A CITIZENS GUIDE TO URANIUM: RECENT EXPERIENCES IN COMMUNICATING WITH THE PUBLIC AND PUBLIC OFFICIALS ON NEW URANIUM RECOVERY PROJECTS

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In our work as health physicists*, we do a lot of public speaking and interaction with the public on issues related to development of uranium mining and milling (“uranium recovery”) in the US. Understandingly, the public has important concerns about this. Accordingly, this paper is presented in a “question and answer” format in which we have tried to capture what are some of the most common concerns we hear from citizens and address them. We have attempted to do so 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. We have included some of the more important of these scientifically-based references to support the information provided. 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.

The health physicist’s primary objective 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 at www.hps.org.

WHAT IS URANIUM AND WHERE DOES IT COME FROM. WHAT ARE THE ORIGINS AND SOURCES OF URANIUM IN THE NATURAL ENVIRONMENT?

Uranium is a naturally occurring radioactive element, which was part of 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.

HOW MUCH URANIUM AND ITS ASSOCIATED ELEMENTS (“DECAY PRODUCTS” *) ARE IN THE FOOD WE EAT AND WATER WE DRINK EVERYDAY AND IN THE SOIL UNDER OUR FEET?

Uranium in groundwater:

The average concentration of uranium in groundwater in the US is about 2 picocuries2 per liter (pCi/liter). The US Environmental Protection Agency’s drinking water standard for uranium is about 20 picocuries per liter (expressed on a mass basis as 30 micrograms (millioths of gram) per liter (USEPA, 2012).

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

A 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 (Hakonson, 2002).

The California Environmental Protection Agency conducted an investigation of uranium in ground water in the community of Glen Avon with some results greater than 40 pCi/liter (OEHHACEPA, 1997).

Typical concentration in soil and rocks (pCi per gram) (NCRP, 1987):

- uranium = 0.6-3.0
- uranium in “phosphate rock” = 40-80
- radium = 0.4-3.6
- thorium = 0.2-2.2

Radioactive isotopes are inherent in all foods. Natural radioactive isotopes, such as potassium 40 (K-40), carbon-14 (C-14), tritium (H-3), and various other radioactive elements which are anthropogenic, primordial, or cosmogenic3 in the nature of their production, are part of the food chain. Plants assimilate radionuclides into their structure through respiration, transpiration, and soil uptake. In some instances, these radioisotopes may be concentrated into certain parts of the plant where other stable isotopes of the same element are also being concentrated, such as the roots, fruits, or nuts. This effect is especially notable in fruits with high levels of potassium, such as bananas.

One banana contains approximately 422 mg of potassium (Chiquita Banana, 2013). The radioactive isotope of potassium identified above, K-40, has a natural occurrence of 0.0117% (Strom et al, 2009). Therefore, of the 422 mg of potassium in a banana, about 0.5 mg are radioactive. With knowledge of the specific activity of natural potassium (31.72 Bq/g) (Strom et al, 2009), this translates into

<table>
<thead>
<tr>
<th>Food</th>
<th>Typical Concentration (pCi)</th>
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<tbody>
<tr>
<td>Meat</td>
<td>50-70</td>
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<tr>
<td>Fresh fruit</td>
<td>30-51</td>
</tr>
<tr>
<td>Potatoes</td>
<td>67-74</td>
</tr>
<tr>
<td>Bakery products</td>
<td>39-44</td>
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</tbody>
</table>

Typical annual uranium intake in example foods (NCRP, 1984; Welford, 1967):

- 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) (NCRP, 1987):

- uranium = 0.6-3.0
- uranium in “phosphate rock” = 40-80
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- thorium = 0.2-2.2

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

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

3 Anthropogenic radionuclides are those that have been created by mankind through nuclear reactions initiated by man (e.g. nuclear reactors, particle accelerators). Primordial radionuclides are radionuclides that were created at the time of the big bang. Cosmogenic radionuclides are those that are created through interactions and collisions in the atmosphere between high energy protons (or other particles) from space, and atoms in the atmosphere. These interactions are called cosmic ray spallation interactions (“cosmic rays”).
13.3 Bq (360 pCi) of radioactivity per banana from K-40. If you were to eat a bunch of 10 bananas, you have consumed 133 Bq of radioactive K-40 (about 3600 pCi).

