Thank you for the opportunity to provide a final submission with respect to Canadian Nuclear Laboratories' application to amend its Chalk River Laboratories site licence to authorize the construction of a near surface disposal facility. This submission summarizes my previously-submitted written and oral interventions [1, 2]. It contains no new information and is less than 5000 words.

Executive Summary

The required functionality for a near surface disposal facility for radioactive waste is that, at some point in the foreseeable future, the safety of humans and non-human biota is no longer dependant upon human intervention (security, maintenance, repairs, remediation, societal and regulatory controls). At that point in the foreseeable future (the end of the Institutional Control Period, ICP) the human interventions can cease, the waste can be abandoned, no further costs are incurred, and the financial liability is extinguished.

The proposed Engineered Containment Mound (ECM) [3] lacks the basic functionality of a near surface disposal facility for radioactive waste. The proponents of the proposed ECM are unable to state when it would be safe to release the radioactive material from regulatory controls. Indeed, the proponents have stated that they have no plans to abandon the material and, in effect, the institutional controls would extend *in perpetuity*. Using the waste acceptance criteria credited in the proponent's Environmental Impact Statement [4], it is possible to calculate when the constituent radionuclides of the stated inventory would decay sufficiently to meet Canada's regulatory criteria for disposal [5]. This calculation reveals that many radionuclides would not decay sufficiently to meet Canada's disposal criteria for many thousands of years and, in some cases, for many millions of years. This means that the safety of humans and non-human biota would be dependent upon institutional controls *in perpetuity*.

The on-going cost of those institutional controls (security, maintenance, repairs, remediation, societal and regulatory controls) for millions of years would continue to be a burden on the public purse and would represent a mind-numbingly large financial liability for the Government of Canada.

The proposal is non-compliant with International Safety Standards, for example, no verification of the radioactive content of emplaced waste and reliance on institutional controls to ensure long-term safety. Canada is bound by international treaty [6] to have due regard to internationally endorsed criteria and standards concerning radioactive waste management. Consequently, giving approval to the proposed ECM would appear to place Canada in contravention of its international treaty obligations.

In order to approve this project, the regulator would have to ignore these fatal flaws. Such a negligent approval would be a strategic error for the long term success of Canada's nuclear industry.

1.0 Introduction

1.1 Objectives of Radioactive Waste Disposal

Radioactive waste is hazardous and must be kept isolated to ensure that humans and non-human biota are not exposed to unacceptable levels of radiation.

Canada has been storing radioactive waste since the 1940s. The cost of operating these radioactive waste storage facilities is not trivial — facilities must be constructed, maintained, remediated, and must be kept secure. In addition, regulatory and other societal oversight is required. The future costs associated with these human interactions (often referred to as *institutional controls*) represents a significant financial liability. If storage facilities are to be operated "in perpetuity" then the financial liability associated with the waste storage is extremely large.

A solution to the safety, cost, and liability dilemma associated with storage facilities is to construct appropriate disposal facilities. Disposal facilities are designed such that, at some point in the foreseeable future, the safety of humans and non-human biota is no longer dependant upon human intervention (maintenance, repairs, remediation, security, societal and regulatory controls, etc). At that point, the disposal of the waste has occurred, no further costs are incurred, and the financial liability is extinguished.

1.2 Classification of Radioactive Waste and Associated Disposal Routes

High level waste (HLW) [7] has levels of activity concentration high enough to generate significant heat by radioactive decay and/or may contain large amounts of long-lived radionuclides. Disposal in deep, stable geological formations, usually several hundred metres or more below the surface, is the generally recognized option for disposal of HLW. The geosphere barrier serves to isolate humans and non-human biota from the radiological hazard over the very long time period that it will take for the radionuclides in the waste to decay to a level where they no longer represent an unacceptable risk.

