Overview of Ontario Power Generation's Proposed Deep Geologic Repository for Low & Intermediate Level Waste at the Bruce Site, Ontario, Canada

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ABSTRACT

A Deep Geologic Repository (DGR) for the long-term management of Low and Intermediate Level Radioactive Waste is being proposed by Ontario Power Generation at the Bruce site near Kincardine, Ontario. The DGR would be located at a depth of approximately 680 m within a 200 m thick layer of low-permeability Ordovician argillaceous limestone, which is below a 200 m layer of low-permeability Ordovician shale. The repository would have the capacity for approximately 200,000 m^3 of as-disposed waste, sufficient for the current fleet of 20 OPG-owned nuclear reactors. The purpose of this paper is to provide a summary of the project.

INTRODUCTION

Ontario Power Generation (OPG) is responsible for the safe management of the radioactive wastes arising from the operation of its 20 CANDU reactors in the Province of Ontario, Canada. These reactors have provided approximately 50% of all the electricity needs of the province of Ontario for the past 30 years.

Currently all of the low and intermediate level wastes (L&ILW) generated from the operation of these reactors is being stored at OPG's Western Waste Management Facility (WWMF) which is located on the Bruce site, along with the eight reactors currently operated by Bruce Power under a lease agreement with OPG. The Bruce site is located about 225 km north-west of Toronto, between the towns of Kincardine and Port Elgin on the east shore of Lake Huron.

The WWMF storage structures have a minimum design life of 50 years and are suitable for the interim storage of L&ILW. Although current storage practices are safe, these wastes will eventually need to be transferred to a long-term management facility as some of the wastes remain hazardous for thousands of years.

The Bruce site is located in the Municipality of Kincardine. In 2001, the Kincardine Council approached OPG regarding its long-term plans for the wastes currently stored at the WWMF. Subsequently, Kincardine and OPG agreed to jointly study options for the long-term management at the site of all L&ILW arising from the operation, refurbishment and decommissioning of OPG-owned reactors in Ontario [1].

Following completion of these studies, the Kincardine Town Council indicated a preference for the deep repository option at the Bruce site, on the basis that:
(a) it was consistent with international best practice;
(b) it was a permanent solution;
(c) it would provide the highest degree of safety.

A Hosting Agreement was signed with OPG in 2004. According to this agreement, this repository will not hold used nuclear fuel, nor L&ILW from nuclear reactors outside Ontario.

A community poll was conducted in early 2005 and the Council's position was endorsed. Subsequently, OPG initiated an Environmental Assessment for the proposed DGR in accordance with the Canadian Environmental Assessment Act [2]. In 2007, the Minister of the Environment referred the project to a Review Panel. The next step in the process is the release of the EA review guidelines.

Documents describing the above processes and studies in more detail can be found on the project website at www.opg.com/dgr.

WASTE CHARACTERISTICS

OPG's Western Waste Management Facility (WWMF) site has received waste from the Pickering, Bruce and Darlington nuclear stations for over 30 years. The waste is stored in engineered above and below ground storage structures, depending on the physical and radiological characteristics of the waste.

Low-level wastes include contaminated clothing, rags, plastics, papers and similar lightly contaminated materials. WWMF receives about 5,000-6,000 m^3 per year of low-level waste. This is incinerated or compacted if possible, and the remainder is stored. Approximately 2,000-3,000 m^3 is stored each year. There is currently about 60,000 m^3 in storage.

Intermediate-level waste includes contaminated resins, filters and reactor core components. It is generally higher activity, and has a significant proportion of long-lived radionuclides. Approximately 200-400 m^3 of intermediate-level waste is received each year at WWMF, where it is stored. There is currently about 8,500 m^3 in storage.

The waste stored at WWMF includes refurbishment waste from the upgrades and retubing of some of the reactors. Some of the replaced components, such as heat exchangers and steam generators, are lightly contaminated and considered low-level waste. Other components, notably pressure tubes and calandria tubes, are highly activated and considered intermediate-level waste.

