QUESTIONS AND ANSWERS
ABOUT IRRADIATED NUCLEAR FUEL IN CANADA

Concerning

A presentation made by Dr. Gordon Edwards

to the South Bruce NWMO CLC

on November 5, 2020

on the topic of

Nuclear Fuel Waste: Before the Burial

(see video at www.tinyurl.com/1h5o464n)

(see slide show at www.ccnr.org/south_bruce_2020.pdf)

Submitted to the South Bruce CLC

Wednesday February 8, 2021

Executive Summary

On November 5, 2020, I gave an invited zoom presentation to the South Bruce NWMO Community Liaison Committee (CLC) dealing with the hazards of Irradiated Nuclear Fuel prior to burial. See the video recording: https://youtu.be/VJvX9qYr4H0 .

The South Bruce Municipality, located about 40 kilometres east of Lake Huron, is one of two remaining candidates – out of an initial field of 22 communities, 3 of them in Saskatchewan and the rest in Ontario – from which a willing host community is to be chosen to receive all of Canada's used nuclear fuel for burial. The other remaining candidate is Ignace, located northwest of Lake Superior on the road to Winnipeg.

Following my presentation, I was asked by the CLC to prepare written answers to a series of wide-ranging questions, some from the committee members (oral) and some from viewers of the zoom session (written).

The following document is a list of 17 questions with answers. I have included 5 pages of background information because the questioners were not always aware of all the basic facts about irradiated nuclear fuel or about the concept of Rolling Stewardship, an alternative strategy for managing nuclear waste without abandoning them underground.

Some of the important insights included in this text are the following:

(1) the used fuel bundles from CANDU nuclear reactors are not themselves the radioactive wastes but merely the containers of the actual radioactive wastes, the hundreds of radioactive materials that are created inside the reactor as a result of the nuclear fission process and trapped in the used fuel;

(2) the radioactive waste materials contained in used nuclear fuel are extremely diverse in their physical, chemical and biomedical properties, each one having its own unique pathways through the environment and through the human body;

(3) used nuclear fuel rods that are damaged will release radioactive materials in the form of gases, vapours, aerosols and particulates, which are then disseminated throughout the primary cooling system of a nuclear reactor and inside the hot cells that must be used to repackage the used fuel before burial;

(4) because radioactivity is a form of nuclear energy that cannot be shut off by any method known to science, heat is generated spontaneously by the nuclear wastes in used fuel and will force the temperature of surrounding materials to increase for many thousands of years after removal from the reactor;

(5) used nuclear fuel needs to be cooled for decades – typically 30 years or more – before it can be sealed in an underground repository and then it will heat up the surrounding rocks which will not return to ambient temperatures for 50,000 years;

(6) Rolling Stewardship is not proposed as a solution to the nuclear waste problem but as a responsible management scheme motivated by the realization that at present there is no proven safe solution to this problem.

Gordon Edwards, February 7, 2021, Hampstead, Quebec

B1. Background - Radioactive Waste

A nuclear reactor is an unusual way to boil water. Instead of burning coal or oil to get heat, a nuclear plant splits uranium atoms using subatomic projectiles called neutrons. This process of "nuclear fission" releases energy (heat) without producing any carbon dioxide. That heat can be used to boil water, and electricity can be produced if the steam is used to turn the blades of a turbine.

Unfortunately, the fission process also creates hundreds of varieties of unwanted byproducts – radio-active elements never found in nature before 1940. These dangerous human-made materials are, for the most part, trapped inside the used nuclear fuel rods. But if an irradiated fuel rod is damaged – even a small crack or a pin-hole leak will do – some of the radioactive materials will escape from the fuel.

An uncontained nuclear accident can release a lot of these materials into the environment. A 1978 report by the Ontario Royal Commission on Electric Power Planning explains:

> *". . . a major reactor accident would lead to the severe overheating, and subsequent melting, of the nuclear fuel, which would give rise to a substantial quantity of radioactive material escaping . . . into the environment. The major health and environmental threat would be due to the escape of the fission products to the atmosphere. The most important of these are caesium, ruthenium, tellurium and the fission gases, iodine, krypton and xenon."*
>
> *A Race Against Time, p. 73*

In themselves, caesium, ruthenium, tellurium, iodine, krypton, and xenon are naturally occurring materials that are not radioactive. The passage quoted above refers to the release of newly created radioactive varieties of these elements, normally not found in nature. Radioactive atoms are unstable. A radioactive atom will explode or disintegrate, suddenly and violently, giving off a kind of subatomic shrapnel called "atomic radiation". Exposure to such emissions will damage nearby living cells. Some of those radiation-crippled cells will develop into cancers many years later.

Once a radioactive variety mixes with a non-radioactive variety of the same element, they cannot be separated again. Radioactivity becomes a permanent feature of that previously non-radioactive material. That's why it is important to keep these human-made radioactive elements out of the environment. Once released, they can enter the human body by contaminating the food we eat, the water we drink, or the air we breathe, becoming internal as well as external health hazards.

B2. Background – Fission Products

Radioactive iodine is a case in point. Natural non-radioactive iodine is routinely added to our table salt – you may have noticed the phrase "iodized salt" – because it has a beneficial effect. When ingested, the non-radioactive iodine goes to the thyroid gland and acts to prevent goiter, a disfiguring disease of the thyroid that used to be quite common.

Radioactive iodine also goes to the thyroid gland, but it causes damage – thyroid cancer and other thyroid-related diseases. After the Chernobyl nuclear accident in 1986, 5000 children in Belarus had to have their thyroid glands surgically removed due to radiation-induced cancers caused by the radioactive iodine-131 released into the air from used nuclear fuel at Chernobyl.

Radioactive iodine is created by nuclear fission and is released from damaged nuclear fuel as a vapour that deposits on cool surfaces. It concentrates on pasture land, then concentrates more in cow's milk, and then concentrates even more in a child's thyroid gland. For this reason nuclear plants in Ontario are required to distribute non-radioactive iodine pills to people in the vicinity of any CANDU reactor, so folks can protect themselves and their kids from radioactive iodine that will likely be released in case of a nuclear accident. When the thyroid is dosed with "safe" iodine, it will reject the "unsafe" iodine.

Radioactive caesium is also created by nuclear reactors; natural caesium is not at all radioactive. Some sheep farmers in England and Wales could not sell their meat to the market for over 20 years because of radioactive caesium contamination from the 1986 Chernobyl accident. Even today, hunters who kill wild boars in Germany, Sweden or the Czech Republic cannot eat the radioactive meat and are compensated by the governments for not eating it. Radioactive caesium released from Chernobyl, 35 years ago, still contaminates the mushrooms that those pigs gorge themselves on. To this day, people cannot live within 20 kilometres of Chernobyl because of radioactive caesium-137 from the melted fuel.

Radioactive iodine and radioactive caesium are only two of more than two hundred different radioactive elements that are created inside the fuel of every nuclear reactor during routine operation; see www.ccnr.org/hlw_chart.html for a partial list. If citizens are to understand the risks of used fuel, they need to be told what these radioactive materials are, why they are dangerous to living things, how they migrate through the environment and where they go in the human body when ingested, inhaled or otherwise absorbed. Once lodged inside the body, many of them are very hard to remove.

B3. Background – Heat Generation

A nuclear reactor can be shut down in less than two seconds by stopping the neutrons needed to keep the fission process going. But radioactivity cannot be shut off. Immediately after shut-down, about seven percent of full-power heat is still being generated by the ongoing disintegration of radioactive atoms in the used fuel. Unless that heat is removed as fast as it is being produced, the temperature of the fuel will rapidly increase and begin to melt, releasing most of the radioactivity contained in the used fuel and precipitating a complete core meltdown. Safety systems are designed to prevent this from happening, including multiple ways of providing emergency cooling to the fuel in the core.