Intermediate level waste (ILW) [7] has, in general, a lower activity concentration than HLW and requires little or no provision for heat dissipation during its storage and disposal. However, because of its content, particularly of long lived radionuclides, it requires a greater degree of containment and isolation than that provided by near surface disposal. ILW may contain long lived radionuclides, in particular, alpha emitting radionuclides, that will not decay to a level of activity concentration acceptable for near surface disposal during the time for which institutional controls can be relied upon. Therefore, waste in this class requires underground disposal at depths of the order of tens of metres to a few hundred metres.

Low level waste (LLW) [7] is above clearance levels, but with limited amounts of long lived radionuclides. Such waste requires robust isolation and containment for periods up to a few hundred years and is suitable for disposal in engineered near surface facilities. The concept of the use of a near surface disposal facility requires that the inventory of radionuclides emplaced in the near surface facility is carefully controlled so that at the end of the isolation and containment period (generally taken to be 300 years), the radionuclides emplaced in the facility will have decayed to a level where they no longer represent an unacceptable risk to humans and non-human biota. At that future point, the material can be released from regulatory control, all other human interventions related to the disposal facility can cease, and the material can be abandoned. Hence, at that point (the end of the *Institutional Control Period*), the disposal of the waste has occurred, no further costs are incurred, and the financial liability is extinguished.

2.0 Radiation Exposure Regulation

2.1 Radiation Exposure Regulation for Material under Regulatory Control

The deliberations of the International Commission on Radiological Protection (ICRP) have been incorporated into the regulatory regimes of many countries around the world, including Canada.

The radiological protection principles of the ICRP are that radiation doses from regulated sources should be *justified, limited, and optimized* [8]:

- *Justification:* There need to be tangible personal or societal benefits from the exposure, such as electricity production and medical isotope production, that outweigh the harm from the exposure.
- *Limitation:* Other than medical exposures, the total dose to an individual from regulated sources should not exceed the specified dose limit.
- *Optimization:* The dose to individuals should be kept as low as reasonably achievable, taking into account economic and societal factors (ALARA).

The ICRP's recommended public dose limit of 1 mSv/year and the requirement to implement the ALARA principle are incorporated into Canada's Radiation Protection Regulations [9].

The ICRP state that the risk of cancer to a member of the public from radiological exposure is 5.5%/Sv, and that the risk of heritable effects is 0.2%/Sv, resulting in a total risk of 5.7%/Sv [8]. Hence, the public dose limit of 1 mSv/year results in an annual risk to an individual of 5.7×10^{-5}.

Application of the ALARA principle is intended to reduce this risk to a more acceptable level. The ALARA principle does not guarantee that individual members of the public will receive only very low doses of radiation because it explicitly allows benefits to be judged against costs.

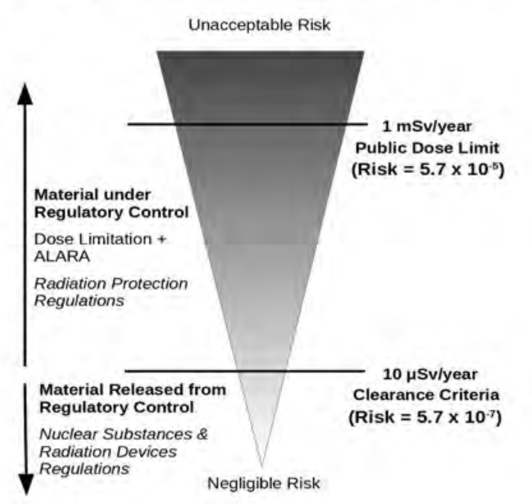
2.2 Radiation Exposure Regulation for Material Released from Regulatory Control

The ICRP-based regulatory regime requires institutional controls to exist at the time of any potential radiological exposure in order to apply the *limitation* and *optimization* principles (i.e., to keep doses limited and as low as reasonably achievable).

