OPG's DEEP GEOLOGIC

REPOSITORY

FOR LOW & INTERMEDIATE LEVEL WASTE

Preliminary ALARA Assessment

March 2011

Prepared by: SENES Consultants Ltd.

NWMO DGR-TR-2011-36

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Document History

Title:	Preliminary ALARA Assessment		
Report Number:	NWMO DGR-TR-2011-36		
Revision:	R000	**Date:**	March 2011
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EXECUTIVE SUMMARY

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, is preparing the Environmental Impact Statement (EIS) and Preliminary Safety Report (PSR) for the proposed repository.

This report provides the methodology, results and recommendations from the preliminary occupational radiation dose ALARA (As Low As Reasonably Achievable) assessment carried out for the DGR. This report assesses all activities beginning with waste receipt in the Waste Package Receiving Building (WPRB) to final emplacement in the repository.

According to the results of this assessment, the collective dose to waste package handling workers is estimated to be 126 person-millisieverts/year (p-mSv/year). A further 11 p-mSv/year is estimated for facility maintenance activities, much smaller than the dose from waste handling, and will be distributed among different workers. From a specific worker activity perspective, the highest dose is to the underground forklift driver. From a waste package perspective, the Light Forkliftable (Group C) waste packages contribute the most to worker dose.

The assessment results provide the information to demonstrate that doses will be kept within target. Areas are identified where design optimization and operational controls could be useful. Also, it is noted that this preliminary collective dose estimate for the DGR is higher than the 55 p-mSv/year benchmark that is estimated by scaling from the WWMF collective dose experience based on the number of packages handled. Given the similarity of activities and wastes at the DGR and WWMF, this suggests that the modelling is conservative and that lower dose estimates may be achieved using a more realistic analysis.

This report provides a first estimate of the operational dose implications of the DGR activities, and therefore provides a basis to support future optimization and dose reduction.

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1. INTRODUCTION

1.1 Background

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, on behalf of OPG, is preparing the Environmental Impact Statement (EIS) and Preliminary Safety Report (PSR) in support of the site preparation and construction licence application for the proposed repository.

The preclosure safety assessment of the DGR is described in the Preliminary Safety Report (PSR Chapter 7, OPG 2011). It includes a normal operations safety assessment and a safety assessment for hypothetical accident scenarios. Radiological safety is evaluated for normal operations, while both radiological and non-radiological safety are evaluated for accident scenarios.

The present report provides the methodology, results and recommendations from the preliminary occupational radiation dose ALARA (As Low As Reasonably Achievable) assessment carried out for the DGR design (PSR Chapter 6, OPG 2011). This assessment addresses all activities beginning with waste receipt in the Waste Package Receiving Building (WPRB) to final emplacement in the repository.

A final ALARA Assessment report will be prepared in support of OPG's application for an operating licence for the DGR.

1.2 Objectives

Dose limits, set by regulation, provide a boundary to protect people against unacceptable risks. However, merely achieving doses below the dose limits is not sufficient if actions can be taken at a reasonable cost to further reduce the doses. Optimization is therefore an essential part of a system of dose limitation.

This report provides an initial preliminary-design-phase ALARA assessment of the DGR. It concludes with an initial estimate of individual and collective occupational doses, and initial recommendations regarding methods for potential dose reduction. Since this is a preliminary design-phase assessment, results are conservative and will be revised when a more detailed design becomes available. This initial estimate provides insight into what activities and what waste packages contribute the most to the individual and collective occupational doses and identifies opportunities to reduce occupational doses. It does not recommend that specific methods should be adopted for specific activities.

1.3 Scope

This assessment was carried out based on the DGR design as described in the PSR (Chapter 6, OPG 2011) and takes into account the requirements of the Canadian Nuclear Safety Commission (CNSC) Regulatory Guide G-129 (CNSC 2004).

The assessment includes calculation of doses to Nuclear Energy Workers (NEWs). As documented in the preclosure safety assessment (PSR Chapter 7, OPG 2011), the preliminary design meets the dose limit of 0.5 μSv/h at the DGR site boundary. Therefore, no specific assessment is presented in this preliminary assessment for hypothetical non-NEWs at the facility site boundary and to other members of the public, further away.

The assessment commences with the receipt of waste containers at the WPRB in the DGR, and concludes with the emplacement of waste packages in the underground emplacement rooms. It also considers DGR worker activities associated with operating and maintaining the DGR systems. The assessment provides initial estimates of the duration, the number of workers, the distance from the waste packages and the dose rates associated with each activity.

The assessment focuses on radioactivity associated with the waste packages themselves. Radon has been separately assessed and determined not to be significant in the DGR, so is not considered further within this ALARA assessment (NWMO 2011).

1.4 Outline

The outline of this report is as follows.

Chapter 2 on Description of the DGR Facility: describes the facility, representative waste packages, the DGR operations and equipment.

Chapter 3 on Radiological Hazards Identifications: describes the radiological hazards associated with L&ILW DGR operations.

Chapter 4 on Regulatory Requirements, Guidelines and Targets: describes the regulatory requirements, as well as OPG management control over work practices.

Chapter 5 on Overall Waste Management Approach: describes the waste handling logistics and single package dose rate estimate for each container group.

Chapter 6 on Occupational Dose Estimates: describes the methodology used in the occupational dose estimate and estimates the individual and collective occupational dose rates.

Chapter 7 on Elimination, Abatement and Control Measures: identifies opportunities for dose reduction and initial recommendations.

Chapter 8 on Summary and Recommendations: provides a summary for the ALARA assessment and general recommendations.

2. DESCRIPTION OF THE DGR FACILITY

2.1 Description of the Facility

The purpose of the DGR is to provide long-term management of OPG's L&ILW. The DGR consists of surface infrastructure for the receipt of waste packages and transfer underground via a main shaft to the repository horizon at a nominal depth of 680 m below surface in a limestone formation. The ventilation shaft will be an up-cast shaft with main exhaust fans to pull the spent air out of the repository.

The underground layout of the repository has two vertical shafts located on a central shaft service area, from which two emplacement room access tunnels extend to the south and east. The layout is shown in Figure 2.1. Ventilation air flows through the access tunnels and emplacement rooms, and back to the ventilation shaft through a return ventilation drift.

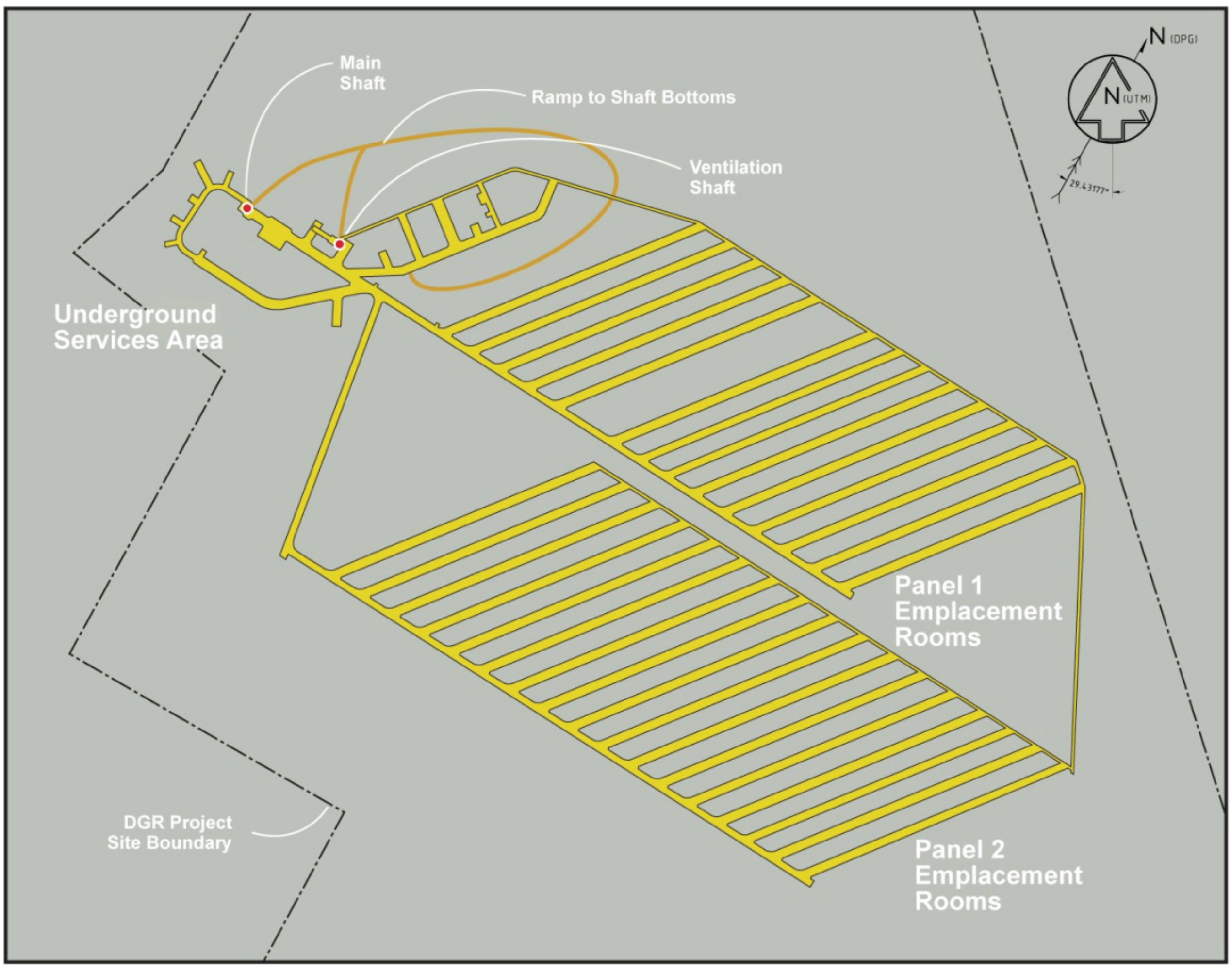

Figure 2.1: Underground DGR Layout

2.2 Waste Packages

The DGR can accommodate a wide range of waste packages (i.e., waste plus container). For general layout purposes, the waste packages are classified into four waste package groups, with similar waste handling, transfer and emplacement methods. Each waste package group typically includes multiple container types and waste types.

For each waste package group, two representative waste packages were selected for the ALARA assessment – a high-volume waste package, and a lower-volume and generally higher-dose-rate package, based on the Reference Inventory Report (OPG 2010). All packages handled at the DGR were assumed to be one of these eight packages. Although this does not directly evaluate all packages, this provides a sufficient indication of the important dose contributors. The representative waste packages are shown in Table 2.1.

Table 2.1: Representative Waste Packages for Each Waste Package Group

Waste Package Group	Container (ID) / Waste
A - LLW Bin Type Waste	Non-Pro Bin, 47" High (NPB47) / Non-Processible
	Non-Pro High Capacity (NPHC) / Feeder Pipes
B - Heavy Non-Forkliftable	Heat Exchanger (HX) / Non-pro Other
	Shield Plug Container (SPC) / Shield Plugs
C - Light Forkliftable	ILW Shield (ILWSHLD) / Filter and Filter Elements
	Stainless Steel Resin Liner (RLSS) / CANDECON Resin
D - Heavy Forkliftable	Retube Waste (RWC(EF)) / End Fittings
	Resin Liner - Shield 1 (RLSHLD1) / CANDECON Resin

2.3 Operations

All waste packages arriving at the WPRB are "DGR-ready" which generally means (Section 5.5, OPG 2011):

- The approved waste package designs meet the DGR weight and size restrictions; no further waste conditioning is required.
- The dose rates on each package meet the DGR dose rate limits (exceptions to these limits can be approved by a responsible health physicist on a case-by-case basis).
- The waste packages accepted at the DGR will be lidded, and will have been checked for loose contamination. Zoning, monitoring and normal operating procedures will also ensure that there is no detectable loose contamination. Loose contamination is therefore not expected to be a significant contributor to worker dose and is not assessed in this preliminary ALARA assessment.
- Packages have good mechanical integrity.