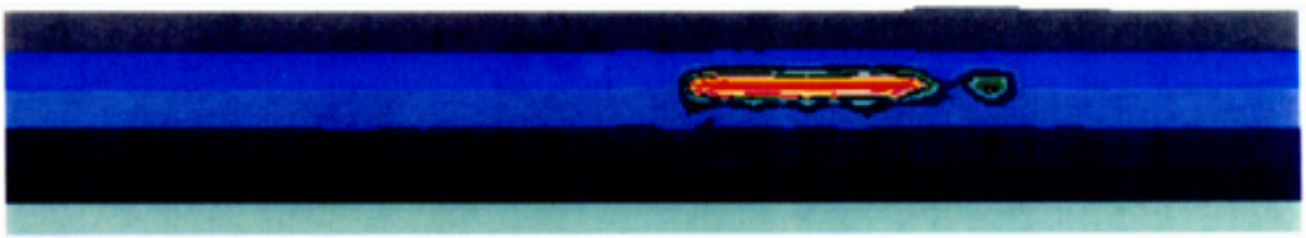
Heat generation continues long after the used fuel is removed from the reactor. CANDU fuel bundles are typically cooled in a pool of circulating water for ten years or more. If the water in the pool were not there, the fuel would spontaneously overheat, the fuel cladding would likely fail, and radioactive gases and vapours (including radioactive iodine and caesium) would be released into the atmosphere.

After ten years of cooling, the radioactivity and heat generation have diminished to the point where the used fuel can be moved into a dry storage cask. This is done by submerging the cask in the pool and transferring the fuel into the lidless cask as an underwater operation using robotic equipment. Once the cask is loaded, it is removed from the pool, drained and vacuum dried, welded shut with a massive lid on top, and filled with an inert gas to prevent oxidation. When sealed, the temperature inside the cask can reach a maximum of 200-300 degrees Celsius, then it slowly declines as the years go by.

NWMO considers the fuel too hot to bury underground until it cools for several more decades. If the used fuel is buried – even after it has been out of the reactor, cooling, for 70 years – the heat will have nowhere to go but into the surrounding rocks, which will therefore heat up. According to an AECL study, the rock temperature will not return to its original ambient level for more than 50,000 years.

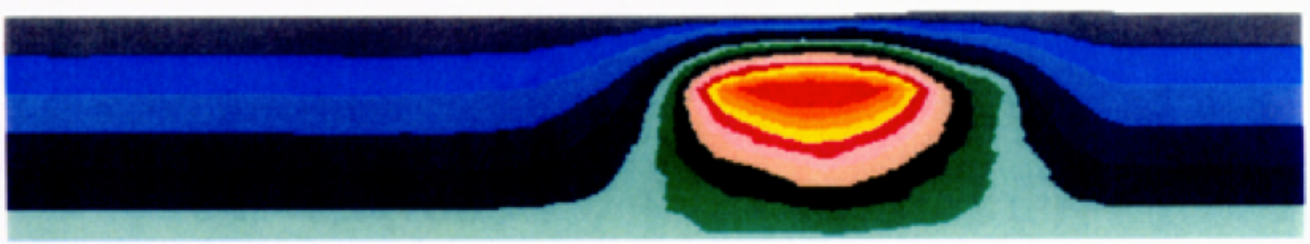
The graphs below are from a 1994 Environmental Impact Statement on the Deep Geological Repository (DGR) Concept, by Atomic Energy of Canada Limited (AECL) after $700 million of research.

These AECL graphs show how, underground, the heat slowly spreads outward from the buried waste. The horizontal lines represent underground rock strata. The colors indicate temperature in degrees C. We begin with hot used fuel (red) that has already cooled for 70 years after removal from the reactor.



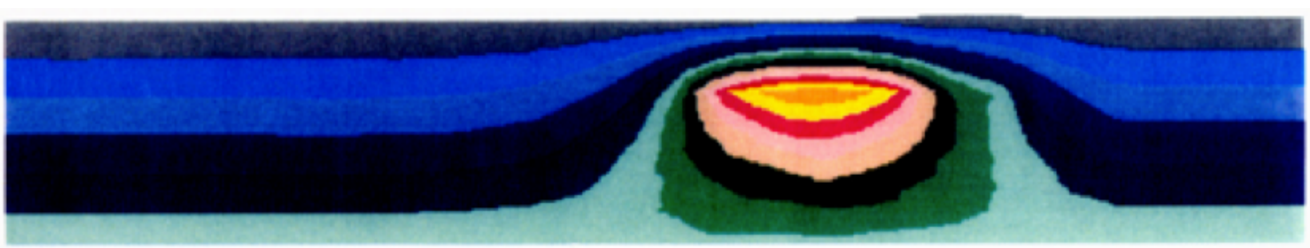
70 years

The heat has no way to escape the underground repository, so the temperature of the rock goes up. Here's how it looks after 4,400 years. Recall: the Egyptian pyramids are only about 5,000 years old.



4,400 years

As more and more radioactive atoms disintegrate, the total radioactivity diminishes and the heat production gradually diminishes. But the rock remains hot for a long time; here it is, at 8,800 years.



8,800 years

These graphs are based on calculations from mathematical models. AECL estimates that the rocks will return to approximately normal ambient temperatures after 50,000 years. That period of time is called "the thermal pulse". A pulse is like a little blip on a radar screen. Because the ingestion toxicity of the radioactive waste material remains high for more than 10 million years, the 50,000 year period of elevated temperatures is just considered to be a tiny blip. Human civilization is an even tinier blip! These buried wastes are not inert – they are active: radioactive, chemically active, and thermally active

Q1. Written Question: *Dr. Edwards, what topics did the South Bruce Citizens' Liaison Committee limit your presentation to? What topics would you have liked to have covered?*

Answer: I was asked by the CLC to address one of my own two suggested topics, namely *"the surface operations – such as the unloading of the irradiated nuclear fuel prior to its emplacement in the proposed repository, and the possible environmental consequences of that operation"*. Consequently my CLC presentation focussed on the nature of irradiated fuel, and the radioactive elements within – all are created during the nuclear fission process – with special emphasis on the "fission products" (broken pieces of uranium atoms) and plutonium.

I described the handling of used fuel in "hot cells" with robotic arms, needed to repackage the fuel bundles into smaller steel-and-copper containers for emplacement in the underground repository. This operation must take place very close to the proposed DGR. Any damage to the fuel will release radioactive poisons of many kinds, each one having its own pathways through the human body. For example, radioactive iodine and radioactive strontium, both of which concentrate in cow's milk and in human breast milk, as well as in certain sensitive organs of the human body (i.e. the thyroid gland – and in the case of radioactive strontium – the skeleton and the bone marrow). A release of such poisons to the outside environment caused by mishandling of the used fuel will pose health problems for residents and possibly marketing problems for dairy farmers of the Teeswater region. Any evidence or even a rumour of radioactive iodine in the milk can be detrimental to the reputation of the dairy farmers.

Plutonium poses special security problems as it can be used as a nuclear explosive. Armed guards and tight security will be needed. Plutonium can also be used as a fuel for nuclear reactors, and many nuclear proponents, especially those pushing for new small reactors, are eager to extract plutonium from the used fuel before the waste is buried. Plutonium extraction would very likely be done in the same location as the DGR. Any community willing to accept a DGR might find itself the unwilling recipient of a reprocessing plant to extract plutonium. Since reprocessing involves converting the solid nuclear fuel waste into a liquid form, it is the most polluting type of nuclear facility, releasing radionuclides into the atmosphere and in liquid effluents, posing a threat of long-term radioactive contamination of the environment.

I did propose another possible topic for my CLC presentation: *"Last year I attended a three-day meeting (by invitation only) in Stockholm, Sweden, regarding the question of how to communicate with future generations, thousands of years hence, to inform them of the radioactive legacy that we are leaving them in the form of abandoned nuclear waste repositories in various parts of the world. I believe that the considerations that informed that discussion would be of interest to the CLC members and the South Bruce community and I would be open to making a presentation on that topic."* However the committee opted for the first topic as it is more directly relevant to the safety and welfare of the Teeswater area.

