Background

June 29 2019

Swedish Conference May 21-23

I recently attended a three-day conference in Stockholm focused on the problem of how to communicate effectively with people living thousands of years in the future, in order to inform them of the radioactive legacy that we are leaving them in the form of abandoned nuclear waste dumps filled with extraordinarily radiotoxic materials, most of them human made radioactive products of nuclear fission.

The meeting was by invitation only. I was hosted by the Swedish Nature Conservancy and funded by Milkas, a Swedish NGO that is highly critical of current plans to abandon radioactive wastes from the nuclear industry in underground chambers excavated at Forsmark, right beside the Baltic Sea. I visited the underground workings with a small group of colleagues, escorted by the Mayor of the nearby town of Osthammar. A little over a year ago, those critical of the industry's plans won a stunning victory as the Environmental Court ruled against granting an immediate go-ahead to the industry to begin emplacing irradiated nuclear fuel in the repository.

Copper Corrosion

The Swedes, like the Canadians, are planning to encase their irradiated fuel assemblies in copper canisters. In the Swedish context there are 6,000 canisters planned, each six metres high, each one using about 5.5 tonnes of copper. The industry claims that, in the absence of oxygen (after the repository is closed and sealed and the trapped oxygen has been "used up") there can be no corrosion of the cooper canisters and so the waste will be protected for more than tens or even hundreds of thousands of years.

The critics presented evidence of five different mechanisms of copper corrosion that can occur in the absence of oxygen, and the court found this evidence so compelling that it ruled the storage scheme can not proceed until these mechanisms have all been thoroughly addressed by the industry. So far, the response from the proponent has been less than stellar. Many other criticisms of the industry's plans were presented to the court, but the copper corrosion arguments were singled out as having special importance.

Rolling Stewardship

Although I had no opportunity to make a presentation during the three-day meeting, I did circulate a four-page pamphlet on Rolling Stewardship as an alternative to abandonment of radioactive wastes (see www.ccnr.org/Rolling_Stewardship.pdf). The Canadian Coalition for Nuclear Responsibility (CCNR) maintains that we humans do not have a "final solution" to the problem of keeping radioactive waste out of the environment of living things, and so we should not abandon these wastes or place them beyond human control.

During the discussion periods I pointed out that it is much easier to transmit information from one generation to the next than to try to communicate with a civilization thousands of years in the future, not even knowing what languages they might be speaking. When information is transmitted from one generation to the next there is less chance of misunderstanding, misinterpretation, or failure to communicate altogether. In this way Rolling Stewardship helps to keep the information fresh by continually re-expressing the key ideas and facts using the appropriate language of the day.

Even in the event of a "discontinuity" in human society, resulting in a collapse of social order and a loss of institutional control, it is more likely that the pertinent information will be retrieved when society re-establishes itself, if the latest version of that information is available to be re-discovered — rather than some ancient stand-alone archive thousands of years old. There are of course no guarantees, but the chances of continuity being re-established may be improved if the information base is maintained as part of a living memory.

Memorandum

To: Whom it may Concern
From: Gordon Edwards
Topic: Rolling Stewardship
Re: Transfer of Records, Knowledge and Memory (RKM) re Radioactive Wastes (an interprofessional meeting in Stockholm, Sweden, from May 21 to 23)
Date: June 6 2019

Thank you for inviting me to attend this interesting three-day meeting in Stockholm. The task of communicating to future generations thousands of years hence is daunting indeed.

I am taking the opportunity to summarize some of the points that I believe are important regarding the Rolling Stewardship concept, which a significant number of participants alluded to in some fashion in their concluding comments. Rolling Stewardship is seen as an alternative to the abandonment of radioactive waste, which ultimately leads to amnesia.

