ONTARIO POWER GENERATION

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Prepared by:	Terri Walsh Safety & Licensing Lead Nuclear Safety & Licensing, Worley	21 OCT 2021 Date	Reviewed by:	Philip Smith Senior Technical Engineer, Nuclear Safety & Technology Department	28 OCT 2021 Date
Reviewed by:	Arvind Misra Sr. Technical Analyst Nuclear Safety & Licensing, Worley	21 OCT 2021 Date	Concurred by:	Rafi Asadi Manager Engineering, Nuclear Safety & Technology Department	Nov 04, 2021 Date
Approved by:	DocuSigned by: Rahul Nandi 1C8C2EB3B7C94D1... Rahul Nandi Manager Nuclear Safety & Licensing, Worley	Oct 21, 2021 Date	Approved by:	Gerry Martin Senior Manager, Nuclear Safety & Technology Department	2021-11-09 Date

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Revision Summary

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R000	2021-10-21	Initial issue.

1.0 INTRODUCTION

The Darlington Waste Management Facility (DWMF) is licensed by the Canadian Nuclear Safety Commission (CNSC) under Section 24(2) of the *Nuclear Safety and Control Act*. It is a Class IB nuclear facility, as defined in the *Class I Nuclear Facilities Regulations*, to provide for the safe handling, management and interim storage of used fuel from Darlington Nuclear Generating Station (DNGS) Units 1-4 and storage of intermediate level waste from the refurbishment of all four DNGS units.

1.1 Objective and Scope

This report presents a summary of the safety assessments prepared by Ontario Power Generation (OPG) for the transfer, processing and storage of used fuel Dry Storage Containers (DSCs) and for the handling and storage of refurbishment waste in Retube Waste Containers (RWCs).

Safety assessment is a systematic evaluation of the potential hazards associated with the conduct of a proposed activity or facility and considers the effectiveness of preventative measures and strategies in reducing the effects of such hazards. It evaluates the risk and consequences of normal and accident conditions, to ensure that the facility does not pose an unacceptable risk to workers or the public. The results of the safety assessments are used in the development of the operating limits and conditions for a facility. Safety assessments of structures, systems, components or facilities are carried out to determine the impact on workers and the public. Safety assessments are presented in a facility safety report, which also provides an overview of the facility design and operations.

To assess the overall safety of the operation of the DWMF buildings and structures, deterministic safety analyses are used. Computational tools are used for the dose consequence calculations when required. Bounding (worst-case) accident scenarios are conservatively identified, and the results of off-site dose consequence calculations are then compared against the regulatory dose limits. The dose limits and targets for the DWMF safety assessment for normal operating conditions and accident scenarios are presented in Section 1.2.

1.2 Dose Limits and Targets

1.2.1 Normal Operating Conditions

Any radiation doses resulting from DWMF operations are within regulatory dose limits and kept As-Low-As Reasonably Achievable (ALARA). The CNSC regulatory dose limits for the public and Nuclear Energy Workers (NEWs) are shown in Table 1-1.

OPG has based the DWMF radiation dose rate design targets on the public dose limits in the Regulations promulgated under the NSCA that came into force on May 31, 2000. Radionuclide emissions are negligibly small.

Table 1-1: Canadian Nuclear Safety Commission Effective Dose Limit

Person	Period	Effective Dose (mSv)
NEW, including a pregnant NEW	1-year dosimetry period 5-year dosimetry period	50 100
Pregnant NEW	Balance of the pregnancy (after the licensee is informed of the pregnancy)	4
A person who is not a NEW	1 calendar year	1

The dose rate targets for DWMF operations, derived from Table 1-1 for a member of the general public, are as follows:

a) ≤ 0.5 μSv/hr outside the DWMF perimeter fence on a quarterly average basis, based on the CNSC dose rate of 1 mSv/year for a member of the public, over a maximum 2,000 hours per year occupancy for non-NEWs.

b) ≤ 10 μSv/y at the Darlington NGS site boundary, based on year-round occupancy – this dose rate target is 1 percent of the CNSC dose limit of 1 mSv/y for a member of the public.

1.2.2 Abnormal Operating Conditions

The radiological doses from radionuclide releases and direct radiation, either to members of the public at the Darlington NGS site boundary or to workers, following an abnormal operating condition event or a credible accident are not expected to exceed the annual dose limits given in Table 1-1.

2.0 OVERVIEW OF THE DARLINGTON WASTE MANAGEMENT FACILITY

The DWMF site is defined by the parcel of land designated for the management of OPG's radioactive waste and licensed for such use by CNSC. It is located within the larger Darlington Nuclear site boundary and to the west of the Darlington Nuclear Generating Station as shown in Figure 2-1.

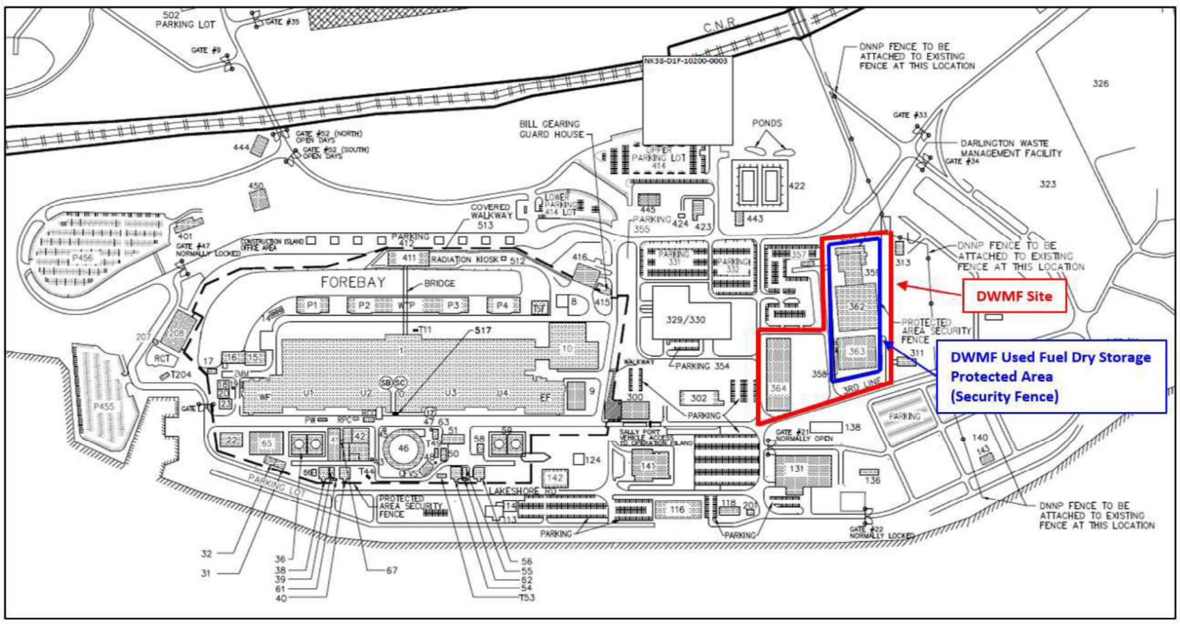

Figure 2-1: Darlington Site

The DWMF consists of a DSC Processing Building, Used Fuel Dry Storage (UFDS) Buildings SB1 & SB2 and the Retube Waste Storage Building (RWSB).

The DWMF site has undergone an orderly development in stages, as additional UFDS buildings are constructed when required. The current layout of DWMF is shown on Figure 2-2.

