June 2007

Figure 1
A Model of the Uranium Atom

Speaker's Notes for the Nunavut Planning Commission

Gordon Edwards Ph.D.

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Figure 2
A Monument to the Splitting of the Atom

Splitting the Uranium Atom – Nuclear Fission

Uranium is the heaviest metal that can be mined from the earth. Uranium was discovered about 200 years ago, but it had no practical use until the beginning of World War II.

In 1938-39 scientists discovered that an atom of uranium can be broken into two or three pieces when struck by a fast-moving particle called a neutron. The splitting of a uranium atom releases energy. This process is called "nuclear fission", since the centre of an atom is called its nucleus.

When a uranium atom splits it gives off more neutrons, which can then split more atoms, and so the energy level rapidly multiplies. When trillions of atoms are split almost simultaneously, the energy released is the power of the atomic bomb. The atomic bomb was the first practical use of uranium.

Figure 1 shows a model of the uranium atom; it is on display at Oak Ridge, Tennessee. That is where the uranium explosive was prepared for the bomb that destroyed the city of Hiroshima. Much of the uranium needed for that bomb came from a mine at Great Bear Lake in the Northwest Territories.

Figure 2 shows a Russian monument built to celebrate the splitting of the atom. The semicircles represent the energy that is released when the atom is split. The two small hemispheres represent the broken pieces of the uranium atom, called "fission products". These fragments of uranium atoms are in fact the atoms of new radioactive materials, most of which cannot be found in nature.

There are over three hundred different kinds of fission products. They are much more radioactive than uranium, and are therefore much more harmful to living things. Fission products are scattered high in the air when an atomic bomb is exploded above ground; the solid varieties return to earth as radioactive fallout. The Inuit people received more radioactive fallout in their bodies than other Canadians because they ate the meat of the caribou who in turn ate contaminated lichen.

Uranium is the only naturally-occurring material that can be used to make an atomic bomb. Plutonium is also used for this purpose, but it is man-made; in fact it is made from uranium.

Figure 3
Henri Becquerel discovered radioactivity

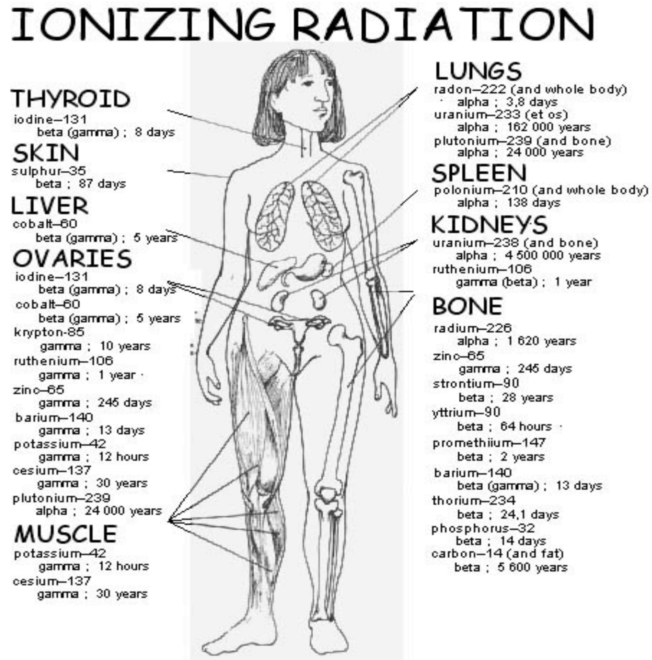

Figure 4
Radioactive materials lodge in the body

Atomic Radiation – Radioactive materials

In 1896 Henri Becquerel (Figure 3) discovered radioactivity. He found that a chunk of uranium ore gives off an invisible kind of light, now called "atomic radiation". One type of atomic radiation has great penetrating power, similar to X-rays; this type is called "gamma radiation". Less penetrating forms of atomic radiation also exist, called "alpha" and "beta" rays. Atomic radiation is harmful to living things because it damages cells and often makes them grow wrong.

Atomic radiation is caused by the spontaneous disintegration of unstable atoms. Any material which gives off atomic radiation is said to be "radioactive". There are dozens of radioactive materials that exist in nature and hundreds more are created by man as fission products. One "becquerel" of radioactivity indicates that one atomic disintegration is taking place every second.

Radioactivity is not the same thing as nuclear fission; unlike fission, it cannot be controlled. Scientists do not know how to speed up, slow down, start or stop radioactivity.

