The Harm Caused by Radioactivity

Prepared for the Algonquins of Pikwakanagan
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Atoms and Molecules

All material things are made up of atoms. There are 92 different kinds of atoms found in nature, ranging from hydrogen (the lightest) to uranium (the heaviest).

Every atom has a tiny but massive core called its nucleus. The nucleus is surrounded by orbiting electrons (one electron for hydrogen, 92 electrons for uranium).

Molecules are combinations of atoms. For example a molecule of water is H_2O – two hydrogen atoms bonded together with one oxygen atom. The bond that holds the atoms together in a molecule is the force of electromagnetic attraction. That force is the result of atoms sharing their orbiting electrons; it does not affect the nucleus.

The cells in our body contain a great many complicated organic molecules, the most important one being the DNA molecule. DNA carries the genetic instructions that we inherited from our parents. DNA tells our cells how to reproduce properly.

All organic molecules have chains of carbon atoms bonded to numerous hydrogen atoms, and other types of atoms too. Such molecules are the building blocks of life.

Chemical energy does not involve the nucleus, it only involves the orbiting electrons. Nuclear energy refers to energy that comes directly from the atomic nucleus; it is millions of times more powerful than chemical energy. Science had no knowledge of nuclear energy until the end of the 19th century.

Ions and Ionizing Radiation

"Ionizing Radiation" refers to any form of energy that is powerful enough to break molecules apart by randomly smashing the bonds holding its atoms together. The electrically charged fragments of broken molecules are "ions" (or "free radicals").

Ions are unstable. Because they are electrically charged they repel and attract other ions, causing chaotic chemical reactions to take place rapidly. Chaos is unhealthy.

The most commonly encountered forms of ionizing radiation are (1) x-rays from an x-ray machine and (2) emissions from the disintegration of radioactive materials.

Most other forms of radiation, such as visible light, infrared, microwaves, radio and television waves, are non-ionizing. They can not break molecular bonds.

Biological Effects of Ionizing Radiation

Massive doses of ionizing radiation are deadly, killing any human being within days of exposure. So many molecules are destroyed, and so many organs are damaged, that the body cannot survive. Such damage can be caused by a nuclear explosion.

Large but not lethal doses of ionizing radiation can cause nausea, vomiting, hair loss, sterility, eye cataracts, and severe burns that are very difficult to heal. Some of these symptoms are experienced by cancer patients undergoing radiotherapy. In the case of pregnant women, such exposures to ionizing radiation can lead to the birth of deformed children, including babies with shrunken heads and impaired intelligence. These effects are all well-documented in the scientific literature.

Low doses of ionizing radiation do not cause any immediately perceptible harm, but there is always damage to living cells within the body of the person so exposed.

The chaotic disruption caused by ionizing radiation is damaging to any exposed cell, often killing the cell, sometimes damaging it beyond repair. Fortunately, the body can replace such dead or non-functioning cells if the damage is not too extensive.

There are mechanisms available within the cell that can sometimes repair the damage done by ionizing radiation, but not always. When repair fails, a cell crippled by ionizing radiation may go on living and reproducing with damaged DNA instructions. It then multiplies in an abnormal fashion, yielding a cancer years later.

Although very few damaged cells develop into cancers, a wide variety of lethal and non-lethal radiation-caused cancers have been observed in populations exposed to low levels of ionizing radiation. These are well described in the scientific literature.

Under a microscope one can see that blood changes occur even with low doses of ionizing radiation. The blood cells most easily harmed are those that are needed by the body to fight infections. Thus ionizing radiation weakens the body's immune system, making the individual more susceptible to a variety of infectious diseases.

In experimental animals it has been demonstrated beyond any doubt that even very small doses of ionizing radiation can damage the DNA of reproductive cells (eggs and sperm) of individuals. Visibly defective offspring eventually result. H. J. Muller won the Nobel Prize in 1946 for showing that there is no dose of ionizing radiation low enough to prevent harmful mutations from being caused by such exposures.

Similar evidence of radiation-induced mutations has not been found in human populations, but it is assumed that harmful mutations probably do occur in humans following exposure of their reproductive organs to ionizing radiation. All other species that have been studied have shown such effects. This is the main reason that lead aprons are used to cover genitals when people are x-rayed in hospitals.

X-Rays – The Discovery of Ionizing Radiation

Ionizing radiation was unknown to science until 122 years ago. Our first notice of ionizing radiation was the discovery of x-rays in 1895 by W. Roentgen in Germany.