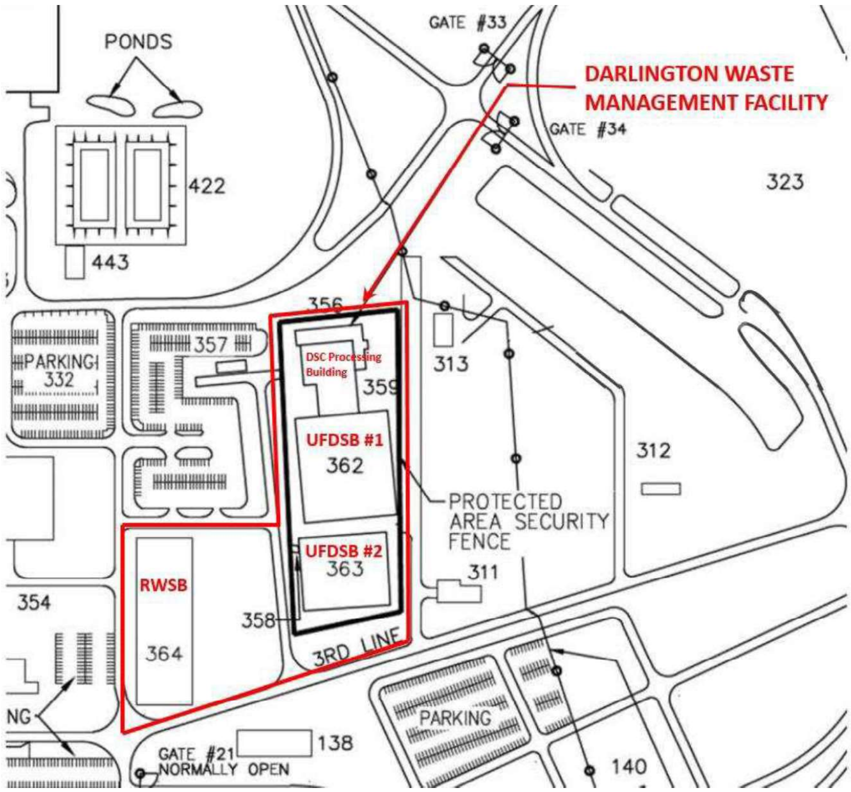

Figure 2-2: DWMF Layout

3.0 SAFETY ASSESSMENT OF THE DARLINGTON WASTE MANAGEMENT FACILITY DRY STORAGE

3.1 DESCRIPTION OF THE USED FUEL DRY STORAGE CONTAINERS AND PROCESS

The DWMF UFDS process encompasses the facilities, Structures, Systems, Equipment, and Components, and the operations necessary to transfer used fuel from the Darlington NGS wet fuel bays to dry storage in the DWMF UFDS buildings. The UFDS process is based on wet-loading of used fuel into Dry Storage Containers (DSCs).

Each existing UFDS building is designed to house up to a maximum of 500 DSCs. There are currently two (2) UFDS buildings on the DWMF site as shown in Figure 2-2.

3.1.1 Dry Storage Containers

The DSC is a free standing reinforced concrete container, with an inner carbon-steel liner and an outer carbon-steel shell, for the storage, on-site transfer and off-site transportation (with an outer packaging) of used CANDU fuel. It is made of two sub-assemblies, a lid and a base. The base provides the storage space for the used fuel.

The DSC has the capacity to store 384 used CANDU long or standard fuel bundles in four storage modules (each module has the capacity to hold 96 long bundles). The DSC provides the necessary radiation shielding, heat removal, and containment of radioactive materials.

The DSC MKII model is the reference container design for the DWMF. The DSC is a double-shell rectangular container, with outside dimensions of 2.121 m x 2.419 m by 3.557 m in height (including the lid), and an inside cavity of 1.046 m x 1.322 m by 2.520 m in height. The thickness of each carbon-steel shell is 13 mm. The DSC walls consist of 52 cm (approximate thickness) high density concrete. The reinforced high-density concrete provides radiation shielding while maintaining adequate used fuel decay heat dissipation. The concrete has a nominal density of 3.5 Mg/m^3. The maximum total mass (including the lid) is approximately 60 Mg when empty and approximately 70 Mg when loaded with four modules (384 used fuel bundles).

All welds that form this containment system and all welds attaching items to the containment system are classified as “nuclear welds”. Helium is used as the inert cover gas in the DSC cavity to protect the fuel bundles from potential oxidation reactions and to facilitate leak testing of the containment boundary.

The DSC is designed with provision for installing safeguard seals. Two separate U-shaped, 25.4 mm outer diameter stainless steel tubes are embedded in the DSC walls and floor in the plane of the outer reinforcing grid. These tubes are placed so that each tube runs across the centre of the opposite container walls. Two similar tubes are embedded in the DSC lid and run diagonally across the lid. The configuration of the safeguard tubes is shown in Figure 3-1. These tubes are used for attaching two different types of IAEA seals.

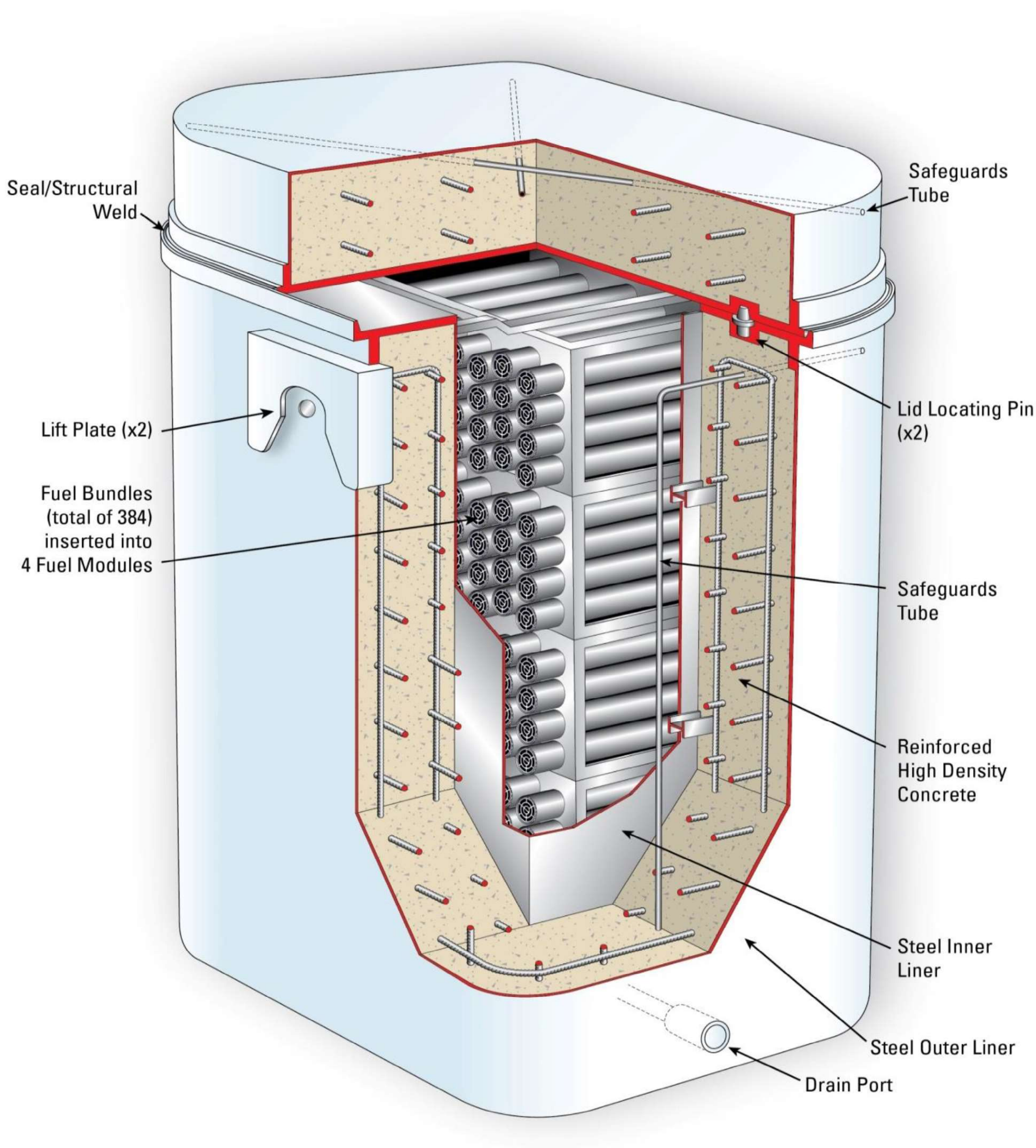

Figure 3-1: Dry Storage Container

3.1.2 Used Fuel Dry Storage Processing

The UFDS process begins with the receipt of new DSCs at the DSC processing building and ends with the storage of loaded DSCs in the DSC storage buildings as illustrated in Figure 3-2 and described below.

3.1.2.1 Empty DSC Processing and On-Site Transfer

New, empty DSCs are received at the DSC processing building. The DSCs are then inspected and prepared for transfer to the station. When a DSC is scheduled for transfer, the DSC transporter picks up the DSC and transfers it to the station for subsequent loading of used fuel.

3.1.2.2 Loading a DSC

Four used fuel storage modules containing a maximum of 384 used fuel bundles, are wet-loaded into a DSC in the existing Wet Cask Handling Bay at each Fueling Facility Auxiliary Area within the station. The loaded DSC is then drained of water, vacuum dried, and decontaminated. The transfer clamp and elastomeric seal are installed to secure and seal the lid during transfer.

