Uranium Mining – The Front End of the Nuclear Fuel Chain

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Contents

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Introduction

Proponents of nuclear power often state that nuclear power is clean. They point out for example that a there are no piles of dangerous waste around a nuclear power plant and no ugly black smoke is released. This is true but not the whole story. The extraction and processing of uranium, the fuel for nuclear power plants, is a very dirty business. Severe environmental impacts and cancer among uranium miners are not the only problems. In many places in the world uranium mining is taking place in disregard of the rights of Indigenous peoples.

Uranium is the raw material used to produce fuel for the vast majority of nuclear reactors and nuclear bombs. In some cases, thorium is used. There are many problems and hazards associated with the use of both uranium and thorium. The focus here is on some of the problems and hazards of uranium mining. It is important to note however that there are also serious problems and hazards associated with exploration of uranium. For this reason some information is included here on uranium exploration. First though is a brief comment on the nuclear fuel chain, which begins with uranium exploration and mining.

Rabbit Lake uranium mine pit, Northern Saskatchewan, Canada.
An admirable wonder of engineering achievement, or
a despicable method of destruction and source of contamination?

The Nuclear Fuel Chain

Uranium exploration and mining are the first two links in the nuclear fuel chain, and are thus referred to as being part of the front end of the fuel chain. The nuclear fuel chain is the whole process of producing fuel for nuclear power plants and dealing with nuclear waste, as well as the process for producing nuclear bombs and solid uranium ammunition (called depleted uranium or DU for short). The civil and military nuclear fuel chains cannot be entirely separated as both streams share the same facilities at several key links in the chain.

Uranium Exploration

The hunt for uranium usually begins from an airplane equipped with a gamma radiation detector flying systematically over an area. The next step is to take water and rock samples along with further gamma radiation surveys in places where gamma radiation was detected from the air. The information from these samples is used to determine whether or not to proceed to drilling in order to extract samples of rock at various depths. If the drill cores contain an adequate amount of uranium the next step is to take a bulk sample of several cubic meters of the uranium ore. The bulk sample is taken to a test uranium mill. The results are used to determine the best chemical process for milling the ore.

The greatest hazard of uranium exploration is that drilling into ore bodies can contaminate the downstream surface water and groundwater with radioactivity and heavy metals. In the late 1970s, due to the controversy over the hazards of uranium exploration and mining in the western Canadian province of British Columbia (BC), a provincial government inquiry was held and completed in 1980. During this period the BC Medical Association, the professional Association of medical doctors in BC, announced it was opposed to uranium exploration due to the health risks. This and other information brought out in the government inquiry led in 1980 to the local municipality of Salmon Arm, BC making it against the law to explore for uranium in their watershed.

Following the government inquiry, the BC government announced a seven-year moratorium on uranium exploration. In 2008, the Province of BC reconfirmed its ban on uranium exploration and mining. In 1982, the Eastern Canadian province of Nova Scotia placed a ban on uranium exploration and mining.

Problems and Hazards of Uranium Mining

It is not possible to mine uranium without producing wastes that have a catastrophic effect on the immediate surrounding environment, especially the downstream area. Uranium mine and mill wastes decline water quality to such a degree that aquatic communities may be completely eradicated in the immediate downstream vicinity. The main forms of waste include: the overburden material; ore not rich enough to mill; mill process chemicals and water; and contaminated clothes, tools and buildings. The following discussion, however, focuses on wastes that come out the discharge pipe from a uranium mill - the water, process chemicals, and sand from crushed ore.

First is an overview of the nature of the waste problem, presented to establish the basic characteristics of mill wastes. Described then is the uranium milling process, a few aspects of radioactivity, the large volume of wastes produced in a short time and why wastes remain toxic for thousands of years - forever in human terms. Included as well are the often overlooked problems of heavy metals and process chemicals.

*The longnose sucker (*Catostomus catostomus*) above was caught in the summer of 1982 downstream from the Beaverlodge mine at Uranium City, Saskatchewan, Canada. The fish is totally blind. The eyes have no pupils at all. The mouth of the sucker is especially adapted for eating off the bottom, where it spends most of its time. Since radioactive particles are heavier than water they quickly settle out and accumulate in the bottom sediment of streams and lakes. Thus, bottom feeding fish such as suckers suffer more from the effects of radiation than other species.*

The Nature of the Problem

Uranium is the heaviest non-manmade substance. Heavier are some radioactive byproducts formed by the atomic reaction inside a nuclear reactor and by the explosion of nuclear bombs.