The handling, transfer and emplacement of all waste packages can be broadly described as follows:

- QA check and unloading upon arrival at the WPRB;
- Loading onto rail cart (see Figure 2.2);
- Transfer to the shaft cage;
- Transfer down the main shaft to the underground;
- Unloading from the shaft cage;
- Transfer to the emplacement rooms (see Figure 2.3); and
- Emplacement.

The major interfacing systems, equipment and surface areas relevant to the DGR that may have an impact on Occupational Radiological Safety are listed as follows:

- Container / Overpack;
- Light / Heavy Duty Forklifts;
- Overhead Crane;
- Rail Cart;
- Flatbed Truck with Tie Downs;
- Gantry Crane;
- Shaft Cage;
- Ventilation System; and
- Radiation Protection Equipment.

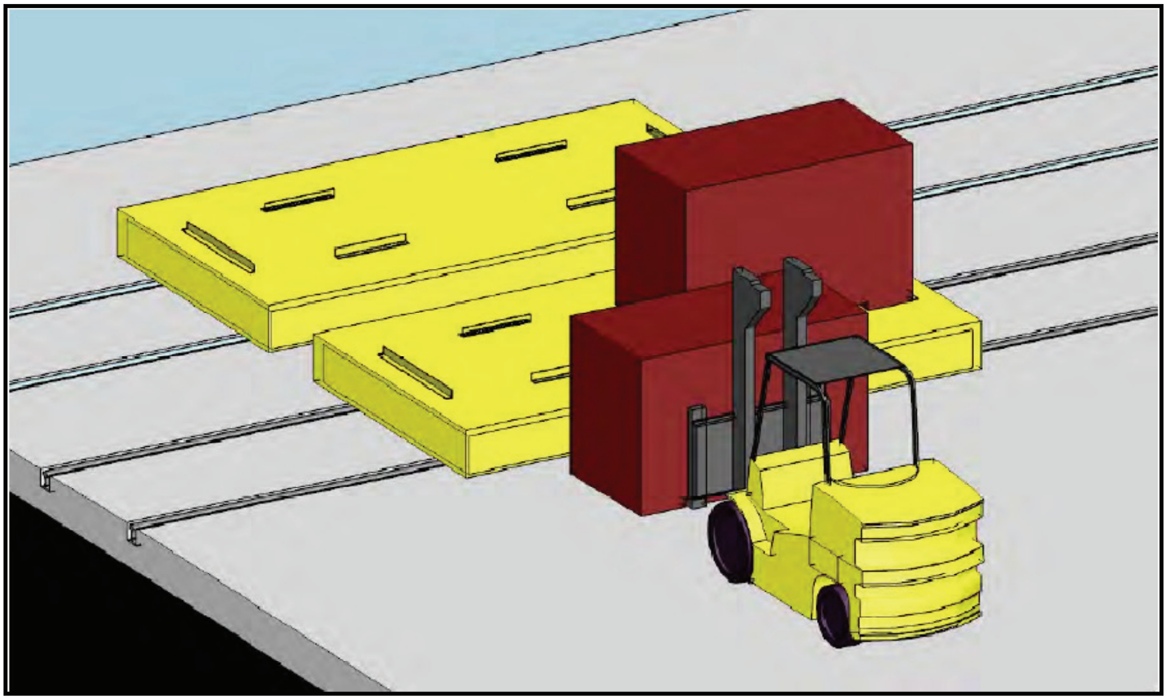

Figure 2.2: Light Forklift Transferring LLW Packages onto Rail Cart at WPRB

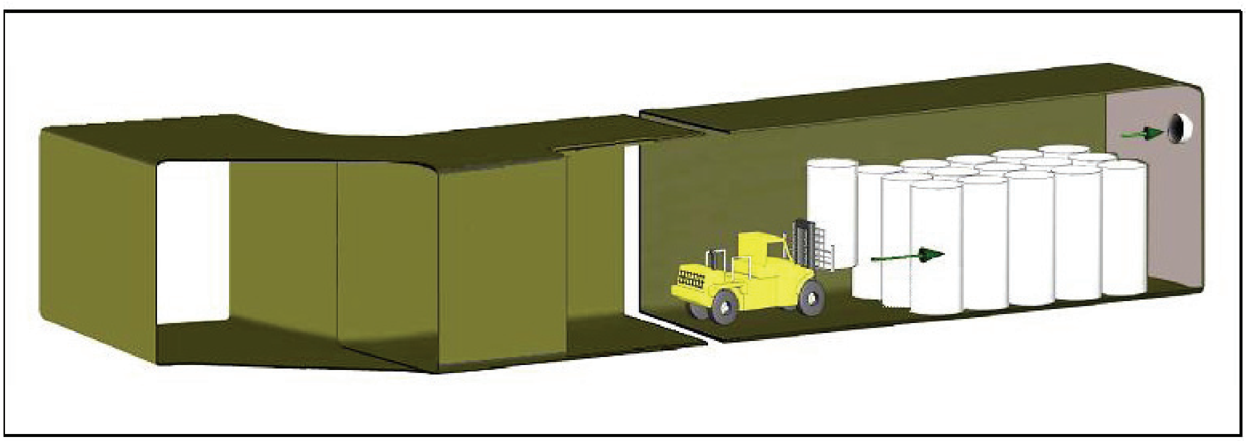

Figure 2.3: Example Emplacement Room with Heavy Forklift Placing ILW Packages

3. RADIOLOGICAL HAZARDS IDENTIFICATIONS

Potential occupational radiological hazards associated with L&ILW long-term storage operations can be categorized into three broad categories:

- Radiological hazards associated with normal operations;
- Radiological hazards associated with maintenance and other activities; and
- Radiological hazards associated with malfunctions/accident conditions.

3.1 Normal Operations – Package Handling

The main source of radiological hazard in the DGR originates from the radioactivity in the waste packages. The majority of the exposure to workers is during the routine transport and handling of waste packages. Personnel working in the vicinity of waste packages are exposed to gamma radiation emanating from the waste packages. It is expected that a maximum of 24 LLW packages and 2 resin liner shields will be staged inside the WPRB (in the corner of the WPRB, as shown in Figure 3.1) at one time.

The dose to workers is expected to be dominated by situations in which they are handling waste packages because they are in close proximity to the waste. In addition to the direct gamma radiation, all personnel in the DGR will be exposed to some level of gamma radiation from skyshine (e.g., air-scattered radiation). However, skyshine dose was not included in this assessment because direct gamma radiation dose is dominant in close proximity to waste packages whereas skyshine dose becomes a relatively larger contributor to dose at greater distances from the waste packages, where the total dose becomes insignificant.

During normal operations, personnel in the DGR should not be exposed to radioactive particulates. This is because all waste packages will arrive at the DGR lidded and will have been checked for detectable loose contamination prior to acceptance at the DGR (Section 5.5, OPG 2011). In addition, there will be no waste conditioning or processing at the DGR that could generate particulates. This is consistent with the zoning within the DGR.

3.2 Normal Operations – Maintenance and Other Activities

Maintenance and other activities may lead to exposure during normal operations.

Radiological hazards originate from waste packages temporarily staged in the above-ground and underground DGR. This applies in particular to workers in the WPRB and the underground shaft station. Personnel working in the vicinity of such waste packages are exposed to gamma radiation emanating from waste packages as well as any H-3 or C-14 off-gassing from waste packages.

Exposure from the inhalation pathway for most workers was not assessed in this preliminary ALARA assessment because of the directional ventilation underground - workers are generally upwind of packages. Inhalation doses to workers from H-3 and C-14 are only expected to be appreciable in the ventilation shaft and drifts. This would affect workers conducting inspections of the ventilation shaft liner and shaft hoisting equipment, or inspecting/maintaining air dampers in ventilation drifts.

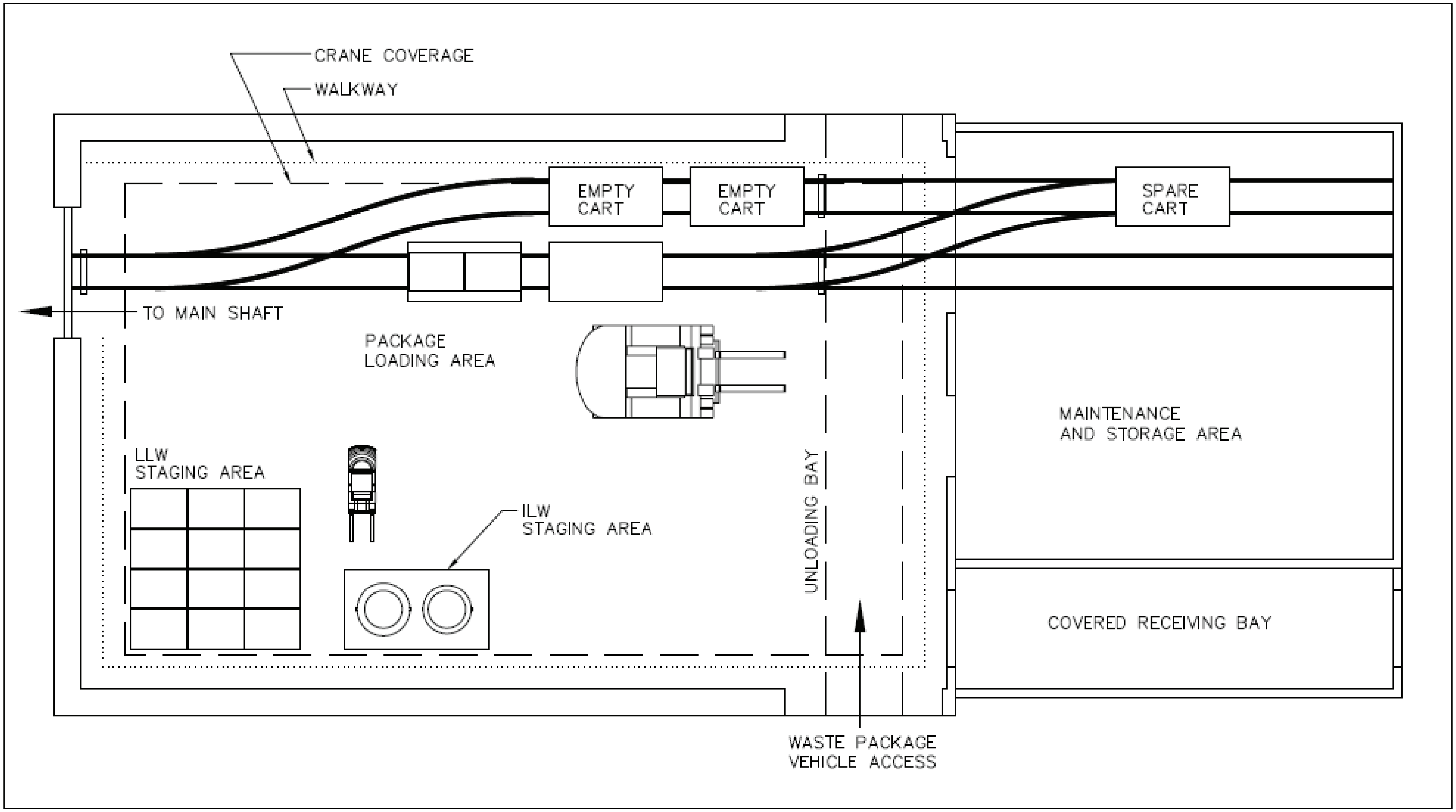

Figure 3.1: WPRB Layout

3.3 Accidents and Malfunctions

Radiological hazards from accidents and malfunctions could occur as a result of either DGR failures or external hazards. As a result, personnel working in the above-ground and underground DGR could be exposed to gamma radiation and airborne releases of radionuclides from waste packages. The radiological doses are expected to be ALARA due to design measures developed using an iterative design approach and through the use of administrative controls and procedures that will be in place during the operational phase. The results of the preclosure accident assessment (Chapter 7, OPG 2011) indicate that worker doses are within criteria.

