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# PROPOSED DEEP GEOLOGIC REPOSITORY FOR LOW AND INTERMEDIATE-LEVEL RADIOACTIVE WASTE AT THE BRUCE NUCLEAR SITE

R.J. Heystee and M.R. Jensen
Ontario Power Generation
700 University Avenue
Toronto, Ontario, CANADA M5G 1X6
richard.heystee@opg.com and mark.jensen@opg.com

## ABSTRACT

This paper describes the current concept for Ontario Power Generation's proposed Deep Geologic Repository (DGR) to be located on the 900 ha Bruce Nuclear site. The Bruce Nuclear site is located approximately 225 kilometres northwest of Toronto. The underground repository concept is comprised of horizontally-excavated emplacement rooms arranged in parallel rows with access provided via two vertical concrete-lined shafts. The emplacement rooms would be constructed at a depth of about 660 m within limestone. This limestone formation is laterally extensive and is directly overlain by 200 m of low permeability shale. The low-permeability diffusion-controlled geosphere immediately surrounding the repository will assure long-term isolation of the low and intermediate-level radioactive waste (L&ILW).

L&ILW will be retrieved from various storage structures at the WWMF and transferred to the DGR. L&ILW will also be shipped directly from the nuclear generating stations to the DGR. In this concept, most waste packages are retrieved and transferred "as is" with shielding added, as necessary, to protect workers. The waste packages are lowered by hoist to the repository horizon and then transferred by forklift or, in the case of heavy packages, by train to emplacement rooms. Waste packages are stacked within emplacement rooms by forklift and, when full, the rooms are isolated by interim seals. It is expected that the repository will be open for at least 50 years to receive L&ILW from the operation and decommissioning of Ontario's nuclear reactors. When filled with waste and after receipt of all necessary regulatory approvals, the repository will be sealed by placing low permeability clay-based plugs in each shaft. A preliminary safety assessment indicates that predicted peak radiological impacts of the sealed repository will be many orders of magnitude below regulatory criteria.

## 1. INTRODUCTION AND BACKGROUND

Low and intermediate-level radioactive waste that is produced during the operation of Ontario's reactors is stored centrally at Ontario Power Generation's (OPG's) Western Waste Management Facility. Although current storage practices are safe, these wastes will eventually need to be transferred to a long-term management facility because some of the wastes remain hazardous for thousands of years. In addition, a significant quantity of L&ILW will be generated during future reactor decommissioning and these wastes will also need to be managed safely over the long-term.

In October 2004, the Municipality of Kincardine and Ontario Power Generation reached an agreement on the terms and conditions under which Kincardine would volunteer to host a DGR facility, subject to achieving all regulatory approvals.[1] The DGR concept was selected by Kincardine's Council members because it would have the largest margin of safety of all options considered and because this concept is consistent with best international practice.[2,3] Through a polling process it was confirmed that the residents of the Municipality of Kincardine agree with Council's decision to support the establishment of a long-term management facility for L&ILW on the Bruce Nuclear site. OPG is now planning a multi-year site characterisation work program to select a suitable location for a DGR, to develop a site-specific repository design, to develop a safety case for the repository, and to obtain federal Environment Assessment (EA) and Canadian Nuclear Safety Commission (CNSC) regulatory approval to build a DGR on the Bruce Nuclear site. The proposed DGR will not be accepting OPG's used nuclear fuel.

A preliminary post-closure safety assessment has been completed for the proposed DGR.[2,4] The preliminary safety assessment indicates that the repository could safely manage all L&ILW to be placed in the repository. The safety assessment will be updated based on new site-specific data collected during future site characterization studies and from future repository design updates.

## 2. OPG'S L&ILW FROM REACTOR OPERATIONS AND DECOMMISSIONING

OPG's L&ILW is generated primarily by the operation of 20 nuclear reactors at Pickering, Bruce and Darlington stations and the waste is sent to WWMF for interim storage (Figure 1). Approximately 5,000 $m^3$ to 7,000 $m^3$ of new waste is received at the WWMF each year, resulting in 2,000 $m^3$ to 3,000 $m^3$ of additional stored waste following volume reduction. If the fleet of 20 reactors operates a nominal 40 years, then about 95,000 $m^3$ (as-stored volume) of operational L&ILW will be produced. In the future, about 108,000 $m^3$ of L&ILW will also be generated during the decommissioning of the reactors and the associated nuclear waste storage facilities.

### *2.1. Operational Low Level Wastes*

LLW consists of common industrial items that have become contaminated with low levels of radioactivity during routine clean-up and maintenance at the nuclear generating stations. It consists of mops, rags, paper towels, temporary floor coverings, floor sweepings, protective clothing, and hardware items such as tools. Where possible, the LLW is processed by either compaction or incineration to reduce volume and the space required for storage and disposal.