Since the ICRP-based regulatory regime requires institutional controls to exist at the time of exposure, a different regulatory approach is required for radioactive substances that are released from regulatory control. This approach was developed by the International Atomic Energy Agency (IAEA) in applying the *clearance* concept [10], and is based on a *de minimis* (negligible risk) approach. Generally, in the IAEA's *de minimis* approach, radioactive materials are not to be released from regulatory control unless it can be demonstrated that potential doses to individual members of the public from the released radioactive materials do not exceed 10 μSv/year. A dose of 10 μSv/year corresponds to an annual risk of 5.7×10^{-7}, and may be considered to be a *de minimis* dose (negligible risk).

The IAEA's *de minimis* approach to applying the clearance concept has been adopted by Canada. Canadian regulations concerning the release of radioactive materials from regulatory control and their entry into the accessible biosphere are provided in the Nuclear Substances and Radiation Devices Regulations [5]. The clearance levels (activity concentrations) given in the Nuclear Substances and Radiation Devices Regulations [5] ensure that potential doses to the public from radioactive materials released from regulatory control are limited to a maximum of 10 μSv/year.

Figure 1:Radiation Exposure Regulation



Overall, therefore, the Canadian regulation of radiation exposures from materials that are under regulatory control and from materials that are released from regulatory control is shown schematically in Figure 1. The Public Dose Limit defines the boundary between unacceptable and conditionally acceptable radiation risks; the Clearance Level defines the boundary between conditionally acceptable radiation risks and broadly acceptable radiation risks.

2.3 Radiation Protection and Radioactive Waste Disposal

There are both ethical and practical problems in applying an ICRP-based regulatory regime to near surface radioactive waste disposal.

From the perspective of a person alive after the end of the Institutional Control Period (e.g., 300 years in the future), it is not possible to apply the ICRP principle of *justification* when there are no personal nor societal benefits from the exposure, and any benefits that may have been received were received 300 years in the past. Similarly, the principles of *limitation* and *optimization* cannot be applied, as there will, by definition, be no institutional controls available.

The ICRP recognize the problems associated with applying their regulatory regime to radioactive waste disposal, in References [11 – 14].

Given the ethical and practical problems in applying an ICRP-based regulatory regime to radioactive waste disposal once institutional controls have terminated, a *de minimis* (clearance) approach is warranted, for example:

1) Canadian Regulations [5] state that a person may abandon or dispose of a radioactive nuclear substance if the activity or the activity concentration of the substance does not exceed its clearance level (equivalent to a dose of 10 μSv/year to individual members of the public);
2) In evaluating the Canadian Nuclear Fuel Waste Management Program [15], the Atomic Energy Control Board specified an upper limit of 10^{-6} fatal cancers and serious genetic effects in a year to individuals [16]; and
3) The United Kingdom's requirements are that an individual risk of 10^{-6} per year should be used [17].

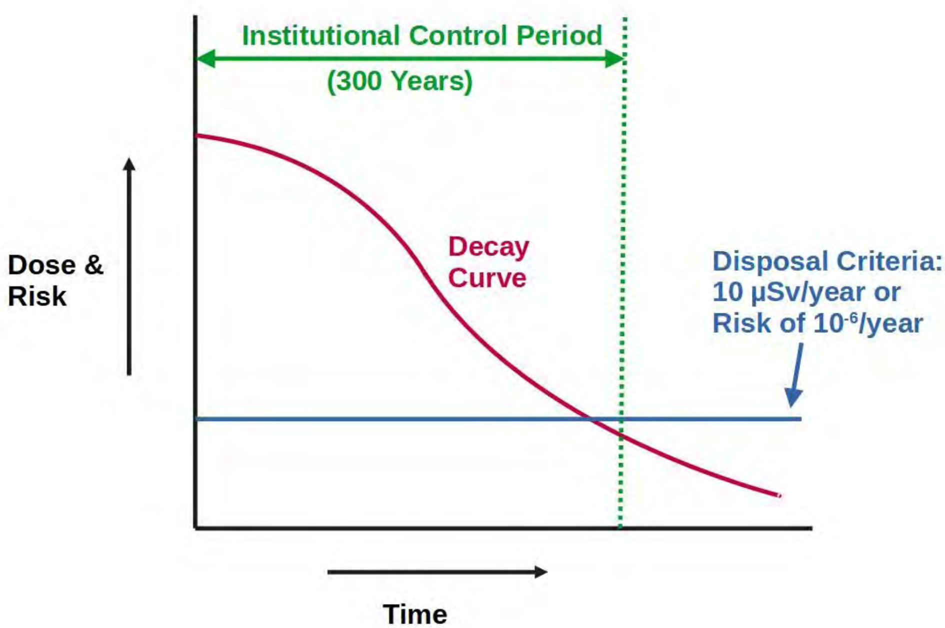
3.0 Functional Requirements for a Near Surface Disposal Facility

