DW [674].

Sed.Concern Levels, Sediment Quality Criteria, LC50 Values, Sediment Quality Standards, Screening Levels, Dose/Response Data and Other Sediment Benchmarks:

Sed.General (General Sediment Quality Standards, Criteria, and Benchmarks Related to Protection of Aquatic Biota in General; Includes Sediment Concentrations Versus Mixed or General Aquatic Biota):

Among aquatic organisms, the developing eggs and young of freshwater fish are among the most sensitive tested organisms; death was observed at acute doses of 0.3 to 0.6 Gy and adverse physiological and metabolism effects were associated with daily exposure rates of 0.01 Gy [674].

Sed.Plants (Sediment Concentrations vs. Plants):

No information found.

Sed.Invertebrates (Sediment Concentrations vs. Invertebrates):

No information found.

Sed.Fish (Sediment Concentrations vs. Fish):

No information found.

Sed.Wildlife (Sediment Concentrations vs. Wildlife or Domestic Animals):

No information found.

Sed.Human (Sediment Concentrations vs. Human):

No information found.

Sed.Misc. (Other Non-concentration Sediment Information):

No information found.

Soil Data Interpretation, Concentrations and Toxicity (All Soil Data Subsections Start with "Soil."):

Note: See Br.Class section at beginning of this entry for conversion factors for radiological and other units.

Soil.Low (Soil Concentrations Considered Low):

No information found.

Soil.High (Soil Concentrations Considered High):

No information found.

Soil.Typical (Soil Concentrations Considered Typical):

The uranium content in soil is related to the bedrock from which the soil is formed. The average concentration of uranium in soils is 1.8 ug/g (ppm) (about 1.2 pCi/g or 0.04 Bq/g radioactivity) [948].

The mean elemental concentration of this metal in plants was 0.05 ppm in the same areas where rocks were 2.6 ppm [951]. Concentration in soils is 1 ppm [951].

Natural uranium is present in soils & rocks in concn generally varying between 0.5 & 5 ppm. The avg is approx 1.8 ppm in most soils (National Research Council. Drinking Water & Health. Volume 5. Washington, D.C.: National Academy Press, 1983. 91) [940].

Information on uranium in soil from ATSDR (see ATSDR for embedded references) [948].

> The levels of uranium in natural igneous rocks and sedimentary rocks may vary from 0.5-4.7 ug/g. In carbonate rocks, the average level is 2.0 ug/g. Unconsolidated beach sands contain an average concentration of 3.0 ug/g of uranium. The uranium content in soil is related to the bedrock from which the soil is formed. The average concentration of uranium in soils is 1.8 ug/g (about 1.2 pCi/g or 0.04 Bq/g radioactivity) (NCRP 1984). The concentrations of uranium in Louisiana soils ranged from 2.35-3.98 ug/g (Meriwether et al. 1988), while its concentrations in phosphate deposits (uranium is known to be found in the deposits) in north and central Florida may range from 4.5-83.4 pCi/g (EPA 1985b). Soil samples adjacent to the Los Alamos area in New Mexico taken during 1974-1977 contained total uranium ranging from 0.1-5.1 ug/g, with a mean value of 2.1 ug/g (Purtymun et al. 1980). The background concentrations of uranium in soils in northern New Mexico during 1974-1986 ranged from 1.3-3.9 ug/g, with a mean value of 2.4 ug/g (Purtymun et al. 1987). The concentrations of uranium in soils adjacent to the Hanford Fuel Fabrication Facility in the state of Washington collected during 1978-1981 ranged from 0.51-3.1 pCi/g (0.02-0.11 Bq/g or 0.8-4.6 ug/g), with a median value of 1.2 pCi/g (0.04 Bq/g or 1.8 ug/g). The control sites, however, contained uranium at concentrations of 0.21-0.86 pCi/g

(0.008-0.03 Bq/g), with a median value of 0.49 pCi/g (0.02 Bq/g) (Price and Kinnison 1982). The soil concentrations of uranium within the property boundary of the Paducah Gaseous Diffusion Plant in Kentucky ranged from 4.9-7.1 ug/g, whereas off-site samples taken up to 12 miles away from the plant had uranium concentrations of 3.8-6.0 ug/g (UCC 1980) [948].

Soil.Concern Levels, Soil Quality Criteria, LC50 Values, Soil Quality Standards, Screening Levels, Dose/Response Data and Other Soil Benchmarks:

Soil.General (General Soil Quality Standards, Criteria, and Benchmarks Related to Protection of Soil-dwelling Biota in General; Includes Soil Concentrations Versus Mixed or General Soil-dwelling Biota):

For the radiological protection of terrestrial biota, the 1993 IAEA Report recommends a screening level dose limit of 1 mGy per day (0.1 rad per day) [National Council on Radiation Protection and Measurements. 1993. Non-human exposures of 1 cGy (rad) per day (aquatic organisms) and 0.1 cGy (rad) per day for (terrestrial organisms) are much higher than would normally be expected for any reasonable scenario involving radiation exposure of biota from natural sources of uranium. Limitation of Exposure to Ionizing Radiation, NCRP Report No. 116; Bethesda, Maryland] (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997). For details, see also: Barnthouse, L.W. 1995. Effects of ionizing radiation on terrestrial plants and animals, a workshop report. Oakridge National Lab Environmental Sciences Division Publication 4494. ORNL/TL-13141, 22 pages.

Soil.Plants (Soil Concentrations vs. Plants):

Oak Ridge National Lab, 1994: Risk Assessment Screening Benchmarks for Terrestrial Plants. To be considered unlikely to represent an ecological risk to terrestrial plants, field concentrations in soil should be below the following dry weight benchmark for soil [651]:

For CAS 7440-61-1 (URANIUM), the benchmark is 5 mg/kg in soil (WILL and SUTER, 1994).

Radiosensitive terrestrial plants are adversely affected at single exposures of 0.5 to 1.0 gray (Gy) and at chronic exposures of 0.2 to 0.65 Gy [674].

For the radiological protection of terrestrial biota, the 1993 IAEA Report recommends a screening level dose limit of 1 mGy per day (0.1 rad per day) [National Council on Radiation Protection and Measurements. 1993. Non-human exposures of 1 cGy (rad) per day (aquatic organisms) and 0.1 cGy (rad) per day for (terrestrial organisms) are much higher than would normally be expected for any reasonable scenario involving radiation exposure of biota from natural sources of uranium. Limitation of Exposure to Ionizing Radiation, NCRP Report No. 116; Bethesda, Maryland] (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997). For details, see also: Barnthouse, L.W. 1995. Effects of ionizing radiation on terrestrial plants and animals, a workshop report. Oakridge National Lab Environmental Sciences Division Publication 4494. ORNL/TL-13141, 22 pages.

Soil.Invertebrates (Soil Concentrations vs. Invertebrates):

Terrestrial insects are comparatively resistant to ionizing radiation, some species showing growth and stimulation even at 2 Gy (a dose harmful to many vertebrates [674].

For the radiological protection of terrestrial biota, the 1993 IAEA Report recommends a screening level dose limit of 1 mGy per day (0.1 rad per day) [National Council on Radiation Protection and Measurements. 1993. Limitation of Exposure to Ionizing Radiation, NCRP Report No. 116; Bethesda, Maryland] (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997). For details, see also: Barnthouse, L.W. 1995. Effects of ionizing radiation on terrestrial plants and animals, a workshop report. Oakridge National Lab Environmental Sciences Division Publication 4494. ORNL/TL-13141, 22 pages.

Soil.Wildlife (Soil Concentrations vs. Wildlife or Domestic Animals):

No information found.

Soil.Human (Soil Concentrations vs. Human):

Preliminary remediation goals (PRGs) [868]:

Residential Soil: 2.3E+02 mg/kg wet weight
Industrial Soil: 5.1E+03 mg/kg wet weight

NOTE:

1) Values are based on a one-in-one million cancer risk.
2) PRGs focus on the human exposure pathways of ingestion, inhalation of particulates and volatiles, and dermal absorption. Values do not consider impact to groundwater or ecological receptors.
3) PRGs are slightly lower concentrations than EPA Region III RBCs, which consider fewer aspects [903].

EPA Risk based concentration (RBC) to protect from transfers to groundwater:

None given [903].

