PRECLOSURE SAFETY ASSESSMENT FOR OPG'S DEEP GEOLOGICAL REPOSITORY FOR L&ILW

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ABSTRACT

The Preclosure Safety Assessment summarized in this paper evaluates the operational safety of OPG's proposed Deep Geologic Repository facility, focusing on safety aspects associated with waste packages. The assessment addresses the safety of members of the public and workers, and includes both radiological and non-radiological (chemical) consequences. It involves an assessment of normal operations as well as hypothetical accident scenarios selected using a hazard identification process. Results indicate that credible hypothetical accidents would not produce exposures that exceed selected radiological and non-radiological dose criteria for members of the public or workers. Similarly, doses generated under normal operations would not exceed radiation dose limits.

1. INTRODUCTION

Ontario Power Generation (OPG) is proposing to build a Deep Geologic Repository (DGR) for Low and Intermediate Level Waste (L&ILW) near the existing Western Waste Management Facility (WWMF) at the Bruce nuclear site in the Municipality of Kincardine, Ontario. The Nuclear Waste Management Organization (NWMO), on behalf of OPG, has managed the preparation of the Environmental Impact Statement and Preliminary Safety Report for the proposed repository. The DGR project involves investigation of the site's geological and surface environmental characteristics, facility design, and safety assessment. More detailed information on the DGR Project can be found in companion papers [1-7].

The Preclosure Safety Assessment discussed in this paper evaluates the operational safety of the proposed facility, focusing on safety aspects associated with waste packages. Conventional workplace hazards and postclosure safety are addressed separately. The assessment addresses the safety of members of the public as well as workers, and includes both radiological and non-radiological (chemical) consequences. It covers the period of time from the start of operations to the closure of the facility. Decommissioning and closure activities are not included in the assessment as the waste packages would have been sealed off. More details on the preclosure safety assessment are provided in [8].

The Preclosure Safety Assessment includes an assessment of normal operations as well as hypothetical accident scenarios.

2. PREVENTATIVE AND MITIGATIVE MEASURES

The DGR design incorporates a number of measures to reduce the likelihood of accidents or exposures. These will be further emphasized during detailed design and later during operations. These measures include:

- Minimization of combustible materials and ignition sources, especially near waste packages;
- Use of overpacking and shielding on higher activity packages;
- Limited number of packages handled in any transfer;
- Limited interim storage of packages outside of the emplacement rooms;
- Fire detection and suppression equipment, such as automatic fire suppression systems on diesel forklifts and fire doors at key locations;
- Access to underground refuge stations and safety equipment, including portable refuge stations near work locations;
- Multiple communication systems, including an underground stench gas warning system.

3. HAZARD IDENTIFICATION

The Hazard Identification (HI) process was carried out to identify and define the hazards associated with operation of the DGR, and to identify bounding hazard scenarios. The HI process was based on a systematic review of relevant site and facility features and processes.

The sources of hazards are defined here as any material, equipment or process that has the ability to cause harm to a person through release of radiological/non-radiological species from the wastes. Potential sources of hazard at the DGR were considered with respect to geology, radioactive waste packages, non-radiological combustible materials, heavy equipment, and utilities.

Initiating events that could involve these sources of hazards were also identified, based on consideration of external events (such as severe weather), geotechnical events (such as rockfall) and operational events (such as human error or equipment failure).

Potential accident scenarios involving an initiating event and a source of hazard leading to potential consequences were considered. The result of this analysis is a list of specific accident scenarios. The accident scenarios were initially screened based on estimated frequencies. Subsequently, a set of bounding accident scenarios were selected for each type of hazardous event (e.g., fire, package breach). The criteria for selection of the bounding accident scenarios were based on qualitative estimation of the magnitude of the consequences which, in turn, is a function of the type and number of waste packages affected.

Hypothetical bounding accidents included the following:

- **Fire - Aboveground & Underground**: External fires may cause the content of some waste packages to ignite and burn, mainly LLW packages and unshielded ILW packages. Shielded ILW packages are unlikely to ignite, but the heat from an external fire can cause release of steam and volatile species (e.g., C-14, H-3, mercury and selenium).

- **Container Breach (Low Energy) - Aboveground & Underground**: Low-height or low-speed impacts resulting in some loss of containment. Waste packages are not crushed. Includes low-speed transfer vehicle accidents, and drops from heights lower than 4 m.
- **Container Breach (High Energy) – Underground**: Drops or impacts that result in significant package failure. Includes drops from heights greater than 4 m (cage fall and roof collapse).
- **Inadequate Shielding – Aboveground**: Inadvertent exposure of staff to high dose rate conditions.
- **Ventilation System Failure – Underground**: Loss of underground ventilation due to loss of power.