Humans are adept at reusing waste materials, sometimes with undesirable consequences. Radioactive materials that were not under appropriate institutional controls have been scavenged to obtain metals, construction materials, and other items of value, for example at Port Hope, Ontario [18], Semiplatinsk, Kazakhstan [19], and Goiânia, Brazil [20]. Such scavenging activities have resulted in costly remediation, excessive radiation exposures, and deaths. Near surface disposal facilities are particularly susceptible to scavenging activities as they are located in the biosphere and, hence, are easily accessible. Therefore it is important to ensure that both packaged and bulk radioactive waste will have decayed to an appropriate level prior to release from institutional controls.

Since institutional controls can only be relied upon for a certain period of time, partly because of the fragility of human society, the IAEA requires that the long term safety of a disposal facility must not to be dependent on active institutional control [21 – 23].

Hence, given the criteria for the release from regulatory controls (10 μSv/year) and the generally-accepted maximum period for Institutional Controls (300 years), then the material placed in any near surface disposal facility must be limited so that the decay curve is below the disposal criteria before the end of the Institutional Control Period (See Figure 2).

Figure 2: Relationship between Radionuclide Inventory, Institutional Control Period, and Disposal Criteria



4.0 CNL's Proposed Engineered Containment Mound

The management of the radionuclide inventory and the length of time until the radioactive material is released from regulatory control is critical to the safety of any near surface radioactive waste disposal facility.

4.1 Inventory Management

CNL's proposal credits a set of radiological "Waste Acceptance Criteria" (WAC) (Table 3.3.3-1 of [4]).

Regrettably, these Waste Acceptance Criteria fail to capture a number of radionuclides of importance in assessing the safety of near surface waste disposal facilities. For example the beta-emitting radioisotopes C-14 and Tc-99 are not captured, even though CNL lists them as being significant in the "licensed inventory" (Table 3.3.1-2 of [4]).

Given the crucial importance of maintaining the radiological inventory of a near surface disposal facility, International Safety Standards [21 – 24] require that a management system be established, and adhered to, that integrates all aspects of the waste acceptance process, eg waste characterization, waste acceptance, verification, inventory management, etc. The management system is to ensure that i) the Waste Acceptance Criteria are derived from the Safety Case, ii) waste packages and unpackaged waste have their radiological contents verified to ensure compliance with the WAC prior to emplacement, and iii) the radiological inventory of the facility complies with the functional requirements (Figure 2).

Hence, given the IAEA's requirements with respect to waste acceptance and verification, one might have expected that CNL's proposal would have included a "waste reception and verification facility", with appropriate technical equipment and management system, to verify compliance with the stated acceptance criteria. However, this does not appear to form part of the proposal. A review of the available documentation does not reveal a technical capability, nor an associated management system, to comprehensively verify that waste packages and unpackaged waste accepted for emplacement comply with the radiological parameters of the stated waste acceptance criteria.