4. REGULATORY REQUIREMENTS, GUIDELINES AND TARGETS

4.1 Regulatory Requirements

The primary federal act governing nuclear related activities in Canada is the Nuclear Safety and Control Act (NSCA 1997) which establishes the authority of the Canadian Nuclear Safety Commission (CNSC). Under this Act, the CNSC has published a number of regulations relating to the use, transportation, and security of radioactive substances. Although the DGR must comply with all regulations, the regulations most applicable to this report are the Radiation Protection Regulations (SOR/2000-203) which define effective dose limits (shown in Table 4.1).

In addition to the Canadian regulatory requirements, international bodies, notably the International Atomic Energy Agency (IAEA) and the International Commission on Radiological Protection (ICRP), produce guidance and recommendations which represent industry-recognized best practice. Significant to radiological protection is ICRP 60 (ICRP 1991), which is the source of the dose limits in the Radiation Protection Regulations, and IAEA Safety Reports Series 21 (IAEA 2002) which provides a framework for optimization of Radiation Protection.

Table 4.1: CNSC Effective Dose Limits from Radiation Protection Regulations

Person	Period	Effective Dose (mSv)
NEW, including a pregnant NEW [a]	One-year dosimetry period	50
	Five-year dosimetry period	100
Pregnant NEW	Balance of pregnancy	4
A person who is not a NEW	One calendar year	1

a - NEW – Nuclear Energy Worker

Further to the numerical limits, the Radiation Protection Regulations require every licensee to “keep the amount of exposure to radon progeny and the effective dose and equivalent dose received by and committed to persons as low as reasonably achievable (ALARA), social and economic factors being taken into account, through the implementation of:

- Management control over work practices;
- Personnel qualification and training;
- Control of occupational and public exposure to radiation; and
- Planning for unusual situations”.

The CNSC have issued the regulatory guide G-129 (CNSC 2004) to assist licensees in demonstrating that their process is ALARA. The ALARA assessment of the DGR project reported here has been completed following the principles set out in this guide.

4.2 OPG Management Control over Work Practices

4.2.1 Dose Requirements

The Nuclear Safety and Control Act and other federal and provincial regulations are implemented at OPG via the OPG Radiation Protection Requirements (RPRs) (OPG 2001). The RPRs cover design, construction, operation, maintenance and decommissioning of all OPGs nuclear facilities and equipment including the use of radioactive materials for any purpose within the corporation. Adherence to the RPRs ensures compliance with regulatory requirements.

Some design-relevant dose rate limits from these RPRs are:

- ≤0.5 μSv/h average gamma dose rate in a Zone 1 area (Sec 4.7.1.1, OPG 2001);
- ≤10 μSv/h average gamma dose rate in an accessible area (Sec 4.7.1.2, OPG 2001); and
- ≤25 μSv/h gamma dose rate outside a long-term storage structure (Sec 4.7.2.1, OPG 2001).

4.2.2 Occupational Individual Dose Targets

In order to ensure that the regulatory dose limits are not exceeded, OPG has defined Exposure Control Limits (ECLs) and Administrative Dose Limits (ADLs) in its “Dose Limits and Exposure Control” procedures (OPG 2006a). Adherence to these levels and limits maintains control on personal dose when working in a radiation area. ECLs are set lower than ADLs to alert employees and supervisors that dose control measures are required to ensure that the ADLs are not exceeded. OPG’s ECLs and ADLs are presented in Table 4.2 and Table 4.3, respectively.

These procedural mechanisms effectively set upper limits on the maximum dose (<20 mSv) and the target dose (<10 mSv) that an individual may receive in a year.

Table 4.2: OPG Exposure Control Levels

Organ or Tissue	NEW	Pregnant NEW mSv/balance of pregnancy	Nursing NEW mSv/CY for balance of nursing	Non-NEW (Public) (mSv/CY)
Whole Body (Effective Dose) including tritium committed dose	10 mSv/Calendar Year (CY)	0.10	10	0.10

Table 4.3: OPG Administrative Dose Limits

NEW or NON-NEW	Whole Body Dose Limits in OPG (mSv/CY)		
	Nuclear Part D & G Employees*	**Other OPG Employees**	**Contract and Building Trades Union Employees**
NEW	20	20	40
NEW with lifetime Whole Body Dose greater than 500 mSv	10	10	N/A
Non-NEW	0.5	0.5	0.5
	Whole Body Dose Limits (mSv/rolling 5 CY)		
NEW	50	90	90

* Part D refers to technical and clerical staff. Part G refers to operating and maintenance employees, and control, chemical, radiation control, planning and training technicians.

4.2.3 Occupational Collective Dose Benchmark

Since the wastes handled at the WWMF are the same as those that will be handled at the DGR, the measured doses at the WWMF are a useful benchmark for the doses at the DGR. The two facilities are performing similar operations – handling and storage of LLW and ILW. However, differences in total volume of wastes handled should be taken into account.

Table 4.4 shows the annual collective doses reported in the Quarterly Operations Reports of OPG's WWMF (OPG 2005-2009). These collective doses include the dose from the Used Fuel Dry Storage Facility, but these are expected to be a small component of the total dose. That is, the collective doses are primarily due to L&ILW handling, maintenance, and storage activities.

Table 4.4: Annual Collective Dose at the Western Waste Management Facility

Year	2005	2006	2007	2008	2009	Average
Annual Collective Dose (p-mSv)	22.78	18.00	16.04	21.11	6.37	16.86
Total Volume of Waste Stored (m^3)	4575	2538	3530	4492	3300	3687
Collective Dose per Volume Stored (p-mSv/m^3)	0.0050	0.0071	0.0045	0.0047	0.0019	0.0046

Based on Table 4.4, the average annual dose per volume of waste handled at WWMF is 0.0046 p-mSv/m^3. Since the operations of the DGR are similar to those at WWMF, this can be considered as a benchmark for the DGR dose estimate. Based on the average annual volume emplaced in the repository in the emplacement period considered in this ALARA estimate, the corresponding benchmark dose estimate for the DGR is given in Table 4.5.

Table 4.5: Benchmark Collective Dose at DGR Based on WWMF Experience

	Over a 10-year Initial Emplacement Period (2018-2027)
Total Volume Emplaced (m^3/year)	12,000
Benchmark Collective Dose (p-mSv/year)	55

Therefore, based on WWMF experience, the annual doses from the DGR are estimated to be around 55 p-mSv per year for a 10-year emplacement period. While this estimate does not take into account differences in decay of package radioactivity with time, and specific differences in operations and package handling, it provides a benchmark estimate of the DGR occupational annual collective dose for comparison with the calculated DGR collective dose provided later in this report.

4.3 OPG Personnel Qualification and Training

OPG has developed and implemented a training program to provide Nuclear Waste Management personnel with the knowledge, skills and expertise necessary to meet the performance requirements of their jobs.

The main objective of the training program is to provide sufficient qualified personnel to operate and maintain the nuclear waste facilities in a safe and efficient manner and to ensure compliance with applicable regulations, operating licences and established operational limits.

The skill, knowledge and expertise of Nuclear Waste Management personnel are developed by initial training; and job performance is maintained and improved by requalification or refresher training. A training plan is developed for each occupation using a systematic approach. The training plan identifies what training is needed to meet the skill and knowledge requirements of the position and allows the supervisor to determine the training each employee needs to take on an annual basis.

The overall training program and its individual elements are periodically assessed. The training program is periodically updated to reflect the results of program evaluations, internal and external operating experiences and changes to equipment, procedures, and regulations (OPG 2006b).

5. OVERALL WASTE MANAGEMENT APPROACH

The ALARA assessment approach relies on estimates of dose rate from waste packages and on the current understanding of activities performed by workers during transport, handling, and emplacement.

At the present stage of the DGR design, there is no firm schedule for package emplacement into the DGR. In order to prepare an initial ALARA assessment, a reference waste handling schedule was therefore assumed. This schedule is summarized in Appendix A. This is a reasonable schedule in that it transfers most of the existing WWMF wastes into the DGR over an initial 10-year period, and then transfers over the more complex WWMF waste packages as well as ongoing station wastes. In this schedule, the high volume of waste handling in the early years of DGR operation (i.e., less time for decay at WWMF) will likely lead to a higher estimate of DGR worker annual doses. Therefore, it provides a useful initial DGR ALARA dose estimate.

In order to calculate the worker doses, it is necessary to know the reference waste packages, radionuclide content and their handling logistics. Waste package inventories are needed, rather than waste package dose rates, in order to calculate the variation in dose rates with distance and with various shielding and other mitigation options, since the dose rates depend on the gamma radiation spectrum of the specific wastes. Section 5.1 describes how inventories in the representative waste packages are determined and Section 5.2 describes the waste handling logistics and staffing model.

5.1 Waste Package Radionuclide Content

As noted in Section 2.2, for each of the four waste package groups defined by the PSR (Chapter 6, OPG 2011), two representative waste packages were selected for the ALARA assessment: a high-volume waste package, and a lower-volume and generally higher-dose-rate package. The eight representative waste packages are shown in Table 2.1.

Furthermore, for each such package, a reference radionuclide inventory was estimated. All packages are present in a range of dose rates, reflecting both the variability in their initial radionuclide content, as well as the amount of time for decay before arrival at the DGR. For ALARA purposes, the corresponding waste package dose rates are intended to be representative, rather than bounding. Nonetheless, the dose rate values selected tended to be more conservative.

For the present ALARA calculations, the inventories in the representative waste packages were determined as follows:

1. Adopt the "as-received at WWMF" reference specific activities, as placed into the reference waste packages, described in OPG (2010). These "as-received at WWMF" specific activities are a somewhat conservative summary of the radioactivity (Bq/m^3) in various standard waste types received at WWMF.
2. Scale the inventories as necessary to define a representative waste package dose rate.
3. Decay-correct the inventories to account for the typical time delay from receipt at WWMF to transfer to the DGR.

The vast majority of the LLW bins are at a low to very low dose rate level. These are represented by the Non-Processible Boxed waste in NPB47 bins, with the as-received inventories scaled to 0.01 mSv/h at contact. This dose rate corresponds approximately to the 80^{th} percentile dose rates of as-received LLW bins at WWMF according to OPG (2010,

Table 4.3), and a higher percentage when taking credit for decay at WWMF before shipping to the DGR.

A very small number of LLW waste packages are at a relatively high dose rate, around 1 to 2 mSv/h. The higher dose rate LLW waste packages are represented by non-processible Feeder Pipes in the NPHC bin, decayed by 15 years. From the as-received dose rates (Table 4.3, OPG 2010) and allowing for some decay before shipping to DGR, these represent about 2% of the LLW bins.

In some cases where the waste package is not yet designed, an approximate package design basis was defined that was consistent with up to 2 mSv/h at contact. Waste packages were assumed to be at this value, without taking credit for decay or actual dose rate distributions. In other cases, credit was taken for up to 15 years of decay at WWMF before shipment to DGR, to reflect the typical age of wastes at WWMF by the time the DGR is in service, as well as to ensure that contact dose rates were within 2 mSv/h.

The highest dose rate waste forms are the retube wastes, irradiated core components, and high dose resins. These would be in robust "Group D" packages, and would generally be allowed time for decay prior to transfer to the DGR. In this assessment, these are represented by Retube Waste (End Fittings) and CANDECON resins in shielded waste containers.

The dose rates at the waste package exterior as shipped to DGR during its 10-year initial emplacement period are shown in Table 5.1. The inventories in the representative waste packages as shipped to DGR are provided in Appendix B. (The dose rates from the waste package exterior as-received at WWMF are also provided in Appendix B.)

5.2 Waste Handling Logistics and Staffing Model

The general steps of waste handling, transfer and emplacement of waste packages were described in Section 2.3. However, in order to estimate the dose rates to staff at the DGR, a detailed reference schedule and staffing model is required. This needs to include:

- Rate of waste package handling;
- Waste handling activities for each waste package group;
- Estimated number of workers required to complete each activity;
- Position and distance of worker relative to the waste package(s); and
- Estimated time of exposure of a worker performing a specific activity.

The following activities were considered in the staffing model:

- Surface facility activities;
- Shaft operation activities;
- Underground facility activities; and
- Facility operations and maintenance activities.