Newsmedia Reports on Radiation Standards, From Greenwire May 9, 1997 --- Vol. 7 --- No. 7, THE ENVIRONMENTAL NEWS DAILY, 3129 Mount Vernon Avenue, Alexandria, VA (703) 518-4600:

> EPA AND NRC CLASH OVER RADIOACTIVITY LIMITS: The US EPA and the Nuclear Regulatory Commission "are on a collision course" over the issue of setting limits on how much radioactivity can be left at sites that use nuclear materials and may eventually be clean up for other uses.
>
> The conflict between the two agencies has escalated in the last few weeks as the EPA has taken "strong and public exception" to the level of cancer risk considered acceptable by the NRC at deactiviated power plants and research facilities. NRC officials set the level at about 25 millirem per year, while the EPA backs an earlier proposal to set the limit at 15 millirem.
>
> The EPA claims the level settled on by the NRC would treat radiation as a "privileged pollutant" compared with other materials subject to cleanup under the Superfund program. EPA Office of Radiation and Indoor Air Director Ramona Trovato claims the NRC proposal would also reduce groundwater protection and diminish public input into cleanup decision-making processes.
>
> But NRC officials say their proposal is "reasonably achievable," citing some researchers who believe people receive up to

350 millirem of natural background radiation in some parts of the country.

Technically, the EPA is supposed to set the cleanup standards, with the NRC responsible for implementation and enforcement, but the two agencies "are supposed to work together" in this case. Meanwhile, the EPA "took a whack" at setting its own standard, which the NRC "dismissed as too stringent and costly." Nuclear industry officials back the NRC proposal and say the EPA standard would "put in place a duplicative set of rules" (Cindy Skrzycki, WASH. POST, 5/9/97).

RADIATION II: LETTERS RESPOND TO CONTROVERSIAL ARTICLE Two letters-to-the-editor in the WASH. POST today attack a 4/97 article in the newspaper saying that several recent studies suggest low-level radiation may be less dangerous than commonly believed (GREENWIRE, 4/14). Marvin Resnikoff, an associate at a New York radioactivity consulting firm, writes that instead of "devoting an article to dubious claims of pro-nuclear groups," the newspaper "should instead have focused on mainstream scientific opinion," which he says supports the "linear no-threshold theory" which says the more radiation one receives, the more likely cancer will occur.

Meanwhile, Arlie Schardt, executive director of nonprofit public-relations firm Environmental Media Services, writes that the article misrepresented the strictness of federal radiation regulations, made use of a "widely discredited" study on radon and "overstate[d]" opposition to existing radiation regs within the Health Physics Society (WASH. POST, 5/9/97).

Soil.Misc. (Other Non-concentration Soil Information):

No information found.

Tissue and Food Concentrations (All Tissue Data Interpretation Subsections Start with "Tis."):

Note: See Br.Class section at beginning of this entry for conversion factors for radiological and other units.

Tis.Plants:

A) As Food: Concentrations or Doses of Concern to Living Things Which Eat Plants:

For the radiological protection of terrestrial biota, the 1993 IAEA Report recommends a screening level dose limit of 1 mGy per day (0.1 rad per day) [National Council on Radiation Protection and Measurements. 1993. Limitation of Exposure to Ionizing Radiation, NCRP Report No. 116; Bethesda, Maryland] (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997). For details, see also: Barnthouse, L.W. 1995. Effects of ionizing radiation on terrestrial plants and animals, a workshop report. Oakridge National Lab Environmental Sciences Division Publication 4494. ORNL/TL-13141, 22 pages.

B) Body Burden Residues in Plants: Typical, Elevated, or of Concern Related to the Well-being of the Organism Itself:

The mean elemental concentration of this metal in plants was 0.05 ppm in the same areas where rocks were 2.6 ppm; the toxicity of uranium to plants is moderate [951].

Tis.Invertebrates:

A) As Food: Concentrations or Doses of Concern to Living Things Which Eat Invertebrates:

For the radiological protection of terrestrial biota, the 1993 IAEA Report recommends a screening level dose limit of 1 mGy per day (0.1 rad per day) [National Council on Radiation Protection and Measurements. 1993. Limitation of Exposure to Ionizing Radiation, NCRP Report No. 116; Bethesda, Maryland] (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997). For details, see also: Barnthouse, L.W. 1995. Effects of ionizing radiation on terrestrial plants and animals, a workshop report. Oakridge National Lab Environmental Sciences Division Publication 4494. ORNL/TL-13141, 22 pages.

B) Concentrations or Doses of Concern in Food Items Eaten by Invertebrates:

For the radiological protection of terrestrial biota, the 1993 IAEA Report recommends a screening level dose limit of 1 mGy per day (0.1 rad per day) [National Council on Radiation Protection and Measurements. 1993. Limitation of Exposure to

Ionizing Radiation, NCRP Report No. 116; Bethesda, Maryland] (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997). For details, see also: Barnthouse, L.W. 1995. Effects of ionizing radiation on terrestrial plants and animals, a workshop report. Oakridge National Lab Environmental Sciences Division Publication 4494. ORNL/TL-13141, 22 pages.

Terrestrial insects are comparatively resistant to ionizing radiation, some species showing growth and stimulation even at 2 Gy (a dose harmful to many vertebrates [674].

C) Body Burden Residues in Invertebrates: Typical, Elevated, or of Concern Related to the Well-being of the Organism Itself:

No information found.

Tis.Fish:

A) As Food: Concentrations or Doses of Concern to Living Things Which Eat Fish (Includes FDA Action Levels for Fish and Similar Benchmark Levels From Other Countries):

For risk to human adults eating fish, separate carcinogenic and non-carcinogenic risk-based fish tissue concentrations were calculated [903]. The following EPA Region III fish tissue risk-based concentration (RBC) benchmark utilizes the lower of the two concentrations (carcinogenic), rounded to two significant figures [903]:

RBC = 4.1 mg/Kg wet weight (based on non-carcinogenic risk, due solely to chemical toxicity).

B) Concentrations or Doses of Concern in Food Items Eaten by Fish:

No information found.

C) Body Burden Residues in Fish: Typical, Elevated, or of Concern Related to the Well-being of the Organism Itself:

A series of studies were performed on several fish species in Beaverlodge Lake, near a uranium mine near Saskatchewan, Canada, in order to assess the chronic effects of low-level uranium-series radionuclides on wild fish. First, radionuclide levels in water, fish, and sediments were determined [972]. Second, food-chain transfer of

U-series radionuclides was examined [973]. Finally, a tumor and parasite survey and measurement of standard blood parameters were used to evaluate potential uranium-series radionuclides effects on fish health [975].

In the first study, Beaverlodge Lake water (the contaminated site) showed some effects from input of the tailings system effluent: sodium sulfate, radium-266 (Ra) and uranium-series radionuclides (U) levels were elevated. Sediment levels of lead-210 (Pb), Ra-266, and U-238 were elevated [972]. Lake whitefish and white suckers had Ra-226 and Pb-210 levels 2 - 63 times those found in nearby controls, while U concentrations were 3 - 115 times higher than control levels. Lake trout had lower radionuclide levels than the other two species, 1.4 - 7 times control values. These radionuclide levels in Beaverlodge fish represent low dose rates compared with those shown to have effects in laboratory experiments. They resemble levels found in fish in other field studies [972]. Actual measured values are listed below:

Measured radionuclide levels in three large fish, Beaverlodge Lake [972]:

NOTE: All these values are approximate b/c they were read off a graph:

Mean 226 Ra content (pCi/l, ash) in Beaverlodge Lake (Fig. 2):

	Skin:	Bone:	Flesh:	Skin & Flesh:	Whole:
Lake Trout	1.5	0.7	0.2	0.8	0.8
Lake Whitefish	4.4	2.7	0.5	1.4	1.8
White Sucker	1.2	17.0	2.1	18.7	14.4

Mean 210 Pb content (pCi/l, ash) in Beaverlodge Lake (Fig. 3):

	Skin:	Bone:	Flesh:	Skin & Flesh:	Whole:
Lake Trout	1.8	0.6	0.5	0.9	0.5
Lake Whitefish	2.2	1.8	0.9	1.2	1.3
White Sucker	8.7	3.5	0.7	3.1	3.5

NOTE: Skin and bone fish samples contain higher levels than flesh since Pb and Ra are known to have longer biological half-lives in the bones than whole body.