4. ASSESSMENT OF NORMAL OPERATIONS

The objective of the Normal Operations assessment was to assess potential radiological doses to members of the public and to workers during normal operations of the DGR. It focused on the safety aspects associated with the handling of the waste packages as well as maintenance activities.

The assessment of doses to members of the public under normal operating conditions included:

- Doses due to releases of radionuclides in air and water; and,
- External radiation dose.

The assessment of doses to workers under normal operating conditions includes:

- External radiation dose; and,
- Inhalation and immersion doses.

The criteria used were the OPG dose targets for members of the public, non-Nuclear Energy Workers and Nuclear Energy Workers. These are equal to or less than the relevant CNSC regulatory dose limits.

4.1 Air and Water Releases

Normal DGR operation involves transfer and handling of packages into emplacement rooms, and then monitored storage until the DGR is closed. Therefore, the impact of the DGR on the public during normal operations will be mostly from Tritium (H-3) and Carbon-14 (C-14) emissions to air and water, as at WWMF.

Airborne releases of H-3 and C-14 from Low Level Waste (LLW) in the DGR will occur due to off-gassing from packages during handling and storage, until emplacement rooms are fully closed. The DGR releases from LLW were scaled based on measured emissions from the WWMF Low Level (Waste) Storage Buildings (LLSBs). H-3 and C-14 airborne releases from Intermediate Level Waste (ILW) were scaled based on estimated emissions from In-Ground Resin Containers.

During DGR normal operations, there will be no direct route for waterborne release. Although the DGR underground is expected to be dry, there will be some water from shaft condensation, operations and seepage, which will be collected, monitored and pumped to the surface for release. H-3 and C-14 levels in the ventilation shaft condensate water were estimated based on the assumption that this water was in equilibrium with H-3 and C-14 air concentrations inside the ventilation shaft. H-3 concentrations in condensate water are potentially possible at times during operations similar in levels and amounts seen in WWMF sumps. This will need to be monitored based on actual operating trends and would be managed in part by prevention via operational controls (e.g. ventilation rates) as well as by collecting such water for off-site treatment as is current practice with the WWMF sumps.

4.2 Public Impacts

The dose impact on the public of any airborne and waterborne releases from the DGR during normal operations was estimated using two methods:

- Derivation of dose based on the DGR estimated releases in comparison to the Bruce nuclear site releases and dose impacts, which are based on measurements from the Bruce nuclear site Radiological Environmental Monitoring Program (REMP) [15] [16] [17].
- Derivation of dose based on the WWMF Pathways Model scaled to DGR release rate estimates.

The REMP method is semi-empirical and includes measurements at receptor sites, and is therefore more realistic than the theoretical Pathways Model method. Both methods are conservative and focus on the (potentially) most exposed receptor groups.

The releases, and therefore dose impacts, will vary over the operating history of the DGR, depending on the ventilated waste inventory. The highest public dose estimates were predicted to occur around the year 2023, based on a schedule in which most of the existing wastes stored at WWMF are transferred within 5 years into the DGR.

The maximum dose to the public from airborne and waterborne releases was estimated to be far below the CNSC regulatory limit of 1 mSv/year, and is similar to the impacts that would be expected from WWMF for similar LLW and ILW radionuclide inventories.

4.3 Worker Impacts

Air concentrations of H-3 and C-14 in the DGR were estimated from container off-gassing rates and room ventilation rates. The airborne release rates in the ventilation shaft and in the emplacement rooms were estimated for the years 2023, 2038 and 2052, representing times at which portions of the repository would have been filled but not yet closed off. These airborne release rates were used to estimate the potential worker inhalation and immersion doses.

Direct radiation dose calculations were estimated with MicroShield Version 8.02 [13]. Some of the underground calculations were also carried out using Monte Carlo N-Particle (MCNP) Version 5.1.40 [14], in particular, to assess the influence of scattering along walls and ceilings in the emplacement room. The assessment was carried out for representative LLW and ILW waste packages.

The calculations included conservative assumptions about waste package inventories, worker location and worker shielding. More realistic calculations were carried out as part of an As-Low-As-Reasonably-Achievable (ALARA) analysis.