By the 1930s it was well known that exposure to atomic radiation can cause many kinds of biological damage, including radiation burns, anemia (blood damage), cataracts (eye damage), cancer, leukemia, damage to unborn babies, and damage to the sperm and eggs of men and women. Thus radiation protection is very important. However, once radioactive materials enter the body, the damage is done internally and protection becomes difficult or impossible (Figure 4).

Each radioactive material has its own characteristics, and each one behaves differently in the environment and in the body. Radium-226 behaves like calcium, so inside the body it goes to the bones, the teeth, and mother's milk. Radon-222 is a gas; it is inhaled into the lungs. Cesium-137 resembles potassium; it goes into muscles. In these cases, the damage is done inside the body.

The consensus of scientific knowledge is that any exposure to atomic radiation increases the risk of cancer and leukemia. There is no truly safe dose, but the risks are small when the doses are small.

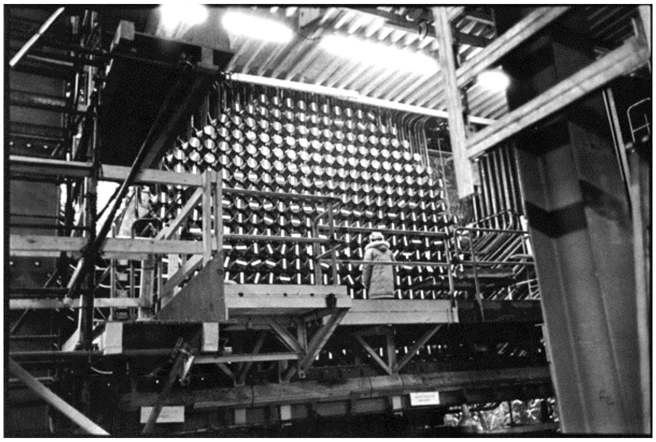

Figure 5
Face of a CANDU nuclear reactor

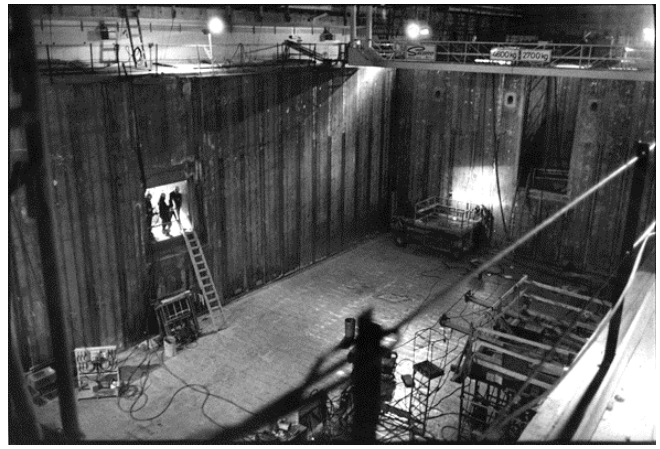

Figure 6
Construction of a "Spent Fuel" Pool

Nuclear-Generated Electricity – High Level Radioactive Waste

Until 1965, all of Canada's uranium was sold to the military for use in nuclear weapons. Some was used directly in bombs, some was converted to plutonium for use in bombs. But since 1965 Canadian uranium has been sold only as fuel for nuclear reactors – not bombs.

A nuclear reactor is a machine that controls the nuclear fission process. It produces a steady stream of heat (caused by the splitting of uranium atoms) and plutonium (an atom of plutonium is created when a uranium atom absorbs a neutron without splitting).

In a CANDU power reactor uranium fuel bundles are inserted into hundreds of tubes (Figure 5) where they will undergo nuclear fission. The energy released is used to boil water, and the resulting steam is used to spin a giant wheel ("turbine") so as to generate electricity.

When uranium atoms are split, fission products are created; so the "spent" fuel is millions of times more radioactive than fresh uranium fuel. An unprotected man standing one metre from a used fuel bundle just out of the reactor would be killed in a less than a minute.

Irradiated nuclear fuel must be cooled even after the reactor is completely shut down. The radioactivity of the fission products is so intense that the fuel, if not cooled, will overheat and melt at temperatures of thousands of degrees without the added heat of nuclear fission.

This type of accident is called a meltdown. The overheated nuclear fuel can melt right through steel and concrete containment structures into the ground below, releasing radioactive materials in a cloud that can drift for thousands of miles. Reindeer in Lappland and sheep in northern England have been so contaminated due to a meltdown in Russia (Chernobyl) that they are still unfit for human consumption twenty years after the event.