The staffing models and waste handling logistics parameters were derived and estimated based on the facility design (Chapter 6, OPG 2011) and from experience handling similar packages at the WWMF.

Table 5.1: Representative Waste Package Dose Rates for a 10-year Initial Emplacement Period

Group	Container Type	Waste Category	Effective Dose Rate at Contact [a] (mSv/h)	Effective Dose Rate at 1 m [a] (mSv/h)	Condition for Radionuclide Inventories [c]
A	NPB47	Non-Processible	0.010	0.0020	Scale to 0.01 mSv/h at contact because ~80% of LLW bins are less than 0.01 mSv/h at contact on receipt [b]
	NPHC	Feeder Pipes	1.8	0.31	Decay as-received inventory by 15 years.
B	HX	Heat Exchangers	0.0054	0.0021	Decay WWMF as-received inventories for 10 years
	SPC	Shield Plugs	1.6	0.96	Decay as-received Co-60 inventory by 15 years
C	ILWSHLD	Filter and Filter Elements	2.0	0.42	As-Received, Maximum contact dose rate
	RLSS	CANDECON Resin	2.0	0.45	Scale as-received inventories to 2 mSv/h at contact.
D	RWC(EF)	End Fittings	0.19	0.13	Decay WWMF as-received inventory by an additional 10 years (for a total of 15 years)
	RLSHLD1	CANDECON Resin	0.82	0.40	As-Received, placed in RLSHLD1 overpack

a - Effective Dose Rate for ICRP 74, Antero-posterior Geometry.
b - PSR Chapter 5, OPG 2011.
c - The conditions for the radionuclide inventories were applied to the as-received inventories at WWMF as defined in Reference Inventory Report (OPG 2010).

In addition to direct exposure during package handling, workers will be exposed to background radiation through various maintenance and support activities. This is limited to regular activities that would be conducted in the presence of waste packages, and therefore does not include a variety of other maintenance activities that would occur under zero or low dose rate conditions.

The staffing model for waste handling, transfer and emplacement of waste packages in each waste package group and facility maintenance activities are provided in Appendix C.

As a preliminary estimate (NWMO 2010), there will be approximately nine Full-Time-Equivalent (FTE) staff for the waste package activities at the DGR. However, the actual number of workers in the DGR has not been finalized. It should be noted that the general practice will be for work activities to be shared by workers; therefore, the individual dose was estimated by dividing the total dose per workgroup by the number of staff in each workgroup. There will also be switching of work teams between above and underground activities.

A brief job description for each workgroup, specific work activity, and number of staff for each workgroup is provided in Table 5.2.

Table 5.2: Job Descriptions

Workgroup	Number of Workers (FTEs)	Specific Work Activity	Job Description
Waste Handling/ Surface	3	Worker	The activities performed by the worker include: removal of tie-downs on waste package, attaching lifting hooks to waste package, lid removal, lid fastening, etc.
		Forklift Driver	The forklift operator operates the light- and heavy-duty forklifts.
		Spotter	The spotter helps equipment operators (forklift and overhead crane) when moving waste packages.
		Inspector	The inspector does the QA check and barcode reading on the waste packages once they arrive at the WPRB. The inspector also performs an external dose measurement and checks background radiation fields.
		Operator/Crane	The operator controls equipment used to move waste packages such as the overhead crane.
Waste Handling/ Surface	1	Cage Tender	The cage tender at the surface transfers the rail cart into the cage and secures the rail cart.
Waste Handling/ Underground	4	Worker	The activities performed by the worker include: removal of tie-downs on waste package, attaching lifting hooks to waste package, etc.
		Forklift Driver	The forklift operator operates the light and heavy-duty forklifts.
		Spotter	The spotter helps equipment operators (forklift, rail cart, gantry crane) when moving waste packages.
		Operator	The operator controls equipment used to move waste packages such as the gantry crane as well as cage tending activities.
		Cage Tender	The cage tender in the underground facility releases the rail cart from the cage.
Waste Handling/ Surface	1	Control Room Operator	The operator controls and co-ordinates waste handling activities.
Total	**9**		

6. OCCUPATIONAL DOSE ESTIMATES

This chapter describes the estimated external dose rates for workers, the dose rates at the facility and site boundaries, and the inhalation dose rates for workers. The details of the shielding calculations methodology are provided in Appendix B and the detailed dose rate results are provided in Appendix C.

MicroShield Version 8.02 (Grove Software 2009) was used to perform the external dose rate calculations. MicroShield is a comprehensive photon/gamma ray shielding and dose assessment program that is widely used for designing shielding, estimating source strength from radiation measurements, minimizing exposure to people, and teaching shielding principles. The main purpose of MicroShield is to estimate the direct exposure rate for simple geometries. The waste packages in the DGR are cylindrical or rectangular, which are geometries that are available in the list of standard configurations in MicroShield.

6.1 External Dose Rate Estimates for Workers

6.1.1 Individual Dose Estimate

The results of the ALARA assessment are summarized in Table 6.1. This shows the breakdown of individual external doses per workgroup for waste handling activities for the 10-year initial emplacement period.

In addition to these package-specific activities, the workers will be exposed via inhalation and ambient external radiation (direct waste package handling accounts for about 10% of their working time). The inhalation doses are discussed in Section 6.3. The inhalation pathway contributes to the total dose but is small relative to the package handling dose. Similarly, other ambient external doses are not expected to be large contributors to dose since packages are not normally stored in routine worker access areas. The emplacement rooms will have shielding end walls if they contain high dose packages, and the rooms will be filled farthest first to minimize exposure during transit. Thus, these preliminary ALARA recommendations are mainly driven by the external doses from waste handling activities.

The forklift drivers (above-ground and underground) receive the highest doses. These workers receive the highest doses because of they spend the most time close to the waste package(s). As shown in Table 6.1, the majority of the dose is received while working underground and in particular while emplacing packages in rooms (see Appendix C). The underground forklift driver is the only specific work activity for which the preliminary estimate of individual dose is above OPG’s Exposure Control Limit of 10 mSv/year, although within the CNSC regulatory limit. The subsequent discussion provides guidance on mitigation measures by which the actual dose will be within the OPG dose limits.

Table 6.1: Breakdown of Annual Average Doses to the Waste Handling Workgroup for the 10-year Emplacement Period

			10-year Initial Emplacement Period (2018-2027)		
Workgroup	**Specific Work Activity**	**Number of Workers (FTE)**	**Average Collective Dose (p-mSv/year)**	**Average Individual Dose per Worker per Work Activity (mSv/year)**	**Total Hours per Year Direct Waste Package Handling**
Waste Handling/ Surface	Forklift Driver	3	10.4	3.5	227.7
	Crane/Operator		0.003	0.001	0.4
	Spotter		0.8	0.3	7.1
	Worker		0.9	0.3	5.0
	Inspector		8.4	2.8	98.8
	Total	**3**	**20.4**	**6.8**	**338.9**
Waste Handling/ Surface	Cage Tender	1	2.4	2.4	89.3
	Total	**1**	**2.4**	**2.4**	**89.3**
Waste Handling/ Underground	Cage Tender	4	2.4	0.6	89.3
	Forklift Driver		71.6	17.9	968.7
	Crane/Operator		0.05	0.01	0.4
	Spotter		27.3	6.8	177.9
	Worker		0.6	0.1	3.3
	Total	**4**	**102.0**	**25.5**	**1239.6**
Waste Handling/ Surface	Control Room Operator	1	<1 [a]	<1	200
	Total	**1**	**<1 [a]**	**<1**	**200**
	Grand Total	**9**	**125.8**	**-**	**1867.8**

a – Expected to be low. Control room location and shielding not finalized, so specific estimate not available.

6.1.2 Collective Dose Estimate

The collective dose to workers handling the waste packages was estimated at 126 p-mSv for waste package handling activities alone, and 137 p-mSv including maintenance and support activities (Table 6.2). This is higher than the collective dose benchmark for the DGR of 55 p-mSv based on WWMF experience (Table 4.5).

The annual collective dose contribution from each waste package group is shown in Table 6.2.

Table 6.2: Annual DGR Collective Dose Summary per Waste Package Group

Waste Package Group	10-year Initial Emplacement Period (2018-2027) (p-mSv/year)	Basis for Doses
A – LLW Bin Type Waste	18.4	Sum of Table C.2 and Table C.3
B - Heavy Non-Forkliftable	1.7	Sum of Table C.4 and Table C.5
C - Light Forkliftable	88.0	Sum of Table C.6 and Table C.7
D - Heavy Forkliftable	16.7	Sum of Table C.8 and Table C.9
Control Room Operator	<1 [a]	
Subtotal	*125.8*	
Facility Maintenance and Support Activities	11.2	See Table C.10
Total	*137.0*	

a – Expected to be low. Control room location and shielding not finalized, so specific estimate not available.

From Table 6.2, the Light Forkliftable (Group C) contributes most (70%) of the total annual collective dose because of the number of packages handled and the higher external dose rate per waste package. It is worth noting that the largest dose contributor is the ILW Shield packages (representative waste package in Group C), a waste package not presently handled at WWMF, so the WWMF experience is not directly applicable. In this preliminary ALARA assessment, all these ILW Shield packages were assumed to be at a high dose rate.

Overall, since generally similar packages are handled at WWMF, and considering the likely conservatisms in this model, it is expected that the current assessment overestimates the dose rate. It is expected that that a lower collective dose closer to the benchmark dose is achievable for the DGR with more detailed analysis. This would include more detailed assessment of actual waste package dose rates, and possibly more detailed staffing and package handling models, and more detailed dosimetry modeling.

In addition, the dose can be reduced by taking into account other design options and operational control measures as discussed in Chapter 7.

6.2 Dose Rate Estimates at the Facility and Site Boundaries

As documented in the design basis and the preclosure safety assessment, the design meets the dose limit of 0.5 μSv/h at the DGR site boundary. Therefore, no specific assessment is presented in this preliminary assessment for hypothetical non-NEWs at the facility and site boundary and to members of the public, further away.

6.3 Inhalation Dose Rate Estimates for Workers

Off-gassing from waste packages during handling and storage will generate gases containing H-3 and C-14. Personnel will be exposed due to inhalation of these gases in both the above-ground and underground DGR.

The maximum concentrations of H-3 and C-14 in air inside the WPRB were calculated in Section 7.4 of the PSR (OPG 2011), assuming the maximum number of packages is constantly staged in the WPRB, and that these have high concentrations of H-3 and C-14. Assuming that these concentrations occur constantly, the resulting inhalation dose rate over 2000 hours is calculated to be 0.09 mSv/year (Table 6.3). Since these conditions are very conservative, the actual worker inhalation dose from this exposure will be much smaller.

Table 6.3: Estimated Maximum Concentrations of H-3 and C-14 in Air Inside the WPRB and Inhalation Dose Rate for 2000 h Occupancy

Maximum Concentration (Bq/m^3)		Total Dose Rate (mSv/year)
H-3	C-14	
863	193	0.09

Low levels of H-3 and C-14 may be present in the underground access tunnels and accessible areas of the emplacement rooms, but the air concentrations and therefore dose rates would be even lower than the above WPRB estimate since there would be fewer packages present and higher ventilation rates than assumed above (see Section 7.4 of the PSR, OPG 2011).

Higher levels would be present in the ventilation shaft. Facility maintenance staff may be exposed, in particular, a technician examining the condition of the ventilation shaft. The estimated concentrations of H-3 and C-14 in air in the ventilation shaft for the 10-year initial emplacement period (Chapter 7, OPG 2011) are shown in Table 6.4. These air concentrations were used to estimate the inhalation dose to the technician. The technician is estimated to be exposed for 256 hours per year.

Table 6.4: Estimated Maximum Concentrations H-3 and C-14 in Air in the Ventilation Shaft and Inhalation Dose for 256 h Occupancy

Concentration (Bq/m^3)		Total Dose (mSv/year)
H-3	C-14	
3912	544	0.05

These inhalation dose rates are small compared to the worker gamma doses received during direct package handling.