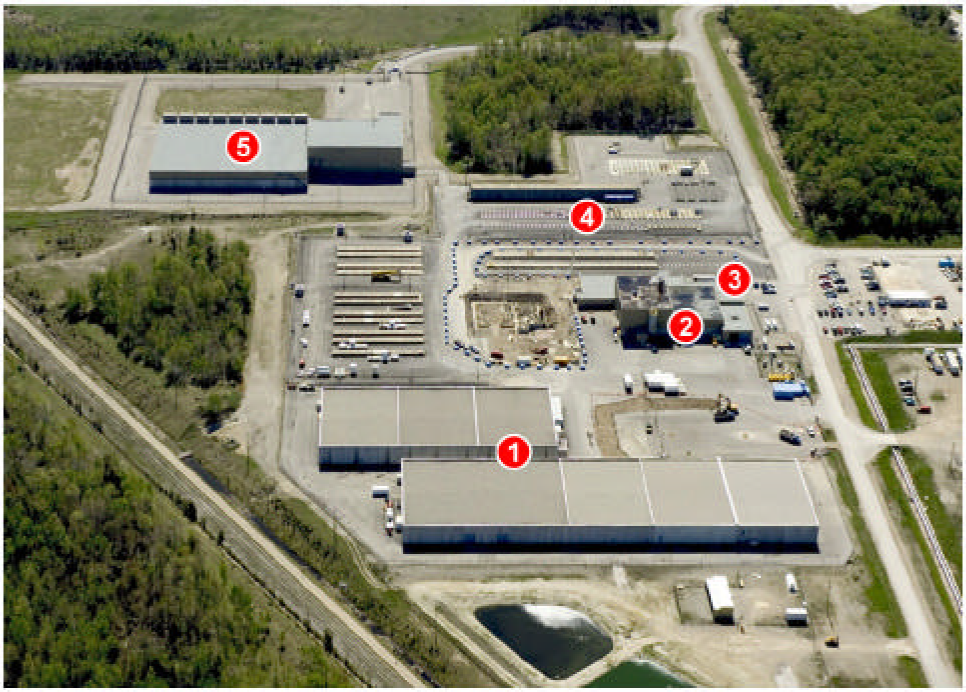


Figure 1: Aerial view of OPG's Western Waste Management Facility (May 2004); 1) Eight Low Level Storage Buildings with ninth under construction, 2) Waste Volume Reduction Building, 3) Amenities Building, 4) In-ground Containers, and 5) Western Used Fuel Dry Storage

Wastes that can neither be compacted nor incinerated are stored as received without processing. The "non-processible" wastes constitute approximately 25 per cent of all wastes received but make up about 55 per cent of the waste stored at WWMF. LLW is stored in a variety of stackable carbon-steel containers and these containers are stored in warehouse-like structures, known as Low Level Storage Buildings (LLSBs) (Figures 1 and 2). There are currently nine LLSBs at the WWMF containing approximately 55,000 m$^3$ of waste. The wastes stored in LLSBs and in all other storage structures at WWMF are continually monitored and can be easily retrieved. All WWMF storage structures have minimum design life of 50 years.

*2.2. Operational Intermediate Level Wastes*

ILW, because of its physical condition and greater levels of radioactivity, is not processed for volume reduction. ILW consists of ion exchange resins, filters and irradiated reactor core components. These wastes are currently stored in concrete- and steel-lined structures constructed in augered boreholes, in concrete-lined and covered trenches, and in concrete above-ground structures (these latter structures are no longer receiving waste). There is 8,500 m$^3$ of ILW in storage and approximately 300 m$^3$ of ILW is received at the WWMF each year. About five per cent of all waste (excluding used nuclear fuel) received at WWMF is classified as ILW.

*2.3. Future Decommissioning Wastes*

Following permanent shutdown the reactors at Pickering, Bruce and Darlington, and the associated nuclear waste storage facilities will be decommissioned generating additional L&ILW. About 96,000 $m^3$ of decommissioning LLW will be produced mainly as metals and concrete, and when sent to a repository would take the form of boxed wastes and various large objects. In addition, approximately 12,000 $m^3$ of ILW will be generated as reactor components, filters and resins wastes.

Figure 2: Containers stacked inside Low Level Storage Building

*2.4. Large Object Waste*

Large object wastes currently in storage at WWMF include redundant heat exchangers and tanks. These and other types of large object waste (e.g. steam generators) will be generated during future reactor refurbishment projects and ultimately during the reactor decommissioning. It has been estimated that about 950 large objects, with a total as-generated volume of 54,000 $m^3$ and a total weight of 62,000 Mg, may require disposal. The largest objects to be handled will be the Darlington steam generators (335 Mg and 258 $m^3$). Because of their dimensions and/or weight, large object wastes will likely require the use of special handling and processing equipment in order to allow transfer into a long-term management facility such as the DGR.