1) Rolling Stewardship is a concept based not on amnesia, but on the persistence of memory. It goes beyond preserving records through archives, museums, time capsules, and other aids for storing and transmitting RKM [Records, Knowledge and Memory]. Rolling Stewardship advocates the establishment of an active "Stewardship Council", independent of the existing nuclear establishment, but endowed with the resources and authority needed (1) to maintain the radioactive wastes in a safe monitored and retrievable condition, well labelled and securely packaged, as well as (2) to ensure that the RKM records are complete and understandable, by bringing those records up-to-date where needed, describing the most important resources for the public and re-expressing the basic facts as clearly as possible in modern language – in the idiom of the time.

At periodic intervals, say every twenty years or perhaps every ten years, the Stewardship Council would organize a very public and ceremonial "changing of the guard". At that time the outgoing Stewardship Council would report on the state of the wastes and the status of the RKM records, while passing on the mantle of responsibility, as well as the resources and authority, to the incoming Stewardship Council. On that day, there would be a public awareness-raising outreach through ritual re-enactments, story-telling, music, film, drama, dance, art and ceremony, to remind the older generation and to inform the younger generation of the existence of the radioactive wastes and the importance of preserving and, when necessary, accessing the associated RKM records.

The central role of ceremony in preserving memory cannot be overstated. For 2000 years the Catholic Church has passed on important traditions and teachings by utilizing repetitious but elaborate and beautiful ritual events. For much longer periods of time indigenous peoples have transmitted important cultural heritage, ancient wisdom and traditional knowledge to successive generations through dance, story-telling, masks, sculptures, totems and other artifacts, as well as ceremonial rituals and re-enactments.

2) In the case of long-lived low and intermediate level wastes, it is necessary to maintain active control over the wastes for the indefinite future. As long as the wastes cannot be destroyed or rendered harmless, they must not be abandoned or placed beyond human control. To facilitate retrieval, repair, re-characterization and repackaging of the wastes, when such actions are advisable, it is essential that the wastes be properly segregated and packaged in well-labelled robust modular containers that can be readily monitored and, when necessary, accessed and handled by future generations. Rolling Stewardship is not intended to be a passive caretaking task that maintains the "status quo" but an active intergenerational guardianship seeking continual improvement in protecting the environment of living things from the stored radiotoxic materials using the best means available at that time. Through all this, the search for a permanently satisfactory solution to the waste problem would continue to be an on-going effort.

3) Rolling Stewardship springs from the recognition that we do not have a solution to the radioactive waste problem at the present time, and that total abandonment of long-lived radioactive wastes, resulting in amnesia, is not an acceptable strategy. This consideration applies to high-level waste as well as low- and intermediate-level waste.

Since plutonium-239 has a 24,000 year half-life, it is evident that there will be enough plutonium in any sizeable high-level waste repository to provide the primary nuclear explosive material for thousands of nuclear weapons, and that will remain true for tens of thousands of years to come. Abandoning such material is no solution.

In addition, the radiotoxicity of the buried high-level waste remains extraordinarily elevated even after a million or even ten million years of storage (as noted in "Geologic Disposal of High-Level Radioactive Wastes; Earth-Science Perspectives", US Geological Survey Circular 779, by J.D. Bredehoeft, A.W. England, D.B. Stewart, N.J. Trask, and I.J. Winograd – https://doi.org/10.3133/cir779)

Humanity cannot afford to forget the existence and/or ignore the nature of this radiotoxic legacy. The RKM project is also predicated on the view that amnesia is not acceptable.

4) There is no operational underground repository for high level waste anywhere in the world, at the present time, despite repeated promises from the mid-1970s onwards that such facilities were "just around the corner" – to be operational within a decade or two. In fact, nuclear authorities in the USA tried eight times in the last century to site a high-level radioactive waste repository, and failed all eight times. There have also been alarming and unanticipated failures at underground repositories for low and intermediate level radioactive wastes in Germany and the USA (Asse-2, Morsleben, and WIPP – the Waste Isolation Pilot Plant located at Carlsbad, New Mexico).