An x-ray machine is powered by electricity. It can be turned on and off, like a light switch. When the x-ray machine is off it is harmless, but when it's on it's dangerous. That's why, before giving an x-ray to a patient, the technician leaves the room.

When the x-ray machine is on, a powerful kind of invisible light – an x-ray – is given off. While it can penetrate right through soft tissue as if it were transparent, x-rays are blocked by denser material like bones. In this way doctors can examine the images of the bones of a human skeleton by catching their "shadows" cast by the x-rays on photographic paper or on an illuminated viewing screen.

The harmful effects of x-rays were discovered almost immediately. Severe burns, eye cataracts, sterilization of experimental animals, and excess leukemia among radiologists, all caused by x-ray exposures, were recognized by the first decade of the 20th century. And the ionizing character of x-rays was documented right away.

Doctors quickly realized that the destructive effects of x-rays could be used to advantage to fight malignant tumors (cancerous growths) by blasting them with x-rays. It works, to a significant degree. Sadly, some of those same doctors years later died of cancers that were caused by their own repeated exposures to x-rays.

Radioactivity – The Discovery of Nuclear Energy

In 1896, just a year after the discovery of x-rays, a scientist in Paris named Henri Becquerel discovered radioactivity. It was an accidental discovery.

Becquerel had a rock containing uranium in a desk drawer. In that same drawer he had a photographic plate wrapped in black paper to block any light. But when the photo was developed, there was a blurry image – apparently caused by the rock.

This was a stunning discovery. Somehow, the rock was giving off an invisible kind of light, penetrating right through the black paper that blocked all visible light, so as to create an unmistakable image on a photographic plate. The rock was behaving like a miniature x-ray machine that could not be shut off. How is that possible?

Where was this powerful invisible light coming from? There was no external power source – no electricity, no sunlight, no chemical reactions. Over the next few years the mystery was unravelled. It was discovered that some atoms have an unstable nucleus, and uranium is one of those. Such unstable atoms are called "radioactive". The nucleus of a radioactive atom spontaneously emits ionizing radiation. And it doesn't stop. It is an ongoing release of nuclear energy that cannot be shut off.

Dangers of Radioactivity 1 – Radium

In 1898, Marie Curie discovered two new radioactive elements that are much more intensely radioactive than uranium alone. She named them "radium" and "polonium". They were found in the same sort of rock that Becquerel had used.

Later that year, Becquerel carried a sealed tube of radium in his vest pocket. As a result he got a nasty "radiation burn" on his torso that was painful, very slow to heal, and left an ugly scar. Marie Curie's hands also suffered painful radiation burns after she handled a thin metal box containing a small tube of radium.

Seeing these burns, doctors used radium-filled "needles" to shrink solid tumors. Such a needle inserted into an unwanted growth delivers most of its harmful ionizing radiation to the diseased tissue while minimizing the dose to healthy tissue. Workers preparing the needles, surgeons implanting them, and nurses attending patients often received substantial doses of ionizing radiation themselves.

In 1908 a radium-based paint was developed that makes things glow in the dark. The invisible ionizing radiation given off by disintegrating radium atoms is absorbed and converted into visible light by specialized paint molecules. The glow that results needs no battery or other power source, not even exposure to sunlight. It just glows.

This soon became big business. Thousands of teenaged girls were hired to paint the dials of watches and instruments with this wondrous new kind of paint. By 1914 radium had become the most expensive substance on earth, at $180,000 per gram. It was painstaking work; the girls often used their lips to put a fine tip on their brush.

By the 1920s many of the dial painters had developed severe anemia, in some cases fatal. Autopsies of the girls' bodies revealed ionizing radiation emanating from their bones, spleen and liver, due to tiny amounts of radium deposited in their organs.

Many girls also had grave dental problems with teeth breaking and falling out due to bone deterioration, plus rampant bacterial infections. Dentists working on the girls' teeth found the jaw bones to be soft and porous, even fracturing spontaneously. Dr. Martland, a forensic pathologist, showed in 1925 that these symptoms (termed "radium jaw") were caused by tiny amounts of radium that had embrittled the bone.

Before long, cases of bone cancer began to be observed among the surviving dial painters. Over 1200 deaths from bone cancer were ultimately recorded in that population. It was crystal clear that ionizing radiation from radium deposited in the girls' skeletons was the cause. In every case, the lethal amount of radium in any girls' body was less than a milligram (a milligram is one thousandth of a gram).