Mean Uranium content (ug/g, ash) in Beaverlodge Lake (Fig. 4):

	Skin:	Bone:	Flesh:	Skin & Flesh:	Whole:
Lake Trout	7.5	4	2	5	6
Lake Whitefish	26	25	3.5	13	25

White Sucker	7.5	35	4	15	90.1

Estimated internal dose rates to the three large fish species in Beaverlodge Lake based on mean radionuclide levels in bone and in whole (eviscerated) specimens (Table 7) [972]:

	Bone		Whole	
	urad/hr	mrad/yr	urad/hr	mrad/yr
Lake trout				
alpha rad	1.5	13	0.2	2
beta rad	0.01	0.09	0.0003	0.003
Lake Whitefish				
alpha rad	5.5	48	0.5	5
beta rad	0.02	0.2	0.006	0.05
White Sucker				
alpha rad	27	240	4	39
beta rad	0.06	0.5	0.009	0.08

Some corresponding water chemistry, Beaverlodge Lake (from Table 1 and 2 [972], and Table 3 [973]):

226 Ra	
Total (pCi/l)	1.5-2.2
Dissolved (pCi/l)	1.2-1.7
210 Pb (pCi/l)	<0.5
Total U (ug/l)	180-390

The following are in mg/l:

HCO3	83-84
Ca as Ca	20-23
Cl	21-23.5
Mg as Mg	5.1-6.3
K	0.8-1.0
Na	24-29.5
SO4	20-43
TDS	124-195
Total Inorganic Carbon	13.3

The only elements that are significantly higher in Beaverlodge water and fish are the radionuclides; specifically uranium, Ra-226, Pb-210, and polonium-210 [972].

The third study assumed approximately the same water and fish concentrations as listed above in the earlier studies. Uranium levels in white sucker bones were measured as a check, and reported to be 58.1 ug/g, ash in 1983, and 47.0 ug/g, ash in 1984 (compared to 35 ug/g, ash in 1979). The lack of tumor involvement in this study indicates that long-term exposure of wild fish to low level of radioactivity did not appear to be teratogenic. However, consistent differences were found in blood parameters (a decrease in packed cell volume, total protein, and red blood cell numbers, and an increase in numbers of white blood cells) in the two species with the highest levels of radionuclides; the physiological significance of these data is unclear. Other factors in this field study, such as small sample size, may have influences the results. The author also speculates that sometimes fish do not live long enough for effects of damage to become manifest and/or that recovery sometimes occurs faster than damage [975].

Tis.Wildlife: Terrestrial and Aquatic Wildlife, Domestic Animals and all Birds Whether Aquatic or not:

A) As Food: Concentrations or Doses of Concern to Living Things Which Eat Wildlife, Domestic Animals, or Birds:

For the radiological protection of terrestrial biota, the 1993 IAEA Report recommends a screening level dose limit of 1 mGy per day (0.1 rad per day) [National Council on Radiation Protection and Measurements. 1993. Limitation of Exposure to Ionizing Radiation, NCRP Report No. 116; Bethesda, Maryland] (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997). For details, see also: Barnthouse, L.W. 1995. Effects of ionizing radiation on terrestrial plants and animals, a workshop report. Oakridge National Lab Environmental Sciences Division Publication 4494. ORNL/TL-13141, 22 pages.

B) Concentrations or Doses of Concern in Food Items Eaten by Wildlife, Birds, or Domestic Animals (Includes LD50 Values Which do not Fit Well into Other Categories, Includes Oral Doses Administered in Laboratory Experiments):

For the radiological protection of terrestrial biota, the 1993 IAEA Report recommends a screening level dose limit of 1 mGy per day (0.1 rad per day) [National Council on Radiation Protection and Measurements. 1993. Limitation of Exposure to Ionizing Radiation, NCRP Report No. 116; Bethesda, Maryland] (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997). For details, see also: Barnthouse, L.W. 1995. Effects of ionizing radiation on terrestrial plants and animals, a workshop report. Oakridge National Lab Environmental Sciences Division Publication 4494. ORNL/TL-13141, 22 pages.

Oak Ridge National Lab, 1994: Risk Assessment Screening Benchmarks for Wildlife derived from No-Observed-Adverse-Effect (NOAEL) levels (mg contaminant per kg body weight per day). To be considered unlikely to represent an ecological risk, wet-weight field concentrations should be below the following (right column) benchmarks for each species present at the site [650]:

CAS 7440-61-1 URANIUM (AS URANYL ACETATE)

SPECIES	NOAEL (mg/kg/day)	FOOD CONCENTRATION (ppm)
Mouse (test species)	3.0700	0.0000
Short-tailed Shrew	3.7720	6.2870
Little Brown Bat	4.7420	14.2250
White-footed Mouse	3.3240	21.5100
Meadow Vole	2.6450	23.2730
Cottontail Rabbit	0.8880	4.4980
Mink	0.9430	6.8860
Red Fox	0.5740	5.7430
Whitetail Deer	0.2490	8.0920

Comment: Actually, the number of significant figures for a benchmark value should never be more than one; even if these values have been taken directly from another report, they should be rounded; otherwise the impression is given of a level of accuracy that is simply unwarranted. The uncertainties are too large to justify such a fine distinction (Owen Hoffman, SENES Oak Ridge, Personal Communication, 1997).

In birds, adverse effects on growth were noted at chronic daily exposures as low as 0.9 to 1.0 Gy and on survival and metabolism from a single exposure of 2.1 Gy [674].

C) Body Burden Residues in Wildlife, Birds, or Domestic Animals: Typical, Elevated, or of Concern Related to the Well-being of the Organism Itself:

No information found.

Tis.Human:

A) Typical Concentrations in Human Food Survey Items:

Most human food items contain less than 10 ppb uranium; however a few were higher, including onion 69 ppb, beef kidney 70 ppb, and parsley 60 ppb

[948]..

B) Concentrations or Doses of Concern in Food Items Eaten by Humans (Includes Allowable Tolerances in Human Food, FDA, State and Standards of Other Countries):

EPA 1996 IRIS database information [893]:

No information given for natural uranium (CAS 7440-61-1).

Information for uranium soluble salts [893]:

Crit. Dose: 2.8 mg/kg-day [Study 1 LOAEL(adj)] UF: 1000 MF: 1

RfD: 3E-3 mg/kg-day Confidence: Medium

The avg daily dietary intake of uranium by man is 1 to 1.5 ug (Venugopal, B. and T.D. Luckey. Metal Toxicity in Mammals, 2. New York: Plenum Press, 1978. 162) [940].

For risk to human adults eating fish, separate carcinogenic and non-carcinogenic risk-based fish tissue concentrations were calculated [903]. The following EPA Region III fish tissue risk-based concentration (RBC) benchmark utilizes the lower of the two concentrations (carcinogenic), rounded to two significant figures [903]:

RBC = 4.1 mg/Kg wet weight (based on non-carcinogenic risk).

C) Body Burden Residues in Humans: Typical, Elevated, or of Concern Related to the Well-being of Humans:

For information on the pharmacokinetics of uranium in humans (like partitioning among tissues, retention times, detailed ingestion dose coefficients) see: The International Commission on Radiological Protection (ICRP). 1994. Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 3, Ingestion Dose Coefficients. ICRP Publication 69. Pergamon. This document is recommended by radiation risk expert Owen Hoffman, but due to a lack of time none of the information therein was included in this Uranium entry.

Information from HSDB [940]:

The uranium content of human tissues obtained at autopsy ... reviewed, and est were made of uranium in human bone and soft tissues. The range of natural uranium in the human skeleton (2-62 ug) is attributed to geographic variation and to analytical and sampling uncertainties. Uranium in the skeleton is believed to be roughly in equilibrium with intake. [Wrenn ME et al; The Potential Toxicity of Uranium in Water p.178 (1987) EPA-600/J-87/096].

The natural uranium content of an adult human kidney is approx 0.1 ug or approx 0.004 ug/g kidney tissue. [Wrenn ME et al; The Potential Toxicity of Uranium in Water p.178 (1987) EPA-600/J-87/096].

Careful measurements of uranium concn in human bones from Nepal and Australia /were made/. /The researchers/ calculated the annual alpha doses to bone from (238)uranium to be 0.039 mrad for the Nepalese and 0.009 mrad for the Australians. Such wide variations are not unexpected because of the known geographic differences in uranium concn in human bone. /(238)uranium/ [Voegtlin C, Hodge HC, eds,; Pharmacology and Toxicology of Uranium Compounds p.VI-8 (1953).].