Indeed, every time a new candidate site for a repository is identified, it seems that new unanticipated problems arise for which there is no ready answer – whether it is the heat-induced migration of pockets of brine in salt formations towards the emplaced waste, or

the eventual dripping of re-condensed pore water requiring titanium gutters in Yucca Mountain, or the discovery of oxygen-free corrosion mechanisms for copper, it seems quite clear that our efforts to force the descriptive science of geology to evolve rapidly into a predictive science in a few decades is unwise, and likely to be unsuccessful.

In view of the many disappointments and failures that have occurred hitherto in the search for a permanent geological repository to store long-lived radioactive wastes, it is not acceptable (given our present state of knowledge) to abandon such wastes, even in a well-engineered facility. For at least a century or two, and probably much longer than that, the wastes should be guarded at all times in a monitored and retrievable state.

5) There are no principles of science that can be invoked to prove that highly dangerous materials stored in one location will stay there forever. In addition, under the best of circumstances, there are a great many unresolved questions in the earth sciences, fundamental questions of a basic scientific nature, that would have to be resolved in order to have even the minimal degree of confidence required to justify a Deep Geological Repository (DGR) abandonment strategy.

This legitimate concern is underscored by the successive chapters in the book *Techniques for Determining Probabilities of Geologic Events and Processes* (International Association for Mathematical Geology, “Studies in Mathematical Geology No. 4”, edited by Regina L. Hunter and C. John Mann, Oxford University Press, 1992).

The chapters of this book, written by different teams of earth scientists, constitute a series of technical papers regarding various unresolved geological problems insofar as predictability is concerned. All of these problems arise solely as a result of the planned geological disposal of radioactive waste. So although radioactive waste is not directly mentioned in most of the papers, it is in fact the motivation behind all of them. Even for non-technical readers, it is worth perusing some of the selected excerpts from this book (see selected easy-to-read excerpts at www.ccnr.org/geology.html); they provide a rapid overview of the uncertainties that we must either overcome – or choose to overlook!

6) The authors of the USGS Circular embrace without hesitation the notion of geologic disposal, identified by the nuclear establishment as its “solution" to the radioactive waste problem. They do not foresee any insuperable obstacles in locating a suitable geologic formation. They nevertheless situate the problem of “proving” the safety of this approach as being among the most "complex and unpredictable” problems of applied science.

One readily discerns a kind of cognitive dissonance between the “certainty" the authors espouse for the geologic disposal concept itself, versus the unresolved — and perhaps unresolvable — “unpredictability” of the scientific models and procedures that are required to validate that concept in any particular case. I quote:

"It is generally accepted that repositories in geologic media can provide the most certain safe containment of radioactive waste...

"We have not had, of course, any working experience with geologic containment for such long periods; thus, predictions must be based on conceptual models of what will happen to the waste after emplacement… The starting point for the models is a set of initial conditions, including emplaced radioactivity, rock geometry, and rock properties around the repository and along potential flow paths. The end point for the models is a set of risks usually expressed in radiation exposures to humans for a series of times after final disposal.

"Application of these models to policy making in the field of radioactive-waste management requires that their limitations be clearly understood. Models of natural systems that have come into use in recent years fall into four categories (Holcomb Research Inst., 1976): (1) simple and predictable, such as agricultural crop patterns; (2) complex and predictable, such as river hydrology or short-term weather patterns; (3) simple and unpredictable, such as ecosystem response to natural disasters; and (4) highly complex and unpredictable, such as interrelations among the species of an ecosystem or, we believe, the fate of radioactive wastes in geologic repositories." [emphasis added]

7) Based on my own personal experience as a pure and applied mathematician, I know that it makes a great deal of difference what axioms you start with. If it is accepted as an axiom that some form of geologic disposal is the "solution" to the problem of the safe long-term storage of radioactive waste, then inevitably all research efforts will be bent on verifying that it is indeed a solution. The science serves to justify the axiom. If on the other hand we begin with the axiom that we do not have a permanently satisfactory solution to the nuclear waste problem, and that ***a priori*** one must assume that all containers will eventually leak, then it must also be assumed that a geological container (i.e. an underground repository) will also leak. Logic would then require that on-going monitoring and retrievability of the radioactive wastes would have to be regarded as essential characteristics of any long-term safety regime.