Even without a major accident, irradiated fuel remains dangerous for millions of years. It is so hot that it has to be cooled by circulating water in special "pools" (Figure 6) for at least 7 to 10 years after it has been removed from the reactor. Then it has to be stored somewhere safe for the next 10 million years, for it remains extremely toxic due to its radioactivity.

And at any time in the future, plutonium can be extracted from the irradiated fuel and used for atomic bombs. India's first atomic bomb, exploded in 1974, used plutonium from a Canadian nuclear research reactor. That reactor was a gift from the Canadian government.

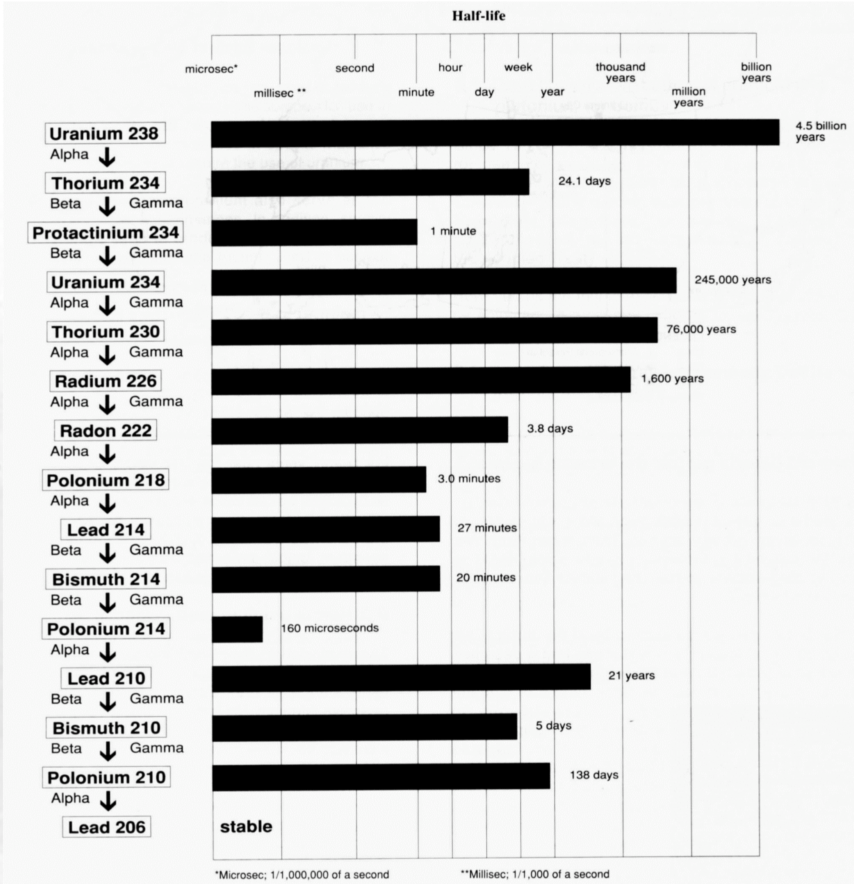

Figure 7
Marie Curie found uranium decay products

Figure 8
The Radioactive Decay Products of Uranium-238

Uranium Decay Products – Radium, Polonium, and Radon

In 1898, Marie Curie (Figure 7) discovered something surprising. After removing the uranium from the ore that contained it, she found that the residues were a lot more radioactive than the uranium itself. She reasoned that there must have been something in the rock besides uranium – some substance that is far more radioactive than uranium.

After months of hard work, she found two new substances in the residues, previously unknown, that she named "polonium" and "radium". These substances are extremely radioactive. They give off both penetrating and non-penetrating forms of atomic radiation. Before long, one of Marie's students discovered a radioactive gas that is given off by radium. This was yet another newly discovered radioactive material called "radon".

It turns out that when a radioactive atom disintegrates and gives off atomic radiation, it becomes a completely different kind of atom, representing a new material altogether. This by-product material is called a "decay product" since it is produced as a result of atomic disintegration – a process commonly called "radioactive decay".

In some cases a decay product is itself radioactive, and then, when its atoms decay they turn into yet another, different decay product. If that second decay product is also radioactive then you will get a third decay product, and possibly a fourth, a fifth, a sixth, and so on.

Radium, polonium, and radon are three of the many decay products of uranium (Figure 8).

