APPENDIX B

STORAGE AT REACTOR SITES

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B1 INTRODUCTION

Used nuclear fuel generated at the Pickering, Darlington and Bruce Power Nuclear Generating Stations (NGS) is stored in irradiated fuel bays (wet storage), and in Used Fuel Dry Storage Facilities (UFDSF) at the respective sites. The Pickering and Western (servicing the Bruce Power reactors) UFDSFs are operational and additional capacity will be constructed as required in the future. A licence to construct a UFDSF at Darlington has been granted by the Canadian Nuclear Safety Commission (CNSC). The three UFDSFs are owned and operated by Ontario Power Generation (OPG). This appendix describes the expected radiation levels and dose rates to workers, the public and the environment at the UFDSFs during construction, operation and decommissioning as described in the corresponding environmental assessments.

B1.1 OBJECTIVE AND SCOPE

The objective of this appendix was to summarize the existing information about radiation doses to workers, the public and non-human biota from the Pickering, Darlington and Western UFDSFs. Baseline doses from natural background radiation and from existing licensed nuclear operations were quantified where possible. Incremental doses from site preparation and construction, operation and decommissioning phases of the UFDSFs were compared to regulatory levels and baseline dose rates. The operational doses were based on estimates of expected doses after the full complement of used fuel has been placed in storage (after shutdown of the reactors). Doses from normal operation and from the bounding malfunction and accident (the malfunction or accident resulting in the highest dose) were described where estimates have been reported.

B1.2 CONTENTS OF THIS APPENDIX

The remainder of this appendix is divided into four sections describing the form and function of UFDSFs, the Site Preparation and Construction Phase, the Operations Phase, and the Decommissioning Phase.

In Section B2, Description of UFDSFs, the purpose and function of UFDSFs are summarized, and site-specific layouts of the Pickering, Darlington and Western UFDSFs are described.

In Section B3, Site Preparation and Construction Phase, the activities occurring during this phase are outlined. Site-specific radiation doses to workers, the public and non-human biota are reported where available from normal operation and malfunctions and accidents.

In Section B4, Operation Phase, the activities occurring during this phase are summarized. Site-specific radiation doses to workers, the public and non-human biota are reported where available from normal operation and malfunctions and accidents.

In Section B5, Decommissioning Phase, the activities occurring during this phase are outlined. Site-specific radiation doses to workers, the public and non-human biota are reported where available from normal operation and malfunctions and accidents.

In Section B6, References, the background material used to prepare this appendix is listed.

B2 DESCRIPTION OF UFDSFS

The used fuel dry storage program facilitates the interim dry storage of used fuel in above-ground storage facilities at the respective NGSs until a long-term management facility for used fuel is available. A brief overview of the used fuel dry storage program is described in this section.

B2.1 SITE PREPARATION AND CONSTRUCTION

The construction phase of the process includes in-station modifications, preparation of the site and construction of facilities. In-station modifications to the irradiated fuel bays and systems accommodate underwater loading of used fuel into Dry Storage Containers (DSCs). Preparation of the site and construction includes construction of the DSC processing systems and storage buildings and installation of services. The storage buildings are single story, commercial-type, pre-engineered or pre-cast concrete structures with a concrete slab-on-grade floor. No hazardous material was used in the construction of the storage buildings.

Locations of the Pickering, Darlington and Western UFDSFs are shown in Figures B2-1, B2-2 and B2-3, respectively. The Darlington and Western UFDSFs were designed as one contiguous structure with internal access among the processing and storage buildings. At Pickering, given the limited space around the existing UFDSF, two additional storage buildings have been proposed to be built approximately 500 m to the east of the UFDSF.