The DGR is presently being designed with a capacity of 160,000 m^3 of as-stored waste, corresponding approximately to the volume of operational and refurbishment L&ILW from the existing Ontario reactors through their present scheduled life. After some overpacking for disposal, the total as-disposed volume would be approximately 200,000 m^3.

Figure 1 illustrates the estimated total radioactivity of the waste to be emplaced in the DGR, divided into operational LLW, operational ILW, and refurbishment L&ILW. The operational LLW, although the largest by volume, is a small contributor to the total radioactivity and decays away relatively quickly. The operational ILW contains significant amount of C-14, which dominates the total activity after a few hundred years. This activity largely decays away after approximately 10,000 years. Refurbishment wastes contain a significant amount of short-lived heat-producing nuclides, such as Co-60, as well as a significant amount of comparatively long-lived Nb-94 and Zr-93. The latter species are activation radionuclides within the Zircaloy pressure tubes.

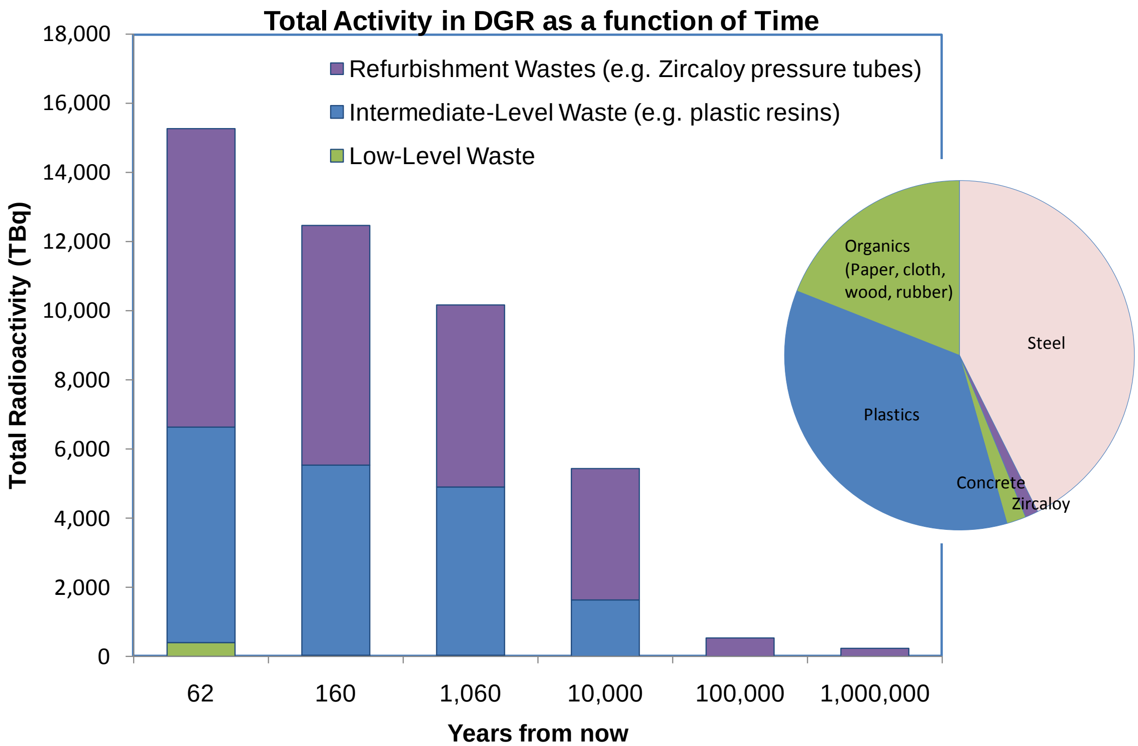

Fig. 1. Total radioactivity of the waste as a function of time. The inset shows the relative volume of each of the waste categories.

GEOLOGIC SETTING

The Bruce site is located on the eastern rim of the Michigan Basin. This is a near-horizontally layered, undeformed sequence of Paleozoic age carbonates, shales, evaporites and minor sandstones that extends for hundreds of kilometers through southern Ontario and Michigan. This sedimentary rock sequence is approximately 840 m thick below the Bruce site, resting upon the crystalline Precambrian basement. Figure 2 shows an illustrative cross-section through the sedimentary rock formations in the vicinity of the site. The gently dipping layers (note the large vertical exaggeration in the figure) reach a maximum depth of a few kilometers under the State of Michigan.

