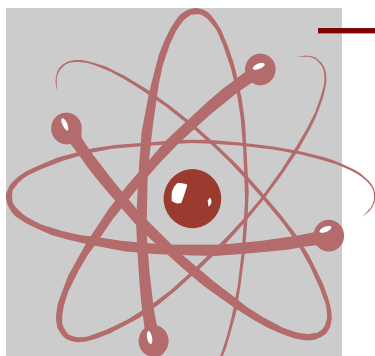




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A Citizen's Guide to Uranium

February 2009

Introduction

In my work as a health physicist, I do a lot of public speaking and interact with the public on issues related to development of uranium mining and milling ("uranium recovery") in the U.S. Understandingly, the public has important concerns about this. In a "question and answer" format below, I have tried to capture what are some of the most common concerns heard from citizens and address them based on the best scientific information we have, representing information well documented in peer-reviewed scientific literature and consensus positions from both national and international scientific standard setting bodies and related committees. Some of the more important of these scientifically-based references are provided to support the information given below. Practical space limitations prevent completeness in this regard in some cases. Visit the Health Physics Society's web site or feel free to contact me directly for additional references, information or detail – Steve Brown.

About the Author

Steve Brown has over 35 years experience as a health physicist* and is certified by the American Board of Health Physics. (<http://www.hps1.org/aahp/abhp/abhp.htm>). Over the years, he has worked extensively in the uranium fuel cycle as a senior manager developing and overseeing radiation safety programs for plant workers and related environmental monitoring programs for the public. He is currently President (2008 – 2009) of the Central Rocky Mountain Chapter of the Health Physics Society. He possesses a

Bachelors degree in Physics and a Masters in Physical Science. He was a high school science teacher prior to entering industry and has taught graduate courses in radiological science as an adjunct professor at the Colorado School of Mines. He is president of SHB Inc, a radiological science consulting firm in Englewood, Colorado and represents SENES Consultants Limited, an internationally respected environmental consulting firm with specialists in a number of disciplines, including mining and radiological science.

*Health Physics Society states the health physicist's job is to manage the beneficial uses of ionizing radiation while protecting workers and the public from potential hazards. For more information on what a health physicist is and on the Health Physics Society, visit the Society's web site <http://www.hps.org>

1. What is uranium and where does it come from?

Uranium is a naturally occurring radioactive element, which was part of the Earth's formation 4.5 billion years ago. Like many other minerals, it has been deposited on land by volcanic action over geologic time, dissolved by rainfall and in some places carried into underground formations. Chemical conditions in some locations resulted in concentration into

“ore bodies”. It is a fairly common element in Earth's crust (soil, rock) and in groundwater and seawater, typically in concentrations almost anywhere of 2-4 parts per million (ppm) – as common as tin, tungsten, molybdenum, etc. A square mile of earth (640 acres), one foot deep, will typically contain over a ton of radioactive uranium.

2. How much uranium and its associated elements (“decay products” ¹) are in the food we eat, water we drink and in the soil under our feet?

Uranium in groundwater:

The average concentration of uranium in groundwater in the U.S. is about 2 picocuries ² per liter (pCi/liter). The U.S. Environmental Protection Agency's drinking water standard for uranium is about 20 picocuries per liter (expressed on a mass basis as 30 micrograms (30 millionths of gram) per liter — see <http://www.epa.gov/OGWDW/radionuclides/basicinformation.html>).

However, concentrations can vary considerably from place to place depending on local geology and other factors. Numerous studies that have been conducted in the U.S. indicate levels in groundwater that are used for domestic purposes including drinking water can be many times higher than EPA's standard.

A recent study performed by scientists at Los Alamos National Laboratory and Colorado State University in the Nambe region of New Mexico found that over 50% of the wells tested exceeded the EPA limit with some values as high as 800 pCi/liter.

The California Department of Health Services conducted an investigation of uranium in ground water in the community of Glen Avon with some results greater than 40 pCi/liter.