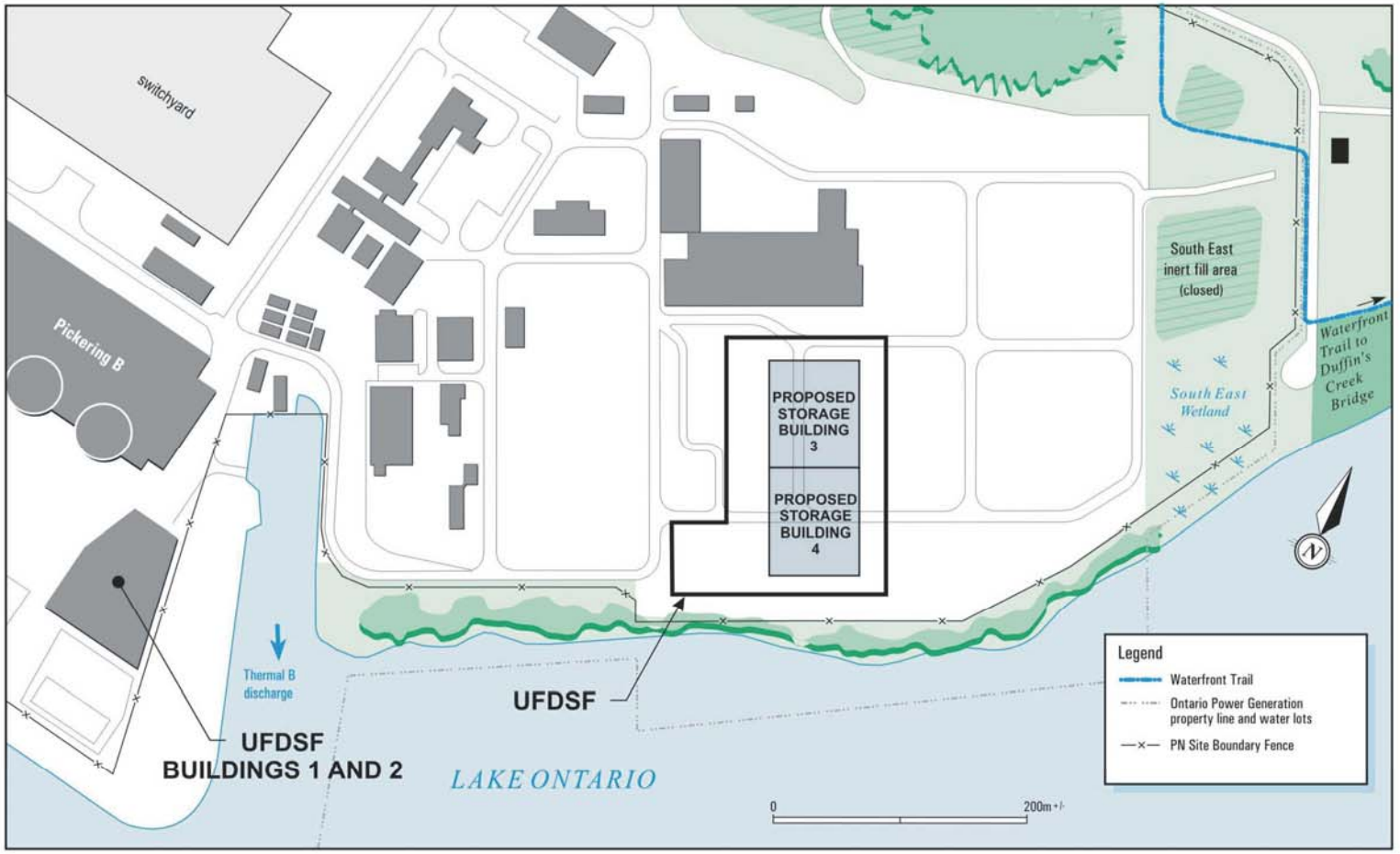
B2.2 OPERATION

The operations phase of the process is summarized in Figure B2-4 and involves the following activities:

- receive DSCs by road transport from the manufacturer;
- prepare the DSCs for transfer to the NGS irradiated fuel bay;
- load the used fuel into DSCs in the irradiated fuel bay;
- transfer the loaded DSCs to the processing building;
- process the loaded DSCs in preparation for storage;
- transfer loaded DSCs to storage; and
- store DSCs in the storage buildings.

FIGURE B2-1

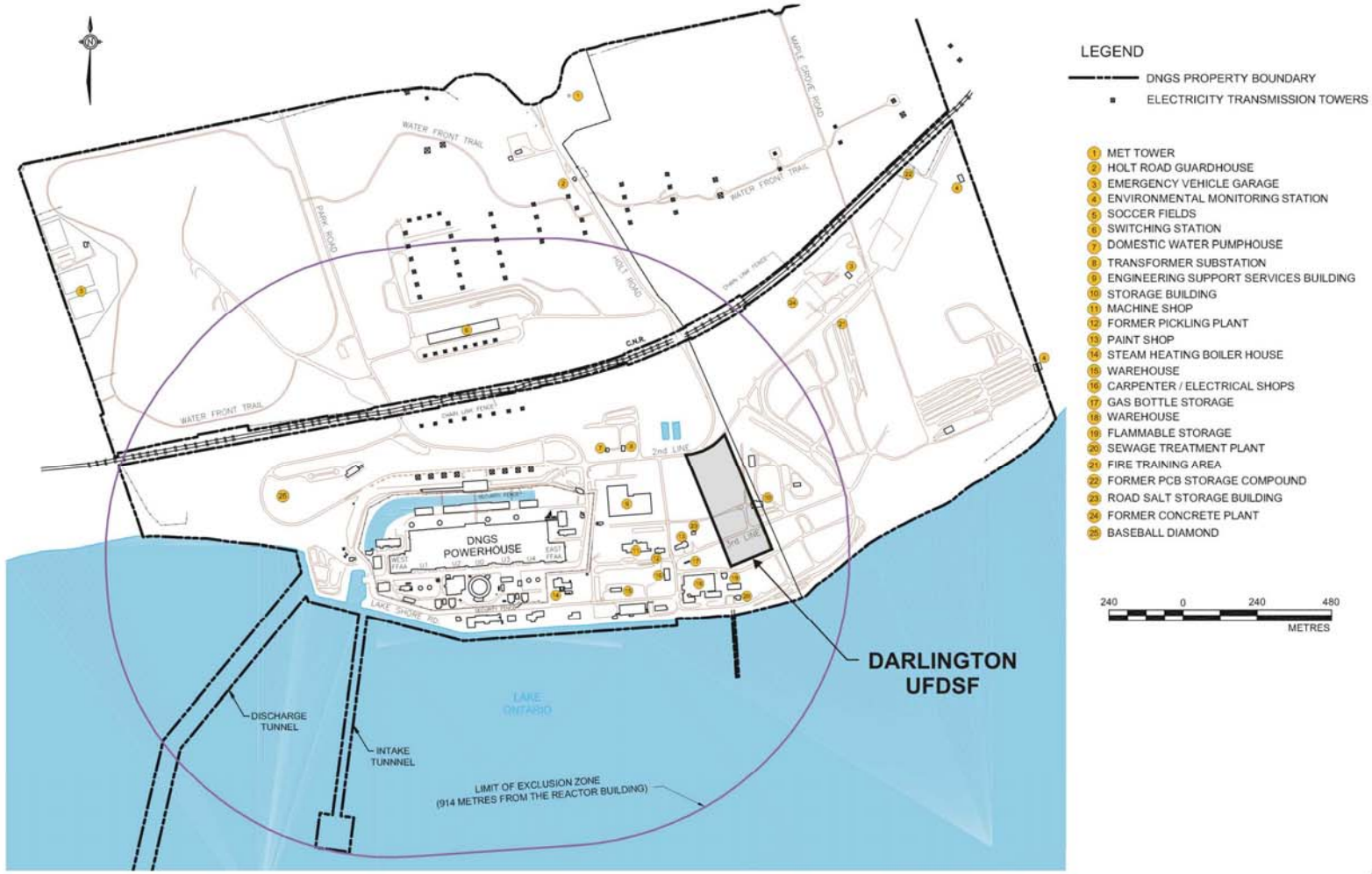
PICKERING USED FUEL DRY STORAGE FACILITY