The repository is planned to be located in an argillaceous limestone formation (the "Cobourg Formation") at a depth of about 680 m below surface. This formation is overlain by 200 m of low-permeability shale, and a further 400 m of dolostones, carbonates and overburden. The deep Ordovician-age (approx. 450 million years old) limestones and shales are expected to have very low permeabilities. A key aspect of the DGR Safety Case is the integrity and long-term stability of these sedimentary rock layers below the Bruce site.

Early in the project, geoscientific studies based on regional data indicated favourable geologic conditions for implementation of the DGR concept [3,4]. In 2006, OPG released its Geoscientific Site Characterisation Plan (GSCP) describing the work to characterize the site and support an Environmental Assessment for the project [5]. Phase I program activities were initiated in fall 2006, and will be completed in 2008 [6].

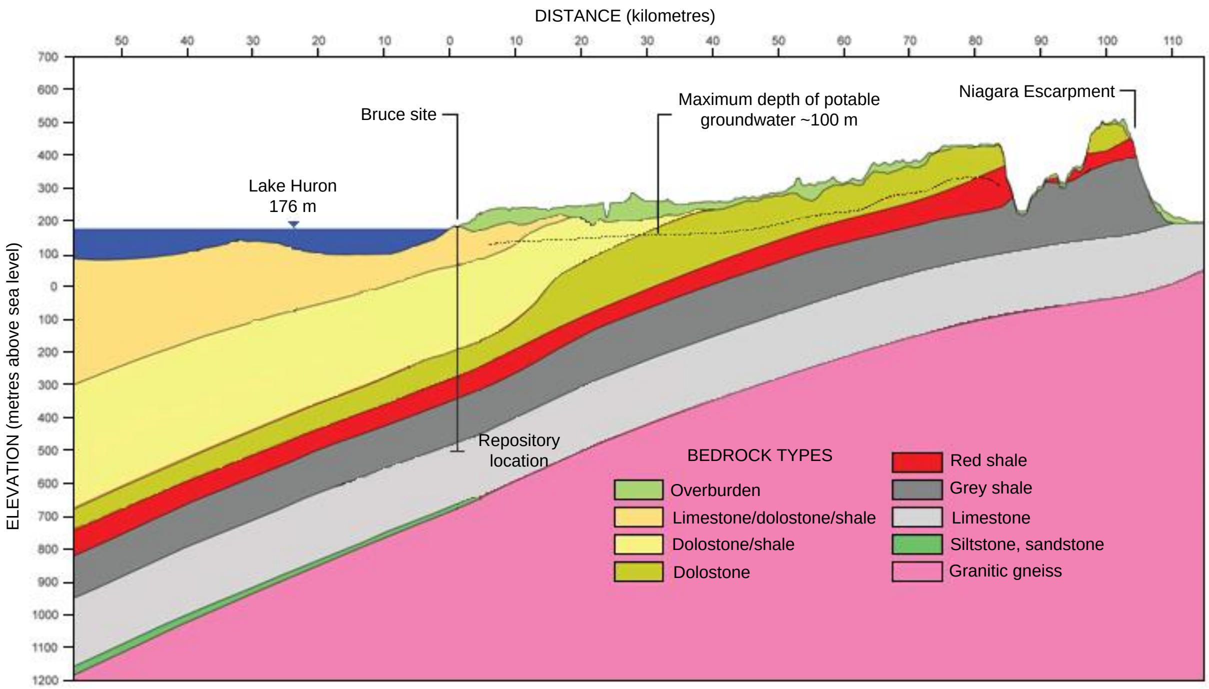

Fig. 2. Illustrative cross-section of the sedimentary rock layers around the Bruce site (x50 vertical exaggeration).