Years later, several hundred of the remaining dial painters developed head cancers – cancers of the sinus and mastoid – caused by a radioactive gas (radon) produced by disintegration of radium atoms in the bones and carried by the blood to the head.

Dangers of Radioactivity 2 – Radon Gas

For 400 years, underground miners in the Schneeburg region of Germany suffered from a mysterious lung ailment that killed up to half the mining population. In the mid-19th century the disease was identified as lung cancer. The cause was unknown.

By the 1930s, scientists learned that the miners' lung cancers were brought about by breathing a radioactive gas called radon. It was pervasive in the underground tunnels. Ionizing radiation given off by the inhaled gas turned lung cells cancerous.

Radon gas is one of the most powerful cancer-causing agents known to science. It is invisible, odourless, and tasteless. It is seven times heavier than air, so it stays close to the ground. It cannot be filtered out of the air. And it is continually being created, one atom at a time, by the disintegration of radium atoms.

When a radium atom disintegrates it does not disappear, it becomes an atom of radon gas. So radium, a radioactive heavy metal, is gradually transforming itself into a radioactive gas. Indeed, every atom of radon was once an atom of radium.

These men were mining for silver and cobalt, but the ore was also rich in uranium. Wherever uranium is found, there also is radium, as Marie Curie demonstrated in 1898. So there will be radon too – the gas is a so-called "decay product" of radium.

Throughout the twentieth century, underground uranium miners around the world suffered excess lung cancers caused by their exposures to radon gas – from the Navajo Indians mining uranium on the Colorado Plateau, to underground miners in Sweden and South Africa, to Canadian miners in the Northwest Territories, Northern Saskatchewan, Elliot Lake Ontario, and Newfoundland – all experienced a dramatically elevated incidence of lung cancer caused by their radon gas exposures.

The US Environmental Protection Agency estimates that currently, between 20,000 and 30,000 lung cancer deaths occur every year from American citizens breathing radon gas in their homes. Radon gas enters homes when the soil has a higher than usual amount of radium, or when radium-contaminated materials are used in the construction of homes, as has happened in many communities.

Sometimes radon enters homes in the form of radioactively contaminated water (i.e. water containing dissolved radon). In such cases high radon exposures often result from showering. Radon gas is the leading cause of lung cancer among non-smokers.

Because radium is such a deadly substance, it is now considered too dangerous to use in commercial applications. So radium became a radioactive waste product of uranium mining. Since the mid-20th century, massive piles of radium-bearing wastes – over 200 million tonnes in Canada – have been stored at the surface in the form of a fine sand. These sandy wastes constantly give off radon gas into the atmosphere.

Dangers of Radioactivity 3 – Polonium

When uranium atoms disintegrate, they change into about two dozen other radioactive materials – these are the "decay products" of uranium. Among these decay products are radium, radon, and polonium. That's why uranium ore always contains radium and polonium; they are both natural byproducts of uranium.

Since the Chalk River Near Surface Disposal Facility is intended to store a very large amount of uranium (1000 tonnes!), there will be always more and more radium, radon and polonium in those wastes as the centuries go by, increasing without end, as more and more uranium atoms disintegrate into their natural decay products.

Polonium is a radioactive solid that occurs in nature as a decay product of radon. When an atom of radon disintegrates, it becomes an atom of polonium. In fact there are 3 different varieties (called "isotopes") of polonium : polonium-218, polonium-214, and polonium-210. They are all radioactive byproducts of radon gas. And, of course, every atom of radon was once an atom of radium, and every atom of radium was once an atom of uranium, so it's all happening all the time – a "decay chain".

It so happens that polonium is the deadliest element on earth. Scientists at Los Alamos Laboratory in New Mexico, the place where they developed the explosive mechanism for the first atomic bomb, say polonium-210 is 250 billion times more toxic than cyanide. So whatever amount of cyanide is needed to kill a human being, that same amount of polonium-210 would be enough to kill 250 billion humans.

In 2008 a small amount of polonium-210 was dumped into a cup of tea in London, England, to murder an ex-Russian spy named Alexander Litvinenko. He died an agonizing death as all his internal organs shut down one by one. Polonium-210 attaches itself to red blood cells and so it spreads all over the body by normal blood circulation. The ionizing radiation given off by disintegrating polonium atoms is particular devastating to living tissue, wherever that tissue may be in the body.