SOURCE: OPG, 2003b

FIGURE B2-2

DARLINGTON USED FUEL DRY STORAGE FACILITY



SOURCE: OPG, 2002a

FIGURE B2-3

WESTERN USED FUEL DRY STORAGE FACILITY

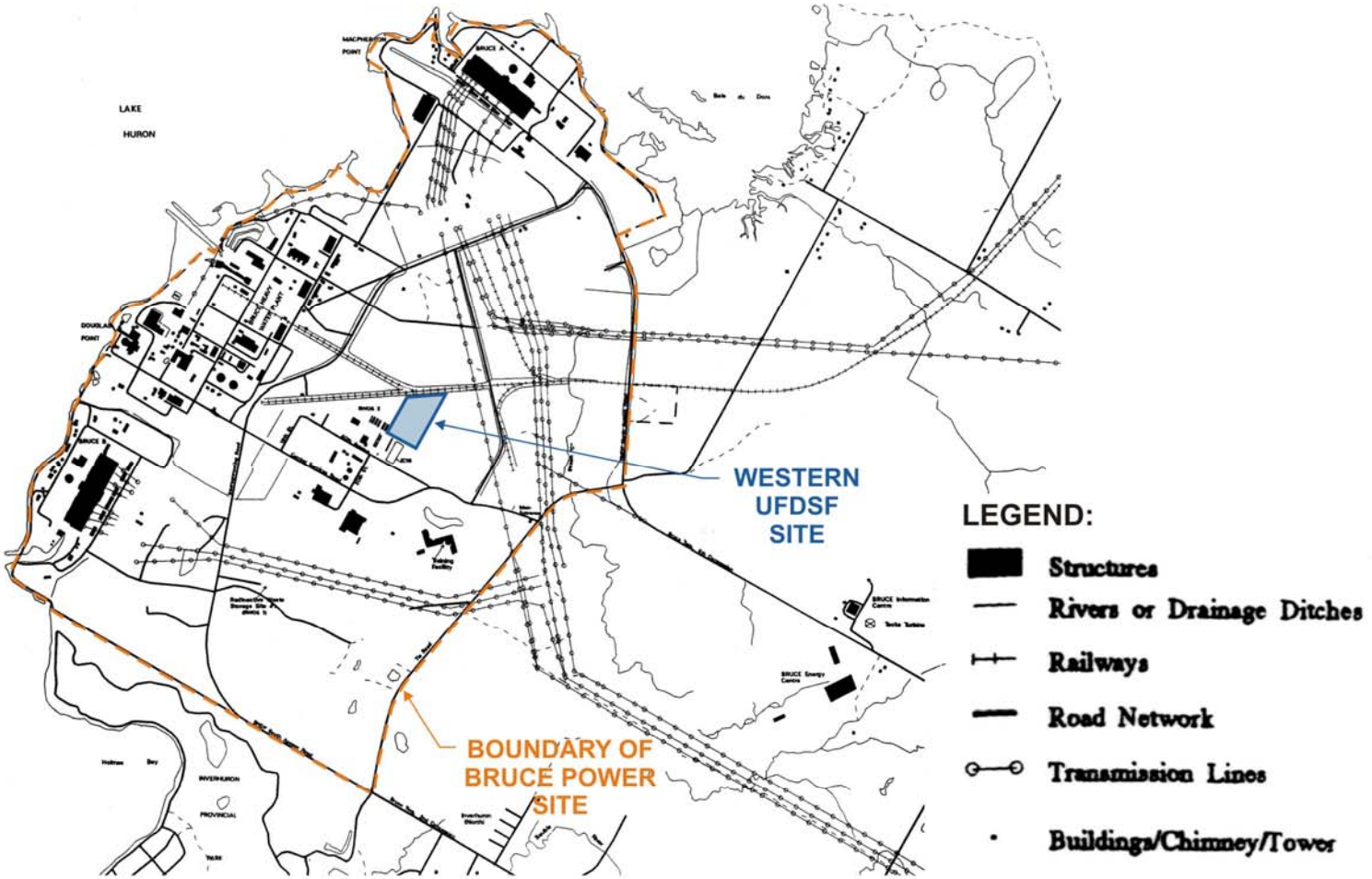
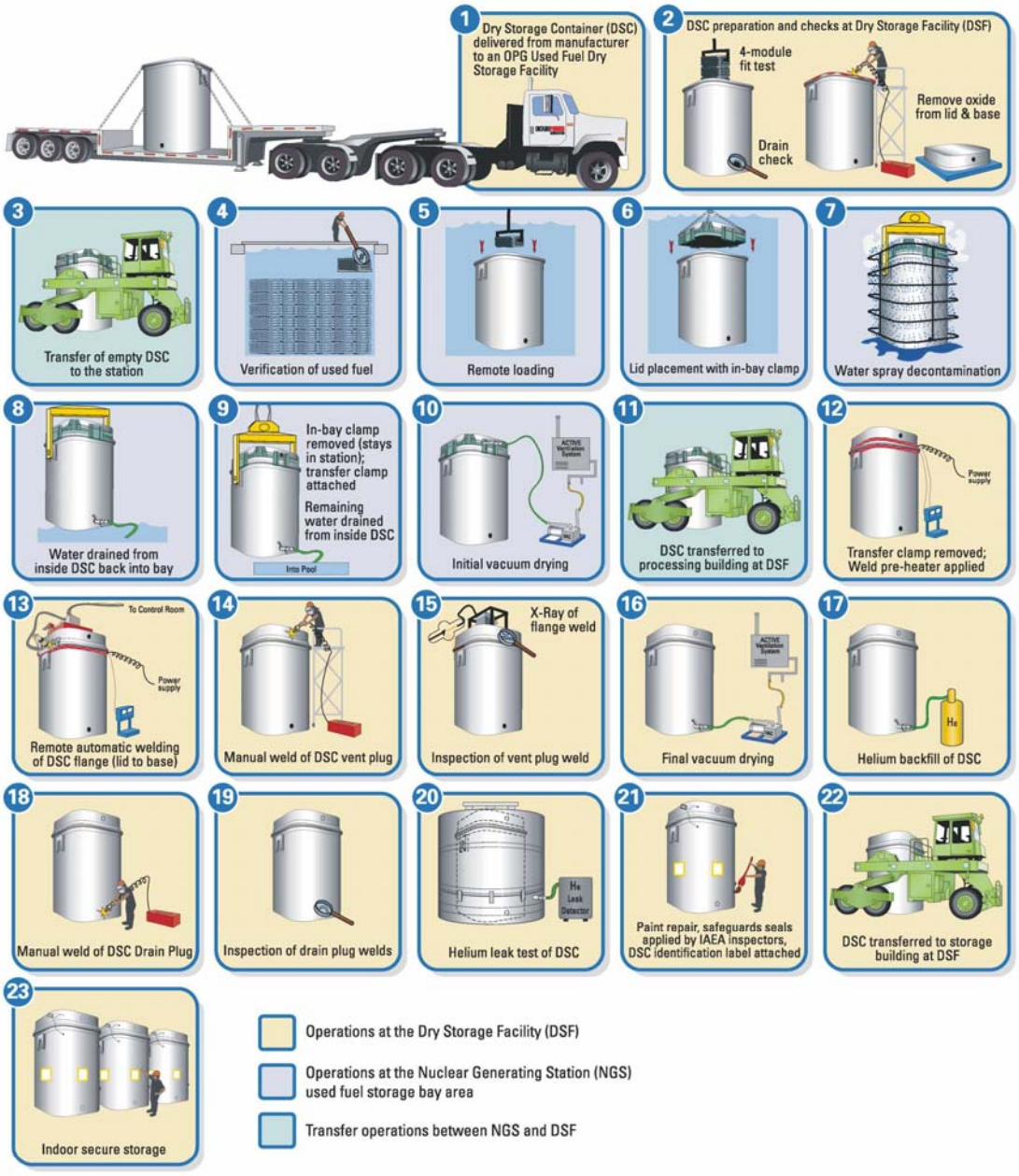