3.1.2.3 DSC Transfer between Darlington NGS and the DSC Processing Building at the DWMF

The DSC transporter picks up the loaded DSC with a transfer clamp installed and transfers the DSC to the DSC processing building at the DWMF following standard OPG Radiation Protection (RP) and security procedures.

3.1.2.4 Receiving a Loaded DSC

After a loaded DSC arrives at the DSC processing building, the transporter places the DSC on the receiving bay floor in the DSC processing building. The DSC is lifted from the floor using the overhead crane and lifting beam, and moved into the welding area of the workshop. A loaded DSC is not moved unless a transfer clamp is installed or the lid is seal welded.

3.1.2.5 DSC Lid Seal Welding

The DSC is moved to a welding station, where the DSC drain port transfer plug, transfer clamp, and seal are removed, and the weld pre-heaters are installed. The pre-heater is used to heat the DSC weld flange to a prescribed temperature. The welding equipment is installed on the container and the DSC lid welded to the base by a full-penetration groove weld. This weld is deposited by a mechanized welding system using a Gas Metal Arc Welding process. At the conclusion of lid welding, the weld machine is removed and the DSC is allowed to cool.

3.1.2.6 Welding Inspection

The Phased Array Ultrasonic Testing system is used for the inspection of the DSC lid-to-base seal weld. The scanner is mounted on the DSC base’s top flange and is held in place by three magnetic wheels. A loading ramp is used to minimize the force required by the operator when engaging and disengaging the scanner. The inspection covers 100% of the weld as well as the Heat Affected Zone.

3.1.2.7 Final Vacuum Drying, Helium Backfill and Drain Port Seal Welding

After successful completion of the weld inspection, the DSC is lifted into another work station for final vacuum drying and helium backfilling. The lifting beam is removed and the vacuum drying/helium backfilling system connected. Following helium backfill, the drain port is welded and inspected via visual and dye penetrant techniques.

3.1.2.8 Helium Leak Testing

Helium leak testing is carried out using a vacuum box (bell jar). The lid of the bell jar is removed and the seal welded DSC is lifted into the lower half of the bell jar. The leak detection bell jar is craned over the DSC and sealed onto the base of the bell jar. Using the vacuum skid, air is first removed from the bell jar and then the helium leak detector is activated. If a leak is detected, the vacuum equipment is removed and remedial work is carried out. A follow-up leak test is then performed.

3.1.2.9 Paint Touch Up and Safeguards Seals

The DSC is craned into the paint area. Weld affected areas are cleaned and painted, and touch-up paint applied to scrapes or scuffs on the DSC that may have resulted from handling. Documentation and identification labeling is completed, and permanent safeguards seals are installed in a designated IAEA surveillance area.

3.1.2.10 DSC Placement and Storage

The DSC is moved, using the transporter, to a DSC storage building for storage. At the DSC storage building, the transporter is positioned to unload the DSC at a designated location.

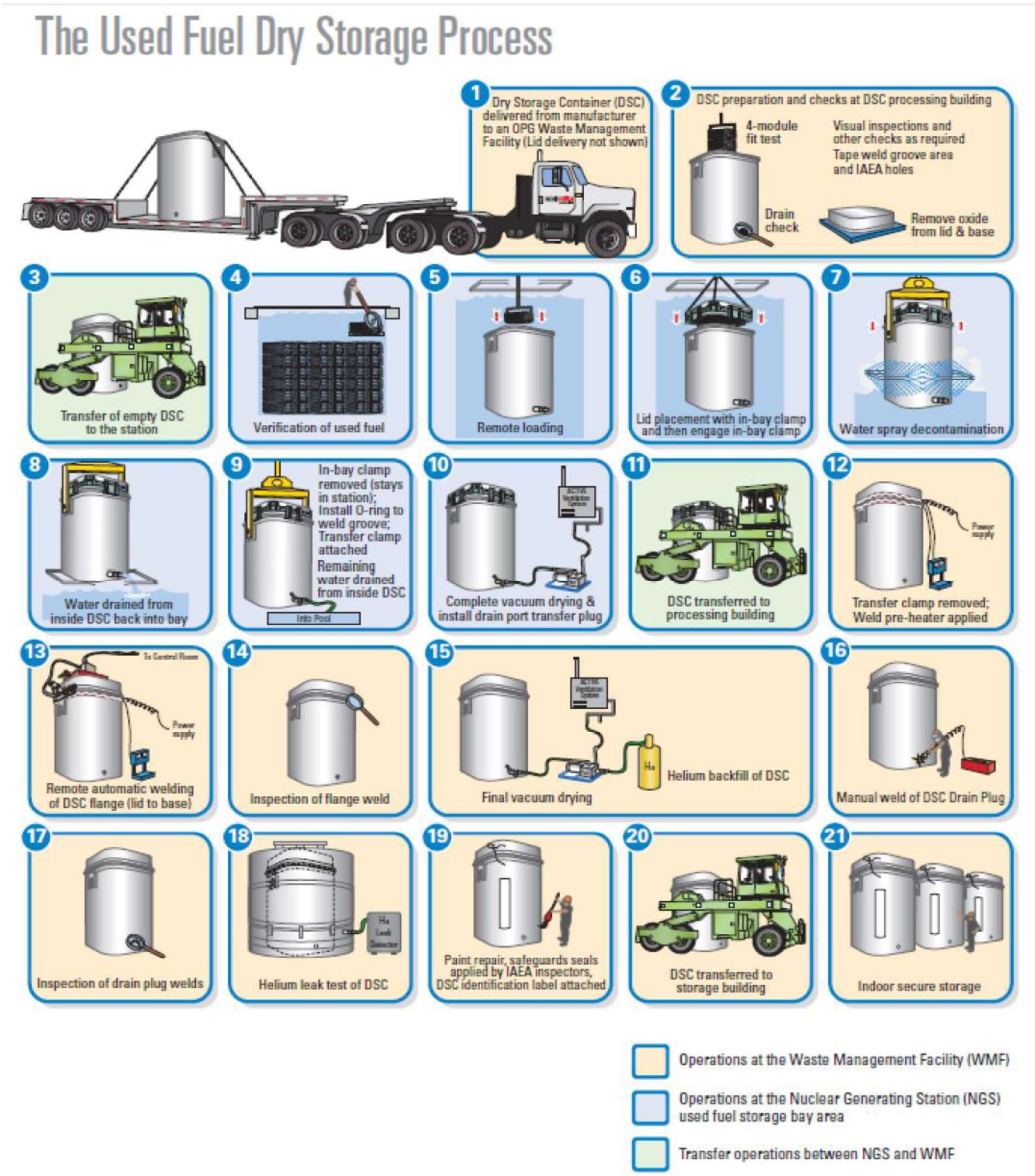

Figure 3-2: Used Fuel Dry Storage Process for Dry Storage Container

3.1.3 Dry Storage Container Handling Systems Description

3.1.3.1 Dry Storage Container Transporters

The DSC transporters are specially designed multi-wheeled vehicles for the transfer of DSCs between the FFAAs and the DSC processing building at the DWMF, between the DSC processing building and the DSC storage buildings, and for placement and retrieval of the seal welded DSCs inside the DSC storage buildings.

The transporters are self-loading and self-powered by a diesel engine and do not require the assistance of a crane when picking up or depositing a DSC. The DSC is lifted and transported via lifting trunnions mounted on the upper frame of the machines. The DSC is carried at a low lift height during transfer (about 0.2 m). Locking arrangements prevent the DSC from being inadvertently lowered to the ground upon hydraulic failure. The tires on the Transporters are designed not to deflate if punctured.

When travelling with a DSC, the transporters operate at low speed and have a short stopping distance (within 3 m). When travelling at minimal speeds (e.g., when moving DSCs within the DSC processing and storage buildings), stopping is essentially instantaneous.

The transporters are capable of forward and reverse motion and have a tight turning radius. A radio remote control may be used to operate the transporter either from the cab or remotely. Vehicle lighting is provided for operation on site roads, if necessary.

3.1.3.2 Dry Storage Container Lifting System

The DSC lifting system consists of lifting plates on the DSC and a lifting beam with trunnions. The lifting beam has been designed for DSC handling and is compatible with the swivel hook on the DWMF overhead crane. The lifting beam is designed to engage into the lifting plates attached on the DSC body and not to disengage from the DSC while the beam is under load.