Figure 9
Young girls working as Radium Dial Painters

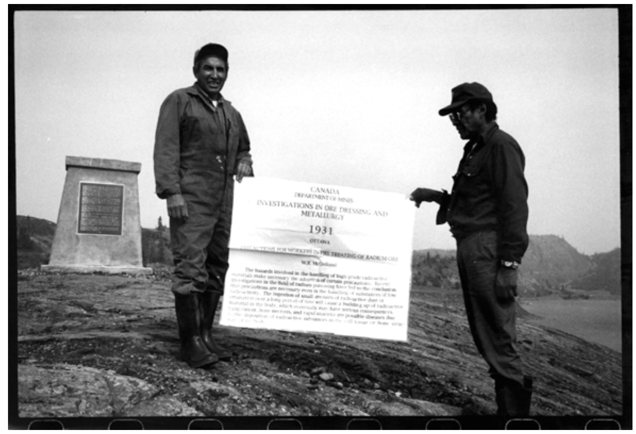

Figure 10
Dene men displaying a 1931 gov't document

Radium – From Priceless to Worthless

Radium soon became the most valuable substance on earth. By the 1920s it was selling for $100 000 per gram. Radioactivity was regarded as magical, and radium was used not only for sensible purposes like shrinking cancerous tumours, but also for foolish things.

Young women (Figure 9) were hired to paint watch faces with radium paint to make them glow in the dark. By the 1920s many of these women had developed severe anemia. Some died quickly. Others had gums that became badly infected and teeth that began falling out. Their jawbones grew soft and were quite easily broken. The dentist who reported these symptoms used the phrase "radium jaw" to describe the situation. The cause was obvious.

By the late 1920s the radium dial painters began to show an epidemic of bone cancer. When their bodies were autopsied it was found that microscopic amounts of radium had been ingested by the girls and had distributed itself throughout their entire skeleton. Years later, many who didn't get bone cancer developed cancers of the head from radium poisoning.

In the 1930s the first radium mine was opened in Canada's Northwest Territories on the eastern shore of Great Bear Lake. Men of the Sahtu Dene Indian nation were hired at a very low rate of pay to carry sacks of radium concentrates on their backs. They loaded the sacks on barges and often lay on them for 8 hours during the crossing so they could unload the sacks at the western end of the lake. They were never told that this work was dangerous.

The Dene settlement of Deline is now known as the "village of widows" because so many men died of cancer years after handling the radioactive ore from the mine. In Figure 10, two Dene men display this excerpt from a 1931 Canadian government document:

> "Recent investigations in the field of radium poisoning have led to the conclusion that precautions are necessary even in the handling of materials of low radioactivity. The ingestion of small amounts of radioactive dust or emanation [radon] over a long period of time will cause a build up of radioactive material in the body, which eventually may have serious consequences. Lung cancer, bone necrosis and rapid anemia are possible diseases due to deposition of radioactive substances in the cell tissue or bone structure of the body." [Canada, Department of Mines, 1931]

This document was prepared to warn the scientists in Ottawa who had to handle samples of radioactive ore, but nobody warned the miners or the Dene men who carried the ore sacks.

By the 1940s, radium had become worthless – a waste byproduct of uranium mining. There was no market for radium any more. Too many people had been killed by handling it.

Figure 11
Mr. Litvinenko was poisoned with Polonium-210

Figure 12
Reindeer meat was contaminated with cesium-137

Polonium – The Assassin's Choice

Since the fall of 2006 there has been a lot of news coverage about the murder of the Russian ex-spy Alexander Litvinenko (Figure 11). He was poisoned with a radioactive material, polonium-210 – a material that also occurs naturally as one of the uranium decay products.

Polonium-210 is incredibly toxic. It is billions of times more deadly than cyanide, which is one of the fastest acting lethal poisons known. An amount of polonium-210 the size of a grain of sugar is enough to kill a thousand men in the manner that Litvinenko was killed.

Polonium-210 gives off no penetrating radiation at all, so it can be safely carried in a sealed container and is impossible to detect as long as it is in a container. It gives off only alpha radiation, which can be stopped by a piece of paper, and has no radioactive decay products. When a polonium-210 atom disintegrates it turns into a non-radioactive atom of lead.

But inside the body, polonium-210 is extremely damaging. Alpha radiation is harmless outside the body, but it is twenty times more damaging to living cells inside the body than the more penetrating types of atomic radiation such as gamma and beta radiation.

Unlike radium, which concentrates in bones and teeth, polonium-210 attaches itself to the red blood cells, and is carried to all the soft organs of the body in turn. There it damages the liver, spleen, bone marrow, lymph nodes, thymus, gastrointestinal tract, and gonads.