FIGURE B2-4

STEPS IN USED FUEL DRY STORAGE PROCESS



SOURCE: OPG

The DSC is currently approved by the CNSC for the storage of used fuel at the Pickering and Western UFDSFs, and is proposed for the storage of used fuel at the Darlington UFDSF. The DSC is a free standing nuclear safety related reinforced concrete container, with an inner steel liner and an outer steel shell, for the storage and transportation (with an outer packaging) of used CANDU fuel. It is made of two sub-assemblies, a lid and a base, Figure B2-5. The base provides storage space for the used fuel, and is designed to accommodate 384 used fuel bundles. The DSC provides radiation shielding and containment of radioactive materials. It is designed to provide a storage life of at least 50 years and to meet all shielding and containment integrity requirements over this period. The maximum total weight (including the lid of 11 Mg) is approximately 60 Mg when empty and approximately 70 Mg when loaded with 384 used fuel bundles (OPG 2003a).

The total quantity of used fuel to be stored at the Pickering UFDSF is forecast as approximately 590,976 bundles, assuming a 40-year operating life for the Pickering NGS (OPG 2003a). The number of DSCs in dry storage is estimated at approximately 1,540 containing approximately 11,000 tonnes of uranium). The remainder of the used fuel will be stored in the existing irradiated fuel bays.

The total quantity of used fuel to be stored at the Darlington UFDSF is forecast as approximately 529,000 bundles (equivalent to 10,050 tonnes of uranium). Over a 40-year operating life, the NGS is expected to produce a total of approximately 876,700 used fuel bundles. The remainder, 347,700 bundles, will be stored in the existing irradiated fuel bays (OPG 2002a).

The total capacity of the irradiated fuel bays at the Bruce Power NGS A and B is approximately 725,000 fuel bundles. Over the current 40-year reference life of these stations, additional storage capacity for about 705,000 fuel bundles will be required. The Western UFDSF is designed to hold approximately 1,940 DSCs at capacity , and the corresponding inventory of used fuel bundles was estimated at approximately 744,000 (assuming 384 bundles per DSC) (OPG 2001).