## 3. GEOLOGIC SETTING AND REFERENCE REPOSITORY DEPTH

The geologic conditions beneath the Bruce Nuclear site have been evaluated through a review of data in existing reports, and in drilling records maintained by OPG and provincial government agencies.[5] The bedrock stratigraphy within the area of the Bruce Nuclear site is currently established by three off-site exploration boreholes that extend into the Precambrian basement. These borehole logs indicate that the site is underlain by approximately 800 m of relatively undeformed, horizontally-bedded carbonates and shales. In general, the stratigraphic sequence is comprised of an upper 400 m of Devonian and Silurian age dolostones with some shale layers. In the geologic past Silurian salt formations with combined thickness up to 100 m were solution-weathered from within this upper sequence of rocks which has contributed to enhanced permeability of the dolostone formations. The lower half of the sequence is Ordovician in age and is comprised of an upper 200 m of shale and a lower 200 m of limestone. The entire sedimentary sequence rests on the crystalline Precambrian basement (Figure 3).

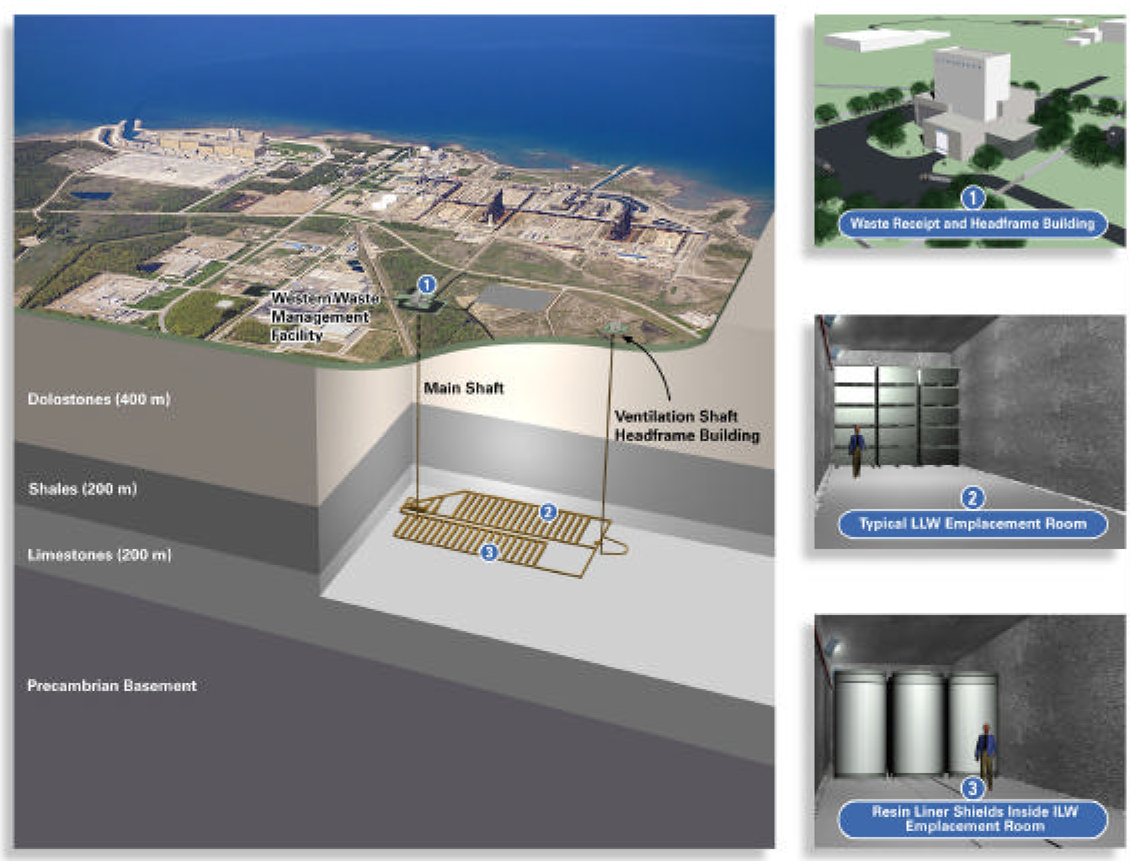


Figure 3: Proposed L&ILW Deep Geologic Repository at OPG's Western Waste Management Facility (conceptual layout shown will accommodate OPG's operational L&ILW only)[6]

The key attributes of this geologic setting with respect to hosting a repository are [5]:

- Extremely low permeability of the 400-m-thick sequence of Ordovician sedimentary rock formations which are proposed for hosting the repository;
- Diffusion-dominated migration regime and the absence of cross-formational ground water flow in the Ordovician rock formations as indicated by distinct hydrogeochemical signatures within specific rock formations. These characteristics have existed over geologic timeframes despite repeated glacial perturbations during the Pleistocene period;
- Nearly stagnant deep-seated groundwater flow domains within the proposed host formations as indicated by the extremely high groundwater salinity (>100 gm/L). The extremely high salinity is the result of rock-water reaction times on the order of millions of years;
- Predictable "layer-cake" geometry and lateral continuity of the sedimentary rock formations over distances of 100s of kilometers; and

- Stability of the lower Ordovician rock formations; they have remained intact and relatively undeformed for hundreds of millions of years.