Typical annual uranium intake in example foods:

Whole-grain products: 10 pCi

Meat: 50-70 pCi

Fresh fruit: 30-51 pCi

Potatoes: 67-74 pCi

Bakery products: 39-44 pCi

Typical concentration in soil and rocks (pCi per gram):

uranium = 0.6-3.0

uranium in “phosphate rock” = 40-80

radium = 0.4-3.6

thorium = 0.2-2.2

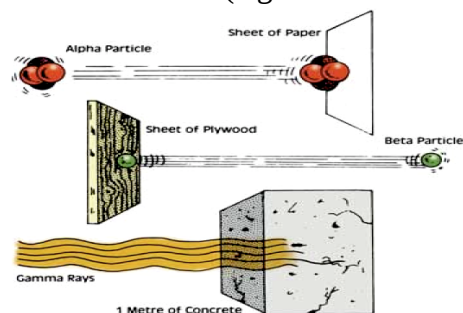
¹Decay products = those chemical elements that uranium decays into as a result of its radioactive properties, e.g., thorium and radium, which are also radioactive.

² A picocurie is a measure of the amount of radioactivity. It is the amount of radioactivity where approximately two atoms decay per minute.

Sources for Q/A # 2: (1) *Assessing Potential Risks from Exposure to Natural Uranium in Well Water*. Hakonson-Hayes A.C., P.R. Fresqueza, F.W. Whicker, *Journal of Environmental Radioactivity*, 59 (2002) (2) *Public Health Goal for Uranium in Drinking Water*. Office of Environmental Health Hazard Assessment California Environmental Protection Agency, 1997 (3) National Council on Radiation Protection and Measurements. *Natural Background Radiation in the United States*. NCRP Report No. 45. 1975. (4) National Council on Radiation Protection and Measurements. *Exposure of the Population in the United States and Canada from Natural Background Radiation*. NCRP Report No. 94. 1992 (5) National Council on Radiation Protection and Measurements. *Exposures from the Uranium Series with Emphasis on Radon and its Daughters*. NCRP Report No. 77. 1987 (6) Welford GA, Baird R. *Uranium Levels in Human Diet and Biological Materials*. *Health Physics Journal* 13(12): 1,321-1,324, 1967

3. How radioactive is uranium and uranium ore compared to other consumer products we use everyday that contain radioactive substances?

First, let's define what we mean when we say that a substance is "radioactive". Certain elements (atoms) contain excess particles in their nucleus (central part of the atom) and therefore have excess energy. Nature attempts to achieve a more stable configuration as the atoms emit particles (alpha, beta) or electromagnetic radiation (x and/or gamma rays) to get rid of this excess energy and become more stable. Radioactivity in the environment can emit three types of radiation to do this as depicted in Figure 1. As illustrated in the figure, gamma rays are very penetrating compared to beta or alpha particles. In fact, alpha particles can be stopped by a sheet of paper and therefore are of primary concern when taken into our bodies (e.g. in our food or water).



Typical uranium ore contains approximately 700 picocuries per gram of uranium assuming 1,000 parts per million of uranium in the ore which is typical in the U.S. at this time. That is, a "handful" of uranium ore, let's say 10 grams (1/3 ounce), would contain about 7000 pCi of uranium (about 50,000 pCi including uranium's other naturally occurring radioactive "decay products").

A common household smoke detector (containing americium, a radioactive substance made in nuclear reactors) has an average of 50,000,000 picocuries. Typical modern luminous wrist watch dials contain an average of 1,300,000,000 picocuries of radioactive hydrogen (tritium – also made in nuclear reactors).

Sources for Q/A #3: National Council on Radiation Protection and Measurements. *Radiation Exposure from Consumer Products and Miscellaneous Sources*. NCRP Report No. 56. 1977

FIGURE 1: Radioactive substances can emit alpha or beta particles and/or gamma or x-rays in an attempt to become more stable.

4. Are existing regulations (Federal or Colorado) for uranium recovery facilities (mines, mills and in situ recovery plants) adequate to protect the public from additional radiation exposure above our natural background exposure?

Our lifestyles, where we choose to live, what we eat and drink, has a much larger impact on our radiation exposure than exposure at these regulatory limits.