To put this in perspective however, the human body contains 1 to 2 grams of potassium per kilogram of body mass. A 70 kg person therefore, would contain 70 to 140 grams of potassium. This means a person that weighs 70 kg might contain between 8 and 16 mg of radioactive K-40, or between 2,220 and 4,440 Bq (60,000 to 120,000 pCi) of radioactivity from K-40 alone. Annually, this results in a dose to that person of 13.6 mrem/year (Strom et al, 2009). However, note that eating extra bananas will not necessarily increase your average annual radiation dose from extra K-40 since your body eliminates excess potassium through homeostasis.

HOW RADIOACTIVE IS URANIUM AND URANIUM ORE COMPARED TO OTHER CONSUMER PRODUCTS WE USE EVERY DAY THAT CONTAIN RADIOACTIVE SUBSTANCES?

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.

Typical US uranium ore contains approximately 700 picocuries per gram of uranium assuming 1,000 parts per million of uranium in the ore which is very typical in the US 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”). Some uranium ore may, however contain much higher concentrations of uranium, although the presented values are representative of average values for what is common in the United States today.

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) (NCRP, 1988).

4 A bequerel (Bq) is a measure of the amount of radioactivity. The definition of one Bq is one radioactive decay per second (which is approximately 27 pCi of radioactivity).

5 A millirem (mrem) is a unit of effective radiation dose. It is related to the amount of energy absorbed by human tissue and other factors. 1,000,000 µrem=1,000 millirem = one rem. More will be said about millirems later in this paper.

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

Natural radiation exposure can vary considerably from place to place across the United States 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 US, 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 potassium 40 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 the differences in annual background exposure based on where one chooses to live, eat and drink in the USA. We see that eating extra bananas will not necessarily increase your average annual radiation dose from extra K-40 since your body eliminates excess potassium through homeostasis.

ARE EXISTING REGULATIONS (FEDERAL OR IN AGREEMENT STATES LIKE COLORADO, UTAH AND TEXAS) 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 mrem per year from all sources including radon and 25 millirem / year excluding radon6 (US 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).

Now let’s compare these numbers 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 (50%) while medical radiation (voluntary) makes up 48% of our radiation exposure (NCRP, 2009).

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The data in Table 1 demonstrates the differences in annual background exposure based on where one chooses to live, eat and drink has a much greater impact on public exposure than the regulatory dose limits we discussed above. An additional perspective is depicted in Figure 3, which shows the change in radiation exposure

6 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 and radium.
rate due to a variation in elevation and mineralization as one travels across the Interstate 70 corridor through the Rocky Mountains between Denver and Grand Junction, Colorado.

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

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<tbody>
<tr>
<td>Cosmic Radiation</td>
<td>28</td>
<td>47</td>
<td>85</td>
</tr>
<tr>
<td>Terrestrial Radiation</td>
<td>28</td>
<td>43</td>
<td>97</td>
</tr>
<tr>
<td>Internal Radiation</td>
<td>200</td>
<td>610</td>
<td>344</td>
</tr>
<tr>
<td>including Radon</td>
<td></td>
<td></td>
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<tr>
<td>Totals</td>
<td>256</td>
<td>700</td>
<td>526</td>
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</tbody>
</table>

#### Figure 3. Variability of terrestrial and cosmic radiation background across the Interstate 70 corridor of Colorado. In units of nano grays per hour – Moving a hundred miles can change exposure by a factor of 4 (Stone, 1999).

**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 (Kathryn, 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 exposure standards are based on the possible chemical toxicity of uranium. (Boice, 1999). No evidence has been observed in any other populations not living nearby. A few sources providing the scientific evidence that supports this very important point include:

- **U.S. Department of Public Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry, Toxological Profile for Uranium, 1999, Chapter 1: Public Health Statement for Uranium, Section 1.5: How Can Uranium Affect My Health? – “No human cancer of any type has ever been seen as a result of exposure to natural or depleted uranium.” (USDHHS, 1999).**

- **National Cancer Institute (NCI), Uranium Mill Tailings and Cancer Mortality in Colorado, Mason, TJ, Freumeni, JF, Jr., and McKay, FW, Jr., Journal of the National Cancer Institute, 49:661-664, 1972. This NCI study investigated claims of increased cancer associated with use of uranium mill tailings in construction materials among residents of Western slope counties in Colorado. They found “no trends associated with this residential exposure to radiation from uranium mill tailings.” (Mason, 1972)**