3.1.3.3 Transfer Clamp

A transfer clamp is used to securely attach the lid to the DSC base during on-site transfer of a loaded DSC between the FFAAs and the DWMF. The transfer clamp is used in conjunction with an elastomeric seal between the lid and base, to permit the cavity of a loaded DSC to be vacuum dried. The transfer clamp is designed to prevent the lid from separating under credible accident scenarios during the transfer of loaded DSCs between the FFAAs and the DWMF, and during DSC handling inside the DSC processing building prior to seal welding the DSC lid.

3.1.4 Darlington Waste Management Facility Structural Description

The DWMF consists of industrial type structures to provide safe processing and indoor storage of DSCs. The DSC processing building at the DWMF is a combination of steel frame, poured concrete, and concrete masonry construction with prefinished metal cladding on the exterior. The building structure and cladding are designed to meet the National Building Code of Canada requirements for wind and seismic loads.

Walls in each DSC storage building consist of 25.4 cm (10 in) thick precast concrete panels from ground level to a 4.2 m height. The precast concrete wall system provides radiation shielding; however, the storage buildings are not safety related structures credited in the containment of radioactive releases. Horizontal louvers and metal cladding are installed at upper wall elevations. Reinforced concrete floor slabs are designed to accommodate heavy vehicles and the weight of the loaded DSCs. The floors are constructed for long service with minimal maintenance.

The DWMF roof has provisions for drainage of rainwater and melted snow. Lightning protection systems are provided for the storage buildings.

3.2 RADIOLOGICAL SAFETY ASSESSMENT – NORMAL OPERATING CONDITIONS

3.2.1.1 Radioactive Emissions and Contamination

Under normal operating conditions, no airborne emissions are expected from loaded DSCs during transfer from the FFAAs to the DWMF. Airborne releases are also unlikely to arise under normal operating conditions during storage of seal welded DSCs. There is a small potential for airborne emissions resulting from DSC processing operations such as welding and vacuum drying. A dedicated active ventilation system is used to deal with any airborne emissions.

Surface contamination on DSC exterior surfaces is effectively controlled through prevention measures and decontamination at the FFAAs. Nevertheless, small quantities of fixed surface contamination may become airborne during welding operations.

The DWMF operating experience demonstrates that particulate emissions in exhaust from DSC processing operations have been typically below the Minimum Detectable Activity.

Since, as described above, the potential for chronic emissions is very low, the assessment presented below is considered to be an upper bound for any possible chronic emissions during normal operating conditions.

The potential emissions under normal operating conditions have been evaluated. Since each DSC has the capacity to hold 384 fuel bundles and assuming the facility processes about 70 containers per year, it is postulated that a total of 280 fuel elements (four elements per DSC, i.e., one fuel element in 1 percent of the fuel bundles is assumed to be damaged) fail during 1 year under normal operating conditions (a very conservative scenario). The chronic off-site dose consequences from this scenario, for a member of the public at the Darlington NGS site boundary, are estimated to be 1.6×10^{-2} μSv/year for an adult and 1.5×10^{-2} μSv/year for an infant, which is less than 0.002 percent of the CNSC regulatory dose limit (1 mSv/year). Given the conservative assumptions used, these values are an upper bound estimate for airborne emissions.

As the DSC is fully drained and vacuum dried at the FFAAs, and the elastomeric seal and the drain plug are present during transfer there will be no liquid emissions from the DSC during on-site transfer to the DWMF.

The exterior surfaces of DSCs are decontaminated prior to their transfer from the FFAAs to the DWMF. Spot decontamination operations, which may be carried out in the DSC processing building, are not expected to generate liquids. No liquid will be present inside DSCs during dry storage in the DSC storage buildings. Liquids are not normally used in the DSC storage buildings.

No loose contamination is permitted (or expected), either on the exterior surfaces of DSCs, or on accessible surfaces such as floors in the DSC processing and DSC storage buildings. This is confirmed through routine contamination monitoring.

Since no liquids are present in the DSC and loose contamination is not permitted on DSC or facility surfaces, no contaminated liquid effluents are expected from DWMF operations

3.2.1.2 Radiation Fields

Dry Storage Container Dose Rates

Figure 3-3 shows the gamma radiation dose rates as a function of the distance from the top, side, front, and bottom surfaces of a fully loaded DSC, as calculated for Darlington reference used fuel.

Because much of the used fuel stored in DSCs will be greater than 10 years old, and based on DWMF DSC monitoring experience, the predicted dose rates are expected to be conservative. Calculations assume a nominal concrete density of 3.5 Mg/m^3, adjusted up to 3.57 Mg/m^3 to account for the presence of steel rebar in the heavy concrete. In practice, densities achieved in received DSCs are at the higher end of the specified range of concrete densities. Analysis has already predicted dose rate reductions up to a factor of three for a 10 percent increase in concrete density. The measured dose rates from the DSCs during actual operations are lower than those predicted.

Analysis has shown that as expected, due to the heavy concrete used as shielding in the DSC, the dose rates produced by neutrons are negligible compared to those generated by gamma radiation.

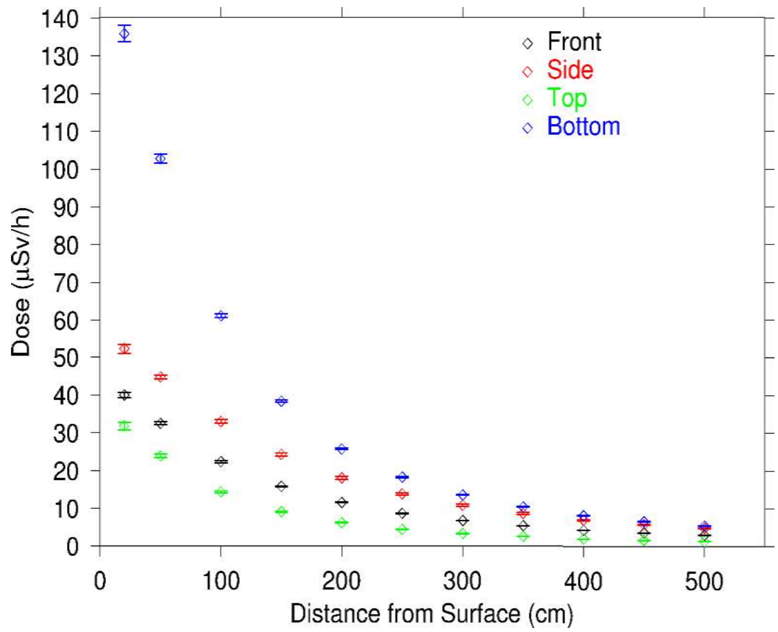

Figure 3-3: Dose Rate versus Distance from the Surface of a Single DSC with 384 10-year Cooled DWMF Reference Used Fuel Bundles

3.2.1.1 Dose Rates inside the Darlington Waste Management Facility

Figure 3-4 depicts the gamma dose rates across the main corridor that runs in the north-south direction in SB1 and SB2. Due to the wider width of the north-south corridor in SB2 in relation to SB1, the dose rates calculated for SB1 will bound those for SB2. As can be observed, the dose rates along the sides of the main north-south corridor are 29.13 μSv/hr ± 18% at UFDSB1 and 23.40 μSv/hr ± 9.7% at SB2.

Due to high simulation uncertainties related to the approach used in the treatment of the source for the Monte Carlo N-Particle (MCNP) calculations of dose rates within the narrow corridors running in the east-west direction, a bounding value was chosen. The bounding value of 105 μSv/h, which is equal to twice the DSC side-surface dose rate, is conservatively assumed for the east-west direction.

Due to the reasons discussed in Section 3.2.1.2, the dose rates observed inside the DSC storage building during the operation of the DWMF have been found to be significantly lower than the calculated dose rates.