B2.3 DECOMMISSIONING

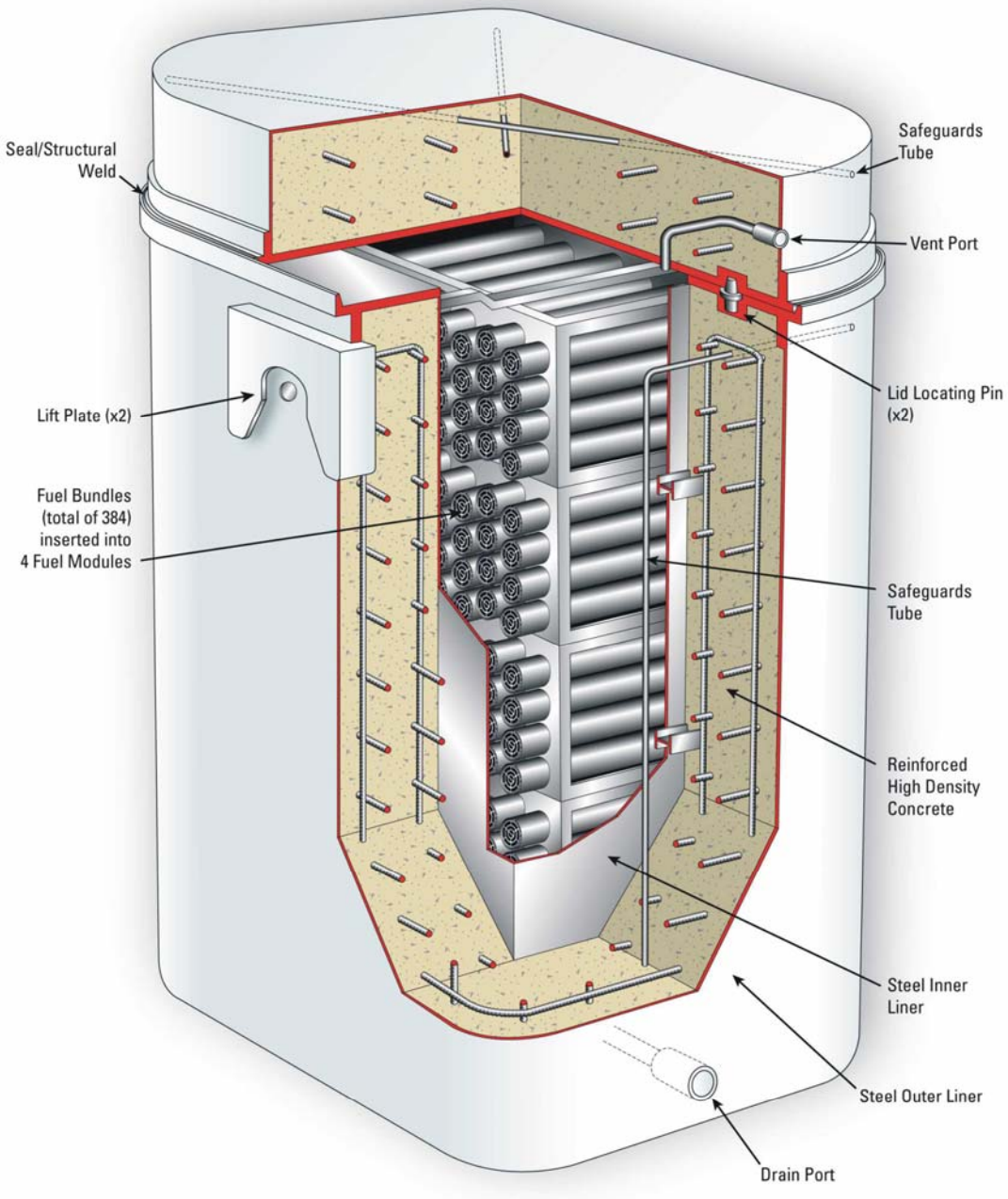
The loaded DSCs will be stored at the UFDSFs until a long-term used fuel management strategy for Canada is determined and implemented. Decommissioning of each UFDSF will commence after removal of all the DSCs from the facility.

Decommissioning will involve three phases: i) preparation for decommissioning, ii) site decommissioning and iii) site restoration. Preparation for the decommissioning phase will begin before the end of operations where detailed decommissioning plans will be prepared and submitted to CNSC in support of a decommissioning licence. The site decommissioning phase will include surveys to determine the extent of contamination, complete removal and disposal of contaminated equipment and the decontamination or removal of all contaminated concrete, metal

and other materials. The site restoration phase will start after radiological and other hazards have been removed from the site. This phase will include demolition of the Storage Buildings. Upon completion of decommissioning, the site will be in a condition that will permit the CNSC to issue a Licence to Abandon where it can then be available for other OPG uses (OPG 2003a).

FIGURE B2-5

LOADED AND SEALED DRY STORAGE CONTAINER (DSC)



SOURCE: OPG, 2003a

B3 SITE PREPARATION AND CONSTRUCTION PHASE

Site preparation and construction activities include:

- in-station modifications;
- preparation of the site, including earth moving and site grading; and
- construction of processing and storage buildings.

These activities take place entirely within the respective site properties.

B3.1 SITE PREPARATION AND CONSTRUCTION (NORMAL)

Site preparation and construction activities (normal) at each of the three NGSs are not expected to result in increased radiation or radioactivity levels in the environment. However, workers carrying out site preparation, roadway and building construction, and construction phase stormwater management will be exposed to radiation and radioactivity from the existing licensed nuclear facilities (NGSs, waste management, etc.). These workers are expected to receive exposures that they would not receive if the same work was conducted at distance from the NGS.

B3.1.1 Public

Site preparation and construction activities (normal) at each of the three NGSs are not expected to result in increased radiation or radioactivity levels in the environment. Therefore, there are expected to be no incremental radiation doses to the public during these activities.

B3.1.2 Workers

In the environmental assessments for the UFDSFs, worker doses from other CNSC licensed activities during preparation of the site and construction of the processing and storage buildings were estimated at less than 1 mSv in a year - the limit for non-nuclear energy workers (non-NEWs). However, worker doses from CNSC licensed activities during completion of in-station modifications were estimated in excess of 1 mSv in a year, and therefore, these workers would be designated as NEWs. The results of the environmental assessments are described below. In future, in-station worker exposures may be controlled to lower levels, and they may also be designated as non-NEWs.

Pickering

The Pickering UFDSF construction was planned in Phases. Construction of the first phase included in-station modifications as well as site preparation and construction of the processing

and storage buildings 1 and 2. The construction of two additional storage buildings (3 and 4) has been proposed.

During Phase I construction involving in-station modifications, workers were exposed to existing gamma radiation and airborne radioactivity present in those areas from normal Pickering NGS operations. However, radiation doses to workers during Phase I construction were not reported in the environmental assessment.

During the construction of storage buildings 3 and 4, it has been estimated that the workers carrying out site preparation and construction activities will be exposed to direct gamma radiation from the existing UFDSF; and radioactivity releases to air from Pickering NGS. Most of the dose rates are too low to be measured and were estimated by modelling and calculation. The annual dose to a worker at the construction site of buildings 3 and 4 due to direct radiation and skyshine from the existing UFDSF was estimated at 0.0027 mSv/y based on 2,000 hours occupancy. The dose rate to workers at the construction site for buildings 3 and 4 from releases to air from Pickering NGS of radioactive noble gases, inhalation and skin absorption of tritium, inhalation of C-14, and inhalation and groundshine from radioiodine and radioactive particulate was estimated at 0.0015 mSv/y. The total individual dose to construction workers of buildings 3 and 4 from the licensed activities on the site (operation of the existing Pickering UFDSF and NGS) was estimated at approximately 0.0042 mSv/y (OPG 2003b), Table B3-1. The estimated dose is a small fraction of the dose from natural background and the regulatory limit for non-NEWs as shown in Figure B3-1. The construction workers will be members of the public and will be subject to the corresponding regulatory dose limits.

