Deep geological repositories for used nuclear fuel: stewardship or abandonment?

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Today many countries that generate nuclear electricity are developing, or plan to develop, a deep geological repository (DGR) for the long-term isolation of used nuclear reactor fuel from the biosphere. The DGR concept involves deep entombment of the used nuclear fuel in stable rock formations for millennia, reflecting both state-of-the-art science and engineering, as well as several aspects of nature's own geological repositories for concentrated radioactive material (for example, the high-grade uranium ore deposits in the Athabasca Basin of western Canada, over a billion years old).

The first operational DGR will be located in Finland[1], now in the final steps of licensing prior to accepting used nuclear fuel from that country's reactors. In Canada the Nuclear Waste Management Organization (NWMO) is nearing the end of a lengthy process to select a suitable site for a DGR[2].

Some criticism of the DGR concept labels it as *abandonment* of the used nuclear fuel once the emplacement period is concluded, and favours instead the concept of *rolling stewardship*, or continual and indefinite surface storage and monitoring[3].

This essay examines the case for both rolling stewardship and geological repositories, and concludes that the facts point to the opposite being true:

Rolling stewardship, in fact, represents *abandonment* of our long-term obligation for managing used nuclear fuel, while geological repositories represent long-term *stewardship*.

We first summarize the challenge presented by used nuclear fuel in terms of ensuring long-term safety, then address how both rolling stewardship and DGRs address this challenge.

The Challenge of used nuclear fuel

"Used nuclear fuel"[4] refers to reactor fuel (usually uranium-based) that has been removed from a reactor following its period of service. It's called "used" since, in addition to containing all of the radioactive waste products from its time in the reactor, it still contains a significant amount of

[1] For more information see https://www.posiva.fi/en/ (from Posiva, the builder/operator of Finland's DGR).

[2] https://www.nwmo.ca/.

[3] See, for example: G. Edwards, *Nuclear Waste: Abandonment versus Rolling Stewardship* (http://www.ccnr.org/Rolling_Stewardship.pdf); *The Nuclear Waste Abandonment Issue in Northwestern Ontario* (https://wethenuclearfreenorth.ca/nuclear-waste-abandonment/); *G. Edwards: "The Age of Nuclear Waste is Just Beginning"* (https://www.dianuke.org/dr-gordon-edwards-age-nuclear-waste-just-beginning/).

[4] See also NWMO, Canada's Used Nuclear Fuel, https://www.nwmo.ca/en/Canadas-Plan/Canadas-Used-Nuclear-Fuel.

potential energy that could be extracted (a hundred times more), using advanced reactor designs and waste reprocessing techniques. Depending on the details of this advanced technology, much of the long-term radioactive waste products would potentially also be destroyed in the process of normal operation.

Since this advanced technology is not yet commercially available, and uranium resources are reasonably abundant, many countries with nuclear programs have adopted a two-pronged approach consisting of: (1) safely storing used nuclear fuel in surface facilities that can last hundreds of years; and (2) developing, at the same time, a long-term solution that addresses the time period during which the used nuclear fuel remains a significant hazard.

In terms of both the radioactive and chemical content of the used nuclear fuel, this time period is essentially *forever*. There is nothing unusual about this length of time – it describes the period that almost every other toxic waste product of our industries remains toxic. There are several key differences with used nuclear fuel however, which explain why it tends to receive more attention; namely, it’s high radioactivity, availability, and manageable size:

1) ***Used nuclear fuel is highly radioactive.*** This means that in addition to being chemically hazardous (chiefly as a heavy metal that can damage the kidneys), it is also radioactively hazardous. Initially, and for several hundred years, this radioactivity is the primary hazard and requires both substantial shielding and careful handling. Due to the nature of radiation, its hazard decreases with time, and after a few hundred years the main risk to humans becomes one of internal uptake rather than external exposure – therefore, for most of the lifetime of the used nuclear fuel, shielding is not as important as measures that keep it out of the drinking water and food cycle: at this point the goal is similar to that of many chemical toxins. Indeed, although the radioactive hazard of used nuclear fuel decreases slowly with time, its chemical toxicity (as with other waste forms) continues forever.