The Phase I work included 20 km of 2-D seismic lines, two deep boreholes, installation of a sensitive seismograph network, and a variety of in-situ borehole and rock core tests. The two boreholes were drilled near one corner of the proposed DGR location (later boreholes will triangulate the site). The first borehole was drilled to about 400 m in depth and is being used to investigate the upper stratigraphy. The second borehole was drilled through to the Precambrian basement rock at about 860 m depth, and is being used to investigate the low-permeability Ordovician-age shales and limestones that would host and surround the repository.

The experimental results, along with regional and site-specific modeling and other information, will be integrated into a Geosynthesis report. This report will present an integrated understanding of site characteristics as they relate to demonstrating long-term DGR performance and safety.

From a hydrogeological perspective, the bedrock sequence below the Bruce site can be divided into 3 distinct horizontally stratified regimes: i) an upper permeable fresh water aquifer (0-100 m depth); ii) an intermediate brackish, moderately permeable, stratified aquifer-aquitard system (~100-400 m); and iii) a deep, saline (TDS 200 g L^{-1}), very low permeability sequence of shales and carbonates (~400-800 m). Within the latter regime, the existence of a stagnant groundwater regime, unperturbed even by recent glaciation cycles, is strongly supported by the low rock permeabilities, the Na-Ca-Cl dominant pore fluids, formation distinct $^{18}O/^{2}H$ isotopic pore fluid signatures, $^{87}Sr/^{86}Sr$ pore fluid signatures consistent with a marine origin and long residence times, groundwater viscosities, and energy gradients in the variably saline groundwater system.

Based on the available information, the principal attributes of the Bruce site geology favourable for the DGR are:

- Predictable - Horizontally layered, undeformed sedimentary rock formations that are geometrically simple, predictable and of large lateral extent;
- Multiple natural barriers - Multiple layers of low permeability bedrock formations enclose and overlie the DGR.
- Seismically quiet - Active faulting and seismicity are low, and comparable to Canadian Shield;
- Diffusion dominated mass transport - The deep groundwater regimes are saline, stagnant and ancient showing no evidence of glacial perturbation or cross-formational flow;
- Shallow groundwaters in the upper bedrock aquifer system are hydrogeologically isolated from the deep groundwaters.
- Low natural resource potential - No commercially viable oil or gas reserves, or salt deposits present. The deep groundwater is too saline to be potable.
- Geomechanically stable - The reference limestone formation will provide stable, virtually dry openings.

FACILITY ENGINEERING

As envisioned, the DGR would involve the excavation of waste emplacement rooms within the argillaceous limestone Cobourg Formation at a depth of 680 m beneath the Bruce site. The repository, accessed via two vertical shafts, would require the excavation of nearly 500,000 m^3 of rock. Support buildings would be located on ground surface above the underground workings.

A preliminary conceptual design envisaged a series of emplacement rooms arranged in parallel rows on either side of central access tunnels. Some of the emplacement rooms would be reserved for LLW and the rest for ILW. The rooms would have a concrete floor. Waste packages would be transferred directly from the main shaft, and stacked within the rooms (Figure 3). Each room would be isolated with a concrete wall when full, but not sealed or backfilled.