Under steady-state conditions in occupationally exposed subjects, 85% of the body burden of uranium was found in bone provided that uranium deposited in the lung is excluded. More than 90% of the remaining uranium was in the kidney, & detectable amt could be found in liver. /TOTAL URANIUM/ [Friberg, L., Nordberg, G.F., Kessler, E. and Vouk, V.B., eds. Handbook of the Toxicology of Metals. 2nd ed. Vols I, II.: Amsterdam: Elsevier Science Publishers B.V., 1986.,p. V2 629].

Human body burden: Uranium 0.02 mg/70 kg. /From table; uranium/ [Doull, J., C.D. Klaassen, and M. D. Amdur (eds.). Casarett and Doull's Toxicology. 2nd ed. New York: Macmillan Publishing Co., 1980. 410].

Tis.Misc. (Other Tissue Information):

Based on consumption rate, root crops such as potatoes, parsnips, turnips, and sweet potatoes may constitute 38% of total dietary intake of uranium [948]. The uranium content in tissues of cattle herds grazing in pastures close to the Rocky Flats Plant in Colorado were found to be slightly higher than in most other cattle, reflecting elevated contamination from this source [948].

Bio.Detail: Detailed Information on Bioconcentration, Biomagnification, or Bioavailability:

The bioconcentration factors (BCFs) for uranium (natural) in algae and plankton were 1576 and 459 [948]. The BCFs for bacteria were higher (2794 to 354,200) but the increase may be partly due to adsorption onto cell surfaces [948]. The BCFs for fish are below 38, indicating relatively little biomagnification of uranium through the fish food chain [948]. Some plants can have 80 times the concentration of uranium as the soil, and root foods like potatoes and radishes might also have adsorption onto surfaces [948].

For more information on the uptake of radionuclides by plants, fish, animals, animal-derived human foods, etc., including transfer and translocation coefficients see: IAEA (International Atomic Energy Agency). 1994. Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments. IAEA Technical Report Series 364. Vienna, Austria. For information on the pharmacokinetics of uranium in humans (like partitioning among tissues, retention times, detailed ingestion dose coefficients) see: The International Commission on Radiological Protection (ICRP). 1994. Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 3, Ingestion Dose Coefficients. ICRP Publication 69. Pergamon. These documents are recommended by radiation risk expert Owen Hoffman, but due to a lack of time none of the information therein was included in this Uranium entry.

Published bioconcentration factors vary widely, e.g., reported U BCFs range from 10 to 1000, while Po BCFs range from 50 to 20,000, again depending in part on the type of organism (see Br.Hazard section above).

Interactions:

To assess the effect of cigarette smoking and of exposure to radon daughters, a prospective survey consisting of periodic sputum cytology evaluation was initiated among 249 underground uranium miners and 123 male controls. The estimated frequency of abnormal cytology was significantly dependent for controls on the duration of cigarette smoking, and for miners on the duration of cigarette smoking and of uranium mining (Band P et al; Cancer 45 (6): 1273-7, 1980) [940].

Uses/Sources:

Uranium is used by humans mainly in nuclear power plants and nuclear weapons. Very small amounts are used in making some ceramics, light bulbs, photographic chemicals, and household products [948]. Depleted uranium (natural uranium depleted of uranium-235) is used to manufacture armor-piercing ammunition for the military, in inertial guidance devices and gyro compasses, as a counterweight for missile reentry vehicles, as radiation shielding material, and x-ray targets [948]. Uranium dioxide is used to extend the lives of large incandescent lamps used for photography and motion pictures [948]. Uranium compounds are used in photography for toning, in the leather and wood industries for stains and dyes, and in silk and wool industries as mordants [948].

Ammonium diuranate is used to produce colored glazes in ceramics [948]. Uranium carbide is a good catalyst for the production of synthetic ammonia [948]. For many years, uranium was used in dental porcelains, but this practice was discontinued [948]. According to USDI (1980), the major uses of depleted uranium in the United States in 1978 were as follows: military ammunition, 71.8%; counterweight, 11.4%; radiation shielding, 13.6%; and chemical catalyst, 3.2%. [948].

Information on uranium in air from ATSDR (see ATSDR for embedded references) [948].

> The annual average concentrations of uranium in ambient air near the Jackpile Open Pit uranium mine in New Mexico were higher than background levels. Compared to the NCRP-45 background concentration of 0.2 fCi/m3 (7.4x10-6 Bq/m3) (fCi = 10-15 Ci), the concentration of total uranium (uranium-234, uranium-235, and uranium-238) in the Jackpile Housing was 5.5 fCi/m3 (2.0x10-4 Bq/m3) and was 2.4 fCi/m3 (8.9x10-5 Bq/m3) near the pit (Eadie et al. 1979). The concentrations of uranium in air within 2 km of a Canadian refinery ranged from 2-200 ng/m3, with a geometric mean of 20 ng/m3 (14 fCi/m3) (5.2x10-4 Bq/m3) (Tracy and Meyerhof 1987). The atmospheric uranium-238 concentration measured during 1977-1978 in the vicinity of the Anaconda Uranium mill in New Mexico was as high as 32.3 fCi/m3 (1.2x10-3 Bq/m3) in one location, although the average concentrations were within the existing limits of maximum permissible concentrations (Momeni and Kisieleski 1980). The maximum total air alpha activity in one location near the Paducah Gaseous Diffusion plant in Kentucky during 1979 was reported to be 0.7 pCi/m3 (2.6x10-2 Bq/m3), compared with the NRC Radioactive Concentration Guide of 4 pCi/m3 (0.15 Bq/m3) in air (UCC 1980).
>
> The ambient air concentrations of total uranium (uranium-234, uranium-235, and uranium-238) in 51 urban and rural areas in the United States were measured by EPA in 1984 (EPA 1986d). The maximum mean concentration (mean of values measured at two different times) of 0.3 fCi/m3 (1.1x10-5 Bq/m3) was recorded at Lynchburg, VA, and a minimum of 0.011 fCi/m3 (0.4x10-6 Bq/m3) at Topeka, KS. Other locations that had high concentrations of uranium (but less than Lynchburg) were Denver, CO; Idaho Falls, ID; Bismarck, ND; Las Vegas, NV; El Paso, TX; and Spokane, WA.
>
> Major Uses [940]:
>
>> Uranium ores as source of radium salts. /Uranium ores/ [International Labour Office. Encyclopedia of Occupational Health and Safety. Vols. I&II. Geneva, Switzerland: International Labour Office, 1983. 2237].
>>
>> Source of fissionable isotope (235)uranium; source of plutonium by neutron capture. [Sax, N.I. and R.J. Lewis,

Sr. (eds.). Hawley's Condensed Chemical Dictionary. 11th ed. New York: Van Nostrand Reinhold Co., 1987. 1207].

(235)Uranium is used in atom & hydrogen bombs; (234)uranium & (235)uranium are used in power reactors. /(234)URANIUM AND (235)URANIUM/ [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 1409].

Used in weapons production. [Considine. Chemical and Process Technol Encyc 1974 p.1116].

For X-ray targets for production of high-energy X-rays. [Weast, R.C. (ed.) Handbook of Chemistry and Physics. 69th ed. Boca Raton, FL: CRC Press Inc., 1988-1989.,p. B-40].

Used in inertial guidance devices and gyro compasses, as a counterweight for missile reentry vehicles, and as shielding material [Voegtlin C, Hodge HC (eds); Pharmacology and Toxicology of Uranium Compounds p.II-5 (1953).].

Natural Sources [940]:

Uranium is widely distributed in nature & accounts for 3 to 4x10-4% of earth crust /2x10-5%/. It is present in a variety of minerals & is also encountered in sea water. ... Chief natural sources are hydrothermal veins in Saxony, Zaire, & Canada; sedimentary rocks in colorado, utah & new mexico; & pyritic conglomerate beds of precambrian age in witwaterstrand & Ontario. [International Labour Office. Encyclopedia of Occupational Health and Safety. Vols. I&II. Geneva, Switzerland: International Labour Office, 1983. 2237].

Uranium is an important constituent of about 155 minerals; in another 60 minerals, it is a minor constituent or an impurity. [Kirk-Othmer Encyclopedia of Chemical Technology. 3rd ed., Volumes 1-26. New York, NY: John Wiley and Sons, 1978-1984.,p. 23(83) 505].

It occurs in numerous minerals such as ... Uranite ... Autunite, uranophane, davidite & tobernite. It is also found in phosphate rock, lignite, /&/ monazite sands. [Weast, R.C. (ed.) Handbook of Chemistry and Physics. 69th ed. Boca Raton, FL: CRC Press Inc., 1988-1989.,p. B-39].