When tobacco is grown, radon gas builds up under the thick leaves, and atoms of polonium are produced there. Polonium adheres to the sticky hairs on the leaves, so a very tiny amount ends up in the harvested tobacco. This situation is made worse when radioactive fertilizer is used to promote the growth of the tobacco plants.

The American Health Physics Society, specializing in monitoring radiation, estimates that 90 percent of the deaths attributed to cigarette smoking are actually caused by polonium-210 in cigarette smoke. So polonium is killing over 200,000 Americans per year, due to lung cancer, heart attacks and strokes caused by ionizing radiation.

Inuit people have more polonium in their bodies than the average Canadian because they eat a lot of caribou meat. Caribou eat a lot of lichen, and the lichen absorbs the polonium dust that slowly settles out from radon gas atoms disintegrating in the air.

Is There a Safe Dose of Ionizing Radiation?

Large doses of ionizing radiation can cause death, radiation sickness, hair loss, sterility, radiation burns, cataracts, and many other harmful effects that are apparent within hours, days, or weeks of exposure – within a year, at least. These are called "prompt effects"; they can all be prevented by lowering the exposure.

Low doses of ionizing radiation can cause cancers, leukemias, genetic damage to the DNA of reproductive cells, and a variety of other ailments that will often not become apparent for years or even decades after exposure. These are called "delayed effects" of ionizing radiation. (The technical term is "stochastic effects".) Delayed effects cannot be altogether prevented just by lowering the level of exposure.

Many scientific bodies exist to sift through the scientific evidence and determine the truth as they see it. These include UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation), the BEIR Committee of the NAS (National Academy of Sciences Committee on the Biological Effects of Ionizing Radiation), and the ICRP (International Committee on Radiological Protection). These bodies have issued a series of reports over many years on the subject of ionizing radiation.

The scientific consensus of all these committees is that any dose of ionizing radiation, no matter how small, can in principle cause the delayed effects mentioned above: cancer, leukemia, or genetic damage. But with very low doses of ionizing radiation, the fraction of the exposed population suffering such harm is also low.

All these scientific committees have accepted the "linear hypothesis" as the best guide. The linear hypothesis implies that there is no safe threshold of exposure to ionizing radiation, because harmful effects – including lethal effects – can be experienced by individuals exposed to even low levels. To be more precise the linear hypothesis states that the number of damaged individuals in an exposed population is roughly proportional to the average dose multiplied by the size of the population.

It is worth noting that every nuclear regulatory body in the world has formally accepted the linear hypothesis. All radiation limits and standards are based on the linear hypothesis, with no assumed safe threshold. This means that there is no absolutely safe dose of ionizing radiation, so all exposures should be kept to zero if possible. The "permissible levels" of radiation exposure are based on the belief that some level of radiation-caused cancers or genetic defects is acceptable in exchange for the benefits of the radiation exposure that caused these harmful effects. It is also well-established that women and children are much more vulnerable than men.

When it comes to very long-lived radioactive waste materials that will be around for hundreds of thousands of years, the linear hypothesis becomes very worrisome, because the exposed population is not just those people who are living near the waste right now, but all the future generations of people who will live near the wastes for thousands of years to come. As the exposed population grows larger and larger with time, the number of cancers and genetic defects becomes incalculable.

Radioactive Emissions: Alpha, Beta and Gamma

Sooner or later the nucleus of any radioactive atom will disintegrate (i.e. explode). Any emission given off during such a disintegration is called “atomic radiation”. The half-life of a radioactive element is the time needed for half its atoms to disintegrate

Radioactivity is measured by how many disintegrations occur in one second. One disintegration per second is referred to as a “Becquerel” (Bq). A terabecquerel (TBq) is a trillion becquerels, indicating that a million million radioactive disintegrations are taking place every second. Many of the radioactive waste materials to be deposited in the Chalk River Near Surface Disposal Facility, according to authorities, are measured in terabecquerels, sometimes even thousands of terabecquerels.

When a nucleus disintegrates, it ejects an electrically charged particle, travelling incredibly fast, that can smash molecular bonds with ease. There are two types of such particles. An “alpha particle” is positively charged, whereas a “beta particle” is negatively charged. Almost all radioactive elements can be classified into one of two categories – either as an “alpha-emitter” or as a “beta-emitter”. For example, polonium is an alpha-emitter, while tritium (radioactive hydrogen) is a beta-emitter.