Uranium atoms were formed billions of years ago by supernovas, or exploding stars. The uranium then became part of the dust forming our solar system and the Earth. Most uranium deposits are ancient sea beds. Since uranium is heavier than water, it slowly accumulated over the millennium in the bottom sediment of water bodies.

Uranium deposits exist today because of their isolation from oxygen and water for millions of years. Uranium mines break this natural containment, allowing water and air to carry contamination throughout the environment. In its natural state, uranium, other radioactive materials, and heavy metals are in the form of solid rock and therefore only tiny amounts, if any, can escape to the surrounding environment.

Once the ore is crushed down to a sand in a mill, its volume is greatly increased. Then, the solid wastes are dumped onto the surface and allowed to mix with air and water, entering into a complexity of biological pathways and spreading contamination far from the mine site. For example, radon gas that escapes from tailings piles is essentially isolated from the biosphere prior to mining. Radon gas can be carried hundreds of kilometres by the wind and affect large numbers of people. Despite these facts industry supporters often state that it is safer to mine and take away the uranium than leave it in the ground. This attitude does not consider the destruction where the uranium is taken to. Dangerous wastes are created at every link in the nuclear fuel chain.

The Milling Process

Uranium ore contains only a few tenths of a percent uranium, except for high grade deposits. All the rest of the rock is considered waste. To extract the small quantity of sought-after uranium, the ore is taken out of the ground and processed in a mill. Uranium mills produce two things - a marketable product, and wastes. The marketable product is a fine, sand-like, yellow material called ammonium diuranate or uranium oxide (U_3O_8), though because of its yellow colour it is generally referred to as yellowcake. Yellowcake consists of up to 90% natural uranium.

At a uranium mill, the rock is crushed, ground down to a fine sand and mixed with large amounts of water and chemicals. The chemicals are either acids or bases, depending on the pH of the ore. Both of the processes are able to remove about 90% of the uranium but only a few percent of the other radionuclides. About 85% of the total radioactivity in the rock goes out the end of the waste outlet pipe.

Waste outlet pipe at the Beaverlodge uranium mill, Northern Saskatchewan, Canada.

Waste rock, Beaverlodge uranium mine, Northern Saskatchewan, Canada.

Radioactivity

Uranium is constantly changing into other radioactive materials that are always present wherever uranium is found. The change from one radioactive material to another is called radioactive decay. The uranium-238 decay series is shown below. The "radon daughters" (explained below) are the 7th, 8th, 9th and 10th decay products. In its natural state, uranium is made up of over 99% uranium-238, less than 1% uranium-235 and less than .01% uranium-234. Uranium-235 has its own decay series.

Uranium-238 Decay Series				
Decay Product	**Symbol**	**Element**	**Main Radiation**	**Physical Half-Life**
	U-238	Uranium-238	alpha	4,460,000,000 years
1	Th-234	Thorium-234	beta	24.1 days
2	Pa-234	Protactinium-234	beta	1.17 minutes
3	U-234	Uranium-234	alpha	247,000 years
4	Th-230	Thorium-230	alpha	80,000 years
5	Ra-226	Radium-226	alpha	1,602 years
6	Rn-222	Radon-222	alpha	3.82 days
7	Po-218	Polonium-218	alpha	3.05 minutes
8	Pb-214	Lead-214	beta	27 minutes
9	Bi-214	Bismuth-214	beta	19.7 minutes
10	Po-214	Polonium-214	alpha	1 microsecond
11	Pb-210	Lead-210	beta	22.3 years
12	Bi-210	Bismuth-210	beta	5.01 days
13	Po-210	Polonium-210	alpha	138.4 days
14	Pb-206	Lead-206	stable	stable

Uranium-238 changes 14 times before it becomes non-radioactive lead. In addition, there are 22 other naturally occurring radioactive materials from separate decay series. Thus, there are always 36 different radioactive materials in the ground, not just uranium. Most of them are ignored by the uranium industry. However, from a health perspective they are all important.