The sparsity of information on the radioactive waste that is proposed to be emplaced in the Engineered Containment Mound has been confirmed by a recent audit by the Office of the Auditor General of Canada (OAG) [25].

As the Waste Acceptance Criteria do not cover all of the radionuclides of importance in assessing the safety of near surface disposal facilities and as there is inadequate verification of the radioactive content of the mound, the dose calculations credited by the proponents are invalid.

4.2 Time to Reach Disposal Criteria

It is stated in [4] and [26] that the maximum doses to persons from the Engineered Containment Mound are 0.015 mSv and 0.14 mSv, for the normal evolution and disruptive events, respectively. These maximum doses occur at 4,100 years and 7,650 years, respectively, both of which are significantly beyond the design life of the Engineered Containment Mound (550 years [4, 26]).

The stated doses of 0.015 mSv and 0.14 mSv are both above the criteria used by our international partners (See Section 2.3) and are non-compliant with the criteria for disposal given in Canadian regulations [5].

Hence, even using the stated "licensed inventory" of the Engineered Containment Mound (Table 3.3.1-2 of [4]), the radionuclides have not decayed sufficiently to meet disposal criteria even after several thousand years.

It is possible to calculate how long it would take for waste at the limits provided by the stated waste acceptance criteria to decay to the unconditional clearance criteria given in the Nuclear Substances and Radiation Devices Regulations [5]. These calculations are given in Table 1. For simplicity, only radionuclides that are unambiguously captured by the stated waste acceptance criteria are included, and only the limits for "leachate-controlled" packaged waste are given in the table.

Table 1: Time to Reach Unconditional Clearance Levels for Radionuclides in the Radioactive Inventory of the Engineered Containment Mound

Radionuclide	Half Life (years)	Predominant Decay Emission	Maximum Activity (Bq) at Closure (Licensed Inventory)	WAC Concentration Limit (Bq/g) (Leachate Controlled, Packaged Waste)	Unconditional Clearance Criteria (Bq/g) [5]	Time to reach Unconditional Clearance level (years)
Silver-108m	438	gamma	2.62×10^{10}			
Americium-241	433	alpha/gamma	9.74×10^{10}	400	0.1	5181
Americium-243	7,360	alpha	5.24×10^{7}	400	0.1	88,068
Carbon-14	5,700	beta	1.70×10^{12}			
Chlorine-36	301,000	beta	3.97×10^{9}			
Cobalt-60	5	beta/gamma	1.47×10^{16}			
Cesium-135	2,300,000	beta	5.19×10^{8}			
Cesium-137	30	beta/gamma	3.17×10^{12}	10,000	0.1	498
Hydrogen-3 (Tritium)	12	beta	2.79×10^{14}	10,000,000	100	199
Iodine-129	15,700,000	beta/gamma/x-ray	1.75×10^{10}	10,000	0.01	3.13×10^{8}
Molybdenum-93	4,000	x-ray	1.47×10^{5}			
Niobium-94	20,300	beta/gamma	2.34×10^{10}	10,000	0.1	3.37×10^{5}
Nickel-59	76,000	x-ray	1.21×10^{9}			
Nickel-63	101	beta	2.59×10^{11}			
Neptunium-237	2,140,000	alpha/gamma	1.74×10^{7}	400	1	1.85×10^{7}
Plutonium-239	24,100	alpha	5.06×10^{10}	400	0.1	2.88×10^{5}
Plutonium-240	6,650	alpha	5.06×10^{10}	400	0.1	79,572
Plutonium-241	14	beta	5.84×10^{11}			
Plutonium-242	375,000	alpha	6.32×10^{7}	400	0.1	4.49×10^{6}
Radium-226	1,600	alpha/gamma	3.61×10^{10}	400	1	13,830
Selenium-79	327,000	beta	9.26×10^{7}			
Tin-126	230,000	beta/gamma	1.24×10^{8}	10,000	1	3.06×10^{6}
Strontium-90	29	beta	3.35×10^{12}	10,000	1	385
Technetium-99	211,000	beta	3.16×10^{11}			
Thorium-230	75,400	alpha	5.30×10^{9}	400	1	6.52×10^{5}
Thorium-232	14,000,000,000	alpha	2.70×10^{10}	400	1	1.21×10^{11}
Uranium-233	159,000	alpha	2.74×10^{8}	400	1	1.37×10^{6}
Uranium-234	246,000	alpha	6.88×10^{10}	400	1	2.13×10^{6}
Uranium-235	704,000,000	alpha/gamma	2.96×10^{9}	400	1	6.09×10^{9}
Uranium-238	4,470,000,000	alpha/gamma	7.57×10^{10}	400	1	3.86×10^{10}
Zirconium-93	1,610,000	beta	4.92×10^{11}			