The basic regulatory limits that operating uranium fuel cycle facilities must comply with are 100 millirem* per year from all sources including radon and 25 millirem / year excluding radon** (U.S. Nuclear Regulatory Commission: 10 CFR 20 and 10 CFR 40 Appendix A; Colorado Department of Public Health and Environment: 6 CCR 1007-1 Part 4 and Part 18 Appendix A)

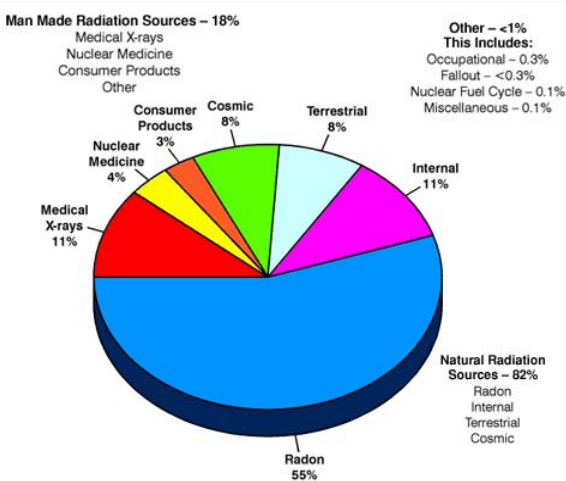
*NOTE: a millirem is a unit of effective radiation dose. It is related to the amount of energy absorbed by human tissue and other factors. 1,000 millirem = one rem.

**Radon is a naturally occurring radioactive gas, which is released into the atmosphere at the Earth's surface. It is a decay product of uranium.

Now let's compare these regulatory levels to the annual radiation doses we receive as citizens of planet Earth. Figure 2 depicts the typical components of human exposure to ionizing radiation.

FIGURE 2: Natural background radiation is generally the largest source of radiation exposure to humans

Ionizing Radiation Exposure to the Public



The above chart is taken from the National Council on Radiation Protection and Measurements (NCRP) Report No. 93, "Ionizing Radiation Exposure of the Population of the United States," 1987. This chart shows that natural sources of radiation account for about 82% of all public exposure while man-made sources account for the remaining 18%.

Natural radiation exposure can vary considerably from place to place across the U.S. or over relatively small areas within a region. This is due to effects of elevation (higher cosmic radiation exposure at higher elevations), greater levels of naturally occurring radioactive elements in soil and water in mineralized areas (e.g., igneous formations in Rocky Mountains) and other factors like local geology and chemistry. This is depicted in Table 1, which compares average annual background radiation exposure for the U.S., all of Colorado and Leadville, Co. (high elevation and in mineralized area). This table shows the major components of natural background radiation including terrestrial radiation (uranium, radium, thorium and a naturally radioactive form of potassium in soil, rocks and water), cosmic radiation (high energy rays from space) and internal radiation (from food, water and radon gas from natural uranium decaying in the ground).

The data in Table 1 demonstrates that the differences in annual background exposure based on where one chooses to live, eat and drink have a much greater impact on public exposure than do the regulatory dose limits.

An additional perspective, particularly of interest to Coloradans, is depicted in Figure 3, which shows the change in radiation exposure rate due to variation in elevation and mineralization as one travels across the Interstate 70 corridor between Denver and Grand Junction.

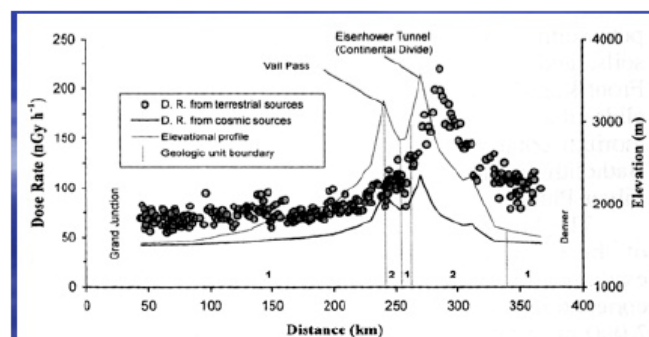
TABLE 1: Comparison of average radiation backgrounds in US vs. Colorado (units of millirem / yr)

Source	U.S. Avg. ¹	Colorado Avg. ²	Leadville ²
Cosmic Radiation	27	50	85
Terrestrial Radiation	28	49	97
Internal Radiation including Radon	200	301	344
Totals	255	400	526

¹ National Council on Radiation Protection and Measurements. *Exposure of the Population in the United States and Canada from Natural Background Radiation*. NCRP Report No. 94; 1992.