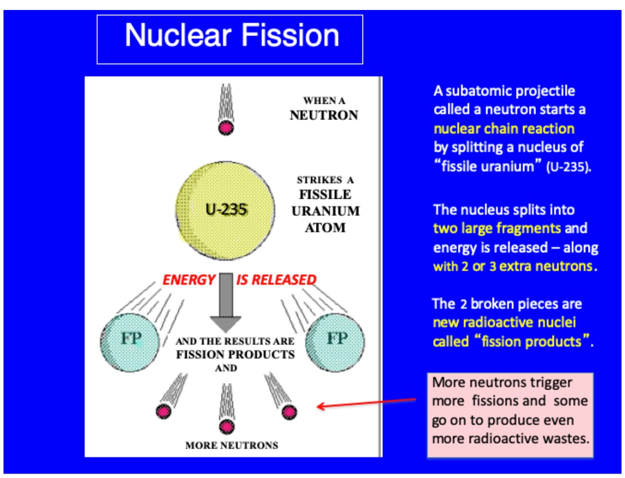
In hindsight, a third topic now suggests itself. A number of participants in the November 5 event have been asking questions about "Rolling Stewardship", as an alternative to the eventual abandonment of the wastes in a Deep Geological Repository. I would certainly be happy to give a CLC presentation comparing the two different approaches point by point.

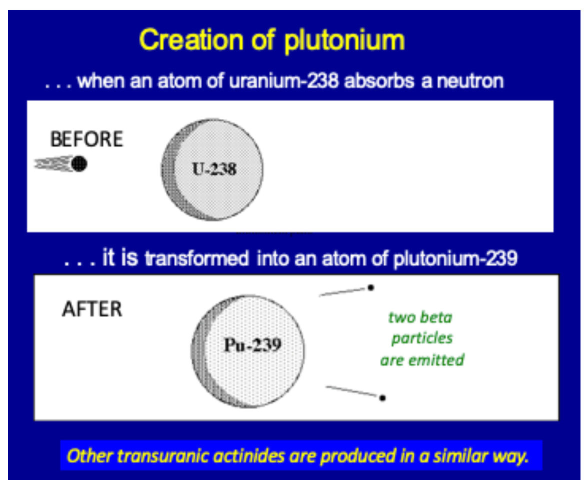
Q2. Oral question: *You mentioned about radioactive materials. I guess that's the first I've heard of them. There are names I have not heard of before – strontium (radioactive strontium), iodine (radioactive iodine). That's the first I've heard of it. How are they created, or generated? How do they come about?*

Answer: The used fuel bundles are not really the radioactive waste; they are simply the containers of the radioactive waste. As long as the fuel rods are intact, the waste is safely trapped inside. But if a fuel rod is cracked or broken or corroded or pierced or crushed or melted, the radioactive waste materials inside will escape and can cause great harm to living things. In a nuclear accident – like the 1986 Chernobyl disaster or the 2011 Fukushima triple meltdown – the used fuel overheats and melts, releasing dozens of radioactive poisons that are normally imprisoned inside the ceramic fuel that is no longer protected by its cladding.

There are **three categories of radioactive poisons** created inside the nuclear fuel. They are (1) fission products; (2) transuranic actinides; and (3) activation products. AECL has published a list of 211 different radioactive elements found inside a ten-year old used fuel bundle (10 years out of the reactor core) from one of the eight Bruce reactors. These newly created poisons are listed by the three given categories. See www.ccnr.org/hlw_chart.html .

Fission products are the most numerous waste products. They are created when a uranium atom is struck by a neutron and splits into two chunks. The broken fragments are called "fission products". There are hundreds of different kinds because atoms split in hundreds of different ways. Fission products are unstable (radioactive) elements that are always lighter than uranium.





Transuranic actinides – like plutonium, americium, neptunium, and curium – are unstable elements that are heavier than uranium. They are created when a uranium atom absorbs a neutron, becomes heavier, and is then transmuted into a new kind of radioactive poison.

An **activation product** is created when a non-radioactive atom – part of the fuel cladding, or a tiny impurity in the fuel itself – is struck by a stray neutron and transformed into a radioactive atom. The atom is "destabilized" (activated) by having too many neutrons in its nucleus.

It is disappointing that NWMO has not described the actual radioactive wastes for you. Without a description of these materials no one can possibly understand the radioactive waste problem.

After learning that used nuclear fuel must be transferred to burial containers using "hot cells":

Q3. Oral question. *This is the first I heard about the hot cells. It is an intriguing thought*.

Answer: Yes, it is intriguing. Have you ever seen a window where the glass is three feet thick? Or maybe even six feet thick? That's about how thick the glass must be in a hot cell. And it's not ordinary glass, it has a very high lead content in order to shield workers from the intense blast of gamma radiation given off by each individual fuel bundle. The hot cell window is made of several slabs of leaded glass separated by mineral oil as a neutron shield between the slabs to preserve visibility. The inside surface of the window and the entire hot cell cavity will become dangerously radioactive in time due to contamination with radionuclides given off by damaged fuel rods. Replacing a hot cell window is a surprisingly hazardous and difficult task because of radioactivity, taking as much as 38 days and requiring meticulous care.

See https://synergist.aiha.org/201709-window-to-the-hot-cell

NWMO workers will be required to manipulate the used fuel bundles behind those thick glass windows using remote controlled robotic arms built right into walls of the hot cell. The room in which the used fuel bundles are being manipulated will be kept under negative pressure – a partial vacuum – so that if any leak occurs the air will flow inwards rather than outwards. This is done so that the radioactive gases and vapours and particulates released by damaged fuel bundles will not escape from the hot cell into the outside atmosphere, contaminating the surrounding environment. For example, radioactive vapours of caesium-137 and iodine-129 will condense onto cool surfaces outdoors, contaminating soil, buildings, vegetation, and skin. The radioactive caesium will accumulate in the fleshy parts of animals and the radioactive iodine will concentrate in cow's milk as well as human thyroid glands. There are dozens of other radionuclides that will also be released and can also escape unless great care is taken.

At present, there are no hot cells at the existing Ontario reactor sites, and neither OPG nor Bruce Power has ever built a hot cell. Also, none of the atomic workers employed at any of the operating nuclear reactors have had any prior experience working with hot cells. It will be an unusual experience for them, the closest encounter they have ever had with an individual, unshielded, highly radioactive fuel bundle, not submerged underwater as it is in a spent fuel pool, but up close and personal, just on the other side of the glass window. And they will have to process up to 300 used fuel bundles per day, 365 days per year, for 50 years or more.

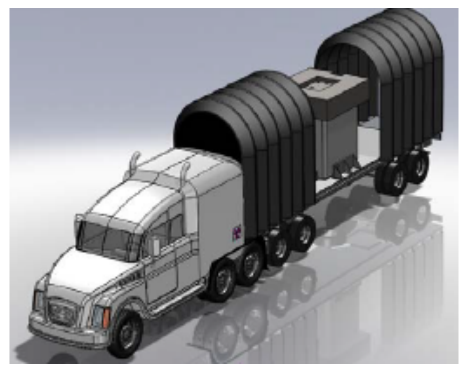
In my view, the probability of accidental leakage is quite high. It will be a miracle if the environment surrounding the proposed DGR does not experience at least some degree of contamination. I find it amazing and irresponsible that NWMO has not explained to all of the candidate communities that used nuclear fuel cannot be put directly underground, it has to be repackaged first. And that requires the use of hot cells since there is no reactor at the DGR site and so no spent fuel pools that would allow the manipulations to take place underwater.

NWMO has been interacting with CLCs for the better part of ten years. Surely these hot cells – which offer the greatest probability of causing local contamination – must be considered a high priority for the communities to know about. Yet NWMO chose not to inform them. Is NWMO's main loyalty to the nuclear industry, to help it in solving its public relations problem, with a somewhat lesser sense of loyalty to the candidate communities? Shouldn't this feature have been explained to all of the candidate communities from the outset, ten years ago?