Selected uranium minerals: Euxenite, polycrase, fergusonite, samarskite, pyrochlore, microlite, brannerite, tyuyamunite, coffinite, thucholite. /From table/ [Kirk-Othmer Encyclopedia of Chemical Technology. 3rd ed., Volumes 1-26. New York, NY: John Wiley and Sons, 1978-1984.,p. 23(83) 507].

Pitchblende found in colorado, utah, bear lake in canada, zaire, joachimstahl in czechoslovakia, cornwall. [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 1409].

Carnotite /a mineral containing uranium occurs in/ Colorado, New Mexico, France, South Africa, Australia, USSR. [Sax, N.I. and R.J. Lewis, Sr. (eds.). Hawley's Condensed Chemical Dictionary. 11th ed. New York: Van Nostrand Reinhold Co., 1987. 1207].

Uranium content of: Igneous rocks, 0.008 wt%; and ore deposits, 0.1 - 0.9 wt% [Kirk-Othmer Encyclopedia of Chemical Technology. 3rd ed., Volumes 1-26. New York, NY: John Wiley and Sons, 1978-1984.,p. 9(80) 742].

Acidic rocks with a high silicate content, ie, granite, have a uranium content above average. ... [Kirk-Othmer Encyclopedia of Chemical Technology. 3rd ed., Volumes 1-26. New York, NY: John Wiley and Sons, 1978-1984.,p. 23(83) 504].

Estimated that the average ... Uranium content of the top 30 cm of soil /is/ ... 2.3 Tons/sq km. [International Labour Office. Encyclopedia of Occupational Health and Safety. Vols. I&II. Geneva, Switzerland: International Labour Office, 1983. 57].

The uranium content of rocks varies widely but is generally higher than that in the earth's crust-on the avg 3 ug/g. [Wrenn ME et al; The Potential Toxicity of Uranium in Water p.177 (1987) EPA-600/J-87/096].

Artificial Sources [940]:

Depleted uranium is a by product of the uranium enrichment process during which natural uranium is enriched by increasing the percentage of the (2350uranium isotope. [Department of the Army; Technical Bulletin on Depleted Uranium TB 9-1300-278 p.1 (1987)].

The following list includes some common operations in which exposure to uranium or insol cmpd may occur ... liberation from mining, grinding, & milling of ores; use of insol cmpd as chemical intermediates in prepn of uranium cmpd; use for nuclear technology; use in nuclear reactors as fuel & to pack nuclear fuel rods; liberation from burning of uranium metal chips & smelting operations; use in ceramics industry for pigments, coloring porcelain, & enamelling; use as catalysts for many reactions; in production of fluorescent glass. /Uranium and insol uranium cmpd as uranium/ [Mackison, F. W., R. S. Stricoff, and L. J. Partridge, Jr. (eds.). NIOSH/OSHA - Occupational Health Guidelines for Chemical

Hazards. DHHS(NIOSH) PublicationNo. 81-123 (3 VOLS). Washington, DC: U.S. Government Printing Office, Jan. 1981. 4].

Forms/Preparations/Formulations:

The symbol for Uranium-233 is 233U, the atomic number is 92, the half-life is 160,000 years, and particle (alpha) emission is the major form of decay [674].

The symbol for Uranium-234 is 234U, the atomic number is 92, the half-life is 245,000 years, and particle (alpha) emission is the major form of decay [674].

The symbol for Uranium-235 is 235U, the atomic number is 92, the half-life is 710,000,000 years, and particle (alpha) emission is the major form of decay [674].

The symbol for Uranium-236 is 236U, the atomic number is 92, the half-life is 23,400,000 years, and particle (alpha) emission is the major form of decay [674].

The symbol for Uranium-238 is 238U, the atomic number is 92, the half-life is 4,470,000,000 years, and particle (alpha) emission is the major form of decay [674].

Information from HSDB [940]:

SOLID PURE METAL; ALLOYS; POWDER (99.7%). [Sax, N.I. and R.J. Lewis, Sr. (eds.). Hawley's Condensed Chemical Dictionary. 11th ed. New York: Van Nostrand Reinhold Co., 1987. 1207].

Available from Cerac, Inc as -60 mesh. [Kuney, J.H. and J.N. Nullican (eds.) Chemcyclopedia. Washington, DC: American Chemical Society, 1988. 218].

Naturally occurring uranium ... contains 99.2830% by wt (238)uranium, 0.7110% (235)uranium, and 0.0054% (234)uranium. [Weast, R.C. (ed.) Handbook of Chemistry and Physics. 69th ed. Boca Raton, FL: CRC Press Inc., 1988-1989.,p. B-40].

Chem.Detail: Detailed Information on Chemical/Physical Properties:

Naturally occurring uranium contains 99.2830% by wt (238)uranium, 0.7110% (235)uranium, and 0.0054% (234)uranium. Studies show that the percentage weight of (235)uranium in natural uranium varies by as much as 0.1%, depending on the source. The USDOE has adopted the value of 0.711 as being their "official" percentage of (235)uranium in natural uranium (Weast, R.C. (ed.) Handbook of Chemistry and Physics. 69th ed. Boca Raton, FL: CRC Press Inc., 1988-1989.,p. B-40) [940].

Solubilities [940]:

INSOL (sic, actually "relatively insoluble") IN HOT OR COLD WATER & ALKALIES; SOL IN ACIDS [Clayton, G. D. and F. E. Clayton (eds.). Patty's Industrial Hygiene and Toxicology: Volume 2A, 2B, 2C: Toxicology. 3rd ed. New York: John Wiley Sons, 1981-1982. 1998].

INSOL (sic, actually "relatively insoluble") IN ALCOHOL [American Conference of Governmental Industrial Hygienists. Documentation of the Threshold Limit Values and Biological Exposure Indices. 5th ed. Cincinnati, OH:American Conference of Governmental Industrial Hygienists, 1986. 617].

Vapor Pressure [940]:

0 mm Hg @ 20 deg C [Mackison, F. W., R. S. Stricoff, and L. J. Partridge, Jr. (eds.). NIOSH/OSHA - Occupational Health Guidelines for Chemical Hazards. DHHS(NIOSH) Publication No. 81-123 (3 VOLS). Washington, DC: U.S. Government Printing Office, Jan. 1981. 2].

Density/Specific Gravity [940]:

19.05 + or - 0.02 @ 25 DEG C [Clayton, G. D. and F. E. Clayton (eds.). Patty's Industrial Hygiene and Toxicology: Volume 2A, 2B, 2C: Toxicology. 3rd ed. New York: John Wiley Sons, 1981-1982. 1998].

Molecular Weight [940]:

238.03 [Weast, R.C. (ed.) Handbook of Chemistry and Physics. 69th ed. Boca Raton, FL: CRC Press Inc., 1988-1989.,p. B-39].

Surface Tension [940]:

1500 + or - 75 mN/m, liquid, purity 99.999% (vacuum) [Weast, R.C. (ed.) Handbook of Chemistry and Physics. 69th ed. Boca Raton, FL: CRC Press Inc., 1988-1989.,p. F-28].

Boiling Point [940]:

3818 DEG C [Weast, R.C. (ed.) Handbook of Chemistry and Physics. 69th ed. Boca Raton, FL: CRC Press Inc., 1988-1989.,p. B-141].

Melting Point [940]:

1132.3 + or - 0.8 DEG C [Weast, R.C. (ed.) Handbook of Chemistry and Physics. 69th ed. Boca Raton, FL: CRC Press Inc., 1988-1989.,p. B-141].

Color/Form [940]:

Silver-white, lustrous, metal; a black powder when obtained by reduction; three allotrophic modifications: orthorhombic alpha-form to 667.7 Deg c; tetragonal beta-form from 667.7 Deg c to 774.8 Deg c; body-centered cubic, gamma-form from 774.8 Deg C TO MP [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 1409].

Other Chemical/Physical Properties [940]:

Metal not as hard as steel; ductile, malleable, can be melted & extruded at high temp; takes high polish after cold working. [International Labour Office. Encyclopedia of Occupational Health and Safety. Vols. I&II. Geneva, Switzerland: International Labour Office, 1983. 2237].

