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Developing a Safety Case for Ontario Power Generation's L&ILW Deep Geologic Repository

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1. Introduction

Ontario Power Generation (OPG) is proposing to build a Deep Geologic Repository (DGR) for low and intermediate level radioactive waste (L&ILW) at the Bruce site in the Municipality of Kincardine, Ontario, Canada. The Canadian Nuclear Safety Commission (CNSC) has issued a draft scoping document for the Environmental Assessment (EA) required prior to licensing [1], and an associated CNSC public hearing took place on October 23, 2006 in Kincardine. Licensing and construction work is expected to take a further twelve years, leading to an in-service date of approximately 2017.

This paper presents a summary of the Safety Case for the DGR as currently developed. The purpose of this iteration of the Safety Case is to provide a common understanding of what needs to be demonstrated within the Safety Case for the EA stage of regulatory approval. This iteration is based on preliminary conceptual design information, general knowledge of the geologic setting, and scoping safety assessment calculations. These need to be verified - and revised if necessary - following site-specific investigations and more detailed and comprehensive design and analyses.

2. Overview of proposed Deep Geologic Repository

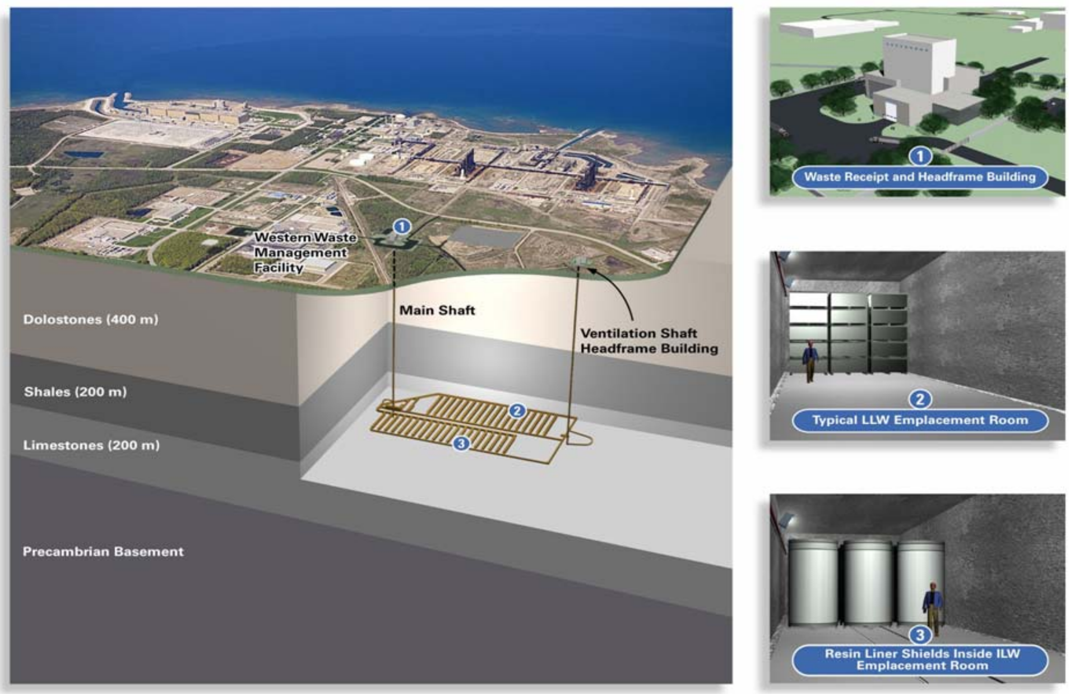
Figure 1 shows an artist's rendering of the current concept for the DGR in the sedimentary rocks of Palaeozoic age underlying the Bruce site. The repository would consist of a series of horizontal emplacement rooms, excavated in low-permeability argillaceous limestone, 660 m below surface. Access to the repository would be either by concrete-lined vertical shaft or inclined ramp (access by vertical shaft is shown in Figure 1 and is assumed in the remainder of this paper).