² Moeller D, Sun LSC. *Comparison of Natural Background Dose Rates for Residents of the Amargosa Valley, NV, to those in Leadville, CO, and the States of Colorado and Nevada*. Health Physics 91:338-353; 2006

FIGURE 3: Variability of terrestrial and cosmic radiation background across the interstate 70 corridor of Colorado.*



*In units of nano grays per hour – divide by 10 to get micro roentgens per hour. Sorry – yet more units and terms. For our purposes here, the technical distinction between micro roentgen and millirem is immaterial.

The point of this graph is that if one "chooses" to live in Colorado mountain communities (lets say Breckenridge e.g., at about 8000 ft above sea level surrounded by igneous rocks) ones annual dose could be 50 -100 millirem per year more than your brother in Denver and 100 – 200 millirem per year greater than your mother in law in New Jersey! Source: Stone, JM, Whicker, RD et al, *Spatial Variations in Natural Background Radiation: Absorbed Dose Rates in Air in Colorado*. Health Physics, Vol. 9(5), May 1999.

5. What are the potential health effects from exposure to uranium?

This is another important concern of many citizens. Our understanding is complicated by much misinformation that we are regularly exposed to. Uranium is a heavy metal and acts similarly to other heavy metals in the body (like molybdenum, lead, mercury). Accordingly, for natural uranium, national and international human exposure standards are based on the possible *chemical toxicity* of uranium (e.g., effect on kidney—nephrotoxicity), not on radiation and possible “cancer effects” (radiotoxicity). However, there has never been a death or permanent injury to a human from uranium poisoning.

Sources: (1) U.S. Nuclear Regulatory Commission. *Standards for Protection Against Radiation*; 10 CFR 20, Appendix B. 1992. (2) International Commission on Radiological Protection. *Limits for Intakes of Radionuclides by Workers*. ICRP Publication 30, 1979. (3) US Dept. of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. *Toxicological Profile for Uranium*. 1999. (4) *Acute Chemical Toxicity of Uranium*. Kathryn, RL and Burkin, RK. *Health Physics*, 94(2), pp 170-179, February 2008.

Regarding ionizing radiation in general, the health effects are well understood. No health effects have been observed in human populations at the exposure levels within the range and variability of natural background exposures in the US. An official position of the National Health Physics Society is that below 5,000 – 10,000 millirem (which includes the range of both occupational and environmental exposures), risks of health effects are either too small to be observed or non-existent (see *Radiation Risks in Perspective* at: www.hps.org/hpspublications/positionstatements). International and national authorities that establish exposure standards for workers and the public rely on the work of scientific committees of the highest professional standing for their evaluations of the scientific information on the health effects of ionizing radiation. These scientific

committees include the United Nations Scientific Committee on the Effects of Ionizing Radiation (UNSCEAR); the International Commission on Radiological Protection (ICRP); the National Academy of Science’s Biological Effects of Ionizing Radiation (BEIR) Committee, the National Council on Radiation Protection and Measurements (NCRP) and others.

But what about the specific concerns regarding health effects to populations living close to uranium recovery facilities? Despite much confusion and misunderstanding, possible health effects in populations living near uranium mines and mills have been well studied. No additional effects have been observed when compared to the health status of other similar populations not living nearby. A few sources providing the scientific evidence that supports this very important point include:

U.S. Department of Health and Human Services, Public Health Services, Agency for Toxic Substance and Disease Registry, *Toxicological Profile for Uranium*, 1999. Chapter 1: Public Health Statement for Uranium, Section 1.5: How Can Uranium Effect My Health? – “No human cancer of any type has ever been seen as a result of exposure to natural or depleted uranium” (Available at: <http://www.atsdr.cdc.gov/toxprofiles/tp150.html>)