Strongly electropositive; poor conductor of electricity; heat capacity 6.6 Cal/mol/deg c; dense solid; forms solid soln with molybdenum, niobium, titanium, zirconium; metal reacts with nearly all nonmetals; heat of fusion: 4.7 KCAL/MOLE [Sax, N.I. and R.J. Lewis, Sr. (eds.). Hawley's Condensed Chemical Dictionary. 11th ed. New York: Van Nostrand Reinhold Co., 1987. 1207].

Alpha emitter, only weakly radioactive [Hamilton, A., and H. L. Hardy. Industrial Toxicology. 3rd ed. Acton, Mass.: Publishing Sciences Group, Inc., 1974. 397].

14 Isotopes all radioactive [Weast, R.C. (ed.) Handbook of Chemistry and Physics. 69th ed. Boca Raton, FL: CRC Press Inc., 1988-1989.,p. B-40].

Pure uranium metal is very reactive as a strong reducing agent. [Friberg, L., Nordberg, G.F., Kessler, E. and Vouk, V.B. (eds). Handbook of the Toxicology of Metals. 2nd ed. Vols I, II.: Amsterdam: Elsevier Science Publishers B.V., 1986.,p. V2 624].

Atomic number 92; not attacked by alkalies; specific heat 6.65 Cal/g atom/deg c @ 25 deg c; on vigorous shaking the metallic particles exhibit luminescence; burns in fluorine to produce mainly a green volatile tetrafluoride; in chlorine @ 180 deg c, in bromine @ 240 deg c; forms an iodide @ 260 deg c; reacts with acids with liberation of hydrogen & formation of salts of tetravalent uranium; attacked by dry hydrogen chloride at a dull red heat with formation of a stable chloride; combines with sulfur @ 500 deg c, with nitrogen @ 1000 deg C. [The Merck Index. 10th ed. Rahway, New Jersey: Merck Co., Inc., 1983. 1409].

Radiation from uranium has low penetration & elaborate shielding is unnecessary. [International Labour Office. Encyclopedia of Occupational Health and Safety. Vols. I&II. Geneva, Switzerland: International Labour Office, 1983. 955].

Fate.Detail: Detailed Information on Fate, Transport, Persistence, and/or Pathways:

Fission of uranium-235 yields as final products molybdenum-95, lanthanum-139, two neutrons, and about 200 MeV of thermal energy [288]. The neutrons then interact with other uranium nuclei, creating new radioisotopes [288].

For additional information on partitioning among tissues in humans, retention times, detailed ingestion dose coefficients, etc., and other pharmcokinetic items) see: The International Commission on Radiological Protection (ICRP). 1994. Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 3, Ingestion Dose Coefficients. ICRP Publication 69. Pergamon. This document is recommended by radiation risk expert Owen Hoffman, but due to a lack of time none of the information therein was included in this Uranium entry.

Information from HSDB [940]:

> Uranium ... has a complex radioactive decay scheme resulting in the emission of different radiations and the production of several radioactive daughter products. [National Research Council. Drinking Water & Health. Volume 5. Washington, D.C.: National Academy Press, 1983. 90].
>
> AQUATIC FATE: Uranium, thorium, radium, radon, lead, and polonium radionuclide concentrations in ground waters from the Hanford Site indicate that uranium, thorium, and radium are highly sorbed. Relative to radon, these radionuclides are low by factors of 1x10(-3) to 1x10(-6). Uranium sorption is likely due to its reduction from the hexavalent state, where it is introduced via surface waters, to the tetravalent state found in the confined aquifers. The distribution of radionuclides is very similar in all of the confined aquifers and significantly different from the distribution observed in the unconfined and surface waters. Barium correlates well with radium over three orders of magnitude, indicating that stable element analogs may be useful for inferring the behavior of radioactive waste radionuclides in this candidate geologic repository. [Smith MR et al; Materials Research Society Proceedings p.10 (1987).].

Absorption, Distribution and Excretion [940]:

> 1. Absorbed into body with difficulty. [Hamilton, A., and H. L. Hardy. Industrial Toxicology. 3rd ed. Acton, Mass.: Publishing Sciences Group, Inc., 1974. 397 [940].
>
> 2. Insoluble uranium particles may be retained in the lung for a long time & constitute a localized radiological hazard. [Friberg, L., Nordberg, G.F., Kessler, E. and Vouk, V.B. (eds). Handbook of the Toxicology of Metals. 2nd ed. Vols I, II.: Amsterdam:

Elsevier Science Publishers B.V., 1986.,p. V2 623].

3. Once absorbed, uranium rapidly leaves blood & is deposited in tissues; hexavalent uranium has a predilection for kidney & bone tissue whereas the tetravalent form shows a preference for liver, kidney (cortex), & bone (epiphyseal tissue). The critical organs are kidney, bones, & in case of inhalation, the lung. In experimental animals, uranium was recovered from placenta, fetus, & milk of female & from tissues & urine of progeny fed milk from exposed females. Sol cmpd are rapidly eliminated in urine (up to 50% in the 1st day) but tetravalent cmpd are found more in stools. Insol cmpd are not readily eliminated. /URANIUM CMPD/ [International Labour Office. Encyclopedia of Occupational Health and Safety. Vols. I&II. Geneva, Switzerland: International Labour Office, 1983. 2238].

4. Uranium forms soluble complexes with bicarbonate ions & with proteins. Thus, uranium in blood is found complexed with the bicarbonate in plasma to 47%; 32% is bound to plasma proteins & 20% to erythrocytes. ... Uranyl cmpd introduced into the bloodstream are rapidly distributed throughout the human organism. In experiments in humans, two-thirds of the injected dose left the bloodstream 6 min after iv admin, after 20 hr this figure has risen to 99%. ... Major part was rapidly excreted by kidney, & the rest was deposited in kidney & in bone. Under steady-state conditions in occupationally exposed subjects, 85% of the body burden of uranium was found in bone provided that uranium deposited in the lung is excluded. More than 90% of the remaining uranium was in the kidney, & detectable amt could be found in liver. /ALL SOL URANIUM CMPD/ [Friberg, L., Nordberg, G.F., Kessler, E. and Vouk, V.B. (eds). Handbook of the Toxicology of Metals. 2nd ed. Vols I, II.: Amsterdam: Elsevier Science Publishers B.V., 1986.,p. V2 629].

5. ratios of lung burden (including lymph tissue) to urinary excretion rates for 50-500 days were calculated for various exposure patterns of uranium. /URANIUM AND URANIUM CMPD/ [JOHNSON JR; AT ENERGY CAN LTD (AECL-6478): 1-39 (1980)].

Laboratory and/or Field Analyses:

In the past, many methods have been used to analyze for uranium [861,948,1006]. Many of the analytical methods used to detect uranium in environmental samples are the methods approved by federal agencies such as EPA, NRC, and the National Institute for Occupational Safety and Health (NIOSH) [948]. Other methods presented in this chapter are those that are approved by a trade association such as the Association of Official Analytical Chemists

(AOAC) and the American Public Health Association (APHA) [948].

In water, uranium can be analyzed with EPA ICP/MS method 200.8 to an instrument detection limit of 0.02 ug/L in the scanning mode or 0.005 ug/L in the SIM mode [1006]. Tissues (and presumably other solids) can be analyzed for total uranium with laser fluorometry to a detection limit of 0.05 mg/kg (ppm) [948].

Radio Chemical methods include: EPA 908.0; SM 7500-UB; ASTM D3972-82); fluorometric (5M 7500-UC; ASTM D2907-83; USGS R-1180-76; DOE E-U-03): PQL= 5 pCi/L [893]. Other EPA lab methods are summarized in EMMI database [861].

It is important to understand that contaminants data from different labs, different states, and different agencies, collected by different people, are often not very comparable (see also, discussion in the disclaimer section at the top of this entry).

As of 1997, the problem of lack of data comparability (not only for water methods but also for soil, sediment, and tissue methods) between different "standard methods" recommended by different agencies seemed to be getting worse, if anything, rather than better. The trend in quality assurance seemed to be for various agencies, including the EPA and others, to insist on quality assurance plans for each project. In addition to quality control steps (blanks, duplicates, spikes, etc.), these quality assurance plans call for a step of insuring data comparability [1015,1017]. However, the data comparability step is often not given sufficient consideration. The tendency of agency guidance (such as EPA SW-846 methods and some other new EPA methods for bio-concentratable substances) to allow more and more flexibility to select options at various points along the way, makes it harder in insure data comparability or method validity. Even volunteer monitoring programs are now strongly encouraged to develop and use quality assurance project plans [1015,1017].