If one acknowledges that in a relatively short time (compared to the multi-million year time span of the repository) there will be no leak-proof containers to contain our toxic legacy of radioactive poisons, then the need for our descendants to be able to access the waste so as to repair, repackage, remediate, re-characterize, reconsolidate, and remedy the situation can scarcely be denied. The possibility of intervention must be seen as the inalienable right of future generations, regardless of what we may think today. Indeed, there is little purpose in preserving and transmitting RKM (Records, Knowledge and Memory) if future intervention is effectively rendered impossible.

Eternity is a very long time. It is always a source of amazement when one discovers that the entire human race can be misled for many centuries into believing that something is absolutely true, only to discover one day that we have all been labouring under a

misconception, and that what we thought was true is not necessarily so. The discovery of non-Euclidean geometry in the nineteenth century falls into that category, as does (in my opinion) the late twentieth-century discovery of chaos theory. The phenomenon of chaos was discovered through the repeated iterations of non-linear models, demonstrating that minute changes in initial conditions can lead to dramatic and qualitatively different results. This type of chaotic behaviour was first observed in the nineteenth century in relation to the three-body problem in Newtonian gravitational theory — notably by Henri Poincaré — but was unexplained until the advent of mathematical chaos theory around 1980. All of a sudden the universal belief that deterministic mathematical models must lead to reliable pre-determined conclusions was called into question, as was the notion that small changes in initial conditions will yield only small changes in the final results. Since most complex phenomena are non-linear rather than linear, the reliability of non-linear mathematical models that depend on millions of iterations became inherently suspect.

Certain ancient mathematical problems are not only unsolved, but have been proven to be unsolvable (in the terms in which they were formulated). In other words, it is known with certainty that no one will ever be able to solve these problems under the given constraints. In some cases this is of no great practical importance, since alternative methods exist to obtain approximate solutions, and those approximations can be made as accurate as desired. But in other cases, mathematical problems have been proven to be unsolvable for which there are no alternative ways to “crack the nut” (e.g. the continuum hypothesis and the set of undecidable algorithms).

8) Given our human experience of self-deception (e.g. the almost universal nineteenth-century belief in a solid “ether" filling all space to allow transverse waves of light to reach us from distant celestial sources, now known to be entirely wrong, or our ignorance of the existence of dark energy and dark matter until the latter part of the twentieth century) we must in all honesty entertain the possibility that the “disposal” of nuclear waste – through geologic containment coupled with abandonment and amnesia – may also be an unsolvable problem in the terms in which it is currently formulated. Geologic disposal may not in fact be a “final solution” to the problem, but just another storage scenario – perhaps more robust than other storage scenarios, but no more of an eternal solution than any of those others. Geologic disposal is an idea, not a solution.

As Swedish Nobel laureate in Physics, Hannes Alfven, wrote many years ago, in the context of radioactive waste disposal, *“You cannot claim that a problem is solved just by pointing to all the efforts that have been made to solve it.”* More specifically, as the California Energy Commission reported in 1978, following an extensive three year investigation into the geologic disposal option for irradiated nuclear fuel:

> *“Excessive optimism about the potential for safe disposal of nuclear wastes has caused backers of nuclear power to ignore scientific evidence pointing to its pitfalls. That's the real crux of what we found -- that you have to weigh scientific evidence against essentially engineering euphoria.” LA Times, January 12, 1978*

9) So how close are we to a solution? Returning to the USGS Circular, we read:

". . . use of the geologic record to predict future events is a formidable task. Certainly, an assumption of the constancy of rates of geologic processes, namely substantive uniformitarianism, is open to question. The past rates of occurrence of geologic events and processes have varied widely over time and there appears to be no clear philosophical basis for determining rates for these events or processes in the future. Geology is basically a retrodictive rather than a predictive science (Kitts, 1976).