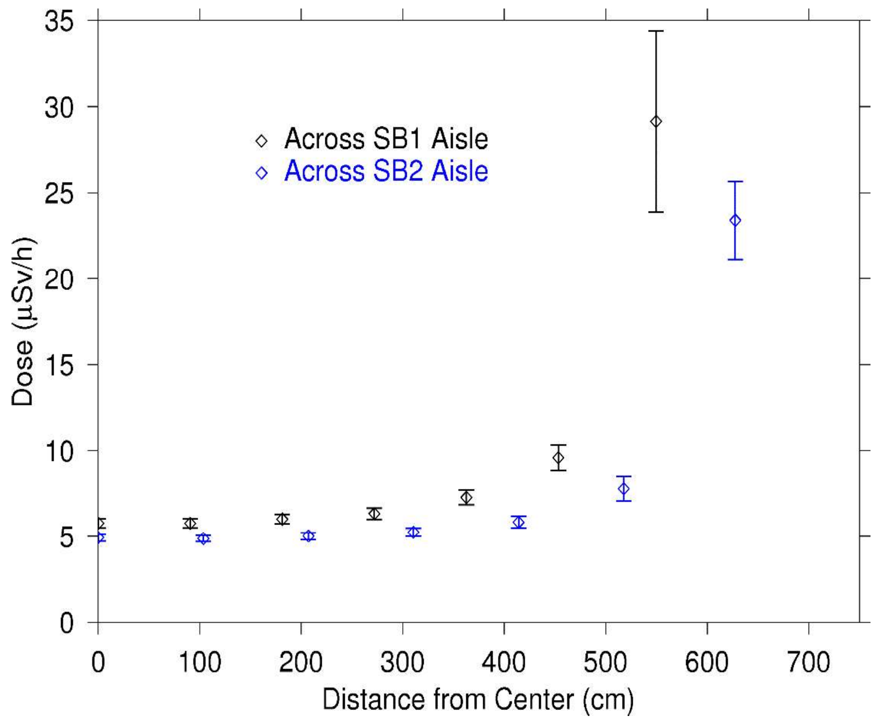

Figure 3-4: Dose Rates Across Central Aisles of SB1 and SB2

3.2.1.2 Dose Rates outside the Darlington Waste Management Facility

Figure 3-5 and Figure 3-6 show estimated dose rates versus distance from two DSC storage buildings, SB1 and SB2, filled with 483 and 500 DSCs respectively, and loaded uniformly with 10-year cooled used fuel. The dose rates at the DWMF wall exterior were calculated along a line centred along the middle of SB2 and travelling eastward toward the DNGS site boundary. SB2, rather than SB1, was applied to generate this curve, as the larger inventory of DSCs in the former is judged to lead to the bounding dose outside of the two buildings. Figure 3-5 shows the total dose rate as a function of distance outside the DWMF for the first 150 m. Figure 3-6 shows the total dose rate as a function of distance outside the DWMF up to 1500 m.

The design assumptions used in the calculations have resulted in conservative dose rate estimates.

The dose rate at the closest in-land portion of the Darlington site boundary, approximately 1,025 m from the DWMF, was calculated to be 2.94 x 10-6 µSv/hr ± 8.1%, equivalent to 2.58 x 10-2 µSv/year for full occupancy (i.e., 24 hours per day x 365 days per year), which is well below the OPG dose rate target of 10 µSv/year.

The dose rates given in Figure 3-5 and Figure 3-6 at varying distances involve additional conservatism since the calculations assume that the two DSC storage buildings are both filled to capacity with 10-year cooled used fuel. This is a conservative estimate since the used fuel will be transferred gradually over many years, during which time the used fuel in storage will continue to decay, resulting in a corresponding reduction of direct radiation fields.

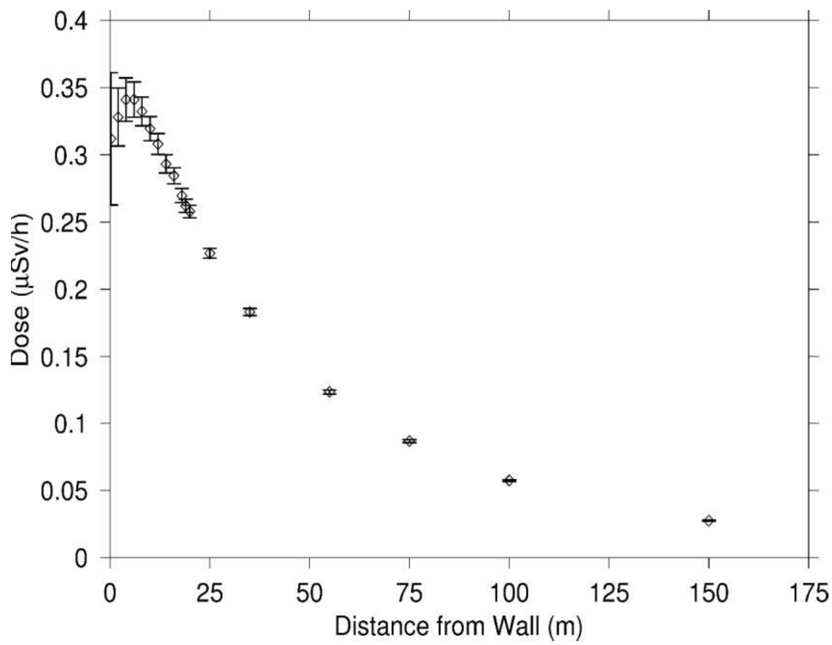

Figure 3-5: Dose Rates Along Line Eastward from SB2, Portion Close to Wall (0 to 150 m)

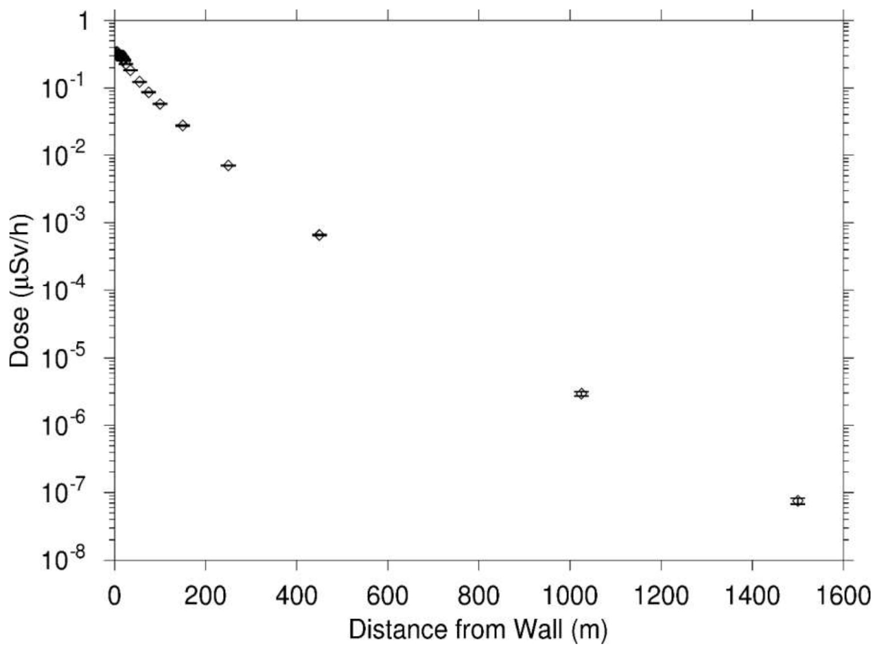

Figure 3-6: Dose Rates Along Line Eastward from SB2 (0 to 1500 m)

3.3 RADIOLOGICAL SAFETY ASSESSMENT – MALFUNCTIONS AND ACCIDENTS

The operation of the DWMF may be affected by abnormal or credible accident conditions. This section provides a summary of the assessment of potential impacts due to postulated events both within and external to the DWMF.

Given the very distinctive stages of the Darlington used fuel dry storage process, the assessment of malfunctions and accidents was divided into the following main stages of the out-of-station UFDS operations:

a) On-site transfer operations;

b) Operations inside the DSC processing building; and

c) Storage.

For each stage of the DWMF operations, release of radiation due to fuel sheath failure can occur due to physical damage and/or failure of the systems and components used during the UFDS operations.

The list of initiating events considered for each assessment is consistent with the list of initiating events used by Darlington NGS.

Each event was screened to establish if it could result in any radiological impact to the public, the workers and the environment. Design provisions and procedural measures that could prevent the event or mitigate its consequences were also considered.

Release of radionuclides from a seal welded DSC is not expected, even under abnormal operating conditions, because of the robustness of the DSC and the fuel bundle design.

However, to assess the overall safety of the DWMF operations, safety analyses presume that abnormal operating conditions and credible accidents will result in the failure of multiple barriers and release of radioactive material. Bounding (worst-case) accident scenarios are conservatively identified even if they are unlikely to occur, and the results of off-site dose consequence calculations are then compared against the regulatory dose limits.

3.3.1 During Dry Storage Container On-Site Transfer

As described in Section 3.1.3., the DSC transporters are used to transfer the new DSCs from the DSC processing building to the east or west Darlington FFAAs. The DSC transporters provide their own motive power and DSC lifting capability via their diesel engine. The vehicles are also used to transfer the loaded DSCs back to the DSC processing building.

The DSC on-site transfer assessment has taken into account postulated malfunctions and accidents that could potentially affect the transfer of a loaded DSC from the Darlington FFAAs truck bay to the DSC processing building.