At minimum, before using contaminants data from diverse sources, one should determine that field collection methods, detection limits, and lab quality control techniques were acceptable and comparable. The goal is that the analysis in the concentration range of the comparison benchmark concentration should be very precise and accurate.

It should be kept in mind that quality control field and lab blanks and duplicates will not help in the data quality assurance goal as well as intended if one is using a method prone to false negatives. Methods may be prone to false negatives due to the use of detection limits that are too high, the loss of contaminants through inappropriate handling, or the use of inappropriate methods.

More detailed discussion of potential sources of variation in contaminants data:

> The way one person collects, filters, and acidifies in the field may be different than the way another does it. Sources of potential variation include the following:
>
> > 1) "As soon as practical." Different situations can change the elapsed time considered by the field collector to be "as soon as practical." It may take different

amounts of time to get to a safe or otherwise optimum place to filter and acidify. In one case precipitation and other changes could be going on in the collection bottle while the bottle in on the way to filtration and acidification, while in another case the field collector filters and acidifies the samples within minutes. Weather, safety concerns, and many other factors could play a role.

2) "Normally 3 mL of (1+1) of nitric acid per liter should be sufficient to preserve the sample." Sometimes it is not, depending on alkalinity and other factors. What field collectors sometimes (often?) do is just use pop tabs of 3 mL of nitric acid and hope for the best rather than checking to see that the acidity has been lowered to below a pH of two. EPA CFR guidelines just call for a pH of below two, whereas samples meant to be "acid soluble" metals call for a pH of 1.5 to 2.0 [25]. See also, various USEPA 1984 to 1985 Ambient Water Quality Criteria Documents for individual metals.

3) One person might use triple distilled concentrated nitric acid rather than reagent grades of acid to avoid possible contamination in the acid, while another may not. When using very low detection limits, some types of acid may introduce contamination and influence the results (Pat Davies, Colorado Division of Wildlife, personal communication, 1997).

4) Holding times can strongly influence the results and there can be quite a bit of variation even within EPA recommended limits (see Silver entry for details). Holding times previously recommended for EPA for NPDES water samples of metals other than mercury or Chromium VI have been as long as 6 months (Federal Register, Volume 49, No. 209, Friday, October 28, 1984, page 43260). In the 1994 version of the CFR, NPDES holding times for mercury and Chromium VI are the same ones listed in 1984, but no EPA holding times are given for other metals (40 CFR, Part 136.3, Table 2, page 397, 1994).

Differences in the details of the method used can drastically change the results. Some cold, wet, hurried, or fire ant-bitten collectors might decide that it is not "practical" to filter and acidify quite so immediately in the field, and may decide the shore, a vehicle, a motel room, or even a remote lab are more "practical" locations. Filtering and acidifying in the field immediately is a better option for consistency (see copper entry for an example of what can happen if there is a delay). If one field filters and acidifies, one may be changing metals and colloidal content. Acidifying effects microbial changes. If one holds the samples a while before filtering and acidifying, the situation changes. In collection bottles there are potential aging effects:

temperature changes, changes in basic water chemistry as oxygen and other dissolved gasses move from the water into the headspace of air at the top, potential aggregation of colloidal materials, precipitation of greater sizes with time, development of bigger and more colloids, and more sorption (Roy Irwin, NPS, personal communication, 1997).

The bottom line: since standard EPA methods for holding times and field preservations change, updates are not always convenient to obtain, since the wording is somewhat imprecise, and since field collectors may actually do different things in different situations, variation in metals concentrations may sometimes be due to differences in how individual investigators treat samples in the field and lab (Roy Irwin, National Park Service, Personal Communication, 1997).

Notes on total vs. acid soluble vs. dissolved metals:

> Although most of the lab tests done to develop water quality criteria and other benchmarks were originally based on "total" values rather than "dissolved" values, the lab settings were typically fairly clean and the numbers generated by the lab tests are therefore often even more comparable to field "dissolved" values than to field "total" values (Glen Suter, Oak Ridge National Lab, Personal Communication, 1995). As of January 1995, the U.S. EPA was recommending that states use dissolved measurements in water quality standards for metals, in concert with recommendations EPA previously made for the Great Lakes [672]. However, generic conversion factors may not hold up for many areas. Both total and dissolved concentrations should be checked at new locations before relying on this conversion factor (Pat Davies, Colorado Division of Wildlife, personal communication, 1997).

Filtration and Holding Times:

> For ICP water samples for metals samples taken for NPDES permits, EPA recommends the following (40 CFR Part 136, Appendix C, 1994 edition of CFR Part 40, page 642):
>
>> 1) For samples of "total or total recoverable elements," samples should be acidified to a pH of two or less at the time of collection or as soon as possible thereafter.
>>
>> 2) For determination of dissolved elements, the samples must be filtered through a 0.45 micron membrane filter as soon as soon as practical after collection, using the first 50-100 ml to rinse the filter flask. Acidify the filtrate with nitric acid to a pH of 2 or less. Normally 3 mL of (1+1) of nitric acid per liter should be sufficient to preserve the sample.

3) For determination of suspended elements, the samples must be filtered through a 0.45 micron membrane filter as soon as soon as practical after collection. The filter is then transferred to a suitable container for storage and shipment, with no preservation required.

EPA 1996 IRIS database information for natural uranium vs. drinking water (CAS 7440-61-1) and for Uranium, soluble salts (no CAS number) [893]:

Monitoring Requirements

All systems monitored for 4 consecutive quarters; repeat monitoring dependent upon detection and vulnerability status.

ATSDR Summaries on Uranium Methods: Information on analytical methods that are available for detecting and/or measuring and monitoring uranium in environmental media and in biological samples (see ATSDR for embedded references) [948].

Many of the analytical methods used to detect uranium in environmental samples are the methods approved by federal agencies such as EPA and the National Institute for Occupational Safety and Health (NIOSH). Other methods presented in this chapter are those that are approved by a trade association such as the Association of Official Analytical Chemists (AOAC) and the American Public Health Association (APHA) [948].

Methods for Biological Materials [948]:

Several methods are available for the quantification of uranium in biological matrices. The commonly used methods that do not require more involved chemical separation steps are spectrophotometric, fluorometric, and gross alpha counting (Wessman 1984). In the spectrophotometric method, certain ions (e.g., Fe [+3]) interfere with the color development and must be eliminated. In the fluorometric method, several ions quench and a few ions enhance the fluorescence of uranium (ASTM 1986) [948].

If a quantification of an individual isotope is needed, the commonly used method is alpha spectrometry. Some of the more capital intensive and sophisticated techniques that will allow isotope quantification are isotope dilution, alpha spectrometry, and isotope-dilution mass spectrometry. The latter technique is probably most sensitive and accurate for the quantification of uranium isotopes (Wessman 1984) [948].

Uranium is likely to be excreted in urine as uranyl ions. A few authors have correlated intake of uranium with rate of urinary excretion (Davis 1985; Schieferdecker et al. 1985; Thind 1987). Therefore, urinary levels of uranium are used to measure exposure. Other soft and hard tissues are also analyzed to measure the distribution of uranium. Since uranium deposits in bone, it is the second most frequently analyzed biological media after urine [948].

Bone is available for analysis only at autopsy and is not used for routine screening purposes. According to NRC Guide 8.22, the acceptable methods for the quantification of uranium in urine must have a detection limit of 5 ug/L and a precision of 30% (Kressin 1984). ... Some of the less common techniques include particle-induced x-ray emission and Rutherford backscattering). A description of the advanced analytical techniques for the quantification of uranium is given by Bushaw (1984). See ATSDR for a table summarizing analytical methods for determining uranium in biological samples [948].

Determining accuracy of the quantification methods for biological samples by the common analytical methods requires that standard reference materials with known concentrations of uranium be available. Two of the standard reference materials (SRMs) available from the National Bureau of Standards are human lung (SRM 4351) and human liver (SRM 4352) (Inn 1987). Another biological reference material containing low levels of uranium that has been standardized recently but not certified is freeze-dried urine (SRM 2670) (Kelly et al. 1987) [948].