- **Boice, J.D. et al. 2003. Cancer Mortality in a Texas County with Prior Uranium Mining and Milling Activities, 1950 – 2001 - Investigated cancer mortality in Karnes County, Texas where three uranium mines and over 40 uranium mines operated between 1954 and early 1990’s. Using methods used by the National Cancer Institute, it was concluded that “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 industries did not increase cancer rates among residents.” (Boice, 2003).**

- **Boice, J.D. et al. 2008. A Cohort Study of Uranium Millers and Miners of Grants, New Mexico, 1979–2005, - “No statistically significant elevation in any cause of death was seen among the 904 non-miners employed at the Grants uranium mill. Among 716 mill workers with the greatest potential for exposure to uranium ore, no statistically significant increase in any cause of death of a priori interest was seen…. Although the population studied was relatively small, the follow-up was long (up to 50 yrs) and complete. In contrast to miners exposed to radon and radon decay products, for uranium mill workers exposed to uranium dusts and mill products there was no clear evidence of uranium-related disease.” (Boice, 2008)**

- **Boice, J.D. et al. 2007. Mortality Among Residents of Uravan, Colorado Who Lived Near a Uranium Mill, 1936–84. - “This community cohort study revealed a significant excess of lung cancer among males who had been employed as underground miners. We attribute this excess to the historically high levels of radon in uranium mines of the Colorado Plateau, coupled with the heavy use of tobacco products. There was no evidence that environmental radiation exposures above natural background associated with the uranium mill operations increased the risk of cancer. Although the population studied was relatively small, the follow-up was long, extending up to 65 years after first residence in Uravan.” (Boice, 2007b).**

**BUT 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 decay products” (which are decay products of uranium) in poorly ventilated underground mines. Many of these miners also had severe smoking habits, which enhanced the ability of the radon decay products to deliver radiation dose to the lung. These conditions existed before we had the Federal Agencies (Occupational Safety and Health Administration – OSHA, Mine Safety and Health Administration – MSHA, US Nuclear Regulatory Commission – USNRC) 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 to some of these early uranium miners was 100 – 1000 times or more greater than our current Federal standards. Exposures were reduced dramatically as more knowledge of the effects of radon and radiation expanded and best practices were adjusted, as is depicted in Figures 4 and 5.

Figure 4. Average Radon Decay Product Exposures in Canadian Uranium Mines in the Past (1940s to 1970s; Lane, 2007).

Figure 5. Average Radon Decay Product Exposures in Canadian Uranium Mines in the Past (1970s to 2000s; Lane, 2007).

As a point of comparison, it is not uncommon in the U.S. for natural radon levels in our homes to be near or in excess of USEPA’s recommended 4 pCi per liter standard. About 6% of homes in the U.S. exceed this concentration (Marcinowski et al. 1994). The 4 pCi per liter concentration corresponds to an indoor exposure of about 0.6 WLM per year, or comparable to the average radon exposure of modern uranium miners.

HOW IS URANIUM EXTRACTED FROM THE EARTH?

There are two basic approaches: (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” (U3O8) product.

In situ recovery methods 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 (similar to a water softener) to concentrate it and then processed similarly to conventional uranium mills to produce the final “yellowcake” product.

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. base load 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 (99Mo) used for over 70% of the world’s nuclear medicine diagnostic studies) and for consumer products as previously discussed (americium for smoke detectors and tritium for luminous watch dials e.g.). 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 (HPS, 2012). The process of “uranium fission” is depicted in Figure 6. 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 (e.g. burning coal or natural gas to boil water to spin turbines)

Regarding uranium’s use and importance as a fuel to generate electricity, it is of interest to note that one pound of yellowcake (the final product of a uranium milling process) has the energy equivalence of 35 barrels of oil. One 7-gram (1/4-ounce) uranium fuel pellet (fuel that goes into reactors) has an energy to electricity equivalent of 17,000 cubic feet of natural gas, 149 gallons of oil, or one ton of coal (Ameren, 2013)

Figure 6. 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.

7 Base load electricity means energy can be "produced 24/7" and therefore is always available when asked for; not reliant on environmental conditions.
The approximately 100 nuclear power plants operating in our country today consume about 60 million pounds of uranium fuel per year but the US'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 Russia, China, and India who plan on building large numbers of new nuclear plants in the next two decades, we will be competing for worldwide uranium supplies. The countries from which the United States currently gets most of its uranium are displayed in Figure 7.

Figure 7. The US gets its uranium from a variety of countries, some of which we may or may not have amicable relationships with currently, or in the future (USEIA, 2012).

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.

But nonetheless, 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 we will 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.

REFERENCES