Table 3-1 shows the public and occupational dose consequences due to those malfunctions and accidents deemed credible (i.e., with a frequency of occurrence $>10^{-7}$ events per year)[1] during DSC on-site transfer.

The bounding dose consequences during this stage of the dry storage process are associated with the drop of a DSC during on-site transfer. Although fuel sheath failure is not expected as a result of a DSC drop from the low-lift height of the transporters, the drop of a DSC during on-site transfer was conservatively assumed to result in 100 percent failure of the fuel elements inside a DSC. Consequently, the free inventory from failed fuel elements is assumed to be released into the environment making this accident scenario the bounding accident scenario during on-site transfer operations.

The total doses to the public due to this event were assessed to be 0.93 μSv for an adult and 0.90 μSv for an infant at the Darlington site boundary which are both less than 0.1 percent of the regulatory public dose limit under abnormal/accident conditions as described in Section 1.2. The occupational dose was assessed to be 10.9 mSv which is less than 25 percent of the OPG dose target for abnormal/accident conditions described in Section 1.2.

[1] The frequency of occurrence 10^{-7} is very conservative. A more reasonable frequency of occurrence would be 10^{-6} which is consistent CSA N292.0-14 – General Principles for the management of radioactive waste and irradiated fuel.

Table 3-1: Postulated Malfunctions or Accidents during Dry Storage Container On-Site Transfer

Malfunction or Accident	Frequency of Occurrence (events per year)	Potential Maximum Dose Consequence to the Public (μSv)		Potential Maximum Occupational Dose Consequence (mSv)
		Adult	Infant	
Transporter Failure	4	2.62×10^{-4}	2.53×10^{-4}	3×10^{-3}
Vehicle Operator Health-Related Emergency	1	$< 2.62 \times 10^{-4}$	$< 2.53 \times 10^{-4}$	$< 3 \times 10^{-3}$
DSC drop during On-Site Transfer	2.3×10^{-3}	9.30×10^{-1}	9.00×10^{-1}	10.9
Fire	2.3×10^{-3}	0	0	0
Criticality	Incredible[2]	-----	-----	-----
Adverse Road Conditions	1	$< 2.62 \times 10^{-4}$	$< 2.53 \times 10^{-4}$	$< 3 \times 10^{-3}$
Earthquake	1.6×10^{-7}	$< 2.62 \times 10^{-4}$	$< 2.53 \times 10^{-4}$	$< 3 \times 10^{-3}$
Tornado	Incredible	-----	-----	-----
Thunderstorms	>1	$< 2.62 \times 10^{-4}$	$< 2.53 \times 10^{-4}$	$< 3 \times 10^{-3}$
Floods	Incredible	-----	-----	-----
Rail Line Blast	Incredible	-----	-----	-----
Toxic Corrosive Chemical Rail Line Accident	Incredible	-----	-----	-----
Tritium Removal Facility Explosion	8×10^{-6}	$< 2.62 \times 10^{-4}$	$< 2.53 \times 10^{-4}$	$< 3 \times 10^{-3}$
Hazardous Material Building Explosion	3.7×10^{-5}	$< 2.62 \times 10^{-4}$	$< 2.53 \times 10^{-4}$	$< 3 \times 10^{-3}$
Aircraft crash	Incredible	-----	-----	-----

Note: the doses for all accident scenarios are for a single occurrence, and do not reflect chronic releases

3.3.2 During Dry Storage Container Processing

The processes and systems taken into account for this assessment encompass those present at the DSC processing building once the transporter arrives at the DSC processing building with a loaded DSC, and before the DSC is taken to the DSC storage building as described in Section 3.1.2.

Table 3-2 shows the public and occupational dose consequences due to those malfunctions and accidents that are deemed credible (i.e., with a frequency of occurrence $>10^{-7}$ events per year) during DSC processing.

[2] The term “incredible” is used for those events with a frequency of occurrence below 10^{-7} events per year

The bounding dose consequences during this stage of the dry storage process are associated with an event in which the DSC drops during handling. Conservatively, it was assumed that as a result of this event 30 percent of the fuel elements inside the DSC during processing are damaged and the free inventory from failed fuel elements is released from the DWMF into the environment

The total dose to the public due to this event was assessed to be 0.28 μSv for an adult and 0.27 μSv for an infant at the Darlington site boundary which are both less than 0.03 percent of the public dose limit under abnormal/accident conditions. The occupational dose was assessed to be 3.26 mSv which is less than 10 percent of the OPG target for abnormal/accident conditions described in Section 1.2.

Table 3-2: Postulated Malfunctions or Accidents during Dry Storage Container Processing

Malfunction or Accident	Frequency of Occurrence (events per year)	Potential Maximum Dose Consequence to the Public (μSv)		Potential Maximum Occupational Dose Consequence (mSv)
		Adult	Infant	
Drop of a DSC during handling	1×10^{-2}	2.79×10^{-1}	2.7×10^{-1}	3.26
Equipment Drop onto DSC	2×10^{-2}	$< 2.79 \times 10^{-1}$	$< 2.7 \times 10^{-1}$	< 3.26
DSC Collision during Craning	8×10^{-2}	$< 2.79 \times 10^{-1}$	$< 2.7 \times 10^{-1}$	< 3.26
Transporter Collision with Loaded DSC	4×10^{-2}	$< 2.79 \times 10^{-1}$	$< 2.7 \times 10^{-1}$	< 3.26
Equipment Collision with Loaded DSC during Craning	1×10^{-1}	$< 2.79 \times 10^{-1}$	$< 2.7 \times 10^{-1}$	< 3.26
Criticality	Incredible	-----	-----	-----
Processing Building Fire	2.3×10^{-3}	0	0	0
Earthquake	1×10^{-7}	$< 2.79 \times 10^{-1}$	$< 2.7 \times 10^{-1}$	< 3.26
Tornado	Incredible	-----	-----	-----
Thunderstorms	>1	0	0	0
Floods	Incredible	-----	-----	-----
Rail Line Blast	Incredible	-----	-----	-----
Toxic Corrosive Chemical Rail Line Accident	Incredible	-----	-----	-----
Tritium Removal Facility Explosion	8×10^{-6}	0	0	0
Hazardous Material Building Explosion	2×10^{-5}	0	0	0
Aircraft crash	Incredible	-----	-----	-----

3.3.3 During Dry Storage Container Storage

Once the DSC processing is completed, the transporter moves the DSC from the DSC processing building to one of the DSC storage buildings for storage.

Table 3-3 shows the public and occupational dose consequences due to those malfunctions and accidents that are deemed credible (i.e., with a frequency of occurrence $>10^{-7}$ events per year) during the storage process.

The bounding dose consequences during this stage of the dry storage process are associated with an event in which DSCs seal weld fails during storage. During storage, both the fuel sheath and the DSC seal weld must fail for a release of radionuclides to occur. Used fuel known to have a damaged or defective sheath is not loaded into a DSC. Failure of the sheath is not expected to occur during the operating life of the storage facility. Nevertheless, to make a conservative assessment of the consequences of a release during storage, it is postulated that 10 percent of the DSCs in the DWMF (two SBs with 500 DSCs per SB) experience a seal weld failure over a 1-year period, resulting in 100 DSCs with failed seal welds.

Conservatively assuming that 1 percent of the 384 fuel bundles in the DSCs are defective (approximately four bundles) with one defective fuel element per bundle (four fuel elements per DSC). For the DSCs with failed seal welds, the free inventory from 100 x 4 = 400 failed fuel elements would be released from the DWMF into the environment over the course of a year.

The total doses to the public due to this event were assessed to be 2.22×10^{-2} μSv for an adult and 2.15×10^{-2} μSv for an infant at Darlington NGS site boundary, which are both approximately 0.002 percent of the regulatory public dose limit. The occupational dose was assessed to be 0.306 mSv which is less than one percent of the OPG dose target for abnormal/accident conditions described in Section 1.2.

Note that, as discussed in Section 3.1.4, the storage buildings are not safety related structures credited in the containment of radioactive releases. As such, the results of this accident assessment have an extra level of conservatism built in as the storage building would likely contain some of the contamination in the event of a seal weld failure.