As can be seen from Table 1, even without performing the sum-of-fractions calculation required by the regulations [5], it is a very long time before many of the radionuclides, at the limit specified in the waste acceptance criteria, decay to the limit specified in the Canadian regulations for disposal.

Hence, the stated waste acceptance criteria are insufficiently protective for the material permitted to be emplaced in the proposed Engineered Containment Mound to qualify as low level waste — the radionuclides do not decay to an acceptable level during the time that institutional controls can be relied upon. Consequently, the emplaced material is intermediate level radioactive waste that requires a greater degree of containment and isolation than that provided by a near surface facility [7].

4.3 Institutional Control Period

The *raison d'être* for a radioactive waste disposal facility is that, at some point in the foreseeable future, the safety of humans and non-human biota is no longer dependant upon human intervention (maintenance, repairs, remediation, security, societal and regulatory controls, etc). At that point, the radioactive waste can be released from regulatory and other institutional controls, the disposal of the waste will have occurred, no further costs will be incurred, and the financial liability will be extinguished.

Consequently, one might have expected details to be presented on why it was considered safe to release the Engineered Containment Mound from regulatory and other institutional controls at the end of the Institutional Control Period (which is stated to be 300 years [4]).

Regrettably, no such arguments are presented in the documentation to demonstrate that the Engineered Containment Mound is safe to be released from regulatory and other institutional controls at the end of the Institutional Control Period.

Instead it is left to a postulated future regulator in the indefinitely-long "Post-Institutional Control Period" to decide when the Engineered Containment Mound can be released from regulatory control (and the liability extinguished). As this future regulator is postulated to exist in a period beyond the time that institutional controls can be relied upon, it is difficult to see how the actions of this future regulator can be credited in a safety case. Similarly, given that there is no system in place to verify compliance with the waste acceptance criteria and given that a number of significant radionuclides are not captured by the waste acceptance criteria, it is difficult to understand how the postulated future regulator could make an informed judgement on releasing the Engineered Containment Mound from regulatory control.

4.4 Technical Deficiencies

The technical deficiencies in the proposed Engineered Containment Mound are disappointing:

- Many radionuclides in the Licensed Inventory will have experienced insignificant amounts of radioactive decay by the end of the design life of the Engineered Containment Mound;
- Many radionuclides of importance in assessing the safety of near surface disposal facilities, e.g., C-14 and Tc-99, are present in the Licensed Inventory in significant quantities but are not captured by the waste acceptance criteria;
- No inventory management system is in place to comprehensively verify that waste packages and unpackaged waste accepted for emplacement comply with the radiological parameters of the stated waste acceptance criteria;