The time it takes for one radioactive material to turn into another is measured by the concept of "half-life," which is the time it takes for half an amount of a radioactive material to decay into the next material (called a decay product). In the Table above, the half-lives are written to the right of each radioisotope. For example, for 1,000 grams of radium-226 (the fifth decay product) it takes 1,600 years for half of it, 500 grams, to decay into radon-222. There are thus 500 grams of radium-226 left. It then takes a further 1,600 years for half of that, 250 grams, to decay, and so on. An individual atom, however, may decay instantly or take thousands of years. Radioactivity is released every time a radioactive material changes to the next material in its decay series.

Some very long-lived radioisotopes are dumped into the environment from a uranium mill. For example, thorium-230 has a half-life of 80,000 years. It is long half-lives like these that make uranium mill wastes stay radioactive so long as to be considered forever in human terms.

Radioactive particles pose the greatest threat to human health when they are inhaled or ingested. They are however so small that they can enter into the skin via the many sweat pores and hair follicles all over the body. The radioactivity is of three types, alpha, beta, and gamma. Alpha radiation is the most harmful to living cells but travels only about a centimetre in air. Beta radiation travels about half-a-metre in air and can not go through thin steel or wood about 5 centimetres thick. The difference between alpha and beta particles is like a cannon-ball compared to a bullet. Alpha particles, like cannon-balls, have less penetrating power but more impact. Gamma radiation is the least harmful but can travel great distances. The majority of gamma radiation is stopped by a few centimetres of lead or about 30 centimetres of concrete.

Radium And Radon Gas, and Cancer Among Uranium Miners

Radium is one isotope in uranium mill wastes that is especially dangerous. This is because it is known to be harmful to life forms at low concentrations and it decays into the even more dangerous radon gas. Chemist Marie Curie discovered radium in the early 1900s. She and her daughter both died from their exposure to radiation.

The radium problem is particularly serious where wastes have been dumped on stream bottoms as radium accumulates in the sediment. About 99% of the total radium-226 in uranium ore is discharged in the waste from a uranium mill. One gram of radium-226 gives off almost 40 billion radioactive disintegrations per second.

Radon gas has been studied in detail. There are three main reasons why radon is so dangerous. First, because it is a gas and can thus be breathed into the body. Radon is the only gas that occurs in the uranium decay series. Otherwise, the materials change from one solid to another.

Unnaturally large amounts of radon gas are continually coming out of the ground at uranium mine and mill waste areas. A research team at Los Alamos Scientific Laboratory, University of California, studied this problem and came to the following conclusion:

> Our research indicates that 4 metres of clay are required to reduce radon exhalation by 99% and the remaining 1% is still about four times the typical soil radon exhalation rate. Perhaps the solution to the radon problem is to zone the land in uranium mining and milling districts so as to forbid human habitation.[1]

The second reason radon is so dangerous is because it releases the most harmful type of radioactivity - alpha radiation. The third reason is that radon has a short half-live, and is followed by the extremely hazardous "radon daughters," or the decay products that immediately follow from the "parent" radon. The first four radon daughters have in total a

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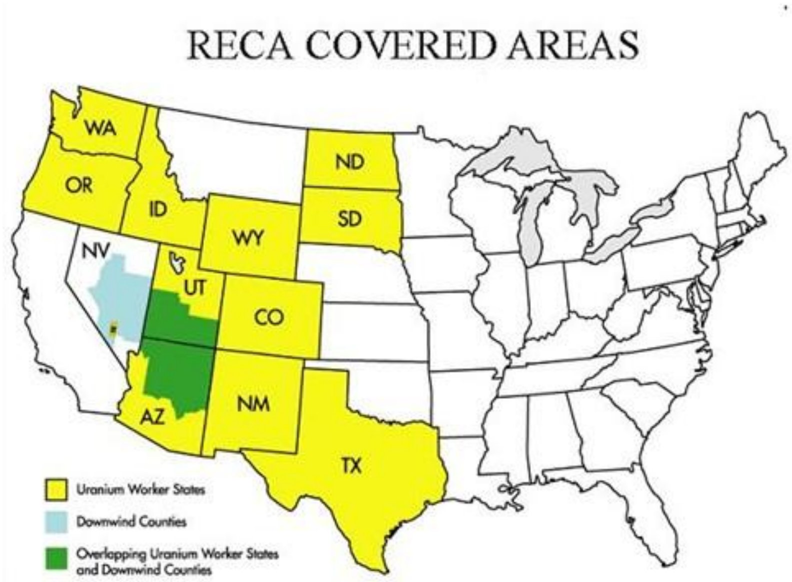
[1] Dreeson, D.R. Feb., 1978. "Uranium Mill Tailings - Environmental Implications." LASL Mini-review. 4 pages. See page 4. LASL-77-37. Los Alamos Scientific Laboratory, University of California, Los Alamos, New Mexico, USA 87545.