Several scenarios were considered for normal operations external worker dose:

Above-ground:

- Scenario 1 – LLW in WPRB
- Scenario 2 – ILW in WPRB
- Scenario 3 – LLW and ILW in WPRB

Underground:

- Scenario 4 – LLW in Underground LLW Emplacement Room
- Scenario 5 – ILW in Underground ILW Emplacement Room

Inhalation doses estimated for DGR workers are all much less than OPG's occupational dose target of 10 mSv/year. The highest dose rate location is expected to be in the ventilation drift because it is where potentially dirty air that flows through the emplacement room ends returns en route to the ventilation shaft. However, workers would not be present at this location under routine circumstances.

The external dose calculations for workers show that high dose rates are possible in specific locations, especially near the face of an array of higher dose rate LLW or ILW packages in emplacement rooms. Generally, workers would not need to spend much time in these locations, nor are most packages at high dose rates. However, it will be planned to monitor the radiation fields in these locations, and if necessary to limit the worker exposure, disperse higher-dose containers, use shielded forklifts and/or use greater stand-off distances. This will be considered further within the context of ALARA.

External (gamma) dose calculations were also carried out to the nearest DGR fence line and at the Bruce site boundary. The estimated dose rate is well below the non-NEW compliance dose limit of 0.5 µSv/h at the DGR fence line and much less than the public dose limit at the site boundary.

5. ASSESSMENT OF HYPOTHETICAL ACCIDENT SCENARIOS

The objective of the accidents assessment was to evaluate the potential consequences of hypothetical accidents selected through the hazard identification process.

5.1 Screening

Potentially important radionuclides (i.e., those with the highest potential contribution to total doses); and non-radiological species (e.g., elements or chemicals) were first identified.

Conservative screening calculations were completed based on a stylized non-fire scenario (waste package breach) and a fire scenario, for all L&ILW waste types, and all radionuclide and non-radiological species identified in the Reference Inventory report [9]. Concentrations of radionuclides and non-radiological species present in each waste type are based on the "asreceived at WWMF" specific activities presented in the Reference Inventory Report [9]; i.e., there is conservatively no allowance for decay during storage prior to emplacement.

For radionuclides, screening was based on identifying all radionuclides contributing up to 99% of the total dose from any waste type for either fire or non-fire screening scenarios. For non-radiological species, screening was based on a comparison of air concentrations to an occupational health and safety criterion representing the inhalation, ingestion, skin or eye contact, or skin absorption pathways. Those that exceed their respective criteria for either fire or non-fire scenarios are carried forward for further assessment. The "screened in" list of radionuclides and non-radiological species that were carried forward to the accident assessment are provided in Table 1.

Table 1. Potentially Important Radionuclides and Non-Radiological Species in OPG L&ILW

Radionuclides			Non-Radiological Species	
Am-241	Fe-59	Pu-241	Asbestos	Manganese
C-14	Gd-153	Ra-226	Antimony	Mercury
Ce-141	H-3	Ru-106	Arsenic	Nickel
Ce-144	La-140	Sb-124	Barium	Selenium
Cm-244	Mn-54	Sb-125	Beryllium	Strontium
Co-60	Nb-94	Sn-119m	Cadmium	Uranium
Cs-134	Nb-95	Sr-90	Chromium	Zinc
Cs-137	Pb-210	Te-125m	Cobalt	Zirconium
Eu-152	Pu-238	Zr-95	Copper	
Eu-154	Pu-239		Dioxins/Furans	
Fe-55	Pu-240		Lead	

5.2 Accidents Assessment

The accidents assessment evaluated potential worker exposure during the hypothetical bounding accident scenarios.

5.2.1 Waste Types

The Reference Inventory report [9] identifies thirteen low level waste categories and eight intermediate level waste categories. For accident assessment, the wastes were grouped into similar categories in terms of characteristics, and representative waste types selected from each category as follows:

- **Ash LLW (spillable, not combustible, contains chemical hazard elements)** – Bottom Ash (Old) selected as these have the highest radiological and non-radiological inventory of ash waste packages.

- **Combustible LLW (combustible)** – Compacted Waste (Boxed) selected since these have higher package radiological inventory.
- **Non-Processible/Other LLW (not readily spillable or combustible)** – Non-Processible (Boxed) selected as these are the largest volume of waste, and Non-Processible (Drummed) as these have the highest LLW package radiological inventory.
- **Resin ILW (spillable, potentially combustible)** – Moderator IX Resin was selected as it has the highest radiological inventory (especially C-14 and H-3).
- **Retube ILW (not spillable, not combustible)** – End Fittings selected as these have the highest radiological inventory of retube waste packages.