Q4. Written Question. *In 2017, the Ontario Clean Air Alliance released a video interview of you discussing the nuclear waste at Pickering Generating Station. In that video you say "the waste needs to be pulled back onto dry land, away from Lake Ontario, in hardened on site storage. If Rolling Stewardship is your preferred storage method, where would you suggest it be implemented?*

Answer: Having the waste *"pulled back . . . away from Lake Ontario"* means that the dry storage casks are simply carted as far away from the lake shore as possible, but still within the existing reactor site boundaries. This can be done using specialized tractor-like vehicles that are routinely used to move dry storage casks on the reactor site *[see picture below]*. They move very slowly and carry the cask to a new location without going onto any highway. No need to cut open the welded-shut casks, as NWMO currently plans to do. The fiercely radioactive fuel bundles inside do not have to be lifted out of the casks and transferred to a smaller transportation container on a flat-bed truck, and then transferred once more into even smaller containers for burial using hot cells, as NWMO would have us do. The used nuclear fuel need not be transported on public roads through dozens of communities, irradiating everyone along the way with gamma radiation and neutrons, as currently planned.

Used fuel in an on-site transport vehicle



Used fuel in a highway transport vehicle

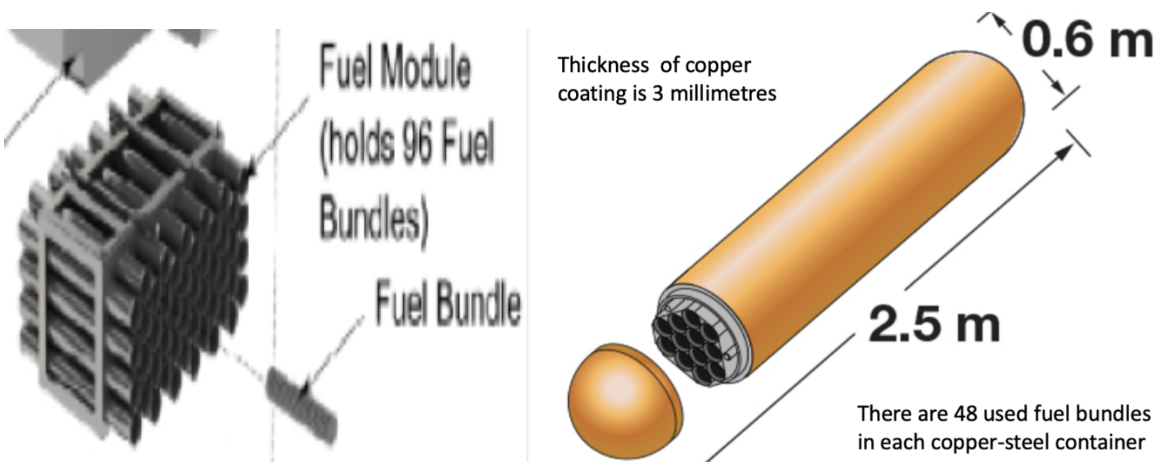
The phrase *"hardened on site storage"* means that the waste is maintained on the reactor site, but with much sturdier protection against potential impacts – attacks, airplane crashes, earthquakes, or whatever else might threaten the waste. For example, the casks might be moved to a thick-walled reinforced steel-and-concrete bunker away from the shore line. At present the waste is stored far too close to the water; the dry storage casks could be toppled into the lake by an impact such as an airplane crash, and – if the radioactive contents leak into the lake – threatening the health and safety of millions of people who draw their drinking water from the Lake. As NWMO itself maintains, the status quo is unacceptably unsafe. But if NWMO has its way, the situation will remain unacceptable for a long time in any event, since NWMO does not intend to move any fuel off site that is less than 30 years old.

For details of one such proposal see section 6 of Dr. Gordon Thompson's 2018 study entitled "Storage of Spent Nuclear Fuel at the Pickering Site: Risks and Risk-Reducing Options" found at https://www.cleanairalliance.org/wp-content/uploads/2018/06/IRSS-Pickering-SNF.pdf

Q5. Oral question. *You talked a lot about all the potential problems that can happen with hot cells, but with rolling stewardship would you not have to have hot cells to repackage the nuclear waste that we have currently? Because those containers are only licensed for 50 years currently, so would you not have to continually repackage them, and do that in hot cells as well? Like, where's the difference there?*

Answer. Yes, with Rolling Stewardship you would have to repackage the used fuel bundles from time to time, and you would have to have something like a hot cell or a spent fuel pool, one or the other, to do so. But because every reactor has a spent fuel pool, no hot cells will be needed. You can transfer the used fuel from one lidless cask into another by doing it underwater, submerging the two casks side by side and using the same robotic equipment that was originally used to fill the original dry storage cask in the first place. The water in the pool prevents the escape of radioactive materials into the atmosphere, and the filtering system built into every spent fuel pool will collect any radionuclides released into the water.

You could transfer fuel in a large hot cell, but with Rolling Stewardship you won't have to cram the individual fuel bundles into a smaller container, like those copper and steel containers that NWMO wants to put underground. You saw the modules of 96 fuel bundles that they move from the dry storage containers to the transport containers? If you're just moving the used fuel from one dry cask to another, you don't have to take the bundles out of their modules.



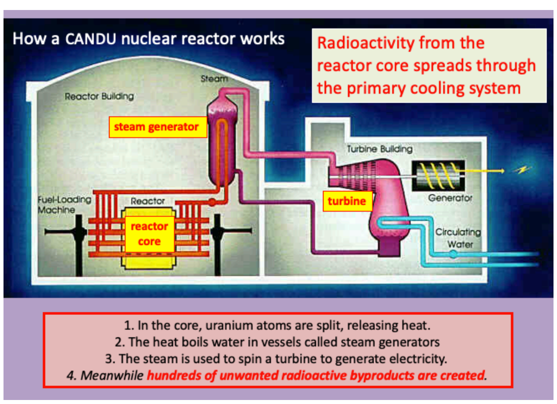
It is much safer to repackage the fuel if it is done under water where the modules just have to be lifted out of one cask and lowered into another one. On the other hand, if NWMO wants to transport the used fuel on public roads, they will have to use spent fuel pools at every nuclear plant for loading the transport containers and then use a specially built hot cell at the receiving end, for unloading the used fuel modules, taking the bundles out of the modules, and inserting them individually into the tight-fitting burial containers at the DGR site. These bundles are very old. They are distorted, embrittled, and fragile. Any damage to the cladding – cracks, perforations, hydride blisters – will release radioactive gases and vapours. Those releases will include radioactive caesium-137 and radioactive iodine-129. Handling the intensely radioactive fuel bundles individually in this way, at the rate of 300 bundles per day, is by far the most dangerous operation since the fuel was first removed from the reactor. And we will no longer have the protection provided by the massive shielding of the reactor building itself.

Q6. Oral Question. *You mentioned steam generators. Can that be high level waste?*

Answer. No, I'm sorry if I misled you on that matter. I didn't mean to suggest that the steam generators are high level radioactive waste. In fact the nuclear industry only uses the term "high level waste" for the used fuel bundles themselves, because they are millions of times more radioactive than anything else.

The steam generators are classified as intermediate level radioactive waste. There are several thousand narrow tubes inside each steam generator and those tubes all become radioactively contaminated – coated with fission products, actinides, and activation products. The question is: where do all these radioactive materials come from? Well, most of them come from the interior of the fuel bundles that are located in the core of the reactor.

If you look at the diagram, however, you will see that the steam generators are very far away from the core of the reactor, where the fuel bundles are. So how come the steam generators are radioactive at all? The answer is quite simple: the fuel bundles leak. There are tiny cracks and pinholes in the metal cladding of some of the fuel rods. These minor cladding defects allow dozens of different radioactive materials to escape from the fuel and enter the primary cooling circuit. The circulating water carries all these radioactive contaminants throughout the primary cooling circuit, depositing radioactive crud on all the inner surfaces of all the pipes.