2) ***Used nuclear fuel is all in one place.*** It is not dispersed to the atmosphere or waterways through normal operation. This is of course a good thing, but a waste product that doesn’t go anywhere must also be responsibly handled and stored. For the nuclear industry this means surface facilities with some impressively high-tech, robust arrangements for continued safe storage and monitoring, which are dependent upon continuing institutional controls – typically with a safety analysis envelope looking ahead several hundred years. Reassessment (and replacement or refurbishment) of the current containment approach will be needed at some point in this time frame.

3) ***Used nuclear fuel is small in volume.*** Uranium contains, gram for gram, millions of times more potential energy than any chemical source, and this means that even a lifetime of operation of a nuclear reactor generates a relatively small amount of used nuclear fuel. “Relatively small”, combined with being “all in one place” as just discussed, translates directly to manageability. The number of used nuclear fuel containers will be in the thousands, which seems large but is an entirely manageable task over several decades.

These unique aspects of used nuclear fuel – its radioactivity, localization, and compactness – are simultaneously what draw society's attention (possibly more than any other waste form), and what provide a unique opportunity to do something about it.

In short – we have a long-term plan for used nuclear fuel because we *should*, and we *can*.

What "long-term" means

As soon as you decide to address the actual, long-term risk of any waste material, you need to remove all institutional controls from the equation – i.e., the humans. This is because we will not be around forever, at least in the location where the waste is stored.

For example, one thing that is likely to happen in the relatively near future (compared to the life of our waste materials), is glaciation. As Figure 1 shows[5], roughly every 100,000 years, our planet drops in temperature and much of the continental land mass in the northern latitudes become covered in ice up to 4 km thick. To say this ice destroys everything in its path would be an understatement: it reshapes the landscape, grinding off several metres of the surface and scattering it around the continent as "glacial till". Much of this glacial till is moulded into today's familiar landforms by the torrents of water from the glacier's eventual melting. The erosion from this melting also leaves behind valleys and lakes where there were none before.

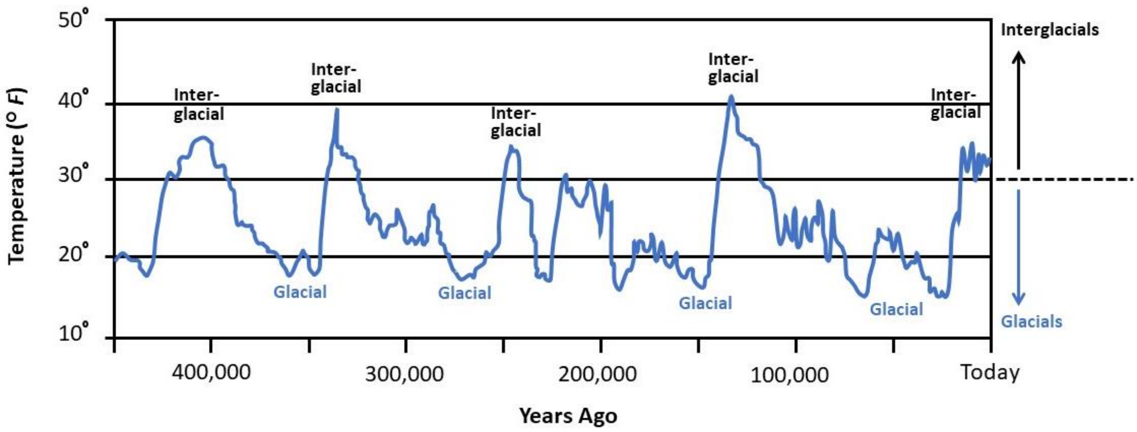

Figure 1. Glacial-interglacial cycles of the past 450,000 years[5]

Clearly, glaciation is a "wiping-the-slate-clean" event that leaves nothing behind, on – or several metres below – the areas of the earth surface that it impacts. The most recent of these glaciations peaked roughly 20,000 years ago, and is directly responsible for much of the striking scenery of Canada today.