half-life of less than one hour. Two of them give off alpha radiation and the other two beta and gamma radiation. Once inside the lungs radon decays rapidly, exposing sensitive lung tissue to deadly radiation. That is why lung cancer is so common among uranium miners and is one of the diseases recognized by the US Radiation Exposure Compensation Act (RECA), along with pulmonary fibrosis, silicosis, cor pulomale and pneumoconiosis . The radon problem is especially serious for underground miners as the gas accumulates in the tunnels.

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

US Radiation Exposure Compensation Act (RECA)



RECA was adopted by the US Congress in 1990. In 2000 it was amended in to include uranium mill and ore workers.

Source: www.justice.gov/civil/common/reca.html (2011-12-02)

Heavy Metals and Process Chemicals

Radioactive materials are not the only hazardous component of uranium mine and mill wastes. Also of concern are heavy metals such as lead, zinc, manganese, cadmium, and arsenic, which are a potential problem with any type of mining. The release of heavy metals to the environment must also be controlled. Heavy metals do not decrease in toxicity with time since there is no decay process, they simply last forever.

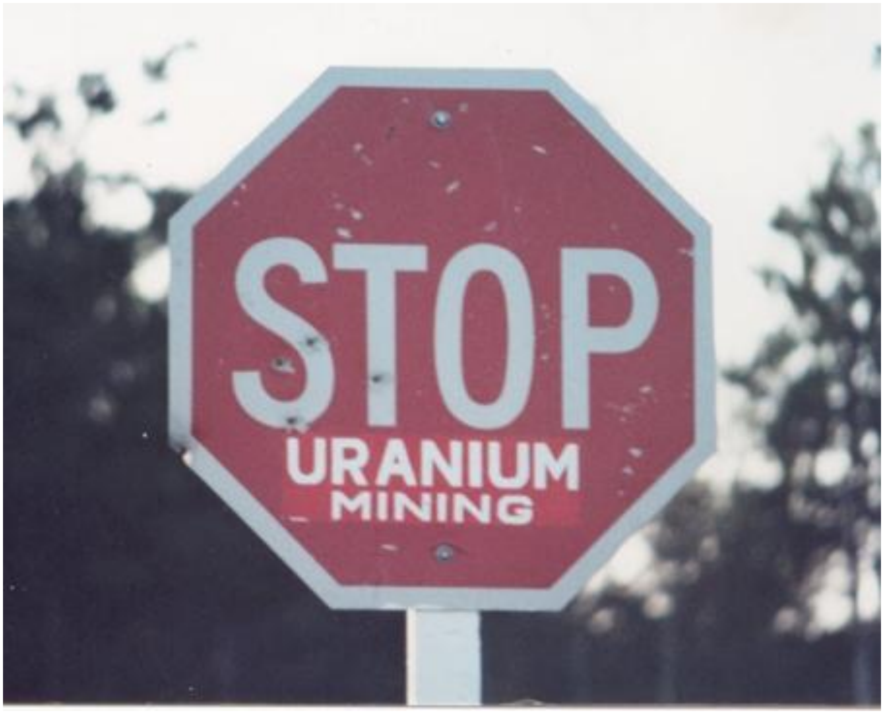
Heavy metal poisoning is usually noticeable long before any effects of radioactivity. It is the heavy metals and process chemicals that are the primary reason plants and fish die downstream from uranium mines.

Huge quantities of process chemicals are used in the milling process, then dumped into the environment. Hundreds of tonnes of concentrated sulphuric acid may be used per day. Some of the other chemicals used are ammonia gas, hydrochloric acid, kerosene, and hydrogen peroxide.