Here is a partial list of radioactive contaminants inside a used steam generator from one of the Bruce reactors. The amount of radioactivity is expressed in becquerels per cubic metre; one becquerel corresponds to one radioactive disintegration every second. (Source: OPG)
http://www.nwmo.ca/uploads_managed/MediaFiles/539_ReferenceLowandIntermediateWasteInventoryfortheDGR.pdf (p. 50)

For Scientists / Engineers			For Citizens / Decision Makers		
Symbol	Half-Life	Amount	Name	Half-Life	Amount
	(y)	(Bq/m3)		(years)	(becquerels per cubic metre)
Ag 108	1.3E+02	2.3E+02	Silver-108	130 y	230
Am-241	4.3E+02	5.9E+07	Americium-241	430 y	59 000 000
Am-243	7.4E+03	3.8E+04	Americium-243	7 400 y	38 000
C-14	5.7E+03	7.6E+07	Carbon-14	5 700 y	76 000 000
Cl-36	3.0E+05	1.4E+04	Chlorine-36	300 000 y	14 000
Cm-244	1.8E+01	1.4E+07	Curium-244	18 y	14 000 000
Co-60	5.3E+00	1.2E+09	Cobalt-60	5.3 y	1 200 000 000
Cs-134	2.1E+00	1.9E+06	Cesium-134	2.1 y	1 900 000
Cs-135	2.3E+06	2.2E+01	Cesium-135	2 300 000 y	22
Cs-137	3.0E+01	2.2E+07	Cesium-137	30 y	22 000 000
Eu-152	1.3E+01	1.8E+06	Europium-152	13 y	1 800 000
Eu-154	8.8E+00	1.6E+07	Europium-154	8.8 y	16 000 000
Eu-155	5.0E+00	3.0E+07	Europium-155	5 y	30 000 000
Fe-55	2.7E+00	5.8E+09	Iron-55	2.7 y	5 800 000 000
I-129	1.6E+07	6.3E+00	Iodine-129	16 000 000 y	6.3
Nb-94	2.0E+04	2.9E+05	Niobium-94	20 000 y	290 000
Ni-59	7.5E+04	2.0E+05	Nickel-59	75 000 y	200 000
Ni-63	9.6E+01	2.9E+07	Nickel-63	96 y	29 000 000
Np-237	2.1E+06	1.8E+03	Neptunium-237	2 100 000 y	1 800
Pu-238	8.8E+01	1.0E+07	Plutonium-238	88 y	10 000 000
Pu-239	2.4E+04	1.2E+07	Plutonium-239	24 000 y	12 000 000
Pu-240	6.5E+03	1.7E+07	Plutonium-240	6 500 y	17 000 000
Pu-241	1.4E+01	5.5E+08	Plutonium-241	14 y	550 000 000
Pu-242	3.8E+05	1.7E+04	Plutonium-242	380 000 y	17 000
Ru-106	1.0E+00	8.4E+08	Ruthenium-106	1 y	840 000 000
Sb-125	2.8E+00	2.1E+07	Antimony-125	2.8 y	21 000 000
Se-79	1.1E+06	7.6E+01	Selenium-79	1 100 000 y	76
Sm-151	1 9E+01	7.6E+01	Samarium-151	19 y	76
Sn-126	2.1E+05	1.2E+02	Tin-126	210 000 y	120
Sr-90	2.9E+01	1.8E+07	Strontium-90	29 y	18 000 000
Tc-99	2.1E+05	2.8E+03	Technetium-99	210 000 y	2 800
U-234	2.5E+05	1.9E+04	Uranium-234	250 000 y	19 000
U-235	7.0E+08	3.2E+02	Uranium-235	700 000 000 y	320
U-236	2.3E+07	3.6E+03	Uranium-236	23 000 000 y	24 000
U-238	4.5E+09	2.4E+04	Uranium-238	4 500 000 000 y	24 000
Zr-93	1.5E+06	3.8E+02	Zirconium-93	1 500 000 y	380
TOTALS					
Long half-lives only (> 1 y)		**8.7E+09**	**Long-lived only (> 1 y half-life)**		**8 700 000 000**
Including short half-lives		**1.6E+10**	**Including all radionuclides**		**16 000 000 000**

When you examine the list of dozens of radioactive materials found inside the steam generators, you will see that they are for the most part the very same materials contained in the used fuel, but in much smaller concentrations. There you will see radioactive iodine, radioactive strontium, radioactive caesium, and four varieties of radioactive plutonium, together with many other fission products and actinides.

What I am trying to point out here is that the used fuel always leaks to a certain extent, and when it leaks it gives off a great many radioactive materials that will travel and contaminate anything in the path. By the time the used fuel bundles are discharged from the reactor they are already damaged, and when they get older they don't get any better. The fuel rods are no longer straight, but bent. The end fittings are no longer parallel. The cladding is weaker, more brittle, more likely to crack, and the bundles may even come apart. Handling used fuel rods is always hazardous, because radioactive gases, vapours, and aerosols can and will escape.

Q7. Written Question: *Dr. Edwards, you state that people could receive radiation dose from spent fuel shipments inside shipping containers. I don't believe this is plausible, as the CNSC would never approve a transport measure that routinely exposed the public to radiation. How much actual radiation would be coming off these transportation containers at 1m distance?*

Answer: There is no doubt that people who drive behind, beside, or in front of any truck carrying used nuclear fuel will receive a radiation dose from highly penetrating gamma rays and neutrons emitted by the radioactive waste materials inside the used fuel bundles. Smaller radiation doses will be received by those that are in cars travelling in the opposite direction.

The driver and the people outside the truck will not receive any exposures from alpha radiation or beta radiation because those are non-penetrating forms of radiation made up of high-velocity charged particles that cannot penetrate through the shielded walls of the truck. However gamma rays and neutrons are highly penetrating forms of radiation that cannot be totally stopped. The same is true of X-rays; that's why X-ray technicians often leave the room.

People living in homes or working in buildings beside the highway will also be exposed to penetrating radiation; those exposures will be fleeting, in most cases, but will be repeated over and over again as more and more transport trucks follow the same route. The actual exposure levels will depend on the design of the transport container, as it is more costly to provide additional shielding. Preventing exposure altogether is impossible.

The NWMO reports that "A recent generic study was conducted to determine the potential exposure to individuals along transportation routes... The study considered individuals including residents living along or in the vicinity of the transport route, people sharing the transport route, and people at rest stops along the route. The annual dose to these people is expected to be lower than the regulatory public dose limit." See https://tinyurl.com/y3em2hbj

The NWMO says it "expects" that the radiation dose to individuals along the transportation route will not exceed the maximum permissible radiation exposure that is legally allowed for members of the public. However, it is not guaranteed that this regulatory limit might not be exceeded. In case of an accident – for example, if a truck is toppled onto its side – there are provisions to send a 75-ton crane at speeds of up to 85 km per hour to arrive at the scene of the accident within 48 hours, but evidently such a dire situation could lead to unusually prolonged radiation exposures, even if there were no leakage of radioactive materials.

Any leakage of radioactive gases or vapours would of course add to the radiation dose and could result in radioactive contamination of soil, buildings, clothing and skin, as well as longer-lasting internal exposures following inhalation, ingestion or absorption through the skin.

The exact radiation dose depends on the amount of shielding, the age of the used fuel, and the proximity of the exposed individual. In reality, the expected radiation dose will be the result of a "cost-benefit" calculation that is carried out by the industry and the regulator without consulting those to be exposed.

B4. Background – Rolling Stewardship and Deep Geological Disposal

By prior agreement, my presentation to the CLC was focussed on what happens to the used fuel before it is buried in a Deep Geological Repository (DGR). The emphasis was on how the local environment might be adversely impacted by the transportation of used fuel to the site, the handling of the used fuel in heavily shielded hot cells, and the repackaging of the fuel in much smaller steel-and-copper containers for burial. These activities provide opportunities for radioactive gases, vapours, aerosols, and dust to escape into the local environment.

Toward the end of my presentation I mentioned the concept of Rolling Stewardship as an alternative to the concept of "geological disposal" without going into details of either concept. Nevertheless, the novelty of the Rolling Stewardship concept apparently stimulated a good deal of interest. A surprising number of the questions focussed precisely on that aspect.