Results of a preliminary geotechnical assessment have indicated that the construction of an underground repository in either an Ordovician shale or Ordovician limestone formation would be feasible.[5] However for the purposes of developing the repository concept, the deep Ordovician limestone was selected as the reference host formation. The depth for the repository is assumed to be about 660 m below ground surface (Figure 3). The potential advantages of constructing a repository in limestone versus shale are: a) the geotechnical properties of limestone allow construction of larger and more stable underground openings, b) the overlying 200-m-thick shale layer offers an ideal location to construct shaft seals; and c) mining limestone to create underground openings will likely produce a resource in the form of aggregate which, as a minimum, could be recycled for other construction purposes at no cost to OPG.[6] A comprehensive site characterization program will be carried out to better define the geologic conditions at the Bruce Nuclear site. The new data will be used to further develop the repository layout and design, and to develop a safety case for the repository in support of the EA submission and the Construction License application.

## 4. LAYOUT AND CONSTRUCTION

A conceptual layout has been developed for the proposed underground repository and the associated surface facilities for the DGR.[6] These layouts are subject to change as the design of the facility progresses. The proposed DGR would be centrally located on the 900 ha Bruce Nuclear site. The underground repository design consists of a series of emplacement rooms arranged in parallel rows on either side of central access tunnels. Access to the repository is assumed to be through two vertical concrete-lined shafts. The new surface facilities are comprised of the Waste Receipt and Headframe Building, Ventilation Shaft Headframe Building, and various ancillary facilities. A more detailed description of the proposed DGR design is provided in the following sections. A conceptual layout of the underground repository is shown in Figure 4. Key features and statistics of the repository, as depicted in Figures 3 and 4, are presented in Table 1.

Table 1: Summary of key repository features and associated value or dimension

| Repository Feature | Value/Dimension |
|---|---|
| Packaged volume of operational LLW | 78,000 $m^3$ |
| Number of operational LLW packages | 22,000 |
| Number of LLW emplacement rooms | 18 |
| Packaged volume of operational ILW | 28,000 $m^3$ |
| Number of operational ILW packages | 3,400 |
| Number of ILW emplacement rooms | 20 |
| Rock pillar width between rooms | 12 m |
| Overall footprint of repository | ~ 20 ha |
| Repository excavated volume | ~ 400,000 $m^3$ |

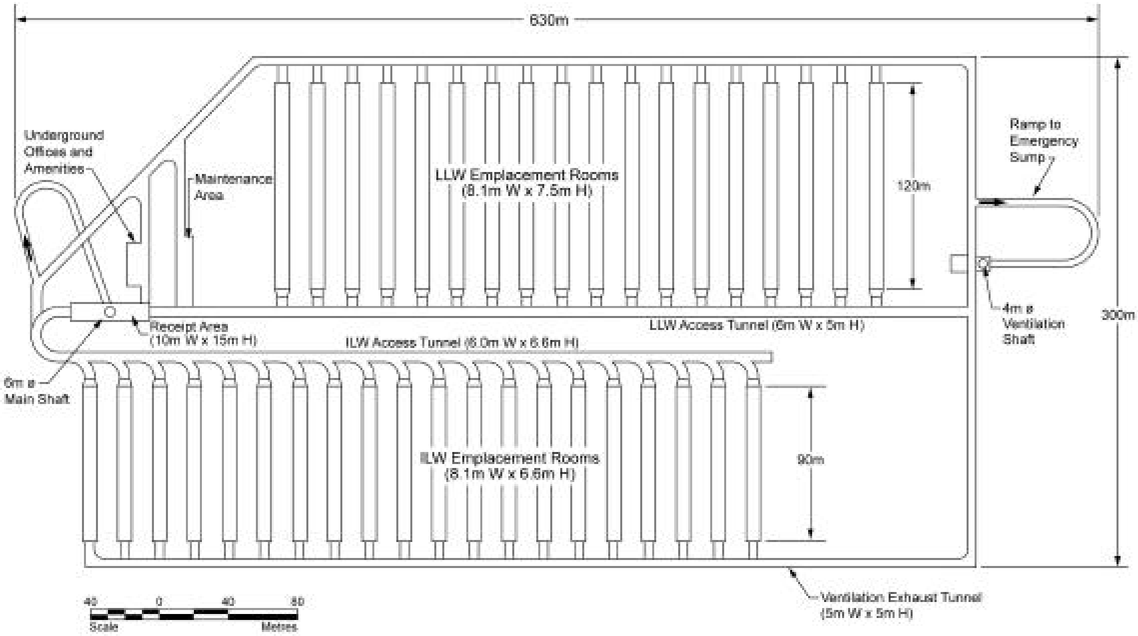


Figure 4: Current conceptual layout of a repository to accommodate OPG's operational L&ILW (i.e., waste inventory on which design is based excludes decommissioning wastes)[6]