The average annual dose from natural background radiation and radioactivity to residents in the vicinity of Pickering and Darlington was estimated at 1.3 mSv/y (OPG 2004). The annual dose received by individuals can differ from the average by a large percentage depending upon dwelling type and location, lifestyle (mainly fraction of time spent outdoors), and food consumption patterns.

Table B3-1
Worker Dose (Construction – Normal)

Worker	Pickering Average/Highest Annual, mSv/y	Darlington Average/Highest Annual, mSv/y	Western Average/Highest Annual, mSv/y	Regulatory Limit, mSv/y
non-NEW	0.0042	0.003	nr	1
NEW	nr	1.3/1.9	nr	20*

* Regulatory limits are 100 mSv over 5 consecutive years, and 50 mSv in any given year
nr not reported in the environmental assessments

Darlington

The Darlington UFDSF will be constructed in three phases. Construction of the first phase will include in-station modifications in the irradiated fuel bays as well as site preparation and construction of the processing and storage buildings 1. Construction of the other phases will require only site preparation and construction of additional storage buildings.

During Phase I construction involving in-station modifications, workers will be exposed to existing gamma radiation and airborne radioactivity present in those areas from normal Darlington Nuclear Generating Station (DNGS) operations. These construction workers will have designation as NEWs, and will be monitored for both external radiation (gamma, neutron and beta) and for internal radioactivity by urinalysis and whole body counting as required (OPG 2002a). Annual doses to individual workers are expected to be less than the average annual dose of approximately 1.3 mSv (ranging up to 1.9 mSv) currently received by DNGS workers in that area (OPG 2002a), Table B3-1 and Figure B3-1.

Site preparation and construction of the processing and storage buildings will occur at a distance from the NGS, Figure B2-2. Worker doses at this location were estimated at 0.003 mSv/y and less (OPG 2002a), Table B3-1 and Figure B3-1, and these workers are expected to be designated non-NEWs.

Western

Worker doses during site preparation and construction were not addressed in the Environmental Assessment (OH 1997).

B3.1.3 Non-Human Biota

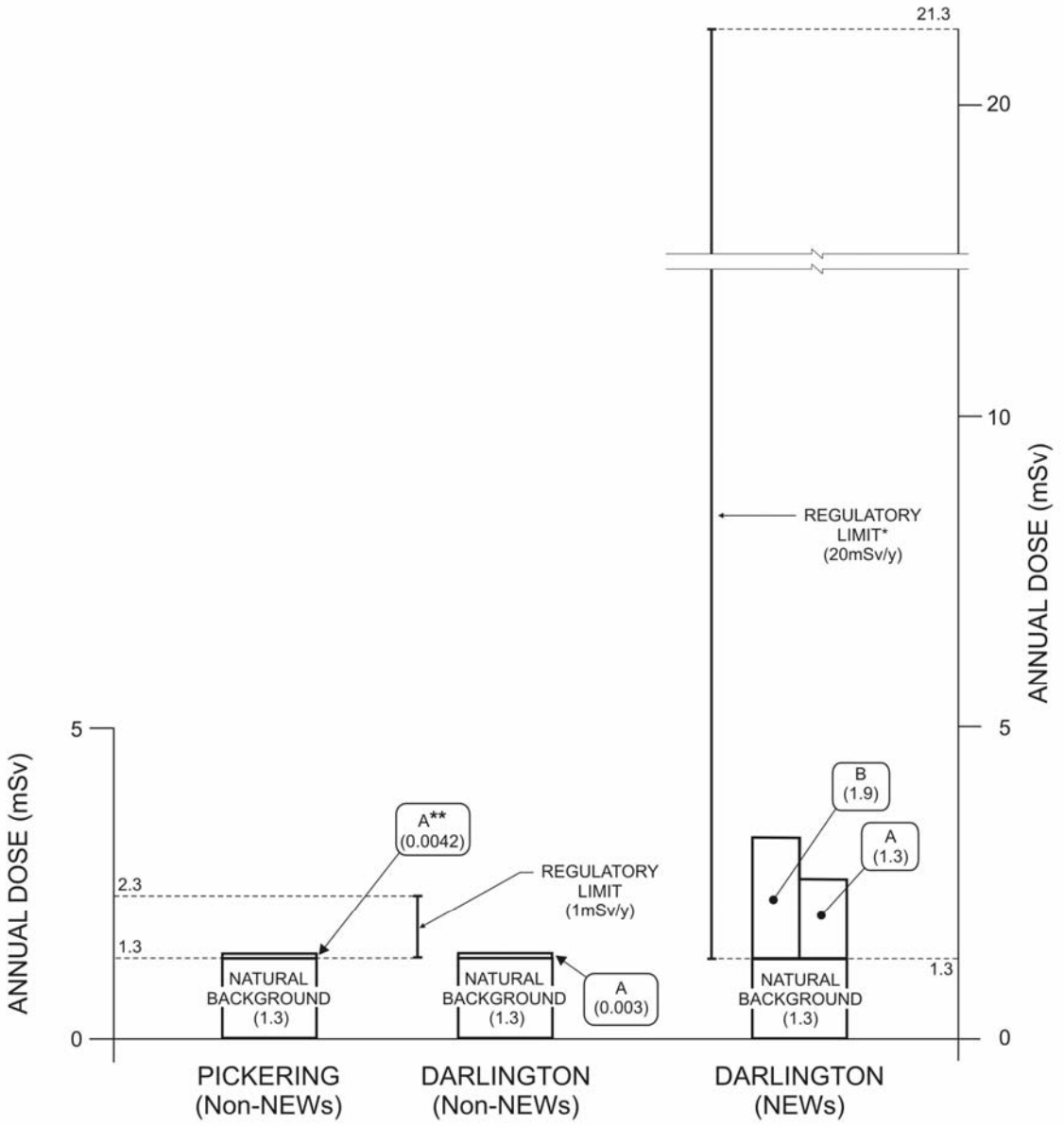
Site preparation and construction activities (normal operation) at each of the three NGSs are not expected to result in increased radiation or radioactivity levels in the environment. Therefore, there are expected to be no incremental radiation doses to non-human biota during these activities.