Following the operational period, shafts and boreholes would be sealed, and the surface environment at the site would be restored. Over thousands of years, the repository would gradually fill with pore water from the surrounding rock, and, potentially, from higher layers via the shaft seals. Small amounts of radioactivity would become dissolved in this water. In addition, gases would be slowly generated in the repository from waste degradation and corrosion. The post-closure safety case is based on the intrinsic quality of the geosphere at the site – its favourable flow system properties, its long-term stability, and its predictability. Together with careful design of shaft sealing systems, these properties ensure that radionuclide transport from the repository would be very slow, and as a result virtually all the radioactivity from the waste would decay within or near the repository.

3. Regulatory context

Under Canada's National Framework for Radioactive Waste Management, waste producers are responsible for funding, organization, management and operation of disposal and other waste

Figure 1. **DGR concept at the Bruce site**



management facilities [2]. For used fuel, the program for long term management is set out further in federal legislation and is a national program. For L&ILW, each waste producer decides on their program for long term management, within the licensing system, guided by principles set out in CNSC's regulatory documents. The Nuclear Safety and Control Act (NSCA) and regulations provide that licences are required to prepare a site, construct, operate, decommission and abandon a nuclear facility such as the DGR. Before issue of a licence by CNSC, a decision statement is required on the acceptability of the proposed project under the Canadian Environmental Assessment Act. A single EA decision covers site preparation, construction and operation.

Further guidance is provided by CNSC's regulatory policies, standards and guides. Policy document P-290 [3] gives the high level expectations relevant to the safety case, in particular that:

- the assessment of future impacts of radioactive waste on the health and safety of persons and the environment encompasses the period of time when the maximum impact is predicted to occur, and
- the predicted impacts on the health and safety of persons and the environment from the management of radioactive waste are no greater than the impacts that are permissible in Canada at the time of the regulatory decision.

Detailed guidance setting out CNSC's expectations for the Safety Case is given in Regulatory Guide G-320 [4], and, for the EA stage, in the scoping document [1]. The DGR program will in addition take into account applicable international guidance.

4. Approach to the Safety Case

Consistent with the NSCA and with CNSC's regulations and regulatory policies, the overall objective of long term radioactive waste management is to protect human health and the environment now and in the future. The specific safety objectives of the proposed DGR are as follows:

(i) Isolation of the waste away from the biosphere.
(ii) Long-term containment of the waste to allow radioactive decay.
(iii) Retardation and attenuation of radionuclide migration to the surface.
(iv) Robust design and location to minimize uncertainty in long-term safety.

The DGR safety strategy has been developed consistent with the international Nuclear Energy Agency's Safety Case approach [5]. Key elements include stepwise planning and implementation, integration in the overall management strategy of technical work in support of the Safety Case, emphasis on the geosphere barrier, an iterative approach for development of technical studies, multiple safety functions contributing to meeting the safety objectives, structured analysis of the evolution of the system and of potential release mechanisms and pathways, simple robust arguments supported by multiple lines of reasoning including more detailed calculations, and consistency with international practice.

Current understanding of the site geologic setting, together with the results of preliminary safety assessment and conceptual engineering work, has allowed formulation of the following set of high level arguments contributing to the safety case:

- The site geoscientific conditions and features provide several independent lines of evidence regarding the setting, which together suggest that the safety objectives can be achieved with a high degree of assurance.
- The wastes are those safely handled at existing storage facilities. The repository can be built and operated safely using proven technologies.
- Postclosure dose estimates are very small because:
  - mass transport of contaminants through the host rock is diffusion limited;
  - construction of the repository will not change the overall diffusion-dominated environment;
  - earthquakes, glaciation or other natural events will not disrupt the repository;
  - gases generated by corroding wastes are safely retained, and disperse slowly; and
  - the repository is safe from inadvertent human intrusion.

These arguments will be tested and supported in ongoing work. Site characterization, design, and development of the safety case are planned as an integrated, iterative process, with common numerical models and representations of the site linking geoscience and safety assessment. The expectation is that results from the first phase of site characterization, conceptual design and safety assessment will be used to support the Safety Case presented for the EA review.

5. Siting of the DGR

The proposed location for the DGR is at the Bruce site in the Municipality of Kincardine, on the eastern shore of Lake Huron. The Bruce site has been the location of nuclear activities since 1960. Currently, L&ILW from the Bruce, Pickering and Darlington nuclear generating stations in Ontario is processed and stored there, at OPG's Western Waste Management Facility (WWMF).