As globally catastrophic as glaciations are, of course, there are a number of other challenges that must be addressed in a long-term strategy for any form of waste: for example, structural decay (erosion, corrosion, etc.), climate change, weather events, seismic events, social developments

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[5] Adapted from S. Eldredge and B. Biek, *Glad you Asked: Ice Ages – What are They and What Causes Them?*, Utah Geological Society, https://geology.utah.gov/map-pub/survey-notes/glad-you-asked/ice-ages-what-are-they-and-what-causes-them.

(including wars and other upheavals), and incursion of plants and animals – and all of these must be accommodated in the long-term strategy without relying upon ongoing human intervention.

Geological repositories vs. rolling stewardship

Around 50 years ago, at the dawn of significant growth of nuclear electricity generation worldwide, several countries, including Canada, decided to take on the above challenge of finding a long-term solution for used nuclear fuel. As a result, today, used nuclear fuel is probably the only waste material that has a true long-term plan, largely due to its unique characteristics as described above[6].

For any type of waste there are two fundamental choices for such a long-term plan: destroy it completely, or deal with it appropriately. As mentioned earlier, destroying used nuclear fuel by recycling it in advanced reactors would potentially lead to significantly more energy production. This may be a commercial possibility someday, but for the foreseeable future a practical solution is needed. Practicality also rules out a few other suggested strategies, such as shooting the waste into space or the Sun.

Amongst the countries addressing this issue, the most popular strategy for appropriate dispositioning of used nuclear fuel is *deep geological repositories*: the packaging of used nuclear fuel in robust containers designed to last hundreds of thousands of years (the duration of the hazard), and emplacing these deep underground in rock formations with certain attractive characteristics (e.g., low seismicity and groundwater movement).

The DGR concept is supported by decades of international research, and involves complex geophysical and geochemical modelling that is scientifically verified based on both experimentation and several analogues in nature itself[7]. As in nature, a DGR relies upon the multiple-barrier concept, which for the Canadian approach means the following[8]:

- At the heart is the nuclear fuel itself, a robust ceramic resistant to dissolution in water;
- Next are the sealed metal fuel tubes, resistant to erosion and corrosion, and designed to survive the high temperatures, radiation, pressures, and vibration of over a year in a reactor core;
- Next is the emplacement container of the DGR, designed to hold the fuel in the underground conditions for the duration of its hazard;
- Next is the highly absorbent bentonite clay surrounding the fuel, preventing both groundwater incursion and radionuclide migration – similar in concept to the clay barrier that protected Saskatchewan's highly-concentrated uranium deposits for over a billion years;

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[6] See also J. Whitlock, *The Good News About Nuclear Waste*, http://nuclearfaq.ca/good-news-about-nuclear-waste.htm (2021).
[7] See also J. Whitlock, *How Can We Have Confidence in Predictions of the Long-term Safety of a Geological Repository?*, http://nuclearfaq.ca/cnf_sectionE.htm#waste-confidence, and *What does Nature tell us about nuclear waste disposal?*, http://nuclearfaq.ca/cnf_sectionE.htm#v2.
[8] NWMO, *Multiple-Barrier System*, https://www.nwmo.ca/en/A-Safe-Approach/Facilities/Deep-Geological-Repository/Multiple-Barrier-System.

- The final barrier is the overlying 500 metres of rock, chosen to have a number of qualities that impede radionuclide movement – chief among these is low groundwater movement, taking hundreds of thousands of years for any dissolved radionuclides to reach the surface, and ensuring that radiation levels on the surface remain forever below natural background levels.