Rolling Stewardship was first described by the U.S. Academy of Sciences in connection with long-lasting indestructible toxic materials such as heavy metals – for example, lead, mercury, cadmium, and arsenic. Rolling Stewardship was seen as a management scheme whereby the toxic legacy is passed on from one generation to the next, always maintained in a monitored and retrievable condition, and never abandoned, with the expectation that each generation will improve on the practices of the previous generation, giving rise to ever better packaging and superior monitoring techniques. The toxic materials would be well contained to begin with and repackaged as necessary to protect the health and safety of humans and the environment. All necessary information would be archived and passed on.

There is no scientific definition of the word "disposal". Nuclear agencies like OPG, NWMO and CNSC, say that the "disposal" of radioactive waste is characterized by the fact that there is no ***intention*** *to retrieve it. But that is a political definition, not a scientific one. "Intentions" cannot be quantified, measured, or verified. The word "disposal" basically means "abandonment".*

Burying waste underground, and then abandoning it, is not always satisfactory, as has been shown many times already. Toxic chemicals found their way back to the surface at the Love Canal, near Niagara Falls. In Carlsbad New Mexica, in 2014, radioactive plutonium dust travelled 700 metres upwards from an exploding steel drum in a deep geological repository, contaminating 20 nuclear workers at the surface. In Germany, the failure of the Asse II nuclear waste repository led to a 30 year project to remove all of the radioactive materials from the underground workings, at a cost of more than five billion dollars. In the USA, nuclear scientists have tried on eight separate occasions to site an acceptable DGR for HLW and have failed all eight times. In light of these examples toxic waste disposal is a problem with no proven solution.

The radioactive wastes contained in the used nuclear fuel did not exist 75 years ago. Nevertheless, they will remain dangerously radioactive for more than 10 million years (see www.ccnr.org/hlw_graph.html). It is probably better to keep the used nuclear fuel in a well-packaged, well-monitored retrievable state until there is a proven safe solution to the problem. Long-term on-site storage was one of the three options presented by NWMO in its first report.

Nuclear Waste: Abandonment versus Rolling Stewardship

The Concept of Abandonment	The Concept of Rolling Stewardship
1. Humans have never permanently disposed of anything.	1. Humans can contain waste securely for decades at a time.
2. Assumes a permanent solution to waste problem exists.	2. Recognizes a solution to the problem does not yet exist.
3. Monitoring the waste ceases after abandonment.	3. Continual monitoring of waste is essential.
4. Retrieval is difficult or impossible.	4. Retrieval is anticipated and actively planned for.
5. Containers will inevitably disintegrate.	5. Periodic repackaging is an integral part of the process.
6. If leakage occurs timely corrective action is not likely.	6. If leakage occurs timely corrective action will be taken.
7. Abandonment will eventually result in amnesia.	7. Rolling Stewardship is based on persistence of memory.
8. Difficulty in communicating to unknown future societies.	8. Information is readily transmitted to the next generation.
9. No intention to truly solve the problem of nuclear waste.	9. Ongoing reminder that the problem remains to be solved.

The concepts of abandonment and disposal are intimately related. According to the IAEA "disposal" means that there is no intention to retrieve the waste in the future – although such retrieval may, with difficulty, be possible; the waste is abandoned.

When disposal attempts fail – as in Port Hope Ontario, the Asse-II salt mine in Germany, the Love Canal in New York State, or the US DOE's "Pit 9" in Idaho – cleaning up and consolidating the waste is often exceedingly costly & difficult because of lack of documentation, failed packaging, and damage already done.

Ironically, the end result of failed disposal is usually some form of Rolling Stewardship – by default, not by intent. Had Rolling Stewardship been instituted from the start, the damage, difficulties and cost would have been greatly reduced.

When abandonment of a repository occurs, the repository becomes a dump. Even if the repository has been well managed, the dump will not be. No matter how well designed a large nuclear power reactor might be, it would be foolish and irresponsible to licence it for operation, start it up and then abandon it. Yet that's what OPG hopes to do in the case of the Deep Underground Dump (DUD).

The pyramids of Egypt are 5,000 years old. The Great Lakes did not exist 15,000 years ago. But the half-life of plutonium-239 is 24,000 years, and plutonium-239 gradually changes into uranium-235 – which has a half-life of 700 million years.

Science is unable to make reliable predictions over hundreds of thousands of years, since the mathematical predictions can't be verified against experience. As the rollout of ObamaCare has shown in the USA, computer bugs often go undetected.

Geology is a descriptive science, not a predictive one. Besides, it is impossible to place wastes in an undisturbed geological formation without disturbing it.

Canadians have much expertise in mining – but a mine is for taking things out, not putting them in. And deserted mines always flood. No one knows how to put a rock formation back together again so that it returns to its original strength and integrity.

Q8. Written Questions. *You've stated that with Rolling Stewardship, there could be a "changing of the guard" every 10-20 years or so, where knowledge and responsibility is transferred to the next generation. Given that monitoring of the DGR and retrievability of the fuel is planned for at LEAST 70 years after closure, could that idea not be used for the DGR?*

You advocate rolling stewardship, which really means nothing more than what's already being done – conscientiously care for and monitor the spent fuel. This is only possible as long as there is a strong company like OPG in a stable state like Ontario, with a strong regulator like the CNSC. How long do you think we can count on those conditions?

Many people believe that spent fuel can be retrieved from the DGR in the future. Do you believe NWMO would ever do that? When pressed, Norm Sandberg of NWMO agreed it would never be retrieved without spending billions. Can you clarify?

Answers: If the contents of the repository are to be retrieved for safety reasons, it would only be motivated by the fact that radioactive materials are found leaking into the groundwater or surface waters or otherwise into the environment. That implies that the damage has already been done. Pathways have been established underground for radioactive poisons to escape from the repository. By the time that leakage is detected, a great deal of radioactive poison would have already dispersed and could not be recovered. It would take a very long time and cost a great deal of money for the remaining waste to be retrieved from the now-contaminated chambers, during which time more leakage of the already escaped waste would occur.

Such a fiasco could be averted if the wastes were safely stored near the reactor site within a strongly reinforced structure that allows constant monitoring and rapid access, facilitating timely intervention (i.e. Rolling Stewardship). Any leakage of radioactivity would be detected quickly, and dispersal into the environment could be prevented or stopped quickly. Repairs would be made within a relatively short time frame. That kind of timely response is a key to responsible management; abandonment underground prevents swift action from being taken.

Rolling Stewardship is not a "status quo" approach. Rolling Stewardship is based on the principle of intergenerational guardianship with continual improvement. One might say that it is Adaptive Phased Management without abandonment. As our knowledge and our technology advance, the wastes will be packaged in ever-more-secure containers and facilities. This will continue until a genuine solution to the problem is found – one that will truly eliminate the risk in a permanently satisfactory manner rather than just putting the waste out of sight and therefore out of mind. As the Nobel-prize-winning physicist Hannes Alfvén famously observed with regard to "disposal" of high-level nuclear waste, "If a problem is too difficult to solve, one cannot claim it is solved simply by pointing to all the efforts made to solve it."

NWMO is owned by the waste producers, and they have no intention of discontinuing the production of used nuclear fuel. As long as reactors continue to operate, used fuel continues to be produced. There will always be a very large inventory of unburied nuclear fuel waste at every reactor site – in pools and in dry storage containers – even if the older fuel bundles are moved away as quickly as possible. So the risk of radioactive leaks and spills at the reactor sites is still there, and a new site – the DGR site – is now an additional place where used fuel is stored and where leaks and spills can occur. The overall risk will be increased because of the unnecessary handling of fragile and fiercely radioactive fuel bundles – repackaging them, and then unpackaging them, and then repackaging them again, with robotically manipulated arms, into ever smaller containers – all the while transporting them over public highways in an unending convoy of high-level radioactive waste. This is more risky than Rolling Stewardship.