The choice of the Bruce site for the DGR resulted from an approach to OPG in 2002 by the Municipality of Kincardine, seeking to study options for long-term management of L&ILW. A consultant was contracted to conduct an Independent Assessment Study (IAS), considering geotechnical feasibility, safety, and potential environmental, social and economic effects of three options: enhanced processing and long-term storage, covered above-ground concrete vaults and a deep geologic repository [6,7]. While the IAS concluded that each of the options was feasible for some or all of the low and intermediate level waste, the Municipality indicated a preference for the DGR option as providing the highest level of safety, and the DGR was selected in April 2004 by resolution of Kincardine Council. In August 2004 the OPG Board approved the DGR proposal.

A Host Community Agreement was signed between OPG and the Municipality of Kincardine in October 2004 [8,9]. As one of the provisions of the Hosting Agreement, community consultation was conducted by Kincardine to gauge community acceptance of the proposed facility. A telephone poll of permanent and seasonal residents endorsed the proposal.

Communications with the host community, other local communities, and First Nations will continue throughout the project.

6. Wastes to be emplaced

The DGR will receive all L&ILW produced by the OPG-owned nuclear generating stations through the remainder of their operating life, as well as L&ILW currently in interim storage at the WWMF. Projected as-stored estimates of waste volume are approximately 130 000 m^3 of LLW and 30 000 m^3 ILW. These volumes include waste from planned refurbishment programs.

LLW consists of industrial items that have become slightly contaminated with radioactivity and are of no further use, such as rags, protective clothing and hardware items such as tools. ILW consists primarily of used reactor components, and the ion-exchange resins and filters used to purify reactor water systems. From an operational point of view, the major nuclides are ^{60}Co (half-life 5.3 a), ^{3}H (12 a) and ^{137}Cs (30 a). Refurbishment waste includes removed reactor core components, which are associated with greater amounts of induced radioactivity. These radionuclides are firmly fixed within the material matrix. The most significant long-lived retube radionuclide is ^{94}Nb (20 300 a).

The total activity at the end of the DGR operational period is estimated as 16 000 TBq. ^{129}I (1.6×10^{7} a) and ^{14}C (5730 a) are the radionuclides of most relevance in the long term safety assessment as they are long-lived and relatively mobile.

7. Engineering design strategy

As part of feasibility studies, a conceptual design has been developed for the DGR [10,11], illustrated in Figure 1. The design is consistent with experience in underground structures, such as limestone mines, in similar sedimentary formations in North America. This design will be further developed in ongoing work contracted with companies with relevant engineering and mining experience.

Geological repository design is an iterative process and the design may be modified based on:

- new data about the site generated during subsurface investigations, for example information related to rock strength, in-situ stress magnitudes and orientation and bedrock bedding;
- the results of safety assessment, in particular the preclosure safety assessment and occupational radiation dose and conventional safety considerations;
- design optimization;
- further definition of the inventory and categories of waste to be emplaced, and
- the establishment of waste acceptance criteria for the DGR.

An important aspect of the DGR design strategy is that containment is provided by the rock mass and repository shaft seals, and there is no additional engineered containment. This is based in part on the expected low permeability and sufficient mechanical strength of the rock. The wastes are emplaced in a range of steel storage containers, as used for interim storage, with steel or concrete overpacks where required. Although the impact of backfill and/or conditioning of the waste will be explored in ongoing safety assessment, it is not currently planned to seek to optimize the design by use of engineered barriers, as current results predict impacts many orders of magnitude below regulatory criteria. This will be reviewed if later results indicate otherwise. Not using additional engineered containment is advantageous both for maximizing monitoring and retrievability in the near-term, and for managing gas generation in the long-term. Design optimization in accordance with CNSC guidance [4] will focus on several areas, including shaft design and sealing, facility location and layout, configuration of selected waste packages, underground waste package handling, and waste rock management.