Cancer and Noncancer Mortality in Populations Living Near Uranium and Vanadium Mining and Milling Operations in Montrose County, Colorado, 1950 -2000. Boice, JD, Mumma, MT et al. *Journal of Radiation Research*, 167:711-726; 2007: “The absence of elevated mortality rates of cancer in Montrose County over a period of 51 years suggests that the historical milling and mining operations did not adversely affect the health of Montrose County residents”

Cancer Mortality in a Texas County with Prior Uranium Mining and Milling Activities, 1950 – 2001. Boice, JD, Mumma, M et al. *Journal of Radiological Protection*, 23:247 – 262; 2003 – “No unusual patterns of cancer mortality could be seen in Karnes County over a period of 50 years suggesting that the uranium mining and milling operations had not increased cancer rates among residents”.

6. What about the known health impacts (e.g., lung cancer) to many uranium miners who worked underground in the 1950s and 1960s?

These miners worked in conditions that by today's standards we would consider unacceptable. They were exposed to very high levels of "radon daughters" (which are decay products of uranium) in poorly ventilated underground mines. Many of these miners also were smokers, which enhanced the ability of the radon daughters to deliver radiation dose to the lung. These conditions existed before we had Federal Agencies (Occupational Safety and Health Administration - OSHA, Mine Safety and Health

Administration - MSHA, US Nuclear Regulatory Commission - NRC) and laws to better protect workers throughout American industry (construction, manufacturing, farming, mining, etc). Based on the best scientific information available, we consider as safe the occupational exposure standards we have today as enforced by these agencies. The level of exposure of some of these early uranium miners were 100 times or more greater than our current Federal standards.

7. How is uranium extracted from the earth?

There are two basic approaches to uranium extraction: (1) conventional mining and milling and (2) in situ recovery (ISR).

Conventional methods involve extraction of large volumes of rock and soil containing uranium ore from underground mines or open pits at/near the surface. The rock is crushed and the uranium is dissolved out of the crushed rock in the mill. Milling processes extract the uranium from solution and concentrate it into the final "yellowcake" (U_3O_8) product (the final product of a uranium milling process).

In situ recovery methods (ISR) involve reversing the natural geochemical processes that lead to uranium concentration into ore bodies. These natural geochemical processes brought uranium out of the groundwater millions of years ago, forming deposits, which are now mined using the ISR process. ISR methods make the uranium again soluble in groundwater, forming a solution that is then pumped to a recovery plant on the surface. Uranium is loaded on resin in closed metallic columns or tanks to concentrate it and then processed similarly to conventional uranium mills to produce the final "yellowcake" product.

8. What is uranium used for and why is it important?

The number one use is for electricity generation via nuclear fission. Approximately 20 percent of U.S. electricity is generated by uranium fuel in nuclear power plants (approximately 100 plants in the US, over 400 currently worldwide and many more planned). Uranium fission in nuclear reactors also makes many isotopes used extensively in medicine (e.g., a form of molybdenum (^{99}Mo) used for over 70% of the world's nuclear medicine diagnostic studies) and for consumer products as previ-

ously discussed (e.g. americium for smoke detectors and tritium for luminous watch dials). The process of "uranium fission" is depicted in Figure 4. Since it is an extremely dense and heavy metal but relatively flexible, uranium is also used in military armor and armament as well as counterweights on ships and aircraft. It has also been used for many years as a coloring agent in ceramics and glass. (e.g., see *Consumer Products Containing Radioactive Materials*. Health Physics Society Fact Sheet. Available at: www.hps.org/hpspublications/radiationfactsheets.html.)