Table 3-3: Postulated Malfunctions or Accidents during Dry Storage Container Storage

Malfunctions or Accident	Frequency of Occurrence (events per year)	Potential Maximum Dose Consequence to the Public (µSv)		Potential Maximum Occupational Dose Consequence (mSv)
		Adult	Infant	
Seal weld Failure during storage	2.3×10^{-3}	2.22×10^{-2}	2.15×10^{-2}	3.06×10^{-1}
DSC drop during Transfer to Storage	7×10^{-7}	0	0	0
Transporter Collision with a DSC	7×10^{-1}	0	0	0
Criticality	Incredible	-----	-----	-----
Storage Building Fire	2.3×10^{-3}	0	0	0
Earthquake	1×10^{-5}	0	0	0
Tornado	1×10^{-6}	0	0	0
Thunderstorms	>1	0	0	0
Floods	Incredible	-----	-----	-----
Rail Line Blast	6.6×10^{-7}	0	0	0
Toxic Corrosive Chemical Rail Line Accident	1×10^{-6}	0	0	0
Tritium Removal Facility Explosion	1×10^{-3}	0	0	0
Hazardous Material Building Explosion	2.3×10^{-3}	0	0	0
Aircraft crash	Incredible	-----	-----	-----

4.0 SAFETY ASSESSMENT OF THE REFURBISHMENT WASTE STORAGE

4.1 DESCRIPTION OF THE RETUBE WASTE STORAGE BUILDING AND CONTAINERS

4.1.1 Retube Waste Storage Building

The refurbishment waste storage area will consist of the RWSB which is a single building located above ground. The RWSB will be used for the interim storage of refurbishment waste generated during the refurbishment of Darlington NGS.

The RWSB will provide storage capacity for retube waste containers from the retubing of Darlington reactor units. The retube waste will arrive at the RWSB, stored within a shielded container.

The RWSB has a nominal capacity for 400 containers which is sufficient (and it includes contingency) for the retubing of the four Darlington units. Spare space is available to accommodate up to 490 containers.

The RWSB floor plan design is approximately 106 m by 41 m. The concrete wall panels are joined in an overlapping configuration to prevent radiation streaming between the panels. The RWSB floor is constructed of reinforced concrete. The interior height will accommodate the movement and placement of containers stacked 2 high. The building conforms to the National Building Code.

The above-ground nature of the RWSB requires additional concrete, in excess of structural requirements, for radiation shielding. The wall thicknesses have been determined to meet radiation shielding requirements. In addition, the concrete wall panels are joined in an overlapping configuration to prevent radiation streaming between the panels.

4.1.2 Waste Containers

Waste to be stored in the RWSB will be inside mobile enclosures each consisting of a container within a container. The inner container is referred to as the Retube Waste Container (RWC). The outer container is referred to as the Darlington Storage Overpack (DSO). The combined shielding of the RWC and DSO will limit the external radiation dose from an individual assembled container and overpack (referred to as RWC/DSO) to less than or equal to 100 μSv/h (10 mrem/h) at one metre. The maximum weight of a loaded RWC/DSO shall not exceed 45 tonnes including the maximum payload. Containers (RWC/DSO) are designed for a minimum fifty-year life. The external surfaces of the RWC and DSO will clearly identify the internal configuration and waste type (Pressure Tube/Calandria Tube, Calandria Tube Inserts, or End Fitting) to ensure correct usage.

4.1.2.1 Darlington Storage Overpacks

The DSO as currently planned is a cylindrical container made of thick steel with a single lid fastened on top. Dimensions are given in Table 4-1 below.

The lid of the DSO is fastened securely to the body. The design of these fasteners is such that they cannot become loose and released unintentionally due to accelerations or vibrations during handling. The closure joint design will preclude the ingress of moisture or debris and provide supplementary contamination control.

The DSO is designed to hold a single RWC. The principal function of the DSO is to supplement the shielding provided by the RWC during the storage period at Darlington.

The fully loaded RWC/DSO is designed to be stacked two-high for storage at Darlington.

Table 4-1: Darlington Storage Overpack Dimensions

Dimensions		Nominal Cavity Volume (without RWC)
Outside Diameter	2.4 m	7.8 m^3
Height	2.8 m	

4.1.2.2 Retube Waste Containers

The RWCs are designed to contain the following irradiated components.

- Pressure Tubes with Annulus Spacers (each Spacer consists of a Garter Spring and Girdle Wire); or
- Calandria Tubes with Annulus Spacers; or
- End Fitting inboard sections with pressure tube stubs, with shield plugs; or
- Calandria Tube Inserts.

The RWC is cylindrical and constructed of heavy concrete lined internally and externally with steel. The RWC has an opening at the top, which is closed with a lid made of steel. Dimensions are given in Table 4-2 below.

The lid of the RWC is fastened securely to the body. The design of these fasteners is such that they cannot become loose and released unintentionally due to accelerations or vibrations during handling. A seal is provided at the closure joint for contamination control during the storage period.

The RWC is designed to provide the primary containment and shielding for the retube waste. The RWC has a maximum mass of 24 tonnes including its maximum payload. To minimize the mass of the RWC and to facilitate off-site transport, the RWC shielding thickness has been established so that after storage at the DWMF (20-30 years), the container meets the 100 μSv/h (10 mrem/h) dose rate acceptance criterion at one metre.

While stored at the DWMF, the RWC is housed within the DSO to supplement its shielding. The design of the DSO has been established such that the combined RWC/DSO package meets the 100 μSv/h dose rate acceptance criterion when the waste is initially received at the DWMF.

Table 4-2: Retube Waste Container Dimensions

Dimensions		Nominal Cavity Volume (without Liners)
Outside Diameter	1.9 m	1.9 m^3
Height	2.4 m	

4.1.3 Handling

The RWCs/DSOs are handled in the RWSB using an overhead crane. The overhead crane will be used to move the containers between the truck bay and the storage area and place the RWCs/DSOs into storage.

4.2 RADIOLOGICAL SAFETY ASSESSMENT – NORMAL OPERATING CONDITIONS

4.2.1 Radioactive Emissions and Contamination

Under normal operating conditions, no airborne emissions are expected during the storage of RWCs/DSOs in the RWSB.

Surface contamination on RWC/DSO exterior surfaces is expected to be controlled through prevention measures and decontamination at the Darlington NGS.

4.2.2 Radiation Fields

4.2.2.1 RWC/DSO Dose Rates

The maximum dose rate from the side of a RWC/DSO has been calculated for each waste type. The height at which this maximum is observed differs for each waste type depending on the manner of its loading and the assumed midpoint of the source volume. Dose rates have been calculated on contact and at one meter. The results are summarized in Table 4-3.

Table 4-3: Dose rates outside a single RWCs/DSO

Distance from RWC	Dose Rate (µSv/h)			
	End Fitting	Pressure Tubes	Calandria Tubes	Calandria Tube Inserts
Contact	21	165	128	11
1 m	4	54	41	4

4.2.2.2 Dose Rates Inside the Retube Waste Storage Building

Dose rates have been calculated at three representative sets of locations within the RWSB. The locations considered include points between two rows of RWCs/DSOs in the fire egress aisle, points in the 'alleyway' between two blocks of RWCs/DSOs, and points in the back of the 'truck bay' area where no containers are present.

The maximum dose rate between two rows of containers in the fire egress aisle was calculated to be approximately 123 μSv/h, corresponding to a dose point halfway between two containers at the source mid-point.

The maximum dose rate along the alleyway was calculated to be approximately 94 μSv/h, corresponding to a dose point halfway between two containers.

The maximum dose rate in the back 'truck bay' area was calculated to be approximately 0.15 μSv/h.

4.2.2.3 Dose Rates Outside the Retube Waste Storage Building

For the dose points located outside the RWSB, the calculated dose rates were all below the target of 0.5 μSv/h.

For the public dose points at the Darlington site boundary, the calculated dose rates were below the target of 10 μSv/y, assuming full occupancy by a member of the public.

Gamma dose rate predictions for normal operating conditions were generated using the analysis code MCNP version 6.1. Dose rate contributions from all exposure pathways are explicitly modeled within MCNP. The use of MCNP for this application is considered industry best practice.

The MCNP model developed for the DWMF includes all of the individual DSCs within the two UFDS buildings and all of the individual RWC/DSO in the RWSB. In this model, a bounding fuel source term is used for the nearly 1,000 DSCs such that the decay of the fuel is minimized and the burnup is maximized. A conservative source term is also applied to characterize the retube waste such that each unit's refurbishment waste is assumed to have no more than nine months decay. The model assumes that both UFDS buildings and the RWSB are loaded to capacity.

Using conservative source terms and at capacity assumptions, DWMF predicted dose rates, for all relevant receptor locations, remain below acceptance criteria.

Although the methodology applied to the development of OPGs waste management facility MCNP models, and the MCNP simulation strategies applicable for dose rate assessments, were originally developed for application to UFDS buildings and DSCs, and validated/ benchmarked for that application, the same methods and strategies were found to be appropriate for all heavily shielded containers such as the RWC and DSO.