8. Site characterization

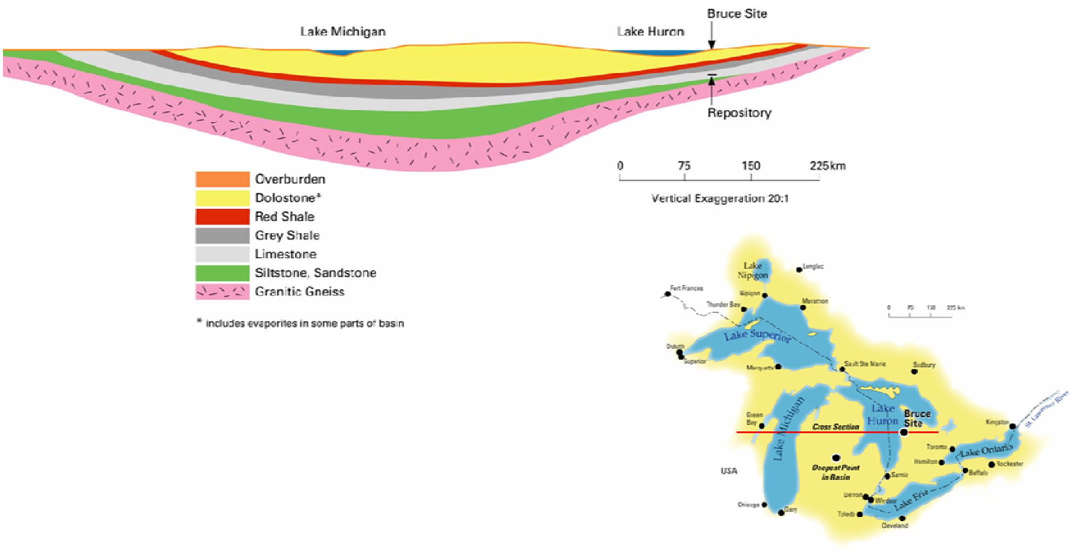
The bedrock underlying the Bruce site occurs within a well-known geologic feature referred to as the Michigan Basin (Figure 2). The studies carried out as part of the IAS [12], together with information compiled by Mazurek [13], indicate that favourable geological and hydrogeological conditions exist at the Bruce site, relevant to demonstrating the safety of the DGR, as follows:

(i) The deep horizontally-layered shale and argillaceous limestone sedimentary sequence that will overlie and host the DGR is geologically stable, geometrically simple and predictable, relatively undeformed and of large lateral extent.
(ii) Active faulting and seismicity at and near the site are very limited.
(iii) The deep argillaceous formations that will host the DGR will provide stable and dry openings.
(iv) The regional stress regime (horizontally compressive) is favourable with respect to sealing of any vertical fractures and faults.
(v) The deep shale and argillaceous limestones are thick and of very low permeability, providing a 200 m thick bedrock horizon for the waste management facility, and an additional 200 m thick barrier to upward migration from the facility.
(vi) The deep groundwater system in the shales and limestones is saline (about 100-200 $g{\cdot}L^{-1}$), stagnant, stable and ancient, not showing evidence of either glacial perturbations or cross formational flow or mixing.
(vii) The shallow water supply aquifer in the upper carbonate bedrock is hydrogeologically isolated and protected from the sluggish deep saline groundwater system.

The Geoscientific Site Characterisation Plan (GSCP) for the DGR is aimed at providing evidence to test the validity, or otherwise, of these assumed favourable characteristics, and also at providing the detailed data and understanding needed to support the Safety Case, to allow quantitative safety assessment for demonstration of compliance with acceptance criteria, and for design of the repository [14]. Site characterization is complemented by studies aimed at developing a geosynthesis, or integrated geoscientific understanding of the past, present and future evolution of the Bruce site, and by studies and projects undertaken to build confidence in site suitability and the Safety Case. Independent oversight of the GSCP through development and implementation is provided by OPG’s Geoscience Review Group (GRG), a group of internationally renowned scientists and engineers who, among other roles, ensure that information and lessons from similar geological repository programs are reflected in site characterization activities.

Implementation of the GSCP is now under way. A 2-D seismic survey was carried out in October 2006, and drilling of the first two deep boreholes started at the end of 2006. Other activities in this phase include installation of an enhanced borehole seismograph network to detect M -1 events within 40 km of the Bruce site, and refurbishment of existing on-site bedrock monitoring wells to establish baseline hydrogeologic conditions in the shallow aquifers to depths of 100 m.