7. ELIMINATION, ABATEMENT AND CONTROL MEASURES

This chapter discusses measures that can help reduce the worker dose rates for the DGR.

7.1 OPG's General Radiation Protection Practices

OPG has general controls on worker dose through its Management Control Practices and Radiation Protection Procedures (RPPs) noted in Section 4.2. These provide requirements and guidelines, as well as recommendations/best practices for optimizing radiation protection in the control of radiation exposure. Key general measures for reducing doses are listed below.

- **Waste Container Design**

The primary control measure to reduce dose to workers is in the design of the waste containers which incorporate shielding. The waste containers are designed to reduce the external gamma radiation field from the waste to an acceptable level, sufficient to ensure operability and maintainability of the DGR.

- **Equipment and Facility Design**

Additional equipment or facility shielding could be provided. Facility operational requirements as stated in OPG's RPRs include access control, signage, contamination control, hazard detection, monitoring and alarms. For example, the use of Electronic Personal Dosimeters (EPDs) will be implemented.

- **Reducing the Exposure Time**

The DGR package handling areas are mostly unoccupied except for the duration of the delivery of items to be emplaced. The procedures for the handling, stacking and placement of waste packages within the buildings and emplacement rooms will minimize worker contact with the waste to reduce radiation exposure and the risk of personal contamination. Facility and equipment inspection and maintenance procedures can be designed to minimize exposure and the proximity of workers to the stored waste packages.

- **Increasing the Distance**

Increasing the distance from waste packages, where practical, is a common method used to decrease dose. This can be ensured by imposing physical barriers and providing the necessary tools to complete the required task at a safe distance. Tasks will be typically performed at the greatest reasonable distance.

- **Reducing the Number of Non-Essential Workers**

Activities are generally performed by a maximum of two workers; the second worker is mostly required to act as a guide or spotter (e.g., for the underground forklift driver in the emplacement rooms). For the proposed design, not using a second worker in such cases to guide the operator represents a greater risk than that from an increased collective dose to workers.

- **Optimizing Work Procedures**

Further reduction of dose rates is afforded by work procedures, including monitoring, to ensure no loose contamination and that the dose rates are within acceptable values. Eliminating loose contamination eliminates the potential for dose from inhalation or ingestion of the contaminants. This is most efficiently achieved by performing contamination checks on waste packages, decontamination and zoning.

- **Specialized Training**

All workers in the DGR will receive specific training, so that their tasks can be performed efficiently and safely. For example, forklift drivers that are trained will take less time to place waste packages in the proper location, thus reducing their dose.

7.2 Identification of Opportunities for Dose Reduction

The following activities/waste package groups contribute significantly to occupational dose. They are flagged as priorities for identifying opportunities for dose reduction.

- Key waste package group - Light Forkliftable (C).
- Key activities - Forklift Driver.

7.3 Initial Recommendations for Dose Reduction for the DGR

The general measures described in Section 7.1 are all potential areas for ALARA dose-reduction. The following specific measures could be implemented to reduce DGR dose:

- **Waste Container Design**

The primary contributors to occupational dose are the ILW shield containers, which have not yet been designed. Therefore, there is an opportunity to reduce individual and collective occupational dose by optimizing the detailed design of these waste containers. The same opportunities exist for other waste containers which have not yet been designed.

- **Equipment and Facility Design**

The light-duty forklift can be equipped with a shield to protect the driver. In the following illustrative assessment, the effects of 2.54 cm (1 inch) iron, lead and lead glass shielding are considered. In terms of dose rate reduction, lead provides the greatest dose rate reduction, followed by iron and lead glass. Iron and lead are opaque and would obstruct the view of the driver; however, a second worker (spotter) can be used as necessary to act as a guide, and may be necessary regardless since some packages are large and may block the driver's view.

The collective and individual doses to forklift drivers driving a shielded light-duty forklift are shown in Table 7.1. The dose rate reduction factor the materials considered for a shielded light-duty forklift are also shown in Table 7.1.

Additional shielding could also be added, or incorporated into the walls, around package staging areas in the WPRB. The staging area could be moved away from the control room location.

- **Increasing the Distance**

If practical, a heavy-duty forklift which has a greater distance (2 m compared to 1 m for a light-duty forklift) between the driver and the load can be used.

The collective and individual doses to the forklift drivers at increased distance from the waste packages are shown in Table 7.2. The dose rate reduction factor obtained by increasing the distance between the driver and the load is also shown in Table 7.2.

- **Optimizing Work Procedures**

There will be variability in dose rates within waste packages. It is recommended that waste packages with relatively high dose rates be emplaced at the far end of the emplacement room or WPRB staging area, so that they are shielded by lower dose rate packages at the front of the room. This is current practice at WWMF, but was not credited in this ALARA assessment.

Table 7.1: Effect of Shielding on Doses - Forklift Handling of Group C Packages

Location	Specific Work Activity	Dose Type	Base Case	Shielded Forklift, 2.54 cm Iron	Shielded Forklift, 2.54 cm Lead	Shielded Forklift, 2.54 cm Lead Glass
Surface	Forklift Driver	Average Collective Dose (p-mSv/year)	7.3	1.8	1.0	2.5
		Individual Dose (mSv/year)	2.4	0.6	0.3	0.8
		Dose Rate Reduction Factor	-	4.1	7.6	2.9
Under-ground	Forklift Driver	Average Collective Dose (p-mSv/year)	46.8	10.8	5.7	15.0
		Individual Dose (mSv/year)	11.7	2.7	1.4	3.7
		Dose Rate Reduction Factor	-	4.4	8.2	3.1

Table 7.2: Effect of Increased Distance on Doses – Forklift Handling of Group C Packages

Location	Specific Work Activity	Dose Type	Base Case (1 m Distance)	2 m Distance
Surface	Forklift Driver	Average Collective Dose (p-mSv/year)	7.3	2.8
		Individual Dose (mSv/year)	2.4	0.8
		Dose Rate Reduction Factor	-	2.6
Underground	Forklift Driver	Average Collective Dose (p-mSv/year)	46.8	24.1
		Individual Dose (mSv/year)	11.7	6.0
		Dose Rate Reduction Factor	-	1.9

8. SUMMARY AND RECOMMENDATIONS

A preliminary ALARA assessment for the DGR was prepared. The results were based on conservative assumptions and on a preliminary design, such that they will be updated when a more detailed design becomes available. This report assesses all activities beginning with waste receipt in the WPRB to final emplacement in the repository.

According to this assessment, the collective dose to waste package handling workers was estimated to be 126 p-mSv/year. The preliminary calculated individual dose estimate is 14 mSv/year, based on a waste package handling work crew of nine FTEs. While this is within CNSC worker dose limits and OPG's internal Administrative Dose Limits, it exceeds OPG's Exposure Control Level of 10 mSv/year. Measures would be taken to prevent this exposure from occurring.

It is expected that lower doses can be achieved. Specifically, the preliminary DGR collective dose estimate is higher by a factor of 2 than the 55 p-mSv/year that was derived by scaling from the WWMF, where generally similar packages are currently handled. This suggests that the modelling is conservative and lower dose estimates may be achieved using a more realistic analysis.

From a specific worker activity perspective, the highest estimated dose rate is for the underground forklift driver. Much of the dose is received while working in emplacement rooms. From a waste package perspective, the Light Forkliftable (Group C) waste packages contribute the most to worker dose, and especially the high-volume ILW Shield packages.

These indicate that effective design and operational control measures to reduce worker doses could include: further evaluation of the ILW Shield package design; placement of packages to avoid concentrations of high dose packages especially at the front of rooms; and possibly use of shielding or increased distance for forklift operators.

Doses are expected to be ALARA due to design measures developed using an iterative design approach and through the use of administrative controls and procedures that will be in place during the operational phase.

9. REFERENCES

CNSC. 2004. Keeping Radiation Exposures and Doses ‘As Low as Reasonably Achievable (ALARA)’. Canadian Nuclear Safety Commission. Guidelines G-129., Rev.1. Ottawa, Canada.

Grove Software, Inc. 2009. MicroShield Version 8.02. Lynchburg, USA.

IAEA. 2002. Optimization of Radiation Protection in the Control of Occupational Exposure. International Atomic Energy Agency, Safety Reports Series No.21. Vienna, Austria.

ICRP. 1991. 1990 Recommendations of the ICRP. Publication 60. Annals of the ICRP Vol 21. No 1-3. Pergamon Press. New York, USA.

NSCA. 1997. Nuclear Safety and Control Act, 1997, c.9. Canada.

NWMO. 2010. Data Clearance for Preclosure Safety Assessment. Nuclear Waste Management Organization Document DGR-REF-01929. Toronto, Canada.

NWMO. 2011. Radon Assessment. Nuclear Waste Management Organization Report NWMO DGR-TR-2011-34 R000. Toronto, Canada.

OPG. 2001. Radiation Protection Requirements-Nuclear Facilities. Ontario Power Generation Document N-RPP-03415.1-10001-R07. Toronto, Canada.

OPG. 2005-2009. Nuclear Waste Management Division Western Waste Management Operations Quarterly Operations Ontario Power Generation. Report Series. W-REP-00531.1-00031-R000 to W-REP-00531.1-00054-R000. Toronto, Canada.

OPG. 2006a. Dose Limits and Exposure Control. Ontario Power Generation Procedure N-PROC-RA-0019 R004. Toronto, Canada.

OPG. 2006b. Western Waste Management Facility Safety Report. Ontario Power Generation Report W-SR-0.1320-00001 R01. Toronto, Canada.

OPG. 2010. Reference Low and Intermediate Level Waste Inventory for OPG’s Deep Geologic Repository. Ontario Power Generation Report 00216-REP-03902-0003-R0003. Toronto, Canada.

OPG. 2011. Deep Geologic Repository for Low and Intermediate Level Waste – Preliminary Safety Report. Ontario Power Generation Report 00216-SR-01320-00001 R000. Toronto, Canada.

SOR/2000-203. Radiation Protection Regulations, SOR/2000-203. Canada.

10. UNITS

Bq	becquerel
h	hour
m	metre
m^3	cubic metres
mSv	millisievert
μSv	microsievert
p-mSv	person-millisievert

11. ABBREVIATIONS AND ACRONYMS

ADLs	Administrative Dose Limits
ALARA	As Low As Reasonably Achievable
C-14	Carbon-14
CNSC	Canadian Nuclear Safety Commission
CY	Calendar Year
DGR	Deep Geologic Repository
ECLs	Exposure Control Limits
EIS	Environmental Impact Statement
EPDs	Electronic Personal Dosimeters
FTE	Full-Time-Equivalent
H-3	Tritium
HX	Heat Exchanger
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ILW	Intermediate Level Waste
ILWSHLD	ILW Shield
L&ILW	Low and Intermediate Level Waste
LLW	Low Level Waste
NEWs	Nuclear Energy Workers
NPB47	Non-Pro Bin, 47" High
NPHC	Non-Pro High Capacity
OPG	Ontario Power Generation
PSR	Preliminary Safety Report
RLSS	Stainless Steel Resin Liner
RPRs	Radiation Protection Requirements
SPC	Shield Plug Container
RLSHLD1	Resin Liner - Shield 1

RWC(EF)	Retube Waste Container (End Fittings)
WPRB	Waste Package Receiving Building
WWMF	Western Waste Management Facility

APPENDICES

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APPENDIX A: REFERENCE SCHEDULE

The operation of the DGR will span a period of about 40 years. A plan for the transfer of packages will be drawn up prior to commencement of emplacement operations, which will take into account the storage locations and accessibility of the packages at the WWMF and the requirements for emplacement underground, so that groups of packages are delivered to the DGR efficiently.

At the present stage of the DGR design, there is no firm schedule for package emplacement into the DGR. In order to prepare an initial ALARA assessment, a reference waste handling schedule was therefore assumed. This schedule is summarized in Table A.1 (NWMO 2010). This is a reasonable schedule in that it transfers most of the existing WWMF wastes into the DGR over an initial 10-year period, and then transfers over the more complex WWMF waste packages as well as ongoing station wastes. In this schedule, the high volume of waste handling in the early years of DGR operation (i.e., less time for decay at WWMF) will likely lead to a higher estimate of DGR worker annual doses. Therefore, it provides a useful initial DGR ALARA dose estimate.