4.3 RADIOLOGICAL SAFETY ASSESSMENT – MALFUNCTIONS AND ACCIDENTS

The operation of the RWSB may be affected by abnormal or credible accident conditions. This section provides a summary of the assessment of the potential impacts of postulated events both inside and external to the RWSB

Malfunctions and accidents were assessed for handling and storage of the RWCs/DSOs in the RWSB.

Initiating events from DWMF and other facility's SRs were reviewed and applied to this assessment as appropriate.

Each event was screened to establish if it could result in any radiological impact to the public, the workers, and the environment. Design provisions and procedural measures that could prevent the event or mitigate its consequences were also considered.

Release of radionuclides from the RWC/DSO assembly is not expected, even under abnormal operating conditions, because of the robustness of the container design.

However, to assess the overall safety of the RWSB operations, safety assessment presumes that abnormal operating conditions and credible accidents will result in a breach in the containment of the container assembly and release of some radioactive material. Bounding (worst-case) accident scenarios are conservatively identified even if they are unlikely to occur, and the results of off-site and on-site dose consequence calculations are then compared against the regulatory dose limits and DWMF Acceptance Criteria.

4.3.1 For the RWC/DSO During Handling in the Retube Waste Storage Building

The handling processes taken into account for this assessment encompass those at the RWSB once the RWC/DSO arrives. Handling operations inside the RWSB will require a crane for placing the RWCs/DSOs into storage.

Table 4-4 shows the public and occupational dose consequences due to the malfunctions and accidents deemed credible (i.e., with a frequency of occurrence $>10^{-7}$ events per year) during RWC/DSO handling in the RWSB.

Table 4-4: Postulated Malfunctions or Accidents identified for the Darlington RWCs/DSOs during Handling

Malfunction or Accident	Frequency of Occurrence (events per year)	Potential Maximum Dose Consequence to the Public (µSv)	Potential Maximum Occupational Dose Consequence (mSv)
Container drop (crane)	1.5×10^{-2}	0.004	0.4
Container collision during craning	1.0×10^{-1}	<0.004	<0.4
Delay in placing container into storage	Credible	0	<0.4
RWSB Fire	Credible	0	0
Rail Line Blast	Incredible	--	--
Earthquake	1.14×10^{-7}	<0.004	<0.4
Tornadoes	Incredible	--	--
Thunderstorms	Credible	0	0
Floods	Incredible	--	--
Toxic corrosive chemical rail line accident	Incredible	--	--
Hazardous material building explosion	6.9×10^{-6}	0	0
Aircraft crash	Incredible	--	--

The bounding dose consequences during RWC/DSO handling are associated with the event in which the RWC/DSO drops from its highest handling elevation. Conservatively, it was assumed that:

- The release will be 0.1% of the particulate of the radioactive material that could become airborne within the container as a result of the accident.
- C-14 is assumed to be only released in particulate form.
- Worker uptake of any release is assumed to be 0.1% of the total release in one half-hour.

The hypothetical public dose for all three age classes specified in CSA N292.0-14 [1] (infant, child and adult) were assessed; the child dose was found to be bounding. The dose was calculated to be approximately 0.004 µSv and the hypothetical worker dose was calculated to be approximately 0.4 mSv. Both dose estimates are within the relevant CNSC regulatory limits and the DWMF Acceptance Criteria.

4.3.2 For Operations During RWC/DSO Storage in the Retube Waste Storage Building

During storage, RWCs/DSOs are stacked two high in the RWSB and it is assumed that there will be no operational activities except for maintenance and monitoring. Table 4-5 shows the public and occupational dose consequences due to the malfunctions and accidents deemed credible (i.e., with a frequency of occurrence $>10^{-7}$ events per year) during RWC/DSO storage in the RWSB

The bounding dose consequences for the internal events considered during RWC/DSO storage are associated with the lid sealing failure during storage. Both the DSO and RWC have lid seals but conservatively only the RWC seal is considered to provide the containment function. The consequences of such an event are expected to be bounded by those associated with the container drop during handling.

Table 4-5: Postulated Malfunctions or Accidents identified for the Darlington RWCs/DSOs during Storage

Malfunction or Accident	Frequency of Occurrence (events per year)	Potential Maximum Dose Consequence to the Public (µSv)	Potential Maximum Occupational Dose Consequence (mSv)
Lid Sealing Failure	Credible	<0.004	<0.4
RWSB Fire	Credible	0	0
Earthquake	1.0×10^{-5}	0	0
Tornadoes	1.0×10^{-6}	0	0
Thunderstorms	Credible	0	0
Floods	Incredible	--	--
Rail Line Blast	6.0×10^{-7}	0	0
Toxic corrosive chemical rail line accident	1.0×10^{-6}	0	0
Hazardous material building explosion	2.3×10^{-3}	0	0
Aircraft crash	Incredible	--	--

5.0 OCCUPATIONAL SAFETY ASSESSMENT

5.1.1 Radiation Protection Program

The OPG Radiation Protection Program applies to all OPG nuclear facilities. ALARA dose targets are set under the RP Program and are reviewed annually for continuous improvement.

5.1.2 Worker Dose Assessment

<u>DWMF UFDS</u>

Based on a throughput of 70 DSCs the estimated collective occupational dose is 35.3 person-mSv. Based on the quarterly reports, the maximum assigned occupational individual dose was in 2014 with a dose of 1.69 mSv. As this value is within the previous ALARA assessment value of 3 mSv/year, it is concluded that the individual dose target should remain unchanged.

DWMF operating experience has demonstrated that employee dose is much lower than what is conservatively estimated through the ALARA assessment. In 2014, the total collective dose was 14.76 person-mSv for 67 DSCs with a maximum individual dose of 1.69 mSv. Operators receive most of their dose performing DSC weld repair work.

<u>RWSB</u>

Estimates of worker dose associated with activities in the RWSB have been determined. The yearly collective dose estimate for a throughput of 100 RWCs/DSOs is approximately 29 Person-mSv/y. Assuming a similar RWCs/DSOs throughput, the individual doses per year are likely to be within the administrative and control levels established by the OPG ALARA program.

6.0 CONCLUSIONS

DWMF UFDS

The radiological safety assessment for the UFDS process at the DWMF has addressed worker and public doses under both normal and abnormal operating conditions, and credible accident conditions.

Based on the DWMF operating experience, the environmental releases from the DWMF under normal operating conditions are expected to continue to be well below regulatory limits. The safety assessment concluded that doses to members of the general public arising from potential radioactive releases would be well below the public dose limits established by the CNSC. Doses to members of the general public, from direct radiation at the Darlington NGS site boundary, are also expected to be well below the CNSC public dose limits.

DWMF operation is expected to meet all regulatory dose limits and ALARA targets set out in the RP Program.

The DSC has been assessed to withstand a range of credible external accident conditions, including fires, tornadoes, earthquakes and thunderstorms. No significant off-site or occupational dose consequences are expected to result from these events.

RWS

The safety assessment of RWS operations at the RWSB has addressed worker and public doses under both normal and abnormal operating conditions.

The safety assessment has concluded that doses to the members of the general public arising from potential radioactive releases would be well below the public dose limits established by the CNSC. Doses to members of the general public, from direct radiation at the Darlington NGS site boundary, are also expected to be well below the CNSC public dose limits.

RWS operations are expected to meet all occupational dose rate limits and ALARA targets set out it the RP Program.

The RWC/DSO has been designed to withstand a range of external accident conditions including seismic events and tornadoes. No significant off-site or occupational dose consequences are expected to result from these events.

7.0 ACRONYMS

ALARA	As Low as Reasonably Achievable
CNSC	Canadian Nuclear Safety Commission
CSA	Canadian Standards Association
DNGS	Darlington Nuclear Generating Station
DSC	Dry Storage Container
DSO	Darlington Storage Overpack
DWMF	Darlington Waste Management Facility
MCNP	Monte Carlo N-Particle
NEW	Nuclear Energy Worker
OPG	Ontario Power Generation
RP	Radiation Protection
RWC	Retube Waste Container
RWS(B)	Retube Waste Storage (Building)
SB(s)	Storage Building(s)
UFDS	Used Fuel Dry Storage

8.0 REFERENCES

[1] Canadian Standards Association, CAN/CSA-N288.2-14, December 2014, Guidelines for Calculating the Radiological Consequences to the Public of a Release of Airborne Radioactive Material for Nuclear Reactor Accidents