Figure 2. **Geological setting of the proposed DGR within the Michigan Basin**



Consistent with the EA scoping document, OPG will consult with CNSC staff with regards to the adequacy of the subsurface characterization data to support EA preparation in 2009.

9. Safety Assessment

The DGR safety assessment provides a quantitative measure of performance to demonstrate compliance with radiological protection and other criteria. The safety assessment work is aimed at carrying forward the understanding provided by geoscience into an examination of the overall system, including potential disturbance caused by the repository, and of the pathways by which radionuclides and non-radiological contaminants may reach the accessible environment. An approach following the IAEA's ISAM safety assessment methodology [15] has been adopted. This methodology encourages a well-structured, transparent and traceable approach. In addition, within the overall iterative structure of the technical studies, safety assessment follows an iterative process, with the results from each iteration used to guide further development work.

The main postclosure safety assessment scenarios of interest are the Reference Scenario, the Human Intrusion Scenario, and Disruptive or failure scenarios

The *Reference Scenario* considers the likely evolution of the site, the repository and the waste. Analysis cases include a constant climate and biosphere, and a climate and biosphere which evolve due to glaciation. Radionuclide movement through the limestone and shale layers would take hundreds of thousands, or millions, of years, and most of the radionuclides from the L&ILW would decay to insignificant levels before they moved even metres from the repository. The only radionuclides of potential concern are ^{129}I and, to a smaller extent ^{36}Cl and ^{99}Tc, because they are potentially mobile and long-lived. Doses calculated in the scoping safety assessment for LLW are many orders of magnitude below criteria [16,17].

The slow degradation of the wastes and the waste packages would also result, over hundreds or thousands of years, in the formation of gases, mostly H_2, CO_2 and CH_4, which contain radioactivity, mainly ^{14}C and ^{3}H. The repository is not backfilled, so there is a large void volume into which these gases could expand, and they are predicted to be retained safely within the DGR due to the favourable properties of the host rock. Even if the gas were to be released from the repository as it is produced, estimated dose consequences are low, because of the slow gas generation rate and dispersion in the upper 400-m groundwater system and atmosphere.

The *Human Intrusion Scenario* considers the hypothetical inadvertent disruption of the wastes in the future, assuming memory of the site had been lost, and essentially bypassing the geosphere barriers. While the likelihood of any intrusion would be very small, in order to demonstrate the robustness of the DGR, a stylized human intrusion scenario is considered. The scenario examined by Quintessa [16,17] for LLW considered extraction of borehole samples that contain waste. The limited amount of waste that would be retrieved in this scenario means that the calculated dose rates are very low.

Disruptive/failure scenarios to be considered in ongoing safety assessment may include seismic events, undetected fracture outside the immediate site area, unsealed (open) borehole, degraded shaft seals, and variability in the permeability and sorption characteristics of the surrounding rock. These scenarios include 'what-if' cases aimed at exploring the robustness of the system.

Preclosure safety assessment is also in progress. Preclosure assessment considers the potential impact on the public, environment and workers during repository operation, decommissioning and closure. The safe operation of the WWMF, of mines, and of other geologic repositories, provides confidence that the preclosure operation of the DGR would be safe.

10. Summary and conclusions

Development of the Safety Case for the DGR is founded on an assumed site descriptive model having a number of favourable features contributing to long-term isolation, containment and retardation. Over several years, an integrated, stepwise program of geoscientific site characterization and complementary studies, linked to safety assessment, will be used to test and refine this model and to build confidence in the Safety Case.

Understanding of the DGR setting and evolution developed to date, together with the results of preliminary assessments, gives confidence that the site possesses favourable geological and hydrogeological characteristics for isolation of the waste from the biosphere and near-surface environment, that there are a number of complementary arguments supporting the conclusion that isolation will be achieved, and that robust safety assessment can be carried out demonstrating that the proposed DGR will meet regulatory criteria for protection of human health and the environment.

No outstanding issues with the potential to compromise safety have been identified, and the DGR program is now moving forward with detailed site characterisation and with development of the studies and analyses needed for the EA review process.

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