The nominal reference schedule of waste packages that will be delivered to the DGR for the 10-year initial emplacement period is summarized in Table A.1.

Table A.1: Summary of Waste Packages Received to DGR in Reference Schedule

Waste Package Group	10-year Initial Emplacement Period (2018-2027)
	Number of Waste Packages Delivered per Year
A – LLW Bin Type Waste	3000
B - Heavy Non-Forkliftable	5
C - Light Forklift	180
D - Heavy Forkliftable	100
Total Volume Emplaced (m^3/year)	12,000

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APPENDIX B: SHIELDING CALCULATIONS AND METHODOLOGY

This appendix provides the methodology used to determine the inputs for the MicroShield shielding calculations in the ALARA assessment. This includes:

- Methodology to estimate inventories for selected wastes; and
- Reference container geometries.

B.1 Methodology to Estimate Inventories

This section describes the methodology to determine the inventories for the representative waste packages emplaced in the 10-year initial emplacement period (2018-2027) considered in this preliminary ALARA assessment.

B.1.1 Methodology

The reference waste radionuclide-specific activities for the selected wastes were the as-received specific activities in Tables B.1 to B.3 of the Inventory Report (OPG 2010). Table B.2 shows the method that was used to adjust the as-received specific activities according to the conditions for the selected waste packages.

Table B.2: Methodology Used to Adjust As-Received Specific Activities

Waste Package Group	Container (Waste)	Conditions for 10-year Initial Emplacement Period (2018-2027)	Rationale
A - LLW Bin Type Waste	Non-Pro Bin, 47" High, NPB47 (Non-Processible)	Scale as-received inventories to 0.01 mSv/h at contact.	77% of LLW bins are less than 0.01 mSv/h at contact on arrival at WWMF (Table 4.3, OPG 2010); most will have decayed further by time of transfer to DGR.
	Non-Pro High Capacity, NPHC (Feeder Pipes)	Decay as-received inventories by 15 years.	Represents the small percentage of higher-dose LLW bins. Packages from WWMF will have at least 15 years of decay prior to emplacement in the DGR.
B - Heavy Non-Forkliftable	Heat Exchanger, HX (Non-pro other)	Decay as-received inventories by 10 years.	Packages will come from the WWMF and will have had at least 10 years to decay prior to emplacement in DGR
	Shield Plug Container, SPC (Shield Plugs)	Decay as-received Co-60 inventory by 15 years.	Detailed inventory was not available, so all dose assumed to be from Co-60 since it is the dominant dose contributor for other steel components in same location such as End Fittings. The dose rate at contact based on the as-received inventory was assumed to be 11 mSv/h. The packages from WWMF will have at least 15 years to decay prior to emplacement in the DGR.
C - Light Forkliftable	ILW Shield, ILWSHLD (Filter and Filter Elements)	No Conditions (use as-received inventories).	No decay, since these containers come directly from the stations. Package design basis assumes maximum contact dose rate.
	Stainless Steel Resin Liner, RLSS (CANDECON Resin)	Scale as-received inventories to 2 mSv/h at contact.	Assumes these are unshielded resin liners at the maximum contact dose rate.
D - Heavy Forkliftable	Retube Waste, RWC(EF) (End Fittings)	Decay as-received inventories by 10 years (for a total of 15 years).	Package design basis is 0.1 mSv/h at 1 m to allow for transportation. Achieved in part by design and in part by decay.
	Resin Liner - Shield 1, RLSHLD1 (CANDECON Resin)	No Conditions (use as-received inventories)	As-received resin liners typically require shielding. This uses RLSHLD1 as the representative package.

B.1.2 Inventories of Representative Waste Packages

In order to carry out dose rate calculations, radionuclide-specific activities were defined for each of the eight representative waste packages. These were based on the as-received inventories defined in Tables B.1 to B.3 of the Inventory Report (OPG 2010). The as-received specific activities were adjusted according to the conditions for the selected waste packages in Table B.2. The radionuclides are those identified in the preclosure safety assessment, excluding some beta emitters that will not affect external dose (Chapter 7, OPG 2011). The adjusted specific activities for the selected waste packages in each waste package group are shown in Table B.3 to Table B.6.

Table B.3: Representative Group A Package Inventories

	Non-Pro Bin, 47" High, NPB47	Non-Pro High Capacity, NPHC
	Non-Pro Boxed [1]	Feeder Pipes [2]
Radionuclide	Bq/cm^3	Bq/cm^3
Am-241	2.85E-02	9.37E+00
Ce-141	0.00E+00	0.00E+00
Ce-144	0.00E+00	4.71E-03
Cm-244	5.12E-04	2.13E+00
Co-60	1.30E+00	1.97E+03
Cs-134	1.95E-02	2.41E-01
Cs-137+Ba-137m	5.06E+01	1.84E+02
Eu-152	0.00E+00	0.00E+00
Eu-154	0.00E+00	1.78E+01
Fe-59	0.00E+00	0.00E+00
Gd-153	0.00E+00	0.00E+00
La-140	0.00E+00	0.00E+00
Mn-54	0.00E+00	0.00E+00
Nb-94	0.00E+00	0.00E+00
Nb-95	0.00E+00	7.95E-45
Pb-210	1.95E-01	0.00E+00
Pu-238	3.50E-04	2.75E+00
Pu-239	6.49E-04	5.80E+00
Pu-240	9.73E-04	7.99E+00
Pu-241	3.50E-02	6.19E+01
Ra-226	5.32E-03	0.00E+00
Sb-124	0.00E+00	0.00E+00
Sb-125	5.06E-02	2.44E+00
Sn-119m	0.00E+00	0.00E+00
Sr-90 + Y-90	9.73E-01	1.68E+03
Te-125m	0.00E+00	0.00E+00
Zr-95	0.00E+00	1.23E-22

1 - As-received inventories scaled down by a factor of 15 for 0.01 mSv/h at contact.
2 - As-received inventories decayed by 15 years.

Table B.4: Representative Group B Package Inventories

	Heat Exchanger (HX)	Shield Plug Container (SPC)
	Non-Pro Other [1]	Shield Plugs [2]
Radionuclide	Bq/cm^3	Bq/cm^3
Am-241	2.56E-02	-
Ce-141	0.00E+00	-
Ce-144	0.00E+00	-
Cm-244	5.38E-03	-
Co-60	5.41E+00	5.09E+04 [3]
Cs-134	1.11E-02	-
Cs-137+Ba-137m	7.14E+01	-
Eu-152	0.00E+00	-
Eu-154	0.00E+00	-
Fe-59	0.00E+00	-
Gd-153	0.00E+00	-
La-140	0.00E+00	-
Mn-54	0.00E+00	-
Nb-94	0.00E+00	-
Nb-95	0.00E+00	-
Pb-210	0.00E+00	-
Pu-238	4.99E-03	-
Pu-239	1.00E-02	-
Pu-240	1.50E-02	-
Pu-241	3.29E-01	-
Ra-226	0.00E+00	-
Sb-124	0.00E+00	-
Sb-125	6.56E-02	-
Sn-119m	0.00E+00	-
Sr-90 + Y-90	7.09E-01	-
Te-125m	0.00E+00	-
Zr-95	0.00E+00	-

1 - As-received inventories decayed by 10 years.
2 - As-received contact dose rate of 11 mSv/h (OPG 2010), decayed by 15 years.
3 - Detailed inventory not available, so all dose assumed to be from Co-60 since it is the dominant dose contributor for other steel components in same location such as End Fittings.

Table B.5: Representative Group C Package Inventories

	ILW Shield (ILWSHLD)	Unshielded Stainless Steel Resin Liner (RLSS)
	Filter and Filter Elements [1]	CANDECON Resin [2]
Radionuclide	**Bq/cm^3**	**Bq/cm^3**
Am-241	2.90E+01	4.87E+00
Ce-141	0.00E+00	3.65E+02
Ce-144	8.80E+01	1.07E+03
Cm-244	2.20E+02	2.08E+00
Co-60	4.50E+03	3.51E+03
Cs-134	0.00E+00	2.79E+01
Cs-137+ Ba-137m	3.00E+02	1.72E+02
Eu-152	0.00E+00	9.31E-01
Eu-154	0.00E+00	5.23E+01
Fe-59	0.00E+00	0.00E+00
Gd-153	0.00E+00	0.00E+00
La-140	0.00E+00	0.00E+00
Mn-54	0.00E+00	0.00E+00
Nb-94	6.70E+01	1.22E-01
Nb-95	1.30E+04	5.51E+02
Pb-210	0.00E+00	0.00E+00
Pu-238	9.70E+00	5.01E-01
Pu-239	1.30E+01	1.15E+00
Pu-240	1.90E+01	1.65E+00
Pu-241	2.50E+01	1.50E+02
Ra-226	0.00E+00	0.00E+00
Sb-124	7.80E+03	2.36E+02
Sb-125	2.20E+03	1.57E+02
Sn-119m	0.00E+00	0.00E+00
Sr-90 + Y-90	2.00E+02	1.79E+03
Te-125m	0.00E+00	0.00E+00
Zr-95	4.70E+03	1.15E+03

1 - As-received.
2 - As-received inventories scaled down by a factor of 14 to represent an unshielded resin liner at 2 mSv/h contact dose rate.

Table B.6: Representative Group D Package Inventories

	Retube Waste (RWC(EF))	Resin Liner - Shield 1 (RLSHLD1)
	End Fittings [1]	CANDECON Resin [2]
Radionuclide	Bq/cm^3	Bq/cm^3
Am-241	0.00E+00	6.80E+01
Ce-141	0.00E+00	5.10E+03
Ce-144	0.00E+00	1.50E+04
Cm-244	0.00E+00	2.90E+01
Co-60	1.27E+07	4.90E+04
Cs-134	8.48E+00	3.90E+02
Cs-137+Ba-137m	3.41E-04	2.40E+03
Eu-152	6.45E-11	1.30E+01
Eu-154	1.18E-08	7.30E+02
Fe-59	2.46E-30	0.00E+00
Gd-153	0.00E+00	0.00E+00
La-140	0.00E+00	0.00E+00
Mn-54	1.58E+02	0.00E+00
Nb-94	3.60E+02	1.70E+00
Nb-95	3.29E-37	7.70E+03
Pb-210	0.00E+00	0.00E+00
Pu-238	0.00E+00	7.00E+00
Pu-239	0.00E+00	1.60E+01
Pu-240	0.00E+00	2.30E+01
Pu-241	0.00E+00	2.10E+03
Ra-226	0.00E+00	0.00E+00
Sb-124	1.31E-21	3.30E+03
Sb-125	5.05E+03	2.20E+03
Sn-119m	2.07E+00	0.00E+00
Sr-90 + Y-90	4.88E-04	5.00E-04
Te-125m	2.30E-15	0.00E+00
Zr-95	1.42E-22	1.60E+04

1 - As-received inventories decayed by 10 years (for a total of 15 years).
2 - As-received.

B.2 Container Geometry

The container geometries used for the selected waste packages in each waste package group are shown in Table B.7. The Inventory Report was used as the main reference for the container dimensions. However, supplementary information and assumptions were also used when dimensions were not available.