*4.1. Shafts*

The Main Shaft and the Ventilation Shaft would be excavated using the drill and blast method to the proposed repository horizon at 660 m. Each shaft would extend an additional 30 m for an emergency sump. The 6-m diameter Main Shaft provides primary access to the underground repository and services for the underground repository, including fresh air, are also provided via this shaft (Figure 5).

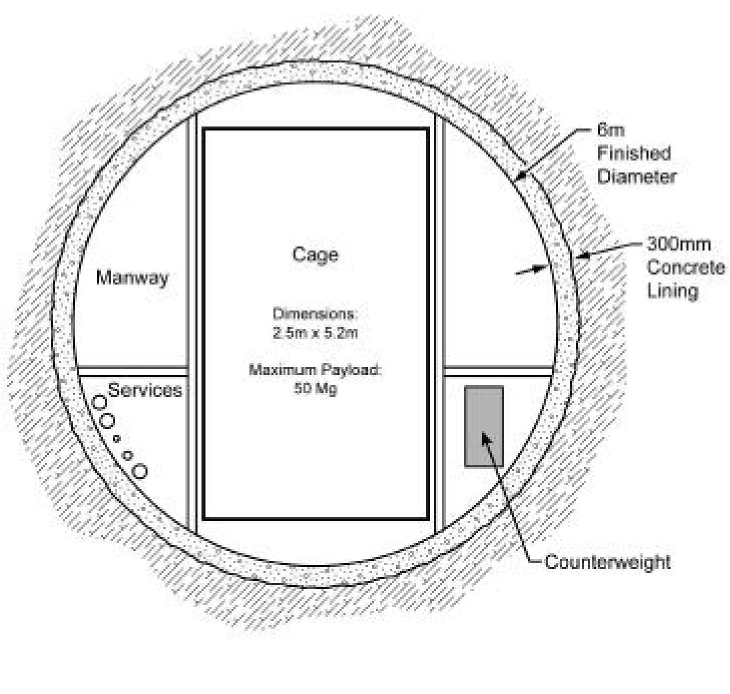


Figure 5: Conceptual layout of Main Shaft for transport of waste packages, personnel, materials and equipment to and from repository[6]

The Ventilation Shaft has a 4-m finished inside diameter and its functions include providing emergency access for staff to and from the repository, routing for exhaust air from the repository, and possibly the removal of excavated rock materials.

The two DGR shafts will be excavated through 400 m of potential water-bearing dolostone rock formations. Excavation grouting will be used to condition rock formations to limit any water inflow during construction, and then the shafts will be concrete-lined to further limit potential water inflow. As successfully demonstrated at a nearby 530-m deep salt mine [5], the constructed features in each DGR shaft and the thick low permeability formations directly overlying and hosting the repository will result in negligible water inflows via the shafts.

*4.2. Underground Tunnels and Ventilation System*

Access to the emplacement rooms from the receipt area at the Main Shaft will be via tunnels. The access tunnels have a poured concrete floor with rails mounted flush to the floor surface to allow movement of both rubber-tired vehicles and a train. A ventilation exhaust tunnel will be located around the perimeter of the repository. It will direct air that has flowed through the active areas of repository to the Ventilation Shaft (Figure 4).

Ventilation of underground repository will be by a push-pull system of surface fans with fresh air introduced via the Main Shaft and then exhausted by the Ventilation Shaft. A Heating, Ventilation and Air Conditioning (HVAC) plant will condition the fresh air prior to delivery to the underground repository. The HVAC system will be required to support repository construction activities (i.e. flush gases from blasting) and to deliver fresh air during waste emplacement operations.

During winter month operations, the HVAC system will heat the air to ambient rock temperature at the repository level (expected to be about 18°C). The air will also be conditioned to assure humidity levels are below the dew point at the repository horizon. This will minimize the amount of condensation water (some potentially contaminated) to be managed at the repository level. Controlling humidity level in the air will also reduce the potential for corrosion of various metal components including the metal waste containers. The HVAC system will be designed and operated to ensure air concentrations of potential contaminants (e.g. tritium and methane) are below acceptable limits in active areas of the underground repository.