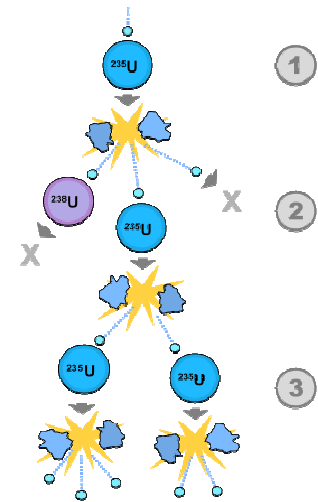
Figure 4: Nuclear Fission - each "fission" of a Uranium 235 atom by a neutron results in release of radiation (heat, light, gamma and X rays) more neutrons and other particles. In a nuclear reactor, the heat produced from fission is used to boil water to make steam to run turbines like in any other electricity generating power plant. (Figure from: http://en.wikipedia.org/wiki/Nuclear_fission)

Regarding uranium's use and importance as a fuel to generate electricity, it is of interest to note that one pound of yellowcake has the energy equivalence of 35 barrels of oil. One 7-gram (1/4-ounce) uranium fuel pellet (fuel that goes into reactor) has an energy to electricity equivalent of 17,000 cubic feet of natural gas, 149 gallons of oil or 1,780 pounds of coal (Source: US Department of Energy, Energy Information Administration and Nuclear Energy Institute)

The approximately 100 nuclear power plants operating in our country today consume about 60 million pounds of uranium fuel per

year but the U.S.'s current annual production is only about 5 million pounds per year. As is our current situation with oil, we are therefore highly reliant on foreign sources and some of these regimes

(now and/or in future) may not be friendly to the US. Given the expansion of economies like China and India who plan on building large numbers of new nuclear plants in the next two decades, we will be competing for world-wide uranium supplies.



9. Don't scientists disagree on many of the health and safety concerns associated with uranium and radiation exposure in general?

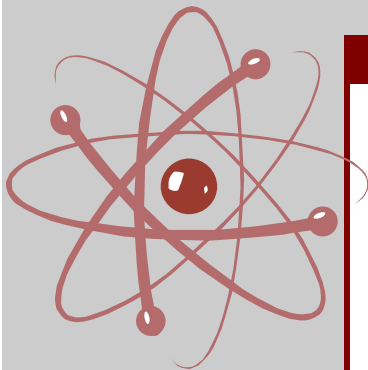
In fact, the vast majority really do not. Much of the information presented here represents "consensus science", that is, the generally agreed-upon positions of national and international bodies of experts, many of who are appointed to these positions by their peers and/or by their governments around the world.

We are often concerned and confused with "who do we believe?" since there are of course alternative opinions offered by some for a variety of reasons, not always because of scientific disagreement based on interpretation of evidence. As citizens, we need to evaluate for ourselves what I'll refer to as the relative "weight of evidence". This includes evaluating the expertise of the "speaker". Lots of folks have lots of degrees in all kinds of things but having advanced degrees in something doesn't necessarily make one an expert in something else. (If I had a high fever, I probably wouldn't consult my dentist, despite the fact that she is also "a doctor".) We should consider as important one's life and work experience relevant to the subject

matter as we evaluate the credibility of individuals and weight of their evidence. Many citizens I interact with are not scientists, and the "weighing" of contradicting claims on what are often complex and emotional issues can be difficult and challenging for many folks. When faced with these apparent "disputes" and upon objective examination, we will often find that the relative weights of these claims are not equal at all.

The importance of some issues to a community as well as to the national interest is often sufficient to require us to demand the evidence and evaluate it on its merit. Apply the challenge of the well-known late American scientist, Dr. Carl Sagan: "*Remarkable claims demand remarkable evidence*". And on the importance of science to the United States' future, I'll defer to Thomas Jefferson: "*The daily advance of science will enable us and future generations to administer the commonwealth with increased wisdom*" *. As we continue to struggle with the relationship between our national security and energy independence, let's try and do Thomas proud.

* Thomas Jefferson to Lafayette, 1823: In *The Writings of Thomas Jefferson* (Memorial Edition - Lipscomb and Bergh, editors), 20 volumes, 1903-04.



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SENES Consultants Limited is a Canadian wholly employee-owned company that specializes in the fields of energy, nuclear, and environmental sciences. Since its inception in 1980, the company has participated in over 4,800 projects throughout Canada, United States, South America, the Caribbean, Africa, Australia, Europe, Asia, the Middle East and the Far East. The



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