The Inuit have larger amounts of polonium-210 in their bodies than any other North American residents because of the "lichen → caribou → human" food chain. Since these measurements were never made before 1960, it is not possible to say how uranium mining in the Northwest Territories and Northern Saskatchewan may have contributed to the levels of polonium-210 in caribou meat and hence in the bodies of the Inuit people.

Measurements of radioactivity in caribou meat began in 1960 primarily to investigate the high levels of cesium-137 deposited on lichen from the atmospheric testing of atom bombs in the American southwest. After Chernobyl, levels of cesium-137 went up in both reindeer and caribou herds (Figure 12). But the high levels of polonium-210 were a bit of a surprise.

Exposure to alpha radiation at non-lethal levels was already well documented as a cancer-causing agent. In the case of polonium-210 the number of organs at risk is especially large. But radiation-induced cancer generally takes decades to show itself, as the damage that is done to individual cells is multiplied and spread by the slow process of cell reproduction.

Figure 13
Navajo uranium miner with lung cancer

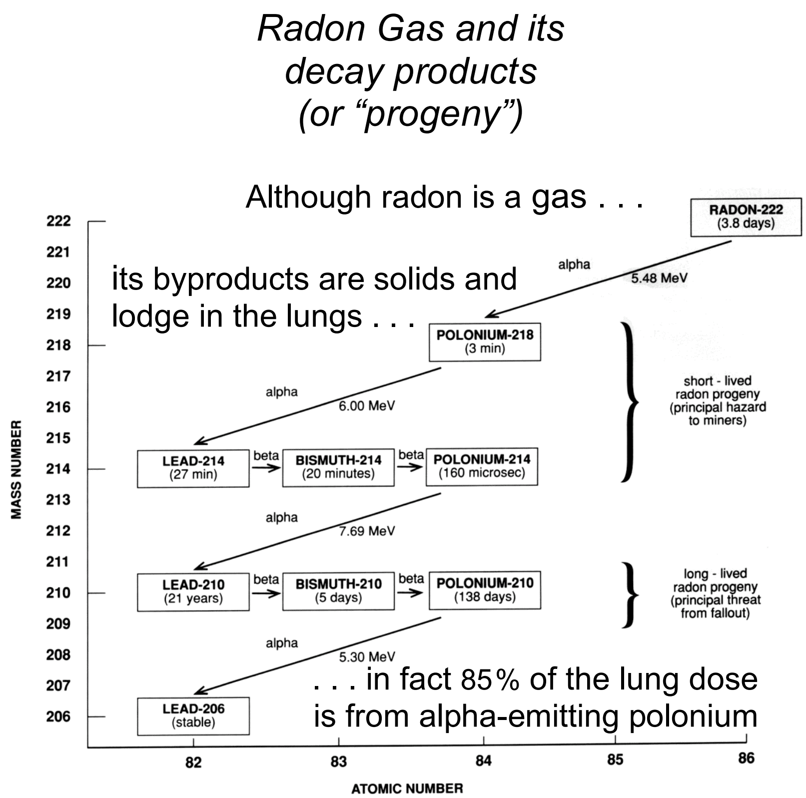

Figure 14
radon gas as a delivery system for polonium

Radon Gas – The Silent Killer

Radon gas has been killing people for centuries. Whenever an underground mine is rich in uranium, a lot of radon gas is always found there too, since every atom of radon is created by the disintegration of a uranium atom; uranium becomes radium which then becomes radon.

Radon is a colorless, odorless, and tasteless gas. It is eight times heavier than air, so it stays close to the ground. Inside the lungs, or suspended in stagnant air, radon gas rapidly disintegrates into three kinds of polonium isotopes and other radioactive solids (Figure 14).

Radon gas is the second largest cause of lung cancer death after cigarette smoking. Tens of thousands of Americans die each year from inhaling radon gas in their own homes. The U.S. government urges citizens to test their homes for radon and take corrective action as needed.

Every population of uranium miners that has been studied for a long enough period of time has shown a marked increase in lung cancer death rates caused by breathing radon on the job (Figure 13). Lung cancer takes decades to develop, so most of the lung cancers only show up after the miners have quit working. The British Columbia Medical Association has described this tragedy as "a gradually flowering crop of radiation-induced lung cancers".

The nuclear industry and its regulatory agency have long underestimated the health effects of radon exposure (as well as other forms of radiation exposure). In 1980, the B.C. Medical Association wrote that the Canadian Atomic Energy Control Board was "Unfit to Regulate" because of its callous disregard of medical evidence regarding lung cancers from radon.
In 1982, an independent scientific study concluded that levels of radon exposure considered "acceptable" by AECB could cause a quadrupling of lung cancers among uranium miners.