Table B.7: Container Geometries

Waste Package Group	Container (Waste)	Container Name (Container Code)	Rectangular Volume				Cylinder Volume			Waste Volume (m^3)
			Outer Length (m)	Outer Width (m)	Outer Height (m)	Container Thickness (mm) (Material)	Outer Diameter (m)	Outer Height (m)	Container Thickness (mm) (Material)	
A – LLW Bin Type Waste	Non-Pro Bin, 47" high NPB47 (Non-Processible)	Non-Pro Container (47'' High) (NPB47)	1.96	1.32	1.19	2.8 (sheet metal)	-	-	-	2.5
	Non-Pro High Capacity* (Feeder Pipes)	Non-Pro High Capacity (NPHC)	1.96	1.32	0.91	2.6 (sheet metal)	-	-	-	2.3
B - Heavy Non-Forkliftable	Heat Exchanger (Non-pro other)	Heat Exchanger (HX)	-	-	-	-	1.83	4.57	15 (carbon steel)	11
	Shield Plug Container (Shield Plugs)	Shield Plug Box (SPC)	3.3	1.9	1.4	58 average (carbon steel)	-	-		7.4
C - Light Forkliftable	ILW Shield (Filter and Filter Elements)	ILW Shield (ILWSHLD)	-	-	-	-	1	1.7	3 (steel, inner), 55 (heavy concrete) + 3 (steel, outer)	0.25
	Unshielded Resin Liners, (CANDECON Resin)	Stainless Steel Resin Liner (RLSS)	-	-	-	-	1.63	1.80	6 (stainless steel)	3
D - Heavy Forkliftable	Retube Waste (End Fittings)	Retube End-Fitting Box (RWC(EF))	1.7	3.35	1.92	100 (inner) + 321 (middle) + 16 (outer) (steel-heavy concrete-steel)	-	-	-	2.7
	Resin Liner - Shield 1 (CANDECON Resin)	Resin Liner Shield1 (RLSHLD1)	-	-	-	-	2.2	4.25	6 (stainless steel) + 250 (concrete)	6

B.3 Waste Package Dose Rates

The dose rates from the waste package exterior using as-received specific activities are shown in Table B.8.

Table B.8: Waste Package Dose Rate Using As-Received Specific Activities

Group	Container	Waste	Effective Dose Rate at Contact [ab] (mSv/h)	Effective Dose Rate at 1 m [ab] (mSv/h)
A	NPB47	Non-Processible	0.2	0.030
	NPHC	Feeder Pipes	14 [c]	2.4 [c]
B	HX	Non-Pro Other	0.013	0.0049
	SPC	Shield Plugs	11 [d]	6.9
C	ILWSHLD	Filter and Filter Elements	2.0 [f]	0.4
	RLSS	CANDECON Resin	28 [e]	6.0
D	RWC(EF)	End Fittings	0.7	0.5
	RLSHLD1	CANDECON Resin	0.8	0.4

a - Effective Dose Rate for ICRP 74, Antero-posterior Geometry.
b - Dose rate estimated using as-received at WWMF specific activities for selected wastes from Reference Inventory report (OPG 2010).
c - Specific activity in Reference Inventory report is conservative (e.g. no decontamination).
d - These are high-dose-rate waste packages that were placed in trenches for shielding while stored at WWMF.
e - Reference CANDECON specific activity corresponds to typical CANDECON resins which would require shielding before transfer to DGR; the inventory is scaled here to represent the fraction of ILW IX resins that have low enough activity that they can be handled without shielding.
f - Reference shield indicated in Table B.7 was sized to limit these waste packages to 2 mSv/h contact.

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APPENDIX C: STAFFING MODELS AND DETAILED DOSE RATE RESULTS

As mentioned in Section 2.2, two representative waste packages were selected for each waste package group. In order to obtain a realistic dose estimate for each waste package group, a weighted average dose from the most frequent and from the radiologically hottest waste packages was determined for each step along the handling route. The weighting corresponds to their relative contribution to the emplacement frequencies within the waste package group (OPG 2010). The weighting factors for the two representative waste packages in each waste package group are shown in Table C.1.

The assumed staffing model and collective dose for waste handling, transfer and emplacement of waste packages in each waste package group are shown in Table C.2 to Table C.9. The staffing model for facility maintenance and support activities is shown in Table C.10.

Table C.1: Weighting Factors for Each Waste Package Group

Waste Package Group	Container (Waste)	Weighting Factor
A - LLW Bin Type Waste	Non-Pro Bin, 47" High (NPB47) / Non-Processible	0.98
	Non-Pro High Capacity (NPHC) / Feeder Pipes	0.02
B - Heavy Non-Forkliftable	Heat Exchanger (HX) / Non-Pro Other	0.79
	Shield Plug Container (SPC) / Shield Plugs	0.21
C - Light Forkliftable	ILW Shield (ILWSHLD) / Filter and Filter Elements	0.85
	Stainless Steel Resin Liner (RLSS) / CANDECON Resin	0.15
D - Heavy Forkliftable	Retube Waste (RWC(EF)) / End Fittings	0.58
	Resin Liner - Shield 1 (RLSHLD1) / CANDECON Resin	0.42

Table C.2: Staffing Model and Dose Rate Results for LLW Bin Type Waste (NPB47 - Waste Package Group A)

Location	Workgroup	Specific Work Activity	Activity	Number of Staff per Activity	Duration (min)	Average Frequency per Year (Years 2018-2027)	Distance (m)	Number of Packages per Activity	Effective Dose Rate [c] (mSv/h) (Years 2018-2027)	Average Collective Dose (p-mSv/year) (Years 2018-2027)
Surface	Waste Handling/ Surface	Inspector	Perform barcode reading	1	1	2940	1	1	1.831E-03	9.0E-02
Surface	Waste Handling/ Surface	Inspector	Perform QA check	1	5	294 [a]	1	1	1.831E-03	4.5E-02
Surface	Waste Handling/ Surface	Forklift Driver	Offload packages from delivery vehicle and transport to staging area with a light-duty forklift	1	2	2940	1	1	1.831E-03	1.8E-01
Surface	Waste Handling/ Surface	Forklift Driver	Pick up packages with light-duty forklift to place onto transfer cart	1	2	2940	1	2	2.805E-03	2.7E-01
Surface	Waste Handling/ Surface	Cage Tender	Cart transfer into cage and secure	1	3	1470	2	2	1.293E-03	9.5E-02
Shaft	-	-	Cage lowered to repository	-	-	-	-	-	-	-
Underground	Waste Handling/ Underground	Cage Tender	Release cart from cage	1	3	1470	2	2	1.293E-03	9.5E-02
Underground	Waste Handling/ Underground	Forklift Driver	Offload packages to emplacement room with a light-duty forklift	1	2	2940	1	2	2.805E-03	2.7E-01
Underground	Waste Handling/ Underground	Forklift Driver	Transport packages to emplacement room with light-duty forklift	1	12	2940	1	1	1.831E-03	1.1E+00
Underground	Waste Handling/ Underground	Forklift Driver	Emplace/Stack package with a light-duty forklift	1	3	2940	1	1 + 20 [b]	1.108E-02	1.6E+00
	Waste Handling/ Underground	Spotter		1	3	2940	3	1 + 20 [b]	4.772E-03	7.0E-01
										4.5E+00

a - 10% of packages are QA checked.
b - Doses in the emplacement room take into account the waste package on the light-duty forklift (1 NPB47) and the front face of the packages already emplaced (20 NPB47).
c - Effective dose rate for ICRP 74, antero-posterior geometry.

Table C.3: Staffing Model and Dose Rate Results for LLW Bin Type Waste (NPHC - Waste Package Group A)

Location	Workgroup	Specific Work Activity	Activity	Number of Staff per Activity	Duration (min)	Average Frequency per Year (Years 2018-2027)	Distance (m)	Number of Packages per Activity	Effective Dose Rate [c] (mSv/h) (Years 2018-2027)	Average Collective Dose (p-mSv/year) (Years 2018-2027)
Surface	Waste Handling/ Surface	Inspector	Perform barcode reading	1	1	60	1	1	2.694E-01	2.7E-01
Surface	Waste Handling/ Surface	Inspector	Perform QA check	1	5	6 [a]	1	1	2.694E-01	1.3E-01
Surface	Waste Handling/ Surface	Forklift Driver	Offload packages from delivery vehicle and transport to staging area with a light-duty forklift	1	2	60	1	1	2.694E-01	5.4E-01
Surface	Waste Handling/ Surface	Forklift Driver	Pick up packages with light-duty forklift to place onto transfer cart	1	2	60	1	2	4.004E-01	8.0E-01
Surface	Waste Handling/ Surface	Cage Tender	Cart transfer into cage and secure	1	3	30	2	2	1.878E-01	2.8E-01
Shaft	-	-	Cage lowered to repository	-	-	-	-	-	-	-
Underground	Waste Handling/ Underground	Cage Tender	Release cart from cage	1	3	30	2	2	1.878E-01	2.8E-01
Underground	Waste Handling/ Underground	Forklift Driver	Offload packages to emplacement room with a light-duty forklift	1	2	60	1	2	4.004E-01	8.0E-01
Underground	Waste Handling/ Underground	Forklift Driver	Transport packages to emplacement room with light-duty forklift	1	12	60	1	1	2.694E-01	3.2E+00
Underground	Waste Handling/ Underground	Forklift Driver	Emplace/Stack package with a light-duty forklift	1	3	60	1	1 + 20 [b]	1.779E+00	5.3E+00
	Waste Handling/ Underground	Spotter		1	3	60	3	1 + 20 [b]	7.450E-01	2.2E+00
										1.4E+01

a - 10% of packages are QA checked.
b - Doses in the emplacement room take into account the waste package on the light-duty forklift (1 NPHC) and the front face of the packages already emplaced (20 NPHC).
c - Effective dose rate for ICRP 74, antero-posterior geometry.

Table C.4: Staffing Model and Dose Rate Results for Heavy Non-Forkliftable (HX - Waste Package Group B)

Location	Workgroup	Specific Work Activity	Activity	Number of Staff per Activity	Duration (min)	Average Frequency per Year (Years 2018-2027)	Distance (m)	Number of Packages per Activity	Effective Dose Rate [b] (mSv/h) (Years 2018-2027)	Average Collective Dose (p-mSv/year) (Years 2018-2027)
Surface	Waste Handling/ Surface	Inspector	Perform QA check and barcode reading	1	5	4	1	1	2.100E-03	7.0E-04
Surface	Waste Handling/ Surface	Worker	Remove tie-downs on package from delivery vehicle and attach lifting hooks to package for overhead crane	2	20	4	1	1	2.100E-03	5.6E-03
Surface	Waste Handling/ Surface	Operator/Crane	Lift package and place onto rail cart	1	5	4	10	1	8.977E-05	3.0E-05
Surface	Waste Handling/ Surface	Spotter		1	5	4	2	1	1.128E-03	3.8E-04
Surface	Waste Handling/ Surface	Worker	Remove lifting hooks from package and tie-downs onto rail cart	2	10	4	1	1	2.100E-03	2.8E-03
Surface	Waste Handling/ Surface	Cage Tender	Cart transfer into cage and secure	1	3	4	2	1	1.128E-03	2.3E-04
Shaft	-	-	Cage lowered to repository	-	-	-	-	-	-	-
Underground	Waste Handling/ Underground	Cage Tender	Release cart from cage	1	3	4	2	1	1.128E-03	2.3E-04
Underground	Waste Handling/ Underground	Spotter	Self-powered cart transports package all the way to the emplacement room	1	15	4	3	1	6.803E-04	6.8E-04
Underground	Waste Handling/ Underground	Worker	Remove tie-downs on package from cart and attach lifting hooks to package for the gantry crane	2	20	4	1	1	2.100E-03	5.6E-03
Underground	Waste Handling/ Underground	Operator	Emplace/Stack package with gantry crane	1	5	4	3	1 + 5 [a]	1.943E-03	6.5E-04
										1.7E-02

a - Doses in the emplacement room take into account the waste package on the gantry crane (1 HX) and the front face of the packages already emplaced (5 HX).
b - Effective dose rate for ICRP 74, antero-posterior geometry.