The safety of the underground storage of used nuclear fuel over the very long term cannot be demonstrated by any scientific principles that are available to us. It is impossible to verify the accuracy of the mathematical models over the enormous time frames that are involved, because there are no ways to verify the correctness of the results. Moreover, there are hundreds of fundamental scientific questions that remain unanswered because they have not even been asked until very recent times – see for example the excerpts given here from a geological text on this very question: www.ccnr.org/geology.html .

Nuclear engineers believe they can design against any eventuality, but that is mere hubris.

American engineers did not predict that a steel drum, filled with radioactive waste, could explode and turn into a flame thrower in a deep underground nuclear waste repository, just because of radiation-induced chemical reactions with the kitty litter that was used as packing "fill" material – and yet that's exactly what happened at the Waste Isolation Pilot Plant in Carlsbad New Mexico in 2014. The resulting explosion sent plutonium dust 700 feet vertically upward where it contaminated the shafts, the passages, and 20 atomic workers at the surface.

At the Bruce Unit 1 reactor, nuclear engineers did not predict that over 500 contract workers would be contaminated with plutonium-bearing dust that they inhaled on a daily basis for almost three weeks in 2009, because of a failure to give those workers protective respirators.

In their proposed DGR, NWMO plans to use steel containers coated with 3 millimetres of copper to encase the used nuclear fuel. The copper coating is supposed to protect the steel from corrosion. When this design was put forward, engineers believed that copper would not corrode in a sealed underground repository once the oxygen is gone. But in Sweden, in 2017, the Environmental Court found that there are several mechanisms that will corrode copper even in the absence of oxygen. Once the thin copper coating is penetrated, at one point, the galvanic interaction of the copper and the steel will cause the steel to corrode much faster and more extensively than if the copper were not there in the first place. And once the hot fuel itself corrodes, a large number of the radioactive poisons inside will escape from the fuel, each of them with unique physical and chemical properties. Some of them may actually escape to the outside environment, creating pathways for others to follow. We simply do not know enough about what happens underground when a burial chamber interacts with nuclear waste that is not inert but very active – chemically active, thermally active, and radioactive.

It is possible that a geological repository will do the job of keeping all the radioactive waste out of the environment forever, although even NWMO staff does not believe that. But they do believe that any leakage that occurs will be small enough and slow enough to be safe enough.

They could be wrong.

Q9. Written Question. *Since the waste is in solid ceramic pellets, encased in a steel/copper canister, within a bentonite "box", how will radiation leak and how can it make it through 500m of bedrock with a hydraulic conductivity of approximately 1 metre per 300,000 years and into the groundwater?*

Answer. I don't know how it happens. How did the Fluorspar miners in Newfoundland suffer such an elevated incidence of lung cancer from breathing radioactive radon gas, when the ore they were mining had no significant amount of uranium or radium in it? I don't know the answer. Every atom of radon gas begins as an atom of radium. Before that it was an atom of uranium. Without one of those precursors you cannot have any radon. So where did it arise?

And how did the uranium deposits on planet Earth come here from some gigantic supernova explosion elsewhere in the Milky Way Galaxy? I do not know the answer. But I do know that if you disturb a geologic formation by blasting and excavating you will never be able to restore it to its original integrity; that no shaft sealant will ever be as strong and secure as the original undisturbed rock; that ten million years is a very long time; that lots of unexpected things can happen; and that humans 1000 years from now will know that something was buried at that spot and might just be curious enough to want to dig it up and see what it is.

If there is a sign (assuming they can still understand the languages we speak) saying "Do Not Dig Here! There is Danger Here!", I suspect that human curiosity will make them all the more eager to dig right there. And I also know that massively funded and financed agencies have calculated (in other locales) that some of the many different radioactive poisons in buried used fuel will indeed leak out of any repository and reach the environment of living things.

Perhaps someone can tell me why we think that NWMO knows all the answers when in some cases they do not even seem to know the questions? or why NWMO uses the copper/steel combination when it is known that contact between two such metals will cause a current to flow that will accelerate any corrosion? or why NWMO chooses to use only 3 mm of copper when Sweden and Finland are using 50 mm of copper (17 times the thickness) and no steel at all? or why NWMO proposes a vertical shaft while others design a gently sloping ramp that spirals down into the rock formation, one that you can drive a bus on?

"You cannot claim that a problem is solved, just by pointing to all the efforts that have been made to solve it" (Nobel-Prize winning physicist Hannes Alfvén).

Q10. Written Question. *If a DGR is not a suitable solution for containing radionuclides, how do you explain the Oklo natural reactor in Africa? It "operated" for millions of years, and the radionuclides never travelled farther than a couple of meters in the surrounding rock.*

Answer. What you say is not true. The event happened before there was any life on Earth. We have no idea where the radioactive iodine went, or the caesium, or the noble gases, but I am sure they did not just "stick around". One anecdote does not make a scientific safety case.

Q11. Written Question. *If there is enough plutonium to make many bombs, isn't it safer to bury this waste deep underground where there is no risk of someone accessing it for nefarious purposes?*

Answer. Plutonum-239, the primary nuclear explosive in the world's nuclear arsenals, has a half-life of 24,000 years. The Bomb that destroyed the city of Nagasaki on August 9, 1945, used a ball of plutonium the size of a small grapefruit, weighing only 6.2 kilograms. The current inventory of plutonium in used CANDU fuel is about 200 tons – enough to build 32,000 atomic bombs – and NWMO expects that amount to almost double before the DGR would be closed. So, even if we waited for 24,000 years, there would still be about 200 tons of plutonium remaining in the buried CANDU used fuel – enough for a huge arsenal of tens of thousands of atomic bombs, each equivalent to the one that destroyed the City of Nagasaki. It is an incredibly dangerous legacy to leave unmonitored and unguarded, even if it is buried.

It is simply incorrect to say that buried nuclear explosive material poses "no risk of someone accessing it". The reason why NWMO wishes to choose a geological formation that does not contain valuable minerals – like gold or silver – is precisely because of the fear of someone digging up the repository at some future time to get at those valuable minerals. Mining is an enterprise even older than civilization. But, in fact, the plutonium itself can be regarded as a resource to be mined out of the ground for military purposes or for use as an energy source.

It seems clear that plutonium requires active surveillance and strict security measures to prevent its theft or diversion for use in nuclear weapons. It cannot be simply abandoned, whether above ground or below ground. Recall that 85 years ago there was no plutonium to be found anywhere on Earth. We have created plutonium as a byproduct of nuclear reactors, and so far, we do not have any satisfactory way of getting rid of it, once it is created. In the next century, or even the next millennium, science may discover a method of destroying the plutonium without simultaneously creating additional radioactive waste. Until then, we should keep an eye on it and make sure that it does not fall into the hands of desperate people.

In some countries, plutonium is extracted from used fuel by dissolving it in boiling nitric acid and chemically separating the plutonium from the rest of the radioactive garbage. That's called "reprocessing". But reprocessing has led to some of the most radioactively polluted places in the world, like Hanford (Washington), Sellafield (England), Chelyabinsk (Russia), and La Hague (France). Moreover, once plutonium has been extracted, it is sometimes used as a reactor fuel. But that makes it an article of commerce. As such, it will inevitably fall into the hands of criminals or terrorists, as is the case with other commodities. Instead of eliminating plutonium, reprocessing makes it more accessible and therefore more of a security threat.

It is regrettable that the issues surrounding plutonium and nuclear weapons have apparently not been discussed within the municipality of South Bruce by NWMO, despite many years of community engagement, millions of dollars in gifts, and hundreds of CLC meetings. The ultimate fate of Canada's plutonium should be a topic of great importance and public debate.

Q12. Written Question. *Please share your top 3 concerns if you were living in Teeswater*.