5.2.2 Methodology

The potential bounding accidents were analyzed for exposure consequences using simple models, consistent with the U.S. Department of Energy (DOE) methodology [18] [19].

For each accident scenario, the amount (or source term) of radionuclides and/or non-radiological species potentially impacting the receptor was calculated as follows:

$$Q = MAR \times DR \times ARF \times RF \times LPF$$

where:

Q	=	Source term (Bq or µg)
MAR	=	Material at risk (Bq or µg) – Maximum amount of material present that may be acted upon with the potentially dispersive energy source
DR	=	Damage ratio – Fraction of MAR actually impacted by the accident condition
ARF	=	Airborne release fraction – Fraction of radioactive material actually impacted by the accident condition that is suspended in air
RF	=	Respirable fraction – Fraction of airborne particles that are in the respirable size range
LPF	=	Leakpath factor – Fraction of the release not attenuated along the leak path (e.g., by deposition as the contaminants move from within the container to the outside of the container)

Values for these parameters were estimated based on the accident scenario, the waste package characteristics, and values adopted for similar accident analyses in WIPP [19].

Average concentrations at receptor locations were determined using simple stylized scenarios appropriate to each accident. For examples, fires were assumed to have constant release rate from fire initiation. Public exposure was estimated using WWMF air dispersion factors, a conservative estimate since the DGR ventilation shafts are slightly farther from the site boundary. In the case of an underground fire, it was conservatively assumed that the contaminated air leaving the shafts had been cooled and behaved as a ground level release rather than a thermal plume release.

External doses to workers were also calculated for breach accidents, assuming the damage fraction (DR) of the wastes was not shielded.

5.2.3 Criteria

For radionuclides, the total dose from each accident scenario was compared to a radiological dose criterion. For abnormal events or credible accidents, the following criteria were used:

- Members of the Public (at or beyond site boundary): 1 mSv;
- Nuclear Energy Workers (NEW): 50 mSv.

For non-radiological species, **worker** inhalation exposures from each accident scenario were compared to concentrations that are Immediately Dangerous to Life and Health (IDLH), provided by the U.S. National Institute for Occupational Safety and Health (NIOSH). IDLH values are generally based on 30-minute exposure [10]. This is longer than the 5 minutes that workers would need to leave an area, reach a refuge station underground, or acquire protective equipment.

For non-radiological species, potential **public** exposure to non-radiological species due to various accident scenarios was assumed to be on the order of one hour, assuming conservatively that the public is at the nearest site boundary, that this location is directly in line with any release plume, and that the accident duration (e.g. fire) lasts this long before being extinguished or isolated (e.g. fire doors).

Some fire accidents could potentially last longer if no suppression was achieved. The longest accident identified was an underground room fire with LLW packages lasting several hundred hours. This case was also considered, taking into account the greater atmospheric dispersion that occurs over long times.

The public exposure criteria adopted for non-radiological species under one-hour accident scenarios are the U.S. DOE Protective Action Criteria (PAC). The PAC data set provides four different benchmark values depending on the health threshold levels with PAC 1 values being chosen. These correspond to mild, transient health effects, or perceiving a clearly defined, objectionable odour.

5.2.4 Public Impacts

Public exposure to radiological doses and air concentrations of hazardous elements in the waste over a 1 hour exposure period at the nearest Bruce nuclear site boundary are much less than the relevant criteria.

Although unlikely that a member of the public would be exposed at the Bruce site boundary for more than one hour, longer exposures would not exceed the criteria. Specifically, assuming complete burn of an underground room over a few hundred hours, the public radiological dose at the nearest site boundary is less than 1 mSv for a room containing LLW and for a room containing unshielded ILW moderator resin.

5.2.5 Worker Impacts

Radiological doses to workers over a 5 minute exposure time are much less than the 50 mSv limit for any accident scenario. In addition, in the case of a ventilation system failure, workers would be exposed to H-3 and C-14 air concentrations much less than the Derived Air Concentration limits for annual exposure. Air concentrations of non-radiological species released during the accident scenarios are less than the IDLH criteria for workers.

6. CONCLUSIONS

The results of this preliminary Preclosure Safety Assessment provide a quantitative estimate of potential hazards and impacts. Overall, both WWMF experience as well as the DGR-specific analyses summarized here, indicate that the wastes can be handled and emplaced without undue risk to workers or the general public.

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