Large Volume

Large volumes of waste are produced in the uranium milling process over a short period of time. Hundreds of tonnes of waste are produced for every tonne of yellowcake. Official reports often only describe the solid component, or "tailings." However, liquid wastes have a greater impact on the surrounding environment than solid wastes as they can carry contamination great distances via streams, rivers and lakes. The highly toxic liquid waste from a uranium mill is usually more than twice as big in volume as the solid waste. What is more, liquid wastes are continually being added to by surface and ground water seepage through waste areas.

The gigantic volume of uranium mill waste produced is easily illustrated. For example, the 1050 MW Forsmark 3 nuclear reactor in Sweden uses about 30 tonnes of fuel per year. Production of this amount of fuel creates over 200,000 cubic metres of solid uranium mill wastes. This is enough to cover a whole soccer field almost 20 metres deep.



Road sign in Northern Saskatchewan, Canada.

Glossary

half-life - There are three different types of half-life: biological, effective, and physical or radioactive. Numbers for half-life vary slightly according to the original source of information. When the type of half-life is not specified, it usually refers to radioactive half-life. Definitions of each follow.

half-life, biological - The time it takes for a living thing to expel half of an amount of a radionuclide by the normal process of elimination. It is influenced by health and diet. The main methods of elimination are via the urine, faeces, exhalation and perspiration.

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

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

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

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

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

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

nuclear fuel chain and cycle - The sequence of interdependent operations involved in producing nuclear weapons, fuel for nuclear electricity generation, and radioactive isotopes for medical and industrial purposes. The links in the chain are so interdependent that it is impossible to completely separate civil and military aspects. Some medical and industrial radioactive isotopes however can be produced by particle accelerators, which are not based on uranium fuel and not connected to nuclear power generation and nuclear weapons production.

Whether regarded primarily civil or military, the nuclear fuel chain requires conversion of large quantities of uranium from one chemical form to another that are transported great distances between links in the fuel chain. The nuclear fuel chain is more technically complex, capital intensive, time consuming, and dangerous than the production process for other forms of energy. These attributes of the nuclear fuel chain are a main reason why there is no nation that operates its nuclear industry entirely within its own borders. The few nations possessing the resources (natural, financial, and human) to completely operate its nuclear industry within its own borders have chosen not to for many reasons, not the least being to minimize local risks such as contamination from uranium mining and weapons testing.

The most common sequence in the civil nuclear fuel chain begins with uranium exploration, proceeds to uranium mining and milling, conversion, enrichment, fuel fabrication, fission in a light-water reactor (LWR), reactor waste storage, and finally reactor decommissioning. A variation of this sequence is when natural uranium is used as fuel in heavy water reactors, such as the Canadian made CANDU. For reactors using natural uranium fuel, the yellowcake is converted to UO2 and shipped directly to a fuel fabrication plant, skipping the conversion to UF6 and enrichment steps. Another variation is when spent reactor fuel is reprocessed.

It takes roughly three years to produce the initial fuel for a LWR. With some overlap, the five major steps of mining, conversion to UF6, enrichment, fuel fabrication, and fuel inspection and loading, each take about a year. The long lead times and overlap of processing steps associated with fuel supply, coupled with inventory supplies of often three or more years, means that disruption at one step must be over five years in order to effect reactor operation.

In the military sequence, uranium is enriched to a higher percentage, and the DUF6 is converted into uranium metal for use in ammunition and nuclear weapons. The production of nuclear weapons usually involves the same uranium mines, conversion, enrichment and reprocessing plants, and often fuel fabrication plants and reactors that produce electricity.

There are two fuel systems that may be described as cycles and two that may be described as chains, though all are loosely referred to as either chains or cycles. However, even the so-called cycles are not true cycles in the sense that the original material does not itself recycle and that in the process wastes are produced that are not part of the cycle.

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

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

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

Sources

Photos and the ”Problems and Hazards of Uranium Mining” section are from:
Goldstick, Miles. 1987. ”Wollaston: People Resisting Genocide.” Available from Black Rose Books in Canada. See http://blackrosebooks.net/go/profile-35372/products/view/wollaston-people-resisting-genocide/28436

The terms in the glossary are adapted from:
Goldstick, Miles. 1990. ”Nuclear Words and Terms.”

For More Information

- World Information Service on Energy (WISE) Uranium Project at www.wise-uranium.org
- Post ’71 Uranium Exposure, Mill Workers, Miners, Transporters: www.post71exposure.org
- www.nonuclear.se: environmental views on energy