The concept of *rolling stewardship*, on the other hand, is a commitment to continuing our monitored, surface storage indefinitely, replacing storage infrastructure as it ages, and communicating knowledge about the facilities from generation to generation. Rolling stewardship represents a fundamental distrust of the science behind the DGR concept (and unfortunately also some misunderstanding, such as claims[9] that "geology is a descriptive science, not a predictive one", which is certainly not true[10]). Rolling stewardship assumes that institutional controls can be maintained on used nuclear fuel for perpetuity, or at least until a better option comes along.

As part of its initial multi-year consultation with Canadians (2002-2005) to gauge the public view on DGR versus other strategies, including continued surface storage, Canada's Nuclear Waste Management Organisation (NWMO) asked this very question[11]. In general, the result was qualified support for doing something concrete today about the long-term hazard, while remaining flexible for opportunities to improve our approach as the science progressed – this led to the concept of *Adaptive Phased Management*,[12] being implemented by the NWMO today.

Stewardship vs. abandonment

Which brings us to the question of *stewardship* vs. *abandonment*.

Stewardship is defined as "*the conducting, supervising, or managing of something; especially: the careful and responsible management of something entrusted to one's care.*" [13]

Abandonment is defined as "*giving up to the control and influence of another person or agent.*" [14]

While it is true that the DGR concept includes, once emplacement activities are complete (taking the better part of a century), the decommissioning of surface facilities and eventual abandonment of the site, this does not imply that stewardship of the used nuclear fuel ends.

On the contrary, the used nuclear fuel will continue to receive the careful and responsible management of the DGR concept for millennia afterwards, developed by thousands of international experts to whom this was entrusted, over two centuries of inquiry (by the time the first DGRs receive final closure).

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[9] G. Edwards, *Nuclear Waste: Abandonment versus Rolling Stewardship*, http://www.ccnr.org/Rolling_Stewardship.pdf.
[10] See, for example, G. De Marsily (Ed.), *Predictive Geology: With Emphasis on Nuclear-Waste Disposal*, Pergamon Press (2013).
[11] NWMO, *Selecting APM: A Three-Year Study*, https://www.nwmo.ca/en/Canadas-Plan/Selecting-APM-A-Three-Year-Study.
[12] NWMO, *About Adaptive Phased Management*, https://www.nwmo.ca/en/Canadas-Plan/About-Adaptive-Phased-Management-APM.
[13] https://www.merriam-webster.com/dictionary/stewardship.
[14] https://www.merriam-webster.com/dictionary/abandon.

The used nuclear fuel will be safe from hurricanes, tornadoes, wars, terrorism, earthquakes, and yes – glaciers. It will most likely be (unless society takes major new steps in this direction) the only waste form on the planet with this level of long-term security, and the only waste form not found in glacial till throughout the continent by civilizations recolonizing the former ice sheet zones in the next interglacial period.

On this time scale, the term "stewardship" clearly has a much broader scope than temporary storage under the watchful eyes of humans. It implies sustainable, long-term protection against forces that will exist long after humans are gone. It implies a sound, conservative, scientific approach that minimizes uncertainties and relies on passive, natural processes (because the level of certainty regarding loss of institutional control on this time scale is 100%).

This is, in fact, *geological stewardship*.

The recognition that we are morally obligated to pursue a long-term solution for used nuclear fuel today, rather than bequeathing this responsibility to future generations, is an important one, but of course is not limited to used nuclear fuel. It applies to everything we do on this planet, including all forms of waste production. It just may be, however, that nuclear waste is the only form of industrial waste for which this responsibility is being acted upon to any significant degree.

To ignore this moral obligation today, while the solution is in our grasp, is abandonment. This brings us to the critical observation:

Rolling stewardship represents *abandonment* of our long-term responsibility for managing used nuclear fuel, while geological repositories represent long-term *stewardship*.

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