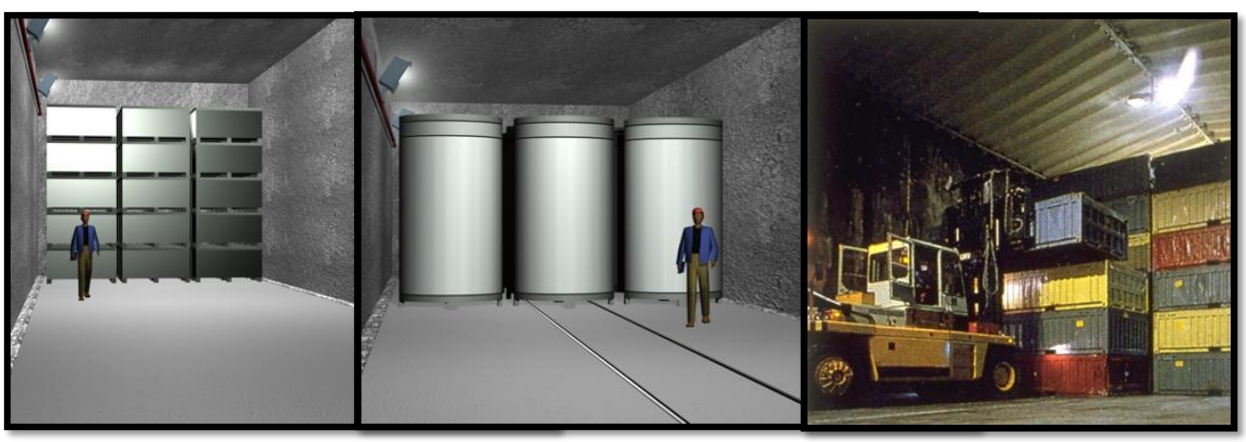

Fig. 3. Illustration of partially filled (a) LLW and (b) ILW emplacement rooms with stackable and shielded waste packages, respectively. Figure 5(c) shows forklift emplacement of LLW boxes at the SFR underground facility (Sweden), similar to the operations at the DGR.

After the repository had been filled, and once suitable agreement had been obtained from the community and the regulators, the DGR would be closed. This would largely involve sealing of the main access shafts and removal and cleanup of the surface facilities. The shafts would be sealed with a combination of concrete caps and low-permeability materials, in particular bentonite-sand.

The conceptual design is currently being revised and updated. Design option studies under evaluation include: shaft versus ramp access, shaft locations and underground layout, main hoisting system, underground waste handling equipment, underground construction method, underground waste handling equipment, waste rock management, and shaft sealing system.

The basic technology required to safely build and operate the DGR is already proven technology. Waste packages are currently transferred and stored in various structures at the surface at WWMF. The DGR transfer and emplacement handling will be similar, and waste packages will be largely transferred as-is, with overpacking only if necessary to meet DGR waste package acceptance criteria, such as surface dose rate.

There is significant useful engineering experience with working in the relevant rock formations, notably including the Goderich salt mine, OPG's Niagara tunnel project, and the Darlington reactor cooling intake tunnels. At the Goderich salt mine, approximately 50 km distant from the Bruce site, the salt mine at a depth of approximately 530 m is accessed by vertical shafts. This facility demonstrates that large shafts can be constructed successfully through the permeable upper rock layers. At the Niagara tunnel project, a large water diversion tunnel is being bored through a section of the shale formations that form the low permeability cap at the DGR location. This demonstrates large-scale construction techniques in these shale formations. Finally, at the Darlington nuclear power station, cooling water intake tunnels were excavated through a section of the same limestone formation that would host the repository at the Bruce site. The cooling tunnels were excavated within this formation, and are about 0.9 to 1.8 km long, and about 30 m below the bottom of Lake Ontario.

SAFETY

Consistent with the Canadian nuclear safety regulations and 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:

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

The DGR safety strategy [7] has been developed consistent with the international Nuclear Energy Agency’s Safety Case approach [8], and with the CNSC's regulatory guidance document G-320 guidance [9]. 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.

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 [10] 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 postclosure safety assessment considers a normal evolution scenario and disruptive or "what if" scenarios.

The *Normal Evolution 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 porewater within the limestone and shale layers would take hundreds of thousands of years, and most of the radionuclides from the L&ILW would decay to insignificant levels before they moved far from the repository.

The slow degradation of the wastes and the waste packages would also result, over thousands of years, in the formation of gases, mostly H_2, CO_2 and CH_4, which contain radioactivity, mainly C-14 and H-3. 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.

Under normal evolution conditions, the two shafts become potentially important pathways because they penetrate the low-permeability rock layers. Preliminary estimates indicate that the long-term impacts will be low, but will be dominated by transport of contaminated gas or water through the shafts. The facility design is taking this into account, and designing a shaft seal system that provides low-permeable materials and incorporates multiple barriers.