Table C.5: Staffing Model and Dose Rate Results for Heavy Non-Forkliftable (SPC - Waste Package Group B)

Location	Workgroup	Specific Work Activity	Activity	Number of Staff per Activity	Duration (min)	Average Frequency per Year (Years 2018-2027)	Distance (m)	Number of Packages per Activity	Effective Dose Rate [b] (mSv/h) (Years 2018-2027)	Average Collective Dose (p-mSv/year) (Years 2018-2027)
Surface	Waste Handling/ Surface	Inspector	Perform QA check and barcode reading	1	5	1	1	1	8.651E-01	7.2E-02
Surface	Waste Handling/ Surface	Worker	Remove tie-downs on package from delivery vehicle and attach lifting hooks to package for overhead crane	2	20	1	1	1	8.651E-01	5.8E-01
Surface	Waste Handling/ Surface	Operator/Crane	Lift package and place onto rail cart	1	5	1	10	1	3.061E-02	2.6E-03
Surface	Waste Handling/ Surface	Spotter		1	5	1	2	1	4.591E-01	3.8E-02
Surface	Waste Handling/ Surface	Worker	Remove lifting hooks from package and tie-downs onto rail cart	2	10	1	1	1	8.651E-01	2.9E-01
Surface	Waste Handling/ Surface	Cage Tender	Cart transfer into cage and secure	1	3	1	2	1	4.591E-01	2.3E-02
Shaft	-	-	Cage lowered to repository	-	-	-	-	-	-	-
Underground	Waste Handling/ Underground	Cage Tender	Release cart from cage	1	3	1	2	1	4.591E-01	2.3E-02
Underground	Waste Handling/ Underground	Spotter	Self-powered cart transports package all the way to the emplacement room	1	15	1	3	1	2.625E-01	6.6E-02
Underground	Waste Handling/ Underground	Worker	Remove tie-downs on package from cart and attach lifting hooks to package for the gantry crane	2	20	1	1	1	8.651E-01	5.8E-01
Underground	Waste Handling/ Underground	Operator	Emplace/Stack package with gantry crane	1	5	1	3	1 + 2 [a]	6.392E-01	5.3E-02
										1.7E+00

a - Doses in the emplacement room should take into account the waste package on the gantry crane (1 SPC) and the front face of the packages already emplaced (2 SPC).
b - Effective dose rate for ICRP 74, antero-posterior geometry.

Table C.6: Staffing Model and Dose Rate Results for Light Forkliftable (ILWSHLD - Waste Package Group C)

Location	Workgroup	Specific Work Activity	Activity	Number of Staff per Activity	Duration (min)	Average Frequency per Year (Years 2018-2027)	Distance (m)	Number of Packages per Activity	Effective Dose Rate [b] (mSv/h) (Years 2018-2027)	Average Collective Dose (p-mSv/year) (Years 2018-2027)
Surface	Waste Handling/Surface	Inspector	Perform QA check and barcode reading	1	5	153	1	1	4.085E-01	5.2E+00
Surface	Waste Handling/Surface	Forklift Driver	Offload packages from delivery vehicle with a light-duty forklift	1	2	153	1	1	4.085E-01	2.1E+00
Surface	Waste Handling/Surface	Forklift Driver	Pick up packages with a light-duty forklift to place onto transfer cart	1	5	153	1	1	4.085E-01	5.2E+00
Surface	Waste Handling/Surface	Cage Tender	Cart transfer into cage and secure	1	3	153	2	1	1.571E-01	1.2E+00
Shaft	-	-	Cage lowered to repository	-	-	-	-	-	-	-
Underground	Waste Handling/Underground	Cage Tender	Release cart from cage	1	3	153	2	1	1.571E-01	1.2E+00
Underground	Waste Handling/Underground	Forklift Driver	Offload packages from cage with a light-duty forklift	1	2	153	1	1	4.085E-01	2.1E+00
Underground	Waste Handling/Underground	Forklift Driver	Transport packages to emplacement room with a light-duty forklift	1	12	153	1	1	4.085E-01	1.3E+01
Underground	Waste Handling/Underground	Forklift Driver	Emplace/Stack package with a light-duty forklift	1	5	153	1	1 + 18 [a]	2.527E+00	3.2E+01
	Waste Handling/Underground	Spotter		1	5	153	2	1 + 18 [a]	1.450E+00	1.8E+01
										8.0E+01

a - Doses in the emplacement room take into account the waste package on the light-duty forklift (1 ILWSHLD) and the front face of the packages already emplaced (18 ILWSHLD).
b - Effective dose rate for ICRP 74, antero-posterior geometry.

Table C.7: Staffing Model and Dose Rate Results for Light Forkliftable (RLSS - Waste Package Group C)

Location	Workgroup	Specific Work Activity	Activity	Number of Staff per Activity	Duration (min)	Average Frequency per Year (Years 2018-2027)	Distance (m)	Number of Packages per Activity	Effective Dose Rate [b] (mSv/h) (Years 2018-2027)	Average Collective Dose (p-mSv/year) (Years 2018-2027)
Surface	Waste Handling/Surface	Inspector	Perform QA check and barcode reading	1	5	27	1	1	4.440E-01	1.0E+00
Surface	Waste Handling/Surface	Forklift Driver	Pick up packages with a light - duty forklift to place onto transfer cart	1	7	27	2	1	1.781E-01	5.6E-01
Surface	Waste Handling/Surface	Cage Tender	Cage transfer into cage and secure	1	3	27	2	1	1.781E-01	2.4E-01
Shaft	-	-	Cage lowered to repository	-	-	-	-	-	-	-
Underground	Waste Handling/Underground	Cage Tender	Release cart from cage	1	3	27	2	1	1.781E-01	2.4E-01
Underground	Waste Handling/Underground	Forklift Driver	Offload packages from cage with a light-duty forklift	1	2	27	2	1	1.781E-01	1.6E-01
Underground	Waste Handling/Underground	Forklift Driver	Transport packages to emplacement room with a light-duty forklift	1	12	27	2	1	1.781E-01	9.6E-01
Underground	Waste Handling/Underground	Forklift Driver	Emplace/Stack package with a light-duty forklift	1	5	27	2	1 + 8 [a]	1.038E+00	2.3E+00
	Waste Handling/Underground	Spotter		1	5	27	2	1 + 8 [a]	1.038E+00	2.3E+00
										7.8E+00

a - Doses in the emplacement room take into account the waste package on the light-duty forklift (1 RLSS) and the front face of the packages already emplaced (8 RLSS).
b - Effective dose rate for ICRP 74, antero-posterior geometry.

Table C.8: Staffing Model and Dose Rate Results for Heavy Forkliftable (RWC (EF) - Waste Package Group D)

Location	Workgroup	Specific Work Activity	Activity	Number of Staff per Activity	Duration (min)	Average Frequency per Year (Years 2018-2027)	Distance (m)	Number of Packages per Activity	Effective Dose Rate [b] (mSv/h) (Years 2018-2027)	Average Collective Dose (p-mSv/year) (Years 2018-2027)
Surface	Waste Handling/ Surface	Inspector	Perform QA check and barcode reading	1	5	58	1	1	9.447E-02	2.3E-01
Surface	Waste Handling/ Surface	Forklift Driver	Offload packages from delivery vehicle with a heavy-duty forklift	1	2	58	2	1	7.007E-02	6.8E-02
	Waste Handling/ Surface	Spotter		1	2	58	2	1	7.007E-02	6.8E-02
Surface	Waste Handling/ Surface	Forklift Driver	Pick up packages with a heavy-duty forklift to place onto transfer cart	1	2	58	2	1	7.007E-02	6.8E-02
	Waste Handling/ Surface	Spotter		1	2	58	2	1	7.007E-02	6.8E-02
Surface	Waste Handling/ Surface	Cage Tender	Cart transfer into cage and secure	1	3	58	2	1	7.007E-02	1.0E-01
Shaft	-	-	Cage lowered to repository	-	-	-	-	-	-	-
Underground	Waste Handling/ Underground	Cage Tender	Release cart from cage	1	3	58	2	1	7.007E-02	1.0E-01
Underground	Waste Handling/ Underground	Forklift Driver	Offload packages from cage with a heavy-duty forklift	1	2	58	2	1	7.007E-02	6.8E-02
	Waste Handling/ Underground	Spotter		1	2	58	2	1	7.007E-02	6.8E-02
Underground	Waste Handling/ Underground	Forklift Driver	Transport packages to emplacement room with a heavy-duty forklift	1	30	58	2	1	7.007E-02	1.0E+00
Underground	Waste Handling/ Underground	Forklift Driver	Emplace/Stack package with a heavy-duty forklift	1	5	58	2	1 + 4 [a]	2.256E-01	5.5E-01
	Waste Handling/ Underground	Spotter		1	5	58	2	1 + 4 [a]	2.256E-01	5.5E-01
										2.9E+00

a - Doses in the emplacement room take into account the waste package on the heavy-duty forklift (1 RWC(EF)) and the front face of the packages already emplaced (4 RWC(EF)).
b - Effective dose rate for ICRP 74, antero-posterior geometry.

Table C.9: Staffing Model and Dose Rate Results for Heavy Forkliftable (RLSHLD1 - Waste Package Group D)

Location	Workgroup	Specific Work Activity	Activity	Number of Staff per Activity	Duration (min)	Average Frequency per Year (Years 2018-2027)	Distance (m)	Number of Packages per Activity	Effective Dose Rate [b] (mSv/h) (Years 2018-2027)	Average Collective Dose (p-mSv/year) (Years 2018-2027)
Surface	Waste Handling/ Surface	Inspector	Perform QA check and barcode reading	1	5	42	1	1	3.772E-01	1.3E+00
Surface	Waste Handling/ Surface	Forklift Driver	Offload packages from delivery vehicle with a heavy-duty forklift	1	2	42	2	1	2.148E-01	3.0E-01
	Waste Handling/ Surface	Spotter		1	2	42	2	1	2.148E-01	3.0E-01
Surface	Waste Handling/ Surface	Forklift Driver	Pick up packages with a heavy-duty forklift to place onto transfer cart	1	2	42	2	1	2.148E-01	3.0E-01
	Waste Handling/ Surface	Spotter		1	2	42	2	1	2.148E-01	3.0E-01
Surface	Waste Handling/ Surface	Cage Tender	Cart transfer into cage and secure	1	3	42	2	1	2.148E-01	4.5E-01
Shaft	-	-	Cage lowered to repository	-	-	-	-	-	-	-
Underground	Waste Handling/ Underground	Cage Tender	Release cart from cage	1	3	42	2	1	2.148E-01	4.5E-01
Underground	Waste Handling/ Underground	Forklift Driver	Offload packages from cage with a heavy-duty forklift	1	2	42	2	1	2.148E-01	3.0E-01
	Waste Handling/ Underground	Spotter		1	2	42	2	1	2.148E-01	3.0E-01
Underground	Waste Handling/ Underground	Forklift Driver	Transport packages to emplacement room with a heavy-duty forklift	1	30	42	2	1	2.148E-01	4.5E+00
Underground	Waste Handling/ Underground	Forklift Driver	Emplace/Stack package with a heavy-duty forklift	1	5	42	2	1 + 3 [a]	7.412E-01	2.6E+00
	Waste Handling/ Underground	Spotter		1	5	42	2	1 + 3 [a]	7.412E-01	2.6E+00
										1.4E+01

a - Doses in the emplacement room take into account the waste package on the heavy-duty forklift (1 RLSHLD1) and the front face of the packages already emplaced (3 RLSHLD1).
b - Effective dose rate for ICRP 74,antero-posterior geometry.

Table C.10: Staffing Model and Dose Rate Results for Facility Maintenance Activities – Years 2018-2027

Location	Workgroup	Specific Work Activity	Activity	Number of Staff	Person Hours	Number of Packages per Activity	Assumptions	Effective Dose Rate (mSv/h)	Average Collective Dose (p-mSv/year)	Total Dose per Worker (mSv/year)
Underground	Maintenance	Construction	Construction of room end walls and other activities	4	2000	20 NPB47	4 people are assumed work a total of 2000 hours (500 hours each). Workers are at a distance of 5 m from a wall of group A bins in emplacement rooms.	2.42E-03	4.8	1.2
Underground	Maintenance	Inspection	Vent shaft / liner inspection	2	512	None	Inhalation dose to workers inspection the vent shaft equipment and liner. Based on part-time exposure in this vent shaft location of 256 hrs/year per person for shaft inspections.	1.88E-04	0.1	0.05
All	Maintenance	Facility Maintenance	Maintaining equipment and systems	-	-	-	Estimate at 5% of direct exposure due to waste package handling	-	6.2	-