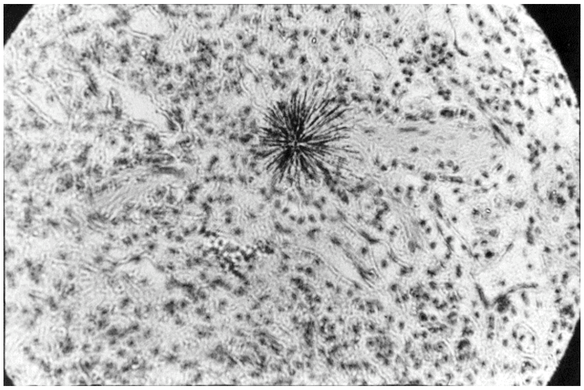

Figure 15
Alpha radiation in an ape's lung tissue

Three Types of Atomic Radiation

Alpha	2 protons + 2 neutrons *(positive electric charge)*	heavy particle *(stopped by paper)*
Beta	1 very fast electron *(negative electric charge)*	light particle *(stopped by aluminum)*
Gamma	1 photon of pure energy *(no electric charge)*	not a particle *(stopped by thick lead)*

INSIDE THE BODY, ALPHA RADIATION IS 20 TIMES MORE DAMAGING (PER UNIT OF ENERGY) THAN BETA OR GAMMA

Figure 16
Three types of atomic radiation

More About Alpha Radiation

This photograph (Figure 15) shows the tracks made by alpha rays emitted from an invisibly small speck of radioactive material in the lung tissue of an ape, over a period of 48 hours.

The star-like "object" in the photo is an optical illusion. It is a photographic record of the atomic disintegrations that have occurred over 48 hours; each "spike" is the track left by an individual alpha ray given off by the disintegration of a single radioactive atom.

Notice that the tracks are very short, since alpha radiation is a non-penetrating form of atomic radiation. Nevertheless, it is estimated that up to 50 000 cells in the ape's lung may be damaged by the rays shown here. If a few of those damaged cells are able to reproduce, they may grow into a cancerous tumour many years later. The invisible damage caused by alpha radiation is magnified by the natural processes of cell growth and reproduction.

The alpha-emitting material in this ape's lung is actually a tiny particle of plutonium, but the same type of damage is done by radon decay products in the lungs of uranium miners, by radium deposited in the bones of dial painters, or by polonium-210 in the soft tissues of Alexander Litvinenko, for all of these radioactive substances are alpha-emitting materials.

More people have been killed by alpha radiation than by any other kind of radioactivity; indeed, alpha-emitting radioactive materials are among the deadliest poisons known. As previously stated, alpha radiation is about 20 times as "biologically effective" as beta radiation or gamma radiation or X-rays. If equal populations of people were exposed to the same amount of alpha radiation energy and beta radiation energy, the alpha radiation would be expected to cause 20 times as many cancers as the beta radiation would cause.

Notice (Figure 8) that eight of the fourteen radioactive elements in the decay chain of uranium-238 are alpha emitters. So wherever uranium mining occurs, there is an enhanced long-term radiation risk because of the presence of so many different kinds of alpha emitters. This comment is not intended to dismiss or to minimize the dangers posed by exposures to beta and gamma radiation, which are also considerable.

Scientists have observed that if a given dose of alpha radiation is spread out equally among a large population, so that each person receives only a small individual dose, the biological damage (number of cancers etc.) is greater than if that same total dose were given to a smaller population, with fewer people exposed to larger doses. Scientists have concluded that there is no such thing as a "safe" dose of radiation exposure. The biological damage is cumulative, and it depends upon the "population dose" – the sum of all individual doses.

Figure 17
30-foot wall of radioactive uranium tailings in Ontario

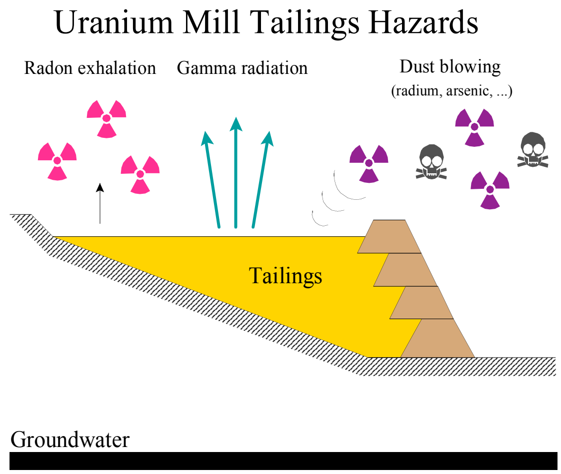

Figure 18
Airborne pathways for radioactive materials

Uranium Tailings – Hazardous for 80 000 years

To get uranium from a mine, the rock must first be dug out of the ground. Rocks that are more radioactive are classified as ore; those that are less radioactive are called waste rock. Waste rocks are often dangerously radioactive even though they do not qualify as ore.