*4.3. Emplacement Rooms*

The repository concept, as depicted in Figure 4, will provide sufficient capacity for 106,000 $m^3$ of operational L&ILW (packaged volume for disposal and includes volume of any overpack and shielding materials). All emplacement rooms will have exposed limestone rock walls and will have a poured concrete floor to allow access by rubber-tired vehicles. On the ILW side only, there will be rails embedded flush to the floor surface for access by the train carrying the heavy ILW packages. The entrance and exit tunnels to the emplacement rooms will be designed to allow interim sealing of the rooms once filled with waste.

Underground openings have been excavated in similar limestone formations and geologic settings elsewhere in Ontario and the United Sates.[7,8] Based on experience in these underground openings, it is expected that there will be no visible seepage into the proposed emplacement rooms and tunnels of the DGR.

### *4.4. Underground Office, Amenities and Maintenance Areas*

Adjacent to the underground receipt area will be excavations to house the underground office and amenities (Figure 4). Refuge areas will be located throughout the underground repository and will be equipped with emergency supplies of fresh water, compressed air, a fireproof door and sealing materials, and a communications link with surface. The maintenance area will be used for servicing of all underground equipment. It will also serve as the terminus and distribution point for services brought underground via the Main Shaft.

### *4.5. Surface Facilities*

Two new surface buildings and new ancillary facilities will be constructed, and they will likely be integrated into the existing infrastructure at the WWMF (Figure 3). The Waste Receipt and Headframe Building will be used to receive waste packages and to house the Main Shaft hoisting system. This building also houses the Heating, Ventilation and Air Conditioning (HVAC) plant.

The Ventilation Shaft Headframe Building is located above the second smaller shaft, and houses exhaust fans and the access/emergency man-hoist equipment. It also houses equipment for monitoring concentration of potential contaminants in repository exhaust air.

### *4.6. Future Design Modifications and Improvements*

The proposed layout of the underground repository is based, by necessity, on assumptions about future waste quantities, form in which wastes will be received, preferred means of repository access, nature of the deep geologic conditions, and preferred methods to handle waste packages in access tunnels and emplacement rooms. As new information is gathered and assumptions are updated, the layout and design of the underground repository will be modified and improved. Future design studies will also define the final locations of various surface facilities taking into consideration factors such as potential construction impacts, traffic flow, material flows, interaction with current operations, and potential environmental impacts.

## 5. REPOSITORY OPERATION

L&ILW retrieved from various storage structures at the WWMF or shipped directly from the nuclear generating stations will be received at the Waste Receipt and Headframe Building and then transferred to the underground repository. The timing and logistics of waste transfer operations have been considered at a conceptual level of detail.[6] It is expected that the LLW containers stored in LLSBs will be transferred first to the underground repository. At the start of repository operations there will be on the order of

20,000 LLW containers in storage and these containers will likely be transferred over a period of two to three years. Retrieval and transfer activities would then be directed to the stored ILW. There will be on the order of 13,000 $m^3$ of ILW in storage at the start of repository operations. Due to the size and weight of the stored ILW containers and the additional weight of shielding, retrieval and transfer operations for these wastes will be more difficult and time consuming. While wastes are retrieved from interim storage, all new wastes arriving from the stations will be processed and then sent directly to the DGR, bypassing interim storage.

### *5.1. LLW Package Handling*

It expected that the majority of LLW packages will be transferred "as is" to the DGR. However all LLW packages will be inspected and if any are found damaged, have high radiation levels, or are otherwise unacceptable for emplacement in the underground repository, they will be placed into an overpack container. The waste packages will be delivered by forklift or truck to the LLW receiving area of the Waste Receipt and Headframe Building and then loaded into the Main Shaft cage. The packages will be unloaded from the cage and then transported by forklift to the LLW emplacement rooms. The LLW packages will be stacked in the rooms in a manner similar to current practice within LLSBs (Figures 2 and 3-2).

### *5.2. ILW Package Handling*

ILW is currently stored in structures that provide shielding against gamma radiation. In order to provide continuous shielding for workers during handling, it has been assumed that the various ILW containers will be placed directly into concrete shields after removal from storage structures. The shields remain in place during movement to the repository, as well as after emplacement. Depending on the type of ILW and the size of the storage container, the full weight of a shielded ILW package is expected to be in the range of 2 Mg to 30 Mg. The majority of the ILW packages will be in the form of two 3-$m^3$ resin liners stacked inside a cylindrical concrete shield. This type of shield would have a 250-mm-thick wall with a nominal outside diameter of 2 m, an overall length of 5 m, and a full weight of 30 Mg (Figure 3-3).