In many cases, a disintegrating nucleus may also give off a burst of pure energy, very similar to an x-ray, but far more powerful. Such emissions are called “gamma rays”. Any radioactive element that gives off gamma rays is called a “gamma-emitter”. Technetium-99m, used in hospitals for diagnostic tests, is a gamma-emitter.

Since alpha particles, beta particles, and gamma rays all break molecular bonds, they are all classified as “ionizing radiation”. As such, they are all able to cause any of the adverse effects described earlier as health consequences of ionizing radiation.

While alpha particles and beta particles are material projectiles, and not radiation at all, they are sometimes incorrectly referred to as “alpha rays” and “beta rays”. Being particles, however, they are much less penetrating than x-rays or gamma rays.

Gamma rays are the most penetrating form of atomic radiation, requiring heavy lead shielding to limit exposures. Beta particles are much less penetrating. They can travel only a few centimetres in soft tissue, and can be stopped by an aluminum plate. Alpha particles are the least penetrating, unable to pass through a sheet of writing paper or even a glass window. Despite the differences they’re all dangerous.

Due to limited powers of penetration, alpha-emitters and beta-emitters are mainly internal hazards (i.e. they normally must be inside the body to do severe harm). Once inside the body, alpha emitters are much more damaging than beta emitters. An alpha particle is 7000 times more massive than a beta particle. If a beta particle is thought of as a kind of subatomic bullet, then an alpha particle is a kind of subatomic cannon ball : the cannon ball is less penetrating but more damaging. Gamma rays, because of their great penetrating power, are external hazards as well as well as internal hazards (i.e. when gamma emitters are ingested or inhaled).

Special Dangers of Alpha and Beta Emitters

Gamma-emitters are easy to detect with radiation monitoring equipment. Even if a gamma emitter is inside your body it can set off a radiation alarm. Alpha-emitters and beta-emitters are more difficult to detect even outside the body, and once inside the body they generally escape routine detection altogether. Laboratory analysis of urine or excrement or some other contaminated samples must then be carried out.

Canadian nuclear authorities have on occasion failed to detect alpha-emitters and beta-emitters for weeks, even while clean-up crews were being contaminated.

During a retubing operation at Pickering in the 1980s, workers were contaminated with a beta-emitting radioactive dust (carbon-14) for weeks. By the time authorities finally identified the danger, workers had been tracking the material to their homes on a regular basis. Bedclothes and some furniture had to be removed from workers' homes and disposed of as radioactive waste. Internal contamination of the worker's bodies by inhalation and ingestion of radioactive carbon dust could not be undone.

More recently, during the refurbishment of the Bruce A nuclear reactors in 2009, over 500 contract workers – not regular employees of Bruce Power – inhaled alpha-emitting dust on the job for several weeks before the authorities detected the hazard. Those alpha-emitting radioactive materials are now lodged inside the worker's lungs and other internal organs, and will be there for years to come. Long after the job has ended, their bodies will continue to be irradiated from the inside.

Both of these episodes could have been avoided if nuclear authorities had tested air samples for radioactive contamination on a daily basis, or if workers had been issued respirators and protective clothing. But incredible as it may seem, the regulator (CNSC) found none of the managers or inspectors guilty of negligence.

It is a fact that alpha-emitters have killed more people during the twentieth century than any other kinds of radioactive materials. Radium, radon, polonium, and uranium are all alpha-emitters, and they have killed hundreds of thousands.

Inside every nuclear reactor, new man-made alpha-emitters are created, such as plutonium, neptunium, americium, and curium. These are among the alpha-emitting radioactive materials that were suspended in the air inside the Bruce reactor building while contract workers without respirators went about their work.

The Chalk River Near Surface Disposal Facility is intended to store a significant amount of plutonium and other alpha-emitting material – all of it difficult to detect, all of it highly dangerous even in tiny amounts. The main reason that the Chalk River radioactive waste will remain dangerous for hundreds of thousands of years is that many of the human-made alpha emitters have very long lives. Plutonium-239 has a half-life of 24,000 years, but its decay product has a half-life of 700 million years.