B3.2 SITE PREPARATION AND CONSTRUCTION (MALFUNCTIONS AND ACCIDENTS)

Malfunctions and accidents during site preparation and construction activities at each of the three NGSs are not expected to result in increased radiation or radioactivity levels in the environment. Therefore, there are expected to be no incremental radiation doses to the workers, the public or non-human biota resulting from malfunctions and accidents during site preparation and construction.

FIGURE B3-1

ANNUAL WORKER DOSE (Construction-Normal)



NOTE:

A) Indicates average annual dose from other licensed operations
B) Indicates highest annual dose from other licensed operations

* Regulatory Limits are 100 mSv/ over 5 consecutive calendar years and 50 mSv in any single year

** Phase II only

B4 OPERATION PHASE

The operation phase of the UFDSFs is outlined at the generic level in Section B2. Site-specific differences among the three facilities affect operations as described below.

At both Darlington and the Western UFDSFs, the storage buildings are attached to the processing building, and post-processing transfers of the loaded DSCs from the processing building to the storage buildings occur completely within the attached structures. Whereas at Pickering, the processing building is attached to storage buildings 1 and 2, and the proposed storage buildings 3 and 4 will be constructed at a distance of approximately 500 m from the existing UFDSF. Therefore after processing at Pickering, some of the loaded DSCs will be stored at the existing Pickering UFDSF and then transferred to the proposed storage buildings 3 and 4 for final storage.

At the Western UFDSF, the processing and storage buildings are located in the Western Waste Management Facility at distances of approximately 6 and 3 km from Bruce A (reactors 1-4) and Bruce B (reactors 5-8), respectively. The transfer distances of loaded DSCs from irradiated fuel bays in the Bruce reactor buildings to the processing building are greater than the corresponding transfer distances at Pickering and Darlington (approximately 0.5 to 1.6 km, respectively).

During normal operation, there have been no radioactivity releases to air and water during transfer and storage of DSCs. Radioactivity releases to air and water from processing of DSCs has been insignificant with respect to radiation doses to workers, the public and the environment. However, gamma radiation from the DSCs is transmitted through the walls and roof of the storage buildings and is the main contributor to dose.

B4.1 OPERATION (NORMAL)

Pickering

The design of the processing and storage buildings 1 and 2 provides sufficient shielding in the walls such that the gamma dose rate at the perimeter of the UFDSF site is less than 0.5 μSv/h. This meets the OPG target of ≤ 0.5 μSv/h corresponding to a dose rate of $\leq 1{,}000$ μSv/y (1 mSv/y) for 2000 h/y occupancy, the CNSC public dose limit for non-NEWs.

The design of Storage Buildings 3 and 4 will provide for sufficient shielding in the walls (30 cm of normal concrete) such that the gamma dose rate at the perimeter of this site is predicted to be 0.13 μSv/h when the full complement of DSCs is in storage. The effect of the gamma radiation from the Storage Buildings 3 and 4 is expected to increase the dose rate at the perimeter of this

site by approximately a factor of 4 times from a baseline of 0.03 μSv/h to approximately 0.13 μSv/h (OPG 2003b).

A dose rate of 50 μSv/h was predicted at the roof of Storage Buildings 3 and 4 from an array of loaded DSCs completely filling the buildings.

The effect of gamma radiation from the Storage Buildings at the PN site boundary (≤ 10 μSv/y) is expected to increase the levels by less than three percent above a baseline of 350 μSv/y. This effect will be indistinguishable from the temporal and spatial variations in natural background radiation levels at this location.

Darlington

A preliminary assessment of gamma radiation levels from the full complement of loaded DSCs (approximately 1,500) in three Storage Buildings predicted a dose rate of 0.345 μSv/h at 18 m from the wall of the Storage Buildings. This level meets the OPG target of ≤ 0.5 μSv/h. In the environmental assessment, the absorbed dose rates were conservatively estimated at 0.35 μSv/h at the UFDSF perimeter, 5.5 μSv/h at the outer surface of the shielding walls, and 90 μSv/h at the outer surface of the roof.

Gamma radiation from the Storage Buildings is expected to increase the dose rate at the UFDSF perimeter by approximately a factor of 10 times from a baseline of 0.04 μSv/h to approximately 0.4 μSv/h.

Gamma radiation from the Storage Buildings is expected to increase the dose rate at the Darlington site boundary by approximately 0.01 percent (0.032 μSv/y) above a baseline of 400 μSv/y. This effect will be indistinguishable from the variations in natural background radiation levels at this location.

Western

An assessment of gamma radiation levels from the full complement of loaded DSCs (approximately 2,000) in the (4) Storage Buildings predicted a dose rate of <0.5 μSv/h at the facility perimeter, and <0.0001 μSv/h at the Bruce site boundary. More detailed dose assessments were not presented in the environmental assessment of the Western UFDSF.

B4.1.1 Public

Pickering

The predicted gamma radiation levels from full Storage Buildings (1 to 4) are expected to result in a dose rate of ≤ 10 μSv/y to a person continuously occupying a location at the Pickering site boundary, Table B4-1 and Figure B4-1 (OPG 2003b). This includes contributions from both direct radiation through the shielding wall and skyshine. Skyshine is gamma radiation that escapes from the top of the DSCs and scatters off the air above the storage building onto the receptors at the site boundary.