- Given the lack of a verified radiological inventory, the dose calculations credited by the proponents are invalid;
- The waste acceptance criteria are insufficiently protective for the material permitted to be emplaced in the proposed Engineered Containment Mound to qualify as low level waste — the radionuclides do not decay to an acceptable level during the time that institutional controls can be relied upon. Consequently, the emplaced material is intermediate level radioactive waste that should not be emplaced in a near surface facility because it requires a greater degree of containment and isolation than that provided by near surface disposal;
- The future safety of Canadians is dependent upon the actions of a postulated future regulator in the indefinitely-long "Post-Institutional Control Period" to decide when the Engineered Containment Mound can be released from regulatory control (and the liability extinguished). As this future regulator is postulated to exist in a period beyond the time that institutional controls can be relied upon, the reliance on the actions of this postulated future regulator is problematical.
- Further, given that there is no system in place to verify compliance with the waste acceptance criteria and given that a number of significant radionuclides are not captured by the waste acceptance criteria, it is difficult to understand how the postulated future regulator could make an informed judgement on releasing the Engineered Containment Mound from regulatory control.

CNSC Staff note that their review of CNL's application has been informed by a number of Safety Standards of the International Atomic Energy Agency (IAEA) relating to the near surface disposal of radioactive waste. It is disappointing, therefore, that CNSC Staff were not seized of the IAEA's requirement to verify the radiological content of waste to be emplaced in the proposed ECM. Similarly, it is disappointing that CNSC Staff were not seized of the IAEA's prohibition on the reliance on institutional controls for extended periods of time.

Canada is bound by international treaty [6] to have due regard to internationally endorsed criteria and standards concerning radioactive waste management. Failing to meet IAEA Safety Standards with respect to inventory management and institutional controls would appear to place Canada in contravention of its international treaty obligations.

While a disposal facility for Chalk River's low level radioactive waste is necessary, it should also comply with international safety standards.

It is an understatement to say that this proposal compares unfavourably with near surface disposal facilities in other middle-income and high-income economies such as Bulgaria, France, and Spain, for example:

> https://www.enresa.es/eng/index/activities-and-projects/el-cabril ;
> https://international.andra.fr/operational-facilities/csa-aube-disposal-facility ; and
> http://dprao.bg/images/Annex_1_NTS_EIA_NDF_EN.pdf .

It is clear from these international examples that compliant near surface disposal facilities can be successfully designed, built, and operated.

5.0 Concluding Remarks

The required functionality for a near surface disposal facility for radioactive waste is that, at some point in the foreseeable future, the safety of humans and non-human biota is no longer dependant upon human intervention (security, maintenance, repairs, remediation, societal and regulatory controls). At that point in the foreseeable future (the end of the Institutional Control Period, ICP) the human interventions can cease, the waste can be abandoned, no further costs are incurred, and the financial liability is extinguished.

The proposed Engineered Containment Mound (ECM) lacks the basic functionality of a near surface disposal facility for radioactive waste. The proponents of the proposed ECM are unable to state when it would be safe to release the radioactive material from regulatory controls. Indeed, the proponents have stated that they have no plans to abandon the material and, in effect, the institutional controls would extend *in perpetuity.* Using the waste acceptance criteria credited in the proponent's Environmental Impact Statement, it is possible to calculate when the constituent radionuclides of the stated inventory would decay sufficiently to meet Canada's regulatory criteria for disposal. This calculation reveals that many radionuclides would not decay sufficiently to meet Canada's disposal criteria for many thousands of years and, in some cases, for many millions of years. This means that the safety of humans and non-human biota would be dependent upon institutional controls *in perpetuity.*

The on-going cost of those institutional controls (security, maintenance, repairs, remediation, societal and regulatory controls) for millions of years would continue to be a burden on the public purse and would represent a mind-numbingly large financial liability for the Government of Canada.

The proposal is non-compliant with International Safety Standards, for example, no verification of the radioactive content of emplaced waste and reliance on institutional controls to ensure long-term safety. Canada is bound by international treaty to have due regard to internationally endorsed criteria and standards concerning radioactive waste management. Consequently, giving approval to the proposed ECM would appear to place Canada in contravention of its international treaty obligations.

In order to approve this project, the regulator would have to ignore these fatal flaws. Such a negligent approval would be a strategic error for the long term success of Canada's nuclear industry.

6.0 References

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