In the mill, the ore is crushed to a fine powder. Acids and other chemicals are used to separate the uranium from the sand-like residues, called "uranium tailings". As Marie Curie showed, the residues are much more radioactive than the uranium that is extracted. In fact, 85 % of the radioactivity in the ore ends up in the tailings; only 15 % is uranium.

The radioactive materials left behind in the uranium tailings are among the deadliest poisons known to science: radium-226, that killed so many of the dial painters; polonium-210, that was used to poison Litvinenko; radon gas, which remains one of the deadliest cancer-causing agent ever encountered; as well as thorium-230, lead-210, and others.

The danger posed by a radioactive substance is not indicated by its weight or its volume, but by its degree of radioactivity. Radioactivity is measured in "becquerels". The number of becquerels is the number of radioactive disintegrations that take place every second.

When uranium ore has lain undisturbed for hundreds of millions of years, then all of the uranium decay products will have exactly the same radioactivity as uranium-238. For example, if a 10-kilogram rock contains 1000 becquerels of uranium (about one gram), it will also contain 1000 becquerels of radium-226, 1000 becquerels of polonium-210, 1000 becquerels of radon, and so on. The total radioactivity of the rock is 14 000 becquerels, since there are 14 different radioactive substances in the "decay chain" (Figure 8). Once the uranium has been removed (two varieties) the residues still have about 12 000 becquerels of radioactivity left.

To make matters worse, most of the uranium decay products are constantly replenished by the on-going radioactive disintegration of thorium-230, which has a 76 000 year half-life. This means that only half of the atoms of thorium-230 will disintegrate in 76 000 years.

Thus the amount of radium, polonium, and radon in the tailings will remain almost the same for thousands of years, and will only be reduced by half in about 80 000 years. So how does one keep millions of tons of radioactive sand out of the environment for 80 000 years?

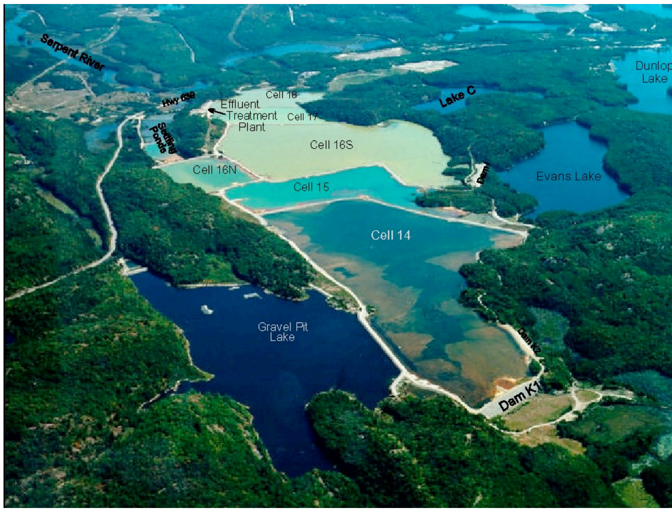

Figure 19
Containment system for Elliot Lake tailings

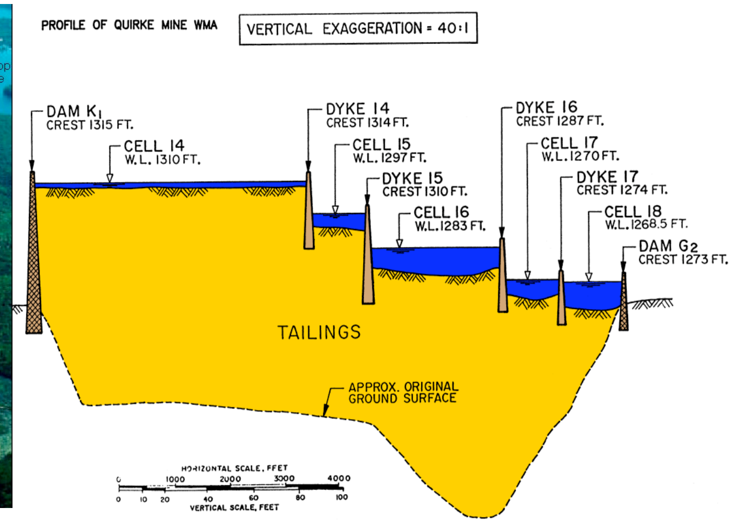

Figure 20
Side-view of the containment system with dykes

Safeguarding the Future

This photograph (Figure 19) shows an elaborate containment system recently devised for the long-term storage of a large volume of uranium tailings in the Elliot Lake region of Ontario. Figure 20 illustrates the many levels of water cover separated by dykes and dams.