It will be possible to handle ILW packages by gantry crane in the surface and underground receipt areas. At the repository level the ILW packages are transferred onto a small battery-electric train to emplacement rooms. Once in a room, a high capacity forklift is used to unload the ILW packages from the rail car and to place the packages into position within the room.

### *5.3. Repository Expansion*

The repository shown in Figure 4 has a modular design that would allow repository capacity to be expanded, as required, to match the L&ILW disposal needs of Ontario's nuclear power program. It is expected that the geologic conditions at the Bruce Nuclear site will allow repository expansion either laterally or vertically; e.g. a multiple level arrangement of emplacement rooms.

During initial repository construction and prior to start of waste emplacement operations, a sufficient number of emplacement rooms will be constructed to accommodate all waste packages in interim storage and for new waste receipts over a predefined time period. Waste receipt and emplacement operations would periodically cease to allow the construction of additional rooms. During these construction campaigns, the waste-filled rooms are isolated to protect the construction workers. While excavating new emplacement rooms, the access tunnels and shafts will be converted to non-radiological working areas to facilitate construction activities. Future design studies will explore options for the timing and execution of these construction campaigns with the objective of selecting an option that will minimize overall life-cycle cost to the project.

### *5.4. Staffing During Repository Operations*

There are about 80 people currently employed at the WWMF to handle, process and store L&ILW. Up to 35 additional staff would be employed at the WWMF when the proposed DGR is fully operational. These new staff will retrieve waste from various storage structures and prepare waste packages for transfer to the DGR. New staff will also be required to operate the main shaft hoisting system and the equipment for handling waste packages in the underground tunnels and emplacement rooms. There would be new management and technical staff providing support to DGR operations. It is expected that the DGR facility will initially operate year-round.

### *5.5. Repository Sealing Systems*

The repository sealing systems are comprised of interim emplacement room seals and permanent shaft seals. At the completion of room filling and prior to the final sealing of the entire repository, walls will be erected to isolate waste-filled rooms from the active emplacement rooms, access tunnels and the ventilation exhaust tunnel. The walls will be designed to limit release of tritiated air, natural and waste-generated methane, and other off-gases from waste packages (e.g. $H_2$ and $CO_2$), as well as potentially contaminated water. Each wall will have provisions to allow venting should monitoring indicate contaminant concentrations in air exceed levels that would not allow safe reentry. Although there is no intention to reenter the emplacement room following sealing, provisions to allow venting and safe reentry are required.

The two shafts will each be permanently sealed with a clay-based plug located near the base of the shafts within the Ordovician shales. A conceptual sequence of shaft sealing has been developed and includes the stripping of the concrete liners and any excavation-damaged rock on the shaft walls, followed by placement of the clay-based seals.[6] The shaft seals will be designed so that the bulk permeability of the seals will be the same as or less than the permeability of the surrounding shale formations. The seals will be in full contact with the surrounding rock and constructed so that there will be no preferential migration pathways between the seals and the rock. The time-dependent deformation characteristics of the Ordovician shale will likely cause “squeezing” of the seals, further enhancing the effectiveness of the shaft sealing systems. It is expected that these clay-based sealing systems will maintain their integrity in perpetuity.

## 6. PRELIMINARY SCHEDULE AND COSTS

A project to establish and operate a DGR facility for OPG's operational L&ILW would result in expenditures of approximately $800 million (all costs in 2004 dollars). A preliminary schedule for the DGR is presented in Figure 6 and estimated expenditures by development phase are shown in Table 2.