Answer. My top concern would be to protect the community against the prospect of a reprocessing plant to extract plutonium from the used fuel. Past experience with plutonium extraction facilities indicates that there will be air-borne and water-borne radioactive releases from such a facility and the radiological environmental impacts will be cumulative. For example, radioactive contamination at the Sellafield reprocessing plant in northern England will cost over 70 billion euros (over 100 billion Canadian dollars) to clean up. See https://www.bbc.com/news/uk-england-cumbria-26124803 . Radioactive releases from the Mayak reprocessing plant in Russia have led to a large radioactively contaminated "no man's land". See https://en.wikipedia.org/wiki/Mayak .

My second concern would be the slow and gradual build-up of radioactive contaminants in the environment and the livestock. Radioactive strontium and radioactive iodine will concentrate in cow's milk and then in the thyroid and the skeleton. Radioactive caesium will concentrate in the soft tissues and the meat of animals. The degree of contamination could vary from slight to significant depending on how carefully the entire operation in run.

My third concern would be the "radioactive stigma" that might damage the town's reputation, negatively affecting property values, markets for agricultural products, and other commercial enterprises. Nobody wants to live in a contaminated area, or buy contaminated produce.

Q13. Written Question. *Is a reprocessing facility part of the NWMO plan? What makes you so sure that would happen in our community? Canada is part of a non-proliferation treaty, and I highly doubt our plutonium would be "extracted" for bombs. And if it is for re-use of the fuel, wouldn't that be an asset as it would reduce the uranium mining requirements?*

Answer. Although NWMO has repeatedly stated that recycling plutonium is too expensive to be worthwhile in the Canadian context, it has never ruled out the possibility. Currently there are two new nuclear reactors proposed for New Brunswick that are promising to recover plutonium from used CANDU fuel in order to provide fuel for their reactor designs. Instead of dissolving the used fuel in nitric acid, the Moltex plant would dissolve CANDU fuel bundles in molten salt and use an electrical refining technique to extract plutonium from the molten fuel.

Moreover, leading Canadian nuclear proponents (e.g. Jeremy Whitlock & Peter Ottensmeyer) and some Canadian corporations (e.g. Cameco, AECL, OPG) have advocated plutonium recovery and recycle for the future of nuclear power. See www.ccnr.org/AECL_plute.htmp

In the 1978 Report, "A Race Against Time", p. 95, we read: "We prefer on-site (i.e. generating station) spent fuel storage to a centralized facility. We believe that a central facility would pre-suppose the reprocessing of used nuclear fuel. It would also involve more transportation and social and environmental problems." (Ontario Royal Commission on Electric Power Planning)

Q14. Written Question. *You introduced yourself as a Doctor. Did you forget to have a slide on the advantages of radioactive isotopes? There are many advantages of Nuclear Energy. Bombs seem to be your main objective and emphasis in your presentation.*

Answer. Although your question has no bearing on my presentation to the CLC, I will briefly reply. I am not a medical doctor. I graduated from University of Toronto with a Gold Medal in Mathematics and Physics, earned two Master's degrees from the University of Chicago under a Woodrow Wilson Fellowship, and obtained a doctorate in mathematics from Queen's University. I have been named Science Advisor to the Canadian Branch of the 1985 Nobel Prize Winning organization, International Physicians for the Prevention of Nuclear War (IPPNW-C).

You are correct in thinking that I am concerned about Bombs, since the Canadian nuclear industry was born as part of the World War II Atomic Bomb Project, and India exploded its first Atomic Bomb in 1964 using plutonium from a Canadian nuclear reactor that was given to that country as a gift. Canada sold and processed uranium for the Manhattan Project and sold both uranium & plutonium to be used in building US nuclear weapons for 25 years after the end of WWII. Other CANDU purchasers – Korea, Pakistan, Argentina and Taiwan – also had nuclear weapons aspirations when we sold them our reactors. So, yes, I am concerned.

As for medical isotopes, they serve a number of valuable functions, none of which are dependent in any essential way on nuclear reactors or the fission process. Isotopes can be and are being produced by particle accelerators such as cyclotrons and linear accelerators, without the need for uranium or reactors. Cobalt-60, which has been used in cancer treatment and to sterilize medical equipment, is being replaced by electron accelerators in both of these applications. The University of Saskatoon, where the first "cobalt bomb" was built for cancer treatment, has now replaced its cobalt irradiator with an electron accelerator.

I have written about medical isotopes: see www.ccnr.org/isotopes.html – and I was asked to appear on a medical TV panel in Ottawa by the Physicians organization (IPPNW-C) to argue for the cessation of the production of medical isotopes at Chalk River using weapons-grade uranium-235 (the same material that was used in the Hiroshima Bomb) because the same isotopes can be obtained using technology that does not risk proliferating nuclear weapons.

Q15. Written Question. *Dr. Gordon Edwards, the fuel bundles release radioactive materials. Which isotopes get on the grass and alfalfa and get consumed by dairy animals? We will see those isotopes back in our milk produced. Will the concentration of some isotopes be a problem for the dairy producers or can it cause problems for the milk delivered to the Gay Lea plant in Teeswater? Do you think it will be an item for the consumers of the processed milk?*

Answer. The answer to your first question is, mainly iodine, strontium and caesium; but there are undoubtedly others. Iodine and strontium would show up in the milk, caesium would normally show up in the meat. The concentrations will depend entirely on the care taken to prevent releases. How consumers will react is difficult to know, but it can't be good.

Q16. Written Question. *You state repeatedly in your comments online that "we should stop producing" the nuclear waste. Is it your position that the nuclear plants should be shut down?*

Answer: The purpose of the DGR is allegedly to make the world a safer place by putting all irradiated nuclear fuel deep underground. But that objective cannot be achieved as long as nuclear plants remain operational. You cannot bury all the waste if you keep on producing it. So yes, you will have to shut the reactors down. If you don't do that – if you don't sooner or later shut down all the nuclear plants – then the whole rationale for a DGR breaks down.

There will always be at least 30 years' worth of unburied nuclear waste sitting right beside each operating nuclear reactor, waiting to become cool enough to be carted away to the DGR. The catastrophe potential at the reactor site will be the same as if there were no DGR. The world is not going to become a safer place. The hazard will be fundamentally unchanged. The DGR will just be one more site where nuclear fuel waste is stored, in addition to all the operating reactor sites, with a fleet of trucks on the road endlessly carrying the wastes from the reactors to the repository. If the plants aren't shut down, the risk will be that much greater – not less in any way.

The only logical way to make sense of a DGR is to shut down all the nuclear plants and keep them shut down. Even after the shut down, it will still take more than 30 years to get all the high-level radioactive waste underground, if society still thinks that that's where it should go. It will then take decades more to finish emplacing the waste and closing the repository.

Q17. Written Question. *Dr. Edwards would you support the use of a DGR if NWMO signed off on abandonment of it?*

Answer. I have addressed this above. The answer is no, if there is no end to nuclear waste production. Many years ago, before the NWMO existed, before it was admitted that nuclear waste is a serious problem, I often debated people from the nuclear industry. They said, many times, that nuclear waste is not a technical problem, but a public relations problem. I think that misperception is still prevalent today. That's why NWMO representatives don't identify the many individual poisons that are inside the used fuel bundles. That's why they don't tell all the candidate communities about Hot Cells. That's why they don't describe the failures of Deep Geological Repositories for radioactive wastes in other countries. That's why they don't take the trouble to explain what reprocessing is and how messy it can be. It's just not good PR.

The success of the nuclear industry is based on a number of fictions. First and foremost is the fiction that nuclear power has nothing to do with nuclear weapons. Second is the fiction that nuclear power is "clean" – a term that fooled many decision-makers into thinking that nuclear waste didn't exist. Then, in the late 70s when the irradiated fuel problem became undeniable, a new fiction emerged: *"We have a solution!"* The industry HAD to claim it had a solution, or it would never be allowed to build another nuclear reactor. Now it has to sell the public and the politicians on its "solution", and it doesn't help to mention all the uncertainties. In every case so far, when industry has gotten close to selecting an actual site, the problems multiply and the "solution" seems less certain. But industry can't let go of the fiction; it must maintain the illusion that the safety case is airtight, although in fact it can't really be proven. No principle of science allows one to verify predictions made over such an extraordinarily long period of time.