Methods for Environmental Samples [948]:

Scott (1973) lists the sampling methods for uranium in occupational atmospheres and Beverly and Ernstberger (1986) report a method for monitoring stack gases of gaseous diffusion plants. In many environmental samples, uranium may be present in several chemical forms. A method for the determination of the oxidation states (U+6 and U+4) of uranium in natural water is available (Anderson 1984). A review and summary table of analytical methods for uranium in water and other enviromental samples is given by ATSDR [948]... Although several methods are available, the choice of method will depend on the type of information required from the analysis. Fluorometry for the determination of total uranium and alpha spectrometry for isotopic quantification are two widely used methods. If the mass of uranium measured by fluorometry needs to be converted to the activity unit, a certain ratio of uranium-234/uranium-238 is assumed. For natural water and soil, this ratio is assumed to be 1, and a factor of 0.67 or 0.72 pci/ug is used for conversion of concentration expressed in ug/L or ug/kg to activity unit (Blanchard et al. 1985). However, the uranium-234/uranium-238 ratio varies in natural soil and particularly in groundwater (NCRP 1984), and the assumption of 1:1 ratio will sometimes lead to erroneous estimation of activity [948].

In enriched samples and samples containing artificial isotopes, the activity due to uranium-234 and uranium-235 are different from samples with natural isotopic distribution. Therefore, counting activity due to an individual isotope or counting the ratio of activity by alpha spectrometry in such samples is one of the methods of choice. However, the abundance of uranium-235 in samples of natural and depleted uranium is such that it may be difficult to resolve the uranium-235 4.58 Mev alpha peak from the tail of uranium-234 4.77 Mev alpha peak, limiting the precision and accuracy of the quantified values for both isotopes (Gladney et al. 1983) [948].

Where accountability of isotopes is critical, as in the case of Nuclear Fuel Cycle, precise isotopic mass measurements using chemical separation and mass spectrometry may be required. In plant uptake studies that use uranium-232 or uranium-233 as tracer, the quantification method may be isotope-dilution alpha spectrometry (Wessman 1984). The sensitivity of different methods are given in Table 6-2. Isotope-dilution mass spectrometry provides the most accuracy and sensitivity (Wessman 1984). See ATSDR for a table summarizing Analytical Methods for Determining Uranium in Environmental Samples [948].

Abbreviations: APDC = ammonium pyrrolidine dithiocarbamate; ASTM = American Society for Testing and Materials; Bq = Bequerel and 1 pCi = 0.037 Bq; dpm = disintegration per minute and 1 pCi = 2.22 dpm; EDTA = ethylenediamine tetracetic acid; HPLC = high pressure liquid chromatography; ICP-MS = inductively-coupled plasma-mass spectrometry; NAA = neutron activation analysis; ng = 10-9 g; nM = nanomole or 10-9 of a mole; ppb = ug/L [948].

Uranium-containing Standard Reference Materials (SRMs) available from the National Bureau of Standards are river sediment (SRM 4350B), soils (SRM 4353 and 4355), and lake sediment (SRM 4354) (Inn, 1987). In addition, Gladney and Rook (1975) determined the uranium content in the commercially available SRMs orchard leaves (SRM 1571), coal (SRM 1632), and fly ash (SRM 1633) [948].

The following categories of possible data needs have been identified by a joint team of scientists from ATSDR, NTP, and EPA. They are defined as substance-specific informational needs that, if met would reduce or eliminate the uncertainties of human health assessment. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed [948]:

Methods for Determining Biomarkers of Exposure and Effect. Several studies attempt to correlate levels of uranium in the environment with levels in human tissues. Analytical methods with satisfactory sensitivity and precision are available to determine the levels of uranium in most human tissues and body fluids of exposed and background populations, and there is no need for developing new analytical methods [948].

In a study reported by NIOSH (Thun et al. 1981, 1985), enhanced levels of beta-2-microglobulin levels in urine of uranium workers were observed. It was suggested that enhanced levels of beta-2- microglobulin in human urine be used as an indication of uranium exposure. However, no correlation was established between urinary beta-2-microglobulin levels and uranium exposure levels (Thun et al. 1981, 1985). Therefore, it would be helpful to develop a biomarker that will serve as an indicator of effects from uranium exposure [948].

Methods for Parent Compound and Degradation Products in Environmental Media. Analytical methods with required sensitivity and precision are available for the quantification of uranium in most environmental matrices. However, there is a lack of analytical methods of required precision and accuracy to determine the background level of uranium in the air. Knowledge of the levels of uranium compounds in environmental media can be used to indicate human exposure to uranium via inhalation of air and ingestion of drinking water and foods containing these compounds [948].

The available analytical methods indicate that the highest percent of total general population exposure to uranium occurs from consumption of foods, although in certain areas drinking water becomes an important or even the dominant contributing factor. In the environment, uranium and its compounds speciate and form radioactive decay products. Analytical methods for the quantification of radioactive decay products, such as radium, radon, polonium, and lead, are available, but there are few analytical methods that will allow quantification of the speciation products formed as a result of environmental reactions (e.g., formation of carbonato complex) [948].

Other Misc. Notes on Analytic Laboratory Methods [940]:

1. General sample; analyte: uranium: manning, dc, atomic absorption newsletter 5, 127 (1966). Goleb, ja, anal chim acta 34, 135 (1966). /TOTAL URANIUM/ [Sunshine, I. (ed.). CRC Handbook of Analytical Toxicology. Cleveland: The Chemical Rubber Co., 1969. 975].

2. Neutron activation analysis appears to be the method of choice for determination of uranium in a wide variety of inorganic ... samples ... provided a reactor is available. With a rapid radiochemical separation chemical yield for complete analysis was 95 + or - 3% for metals. ... /Total uranium/ [Clayton, G. D. and F. E. Clayton (eds.). Patty's Industrial Hygiene and Toxicology: Volume 2A, 2B, 2C: Toxicology. 3rd ed. New York: John Wiley Sons, 1981-1982. 1999].

3. A simple, rapid colorimetric method utilizing ferrocyanide for the determination of uranium in dust samples ranging upward from 80 ug is described. ... /Total uranium/ [Clayton, G. D. and F. E. Clayton (eds.). Patty's Industrial Hygiene and Toxicology: Volume 2A, 2B, 2C: Toxicology. 3rd ed. New York: John Wiley Sons, 1981-1982. 1999].

4. /Investigators/ ... have recovered uranium quantitatively from seawater by spectrophotometric estimation with 8-hydroxyquinoline after passage through a chelating ion exchange column, & preceded by a trioctylamine extraction. This procedure allowed determination of 200 ug uranium. ... /Total uranium/ [Clayton, G. D. and F. E. Clayton (eds.). Patty's

Industrial Hygiene and Toxicology: Volume 2A, 2B, 2C: Toxicology. 3rd ed. New York: John Wiley Sons, 1981-1982. 1999].

5. In neutron activation analysis, the uranium ... can be determined by a number of nuclear techniques incl: direct alpha-counting, delayed neutron counting, fission track counting, nuclear activation techniques utilizing (239)Np (a daughter of (239)uranium), several different fission products of (235)uranium, & a number of procedures using the nuclear reaction. ... /Uranium/ [Friberg, L., Nordberg, G.F., Kessler, E. and Vouk, V.B. (eds). Handbook of the Toxicology of Metals. 2nd ed. Vols I, II.: Amsterdam: Elsevier Science Publishers B.V., 1986.,p. V2 625].

Clinical Laboratory Methods [940]:

1. In the determination of the uranium content of biological samples, the organic material must first be destroyed by ashing or by acid treatment. Interfering substances may be removed by ion exchange or by solvent extraction after the addition of appropriate chelating agents. After uranium recovery has been ascertained through these separation techniques, the uranium content of the purified sample may then be determined by mass spectrometry (detection limit 2x10-12 g), fluorimetric method (1x10-9 g) or radiometric method (1x10-9-1x10-12 g). /Total uranium/ [Friberg, L., Nordberg, G.F., Kessler, E. and Vouk, V.B. (eds). Handbook of the Toxicology of Metals. 2nd ed. Vols I, II.: Amsterdam: Elsevier Science Publishers B.V., 1986.,p. V2 624.

2. For small samples ... of biological origin, the fluorophotometric method is recommended. It is suitable for the determination of uranium in the ppb range if preliminary protein isolation & electrolysis procedures are used. Polarographic determination of uranium is ... valuable for determination of trace amt of hexavalent form in the presence of tetravalent uranium because it requires no prior separation procedures. /Total uranium/ [Clayton, G. D. and F. E. Clayton (eds.). Patty's Industrial Hygiene and Toxicology: Volume 2A, 2B, 2C: Toxicology. 3rd ed. New York: John Wiley Sons, 1981-1982. 1999].