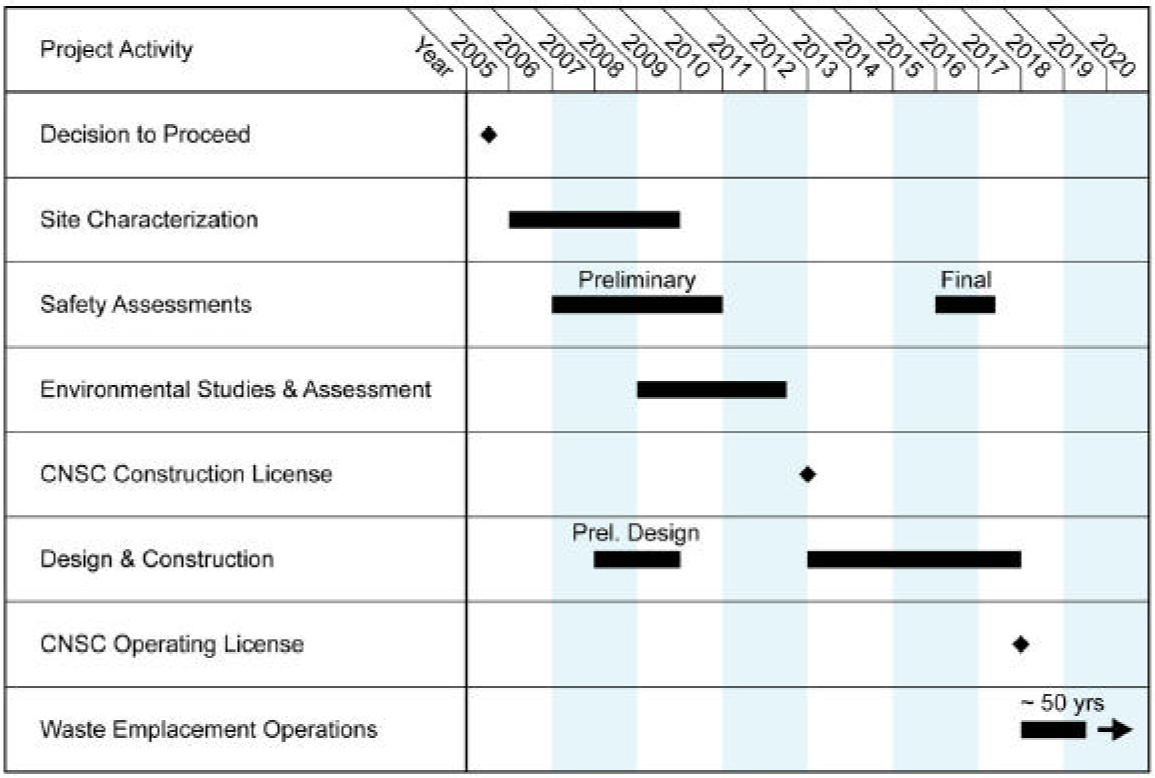


Figure 6: Preliminary schedule for establishment and operation of proposed Deep Geologic Repository

It will likely take about 8 years to complete all Approvals Phase work, and to secure all necessary approvals for the construction of the DGR. It is expected that site characterization work will begin in early 2006 and will take at least 4 years to complete. Preliminary safety assessment and repository design work will be carried out in parallel to the site characterization work. These work activities will be required to supply information for the project Environmental Assessment and CNSC regulatory approval. It is currently assumed that the EA Study report will be submitted in 2010 and EA approval will be received in late 2011. CNSC Construction Licence approval is assumed to be in 2012.

Table 2: Expenditure estimates over life of DGR project (2004 dollars)

| Project Phase (assumed duration) | Expenditure ($ million) |
|---|---|
| Approvals (8 years) | 80 |
| Construction (5 years) | 385 |
| Operations (23 years) * | 300 |
| Decommissioning & Closure (4 years) | 35 |
| **Total** | **800** |

* based on 18 years of operational L&ILW receipts followed by 5 years of extended monitoring. Construction phase estimate assumes initial construction of 12 emplacement rooms and operations phase estimate includes approximately $130 million for the construction of remaining 26 emplacement rooms. If decommissioning wastes are included in the repository waste inventory, operations phase cost estimate will be larger and duration of operations phase will likely be about 50 years.

Depending on the number of emplacement rooms constructed, the initial construction of the DGR could take 5 years to complete at a cost of about $385 million. Construction work would begin with the concurrent sinking of the two shafts in 2013, followed by the excavation of access tunnels and the ventilation exhaust tunnel, and then the construction of the first set of emplacement rooms. The peak construction workforce may be as large as 300 people.

L&ILW receipts at the DGR will start in 2018, and span several decades depending on future developments in Ontario's nuclear power program. The average annual expenditures during DGR operations could be on the order of $7 million per year which includes cost for the staff and other resources to operate the facility, overpack and shield materials, and various community payments. This annual operating cost estimate excludes the cost of periodic construction campaigns to extend access tunnels and to build additional emplacement rooms.

The cost estimate in Table 2 is based on the assumption that current reactors will operate a nominal 40 years and only considers operational waste. If a future decision is made to refurbish the reactors in order to extend their operating life or to build new reactors, then additional emplacement rooms would need to be constructed and the repository operating life extended. Similarly, the inclusion of decommissioning wastes will lead to an expansion of the repository and an extension to operating life. The DGR would likely have to be open for at least 50 years to be available for receipt of all operational and decommissioning L&ILW. All repository hoisting systems, access tunnels, equipment and services would have to be maintained and provided over this time period.

It is estimated that decommissioning of the surface and underground facilities, sealing of the shafts, and closure of the repository will take approximately 4 years to complete and cost about $35 million. An environmental assessment would have to be completed and a CNSC decommissioning licence obtained before work could begin on decommissioning and permanent sealing of the repository. An application seeking approval to permanently seal the repository would be supported by an updated safety assessment, and by an extensive database on the characteristics of the host rock formations and the behaviour of waste packages. These data would be collected over a period of decades during repository operations.

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Note: References [2], [5] and [6] are available at http://www.opg.com/ops/N_waste_man.asp