The water helps to prevent the escape of radon gas into the atmosphere. Radon has a four-day half-life, meaning that half of the radon atoms will disintegrate in four days. The decay products of radon (the "radon progeny" – see Figure 4) are solid materials, including three varieties of polonium. If radon escapes into the air from the tailing pile, lead-210 and polonium-210 will be deposited on the vegetation and will find its way into caribou meat.

The different water levels also allow for solid radioactive materials such as radium to be precipitated out, meaning that these solids will accumulate at the bottom of each pond and will not pass into the next level of water lower down, because of the presence of the dyke.

But will these engineered structures succeed in preventing the spread of radioactive materials into the environment for the next 80 000 years? Will these structrues withstand freezing and thawing, floods and droughts, earthquakes and tornados – not to mention the natural deterioration of dykes and dams, the effects of burrowing animals and the root systems of plants, and the depradations of migrating herds, marauding teenagers, or the blundering of snowmobiles or heavy machinery in the distant future?

The tailings shown above have been abandoned by the company that mined the uranium. The jobs are gone, the profits have been taken, the uranium has been extracted. The radioactive wastes remain behind as a perpetual legacy for future generations of people who received none of the benefits of the mining operation. Future generations will have to spend their own money to rebuild the dykes, and to maintain and monitor the water flows, or to suffer the consequences of large-scale and irreversible radioactive contamination.

In the past, there have been over 30 tailings dam failures in the Elliot Lake area. In 1979, a massive state-of-the-art tailings dam experienced a catastrophic collapse at Churchrock, New Mexico. It was the second largest release of radioactive material into the environment, after Chernobyl. Cattle were slaughtered for many miles downstream due to radioactive contamination of the meat and the milk. No one knows how to clean up such a mess.

Conclusion – Leave It In The Ground?

Many people around the world believe that uranium should be left in the ground because the dangers that it poses to the planet overshadow any good that it can do. This is, first and foremost, because of the intimate connection between uranium and nuclear weapons; and secondly because of the dangers of radioactive contamination of the environment.

Without uranium, there could be no nuclear weapons of any description. Most nuclear weapons use plutonium as the primary nuclear explosive, but every atom of plutonium is created from an atom of uranium. Uranium is the essential raw material for all of them.

Even if uranium is used for peaceful purposes – that is, as fuel for a nuclear reactor – the irradiated fuel ("spent fuel") inevitably contains plutonium. That plutonium can be used to build nuclear weapons at any time in the future, even thousands of years after the nuclear reactor that produced the plutonium has been completely shut down and forgotten.

From this perspective, all extracted uranium ends up (after a number of years) either

- in nuclear weapons;
- as radioactive waste;
- as plutonium; or
- as depleted uranium.

Many people, including myself, believe that the long-term danger to the planet caused by the spread of nuclear technology is greater than any benefit that uranium has to offer.

Minimizing the Long-Term Environmental Impact

But if uranium is to be mined, there are ways to minimize the long-term radiological impacts on the community that hosts the mining operation.

Ideally, any mining company that wishes to extract uranium and take it away, should be required to take away the most significant radioactive waste byproducts as well. In other words, the company should not be allowed to extract the valuable commodity, uranium, without also taking direct control and ownership of the hazardous waste byproducts. There are at least two ways that this can be done.

1) The ore could be shipped away from the mine site to a mill that is far removed from the mining community. The extraction of uranium and the production of uranium tailings would then take place at that distant location. In the case of Baker Lake, this could be accomplished by requiring that the milling be done in Saskatchewan.

2) If a mill is to be operated near the mine site, the mining company could be required to extract not only uranium, but also the other long-lived radioactive materials. In practice, this would mean that the uranium, thorium, and radium are all removed from the crushed ore, and taken into permanent custody by the mining company.

   If the thorium and radium are removed, the radiological hazard of the tailings will be dramatically diminished, and the radioactive half-life of the tailings will be reduced from thousands of years to just a couple of centuries.