The *Disruptive/"what if" scenarios* consider possible scenarios in which the primary barriers of the DGR fail. These are unlikely or hypothetical scenarios, such as large earthquakes or complete shaft seal failure, intended to test or demonstrate the robustness of the DGR. A specific case is *Human Intrusion*, which considers the possibility of inadvertent intrusion into the repository in the future, assuming memory of the site had been lost. While the likelihood of any intrusion would be very small (e.g. there are no resources in the deep rocks at the site, nor drinkable water, to encourage deep drilling), a stylized human intrusion scenario is considered in which a borehole is drilled at the site and intercepts the waste. This brings a sample of waste to the surface, bypassing all the geosphere barriers. However, the limited amount of waste that would be retrieved in this scenario, and the nature of the L&ILW, means that the calculated dose rates are still low.

Preclosure safety assessment is also in progress. During the preclosure period, wastes are retrieved from storage or received from the stations, transferred to the DGR and emplaced underground. The general operations are not significantly different from those currently safely undertaken at the WWMF surface storage facility. Based on WWMF experience, the main exposure risks would be from tritium or C-14, released in small amounts from the waste packages, and radiation dose to workers while near packages. Consistent with experience at the WWMF, the normal operation doses to public should be much less than 0.4 uSv/a, and worker doses will be below the regulatory limit of 20 mSv/a.

The safety assessment is being conducted in an iterative manner. The next iteration will take into account the first site-specific information from the two deep boreholes and other geoscience work, as well as the revised conceptual facility design and an updated reference waste inventory. The models will also be improved to better address key uncertainties identified in the first "dry run" iteration, such as the behavior of the shaft seal system and gas phase transport.

COMMUNITY COMMUNICATIONS

OPG, and its predecessor Ontario Hydro, have a long history of working in partnership with the Bruce Community, including the local First Nations. The community relationship has been built on trust and transparency and channels of information exchange are well established. Within this context, communications on the DGR proposal have been extensive over the last four years and the plan is to continue this throughout the regulatory approvals phase. The plan includes displays at community events, internet, advertising, media events, newsletters, key stakeholder briefings, open houses, speaking engagements and public attitude research.

INTERNATIONAL EXPERIENCE

The concept of underground disposal for low and intermediate level wastes is being pursued in several national programs, as summarized in Table I.

More specifically, the understanding of the basis for long-term radioactive waste management in sedimentary media has advanced significantly during the last decade. Waste management programmes in Switzerland, France, Belgium, Spain and Japan have focussed on or are evaluating argillaceous media for their used fuel management programs in particular, but also for some long-lived intermediate level wastes. The development of these concepts is supported by research programmes at underground facilities in sedimentary rock at Mont Terri (Switzerland), Bure (France), Mol/Dessel (Belgium) and Honorobe (Japan).

Table I. Underground repositories for low and intermediate level waste

Facility	**Country**	**Waste type**	**Depth**	**Host rock**	**Status**
Olkiluoto	Finland	L&ILW	60 m	Crystalline	Operating
SFR	Sweden	L&ILW	50 m	Crystalline	Operating
WIPP	US	ILW (TRU)	650 m	Sedimentary salt	Operating
Konrad	Germany	L&ILW	~1000 m	Sedimentary carbonate	Licensed
Gyeongju	Korea	L&ILW	~100 m	Crystalline	Under construction
Bataapati	Hungary	L&ILW	250 m	Crystalline	Under construction

As part of the overall DGR program, international input is being used to provide guidance and peer review. Currently, the site characterisation work benefits from an international Geoscience Review Group that has been assembled by OPG to provide an advisory and oversight role on the site characterization activities.

SUMMARY

Ontario Power Generation is proposing the development of a Deep Geologic Repository (DGR) at the Bruce site for the long-term management of low and intermediate level radioactive waste produced by OPG-owned nuclear generating stations. The DGR concept envisions a shaft accessed repository excavated at a depth of approximately 680 m within the argillaceous limestone Cobourg Formation, overlain by 200 m of shale. Site-specific studies to confirm the suitability of the site to host the DGR were initiated in 2006. These studies include site characterization, environmental assessment, facility engineering and safety assessment. The preliminary results of this work, which is ongoing, continue to confirm our expectations that the site is suitable.

ACKNOWLEDGEMENTS

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