Conclusion

Here are some statements from various official bodies in Canada and elsewhere:

1. Report to the U.S. Congress by the Comptroller General of the United States
   "Nuclear Energy's Dilemma: Disposing of Nuclear Waste Safely" (Sept 1977)

"Radioactive wastes, being highly toxic, can damage or destroy living cells, causing cancer and possibly death depending on the quantity and length of time individuals are exposed to them. Some radioactive wastes will remain hazardous for hundreds of thousands of years. Decisions on what to do with these wastes will affect the lives of future generations…."

"To safeguard present and future generations, locations must be found to isolate these wastes and their harmful environmental effects. A program must be developed for present and future waste disposal operations that will not create unwarranted public risk. Otherwise, nuclear power cannot continue to be a practical source of energy."

2. Nuclear Policy Review, Background Papers (Report ER81-2E)
   Energy Mines and Resources, Government of Canada, 1982

"Despite repeated assurances that nuclear waste disposal presents no insoluble scientific, engineering, or environmental problems, the issue remains in the minds of the public and some members of the scientific community as a serious unresolved issue associated with the development of nuclear energy…."

"Three general issues can be highlighted. First, there is a concern that society is imposing a serious burden on future generations by leaving behind a legacy of radioactive wastes which may prove difficult to manage….

"This naturally raises a second question. How can it be proven that waste disposal systems will perform adequately over very long periods of time? ….

"Finally, there is the problem of establishing what the words "perform acceptably" mean. A clear general statement of overall principles applying to radioactive waste management has yet to be agreed upon within Canada or internationally."

3. BEIR-VII – 7th Report on the Biological Effects of Ionizing Radiation (2008)
   The National Research Council of the US National Academy of Sciences

"The scientific research base shows that there is no threshold of exposure below which low levels of ionizing radiation can be demonstrated to be harmless or beneficial. The health risks – particularly the development of solid cancers in organs – rise proportionally with exposure. At low doses of radiation, the risk of inducing solid cancers is very small. But as the overall lifetime exposure increases, so does the risk."

Committee Chair Richard R. Monson, Professor of Epidemiology,
Harvard School of Public Health, Boston; Press Release, June 2007

4. Nuclear Power and the Environment, Sir Brian Flowers (Sept 1976)
   Sixth Report of the UK Royal Commission on the Environment

"We must assume that these wastes will remain dangerous, and will need to be isolated from the biosphere, for hundreds of thousands of years. In considering arrangements for dealing safely with such wastes man is faced with time scales that transcend his experience….

"The creation of wastes which will need to be contained for such periods of time, and hence of a legacy of risk and responsibility to our remote descendants, is a matter of great concern to many people. We think, however, that some continuity must be assumed in human affairs and institutions, and in the ability of future generations to maintain the necessary containment."

"We are confident that an acceptable solution will be found and we attach great importance to the search; for we are agreed that it would be irresponsible and morally wrong to commit future generations to the consequences of fission power on a massive scale unless it has been demonstrated beyond reasonable doubt that at least one method exists for the safe isolation of these wastes for the indefinite future."

5. Select Committee on Ontario Hydro Affairs, Ontario Legislature (June 1980)
   The Management of Nuclear Fuel Waste, Final Report

"The consensus of the Committee is that communities are not likely to easily accept the siting of what will be perceived as a garbage dump for frightening nuclear poisons. The waste must be disposed of. It must be disposed of safely and permanently. In the Committee's view, it is most likely that government will ultimately have to choose where the unpopular site will be located...."

"One of the major problems AECL must overcome is the public's perception that its entire program -- from basic research to public information -- is biased by its commitment to nuclear power and consequent desire to show that waste disposal is not an insuperable problem. The Committee's view is that AECL compounded its credibility problem by its one-sided, overly positive and broadly pro-nuclear presentation of information."

6. A Race Against Time, Interim Report on Nuclear Power In Ontario (Sept 1978)
   Ontario Royal Commission on Electric Power Planning, Arthur Porter

"Given the very long life of these toxic materials, no man-made containment system can ever be predicted to give sufficient protection. All over the world scientists are looking for ways to use nature as a final barrier."

Articles by Dr. Gordon Edwards on the Biological Effects of Ionizing Radiation

Open Letter to Physicists: http://www.ccnr.org/open_letter.html
Report for Environmental Advisory Council: http://www.ccnr.org/CEAC_B.html
Estimating Lung Cancers: http://www.ccnr.org/lung_cancer_1.html
Review of Tritium Report: http://www.ccnr.org/GE_ODWAC_2009_e.pdf