"In summary, predictive models are an essential step in the selection and implementation of a radioactive waste repository and a radioactive waste management system. They are invaluable tools for analyzing the problem and for identifying factors that are likely to have the greatest effect on radionuclide migration. However, some components of the models are inherently unpredictable at present and are likely to change at different times. In no sense, therefore, will these models give a single answer to the question of the fate of radioactive waste in geologic repositories; rather they will provide a spectrum of alternative outcomes, each based on a set of uncertain assumptions about the future….

"A concluding statement concerns the uncertainties involved in geologic prediction for long timespans, discussed earlier. These uncertainties need to be faced candidly in public discussions of radioactive waste disposal. Earth scientists can indicate which sites have been relatively stable in the geologic past, but they cannot guarantee future stability. Construction of a repository and emplacement of waste will initiate complex processes that cannot, at present, be predicted with certainty.

"The inability to predict can be offset in part by adoption of a multiple-barrier or "defence-in-depth" philosophy for radionuclide containment. Such a philosophy provides a succession of independent barriers to nuclide migration. The waste form, the host rock, and the ground-water flow path all provide potential barriers. Continuing research is needed to measure the efficacy of these barriers and to obtain a better understanding of the processes involved." [emphasis added]

10) It is sobering to realize that the USGS document was written in 1978, before the full impact of chaos theory had even been glimpsed. At that time, it was commonly believed that non-linear models iterated a great many times will give stable and reliable results even with input data that is only approximate. This is now known to be untrue in general. Moreover, validation of such models over enormous time spans remains an unsolved problem, for we are unable to compare the predictions with the actual results, a million years hence. Such models are in effect untested hypotheses expressed in mathematical language, based on very limited data, and calibrated to the initial conditions of the problem only.

At least for the next century or two, it would be unwise to abandon these wastes, to put them beyond human control, or to render them inaccessible and/or irretrievable. Rolling Stewardship is a more appropriate course of action. While Rolling Stewardship by itself is not a solution to the waste problem, it does represent a responsible management regime that can be pursued over many generations until a permanently satisfactory solution to the radioactive waste problem is found, if ever.

To conclude, I believe that the concept of Rolling Stewardship should be given a prominent place in the Final Report of the Stockholm discussions. A significant number of participants seemed willing to entertain and support certain aspects of this concept.

Thank you again for inviting me to attend the Stockholm discussions, and for providing such a stimulating context for our consideration.

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Additional resources related to Rolling Stewardship.

1. Video of May 24 presentation at the Nature Conservancy in Stockholm – "Radioactive Waste and Rolling Stewardship":
https://youtu.be/iyf3nncceBg

2. In the Stockholm video cited above the slides cannot be seen clearly, so here they are in another link as a pdf:
www.ccnr.org/GE_Stockholm_2019.pdf

3. Submission to the US NRC regarding Yucca Mountain
www.ccnr.org/CCNR_NRC_Yucca_pack_2015.pdf

4. CCNR four page leaflet on Rolling Stewardship
www.ccnr.org/Rolling_Stewardship.pdf

5. Five guiding principles for the long-term management of radioactive wastes (from the Joint Declaration on Radioactive Wastes by the Anishinabek/Iroquois Alliance)
www.ccnr.org/Five_Principles.pdf

6. Oral testimony on OPG's Deep Geological Repository for Ontario's Low and Intermediate Level Waste
www.ccnr.org/GE_DGR_Transcript_Sept_9.pdf

7. CCNR Undertaking – Examples of Rolling Stewardship
www.ccnr.org/CCNR_Undertaking_final.pdf

8. Nuclear Waste Governance in Canada (2014 presentation in Salzburg Austria)
www.ccnr.org/salzburg_2_2014.pdf