The annual dose from other licensed activities on the Pickering site to a person continuously occupying the nearest property (a correctional institute) was reported at approximately 0.005 mSv/y in the most recent Annual Summary and Assessment of Radiological Data (OPG 2004).

Table B4-1
Annual Public Doses (Operation – Normal)

Source	Pickering Average Annual, mSv/y	Darlington Average Annual, mSv/y	Western Average Annual, mSv/y	Regulatory Limit, mSv/y
From UFDSF	< 0.01	0.000032	< 0.001	1
From other licensed activities	0.005	0.002	0.002	1

Darlington

The preliminary assessment of gamma radiation levels from full Storage Buildings at the UFDSF predicted a dose rate of 0.032 μSv/y at the Darlington site boundary, Table B4-1 and Figure B4-1. The receptor was at the closest point on the boundary to the Storage Buildings, a distance of approximately 1023 m, and includes both direct and skyshine contributions (OPG 2002a).

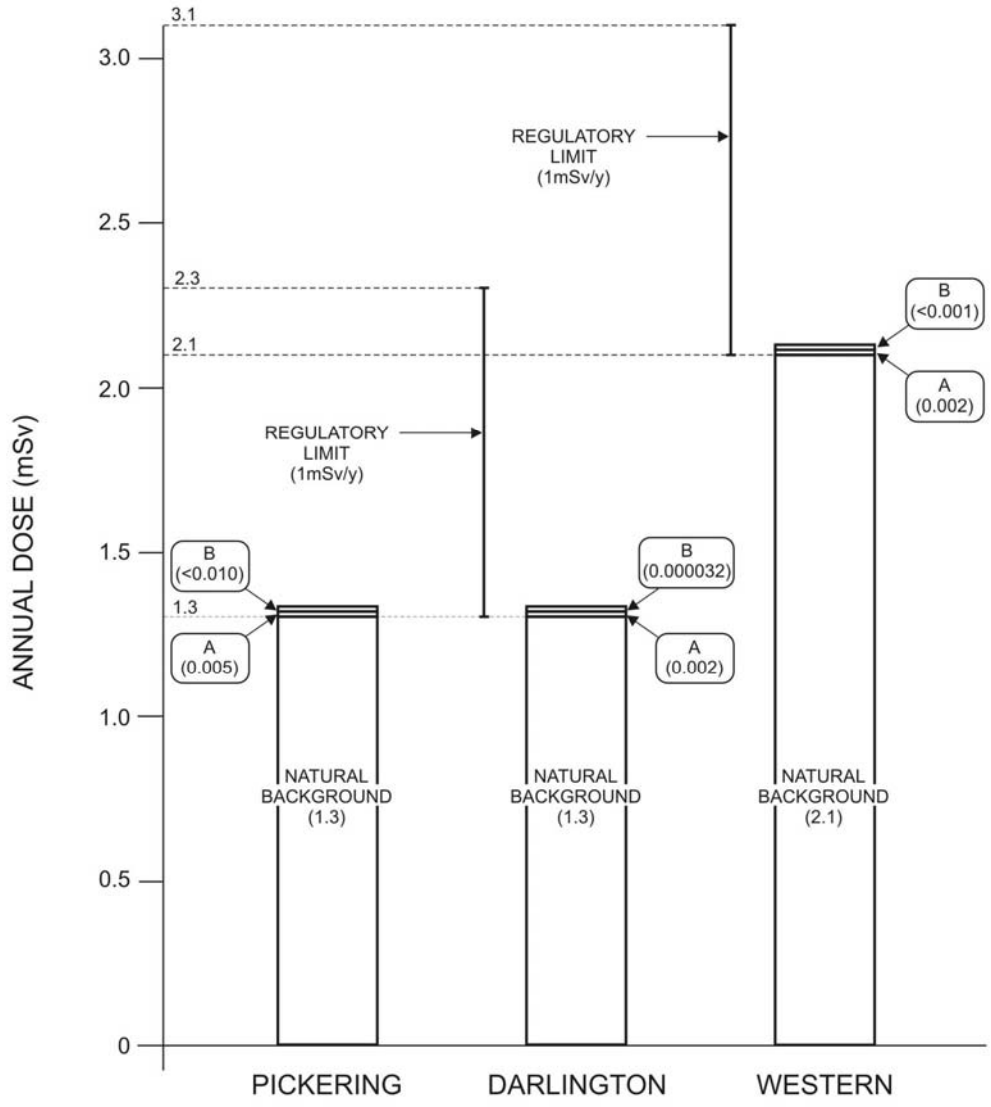
The annual dose from other licensed activities on the Darlington site to a person (infant) continuously occupying the closest property was reported at approximately 0.002 mSv/y in the most recent Annual Summary and Assessment of Radiological Data (OPG 2004).

Western

The assessment of gamma radiation levels from full Storage Buildings at the Western UFDSF predicted a dose rate of 0.001 mSv/y at the Bruce site boundary, Table B4-1 and Figure B4-1. The receptor was at the closest point on the boundary to the Storage Buildings, and includes both direct and skyshine contributions (OPG 2001).

FIGURE B4-1

ANNUAL PUBLIC DOSE (Operation - Normal)



NOTE:

A) Average annual dose from normal operation of other licensed nuclear facilities on site; Estimated from environmental measurements.
B) Average annual dose from normal operation of UFDSF; Hypothetical conservative estimate.

The annual dose from other licensed activities on the Bruce site to a person continuously occupying the site boundary was reported at approximately 0.002 mSv/y in the most recent Annual Summary and Assessment of Radiological Data (Bruce Power 2004).

B4.1.2 Workers

Pickering

Radiation doses to two designations of workers are described in these sections. Workers designated as NEWs carry out all activities involving used fuel from transfer into the DSC to final storage and monitoring. Other workers (non-NEWs) may be involved in work on the Pickering site in the vicinity of the UFDSF and in the UFDSF.

Doses to UFDSF workers (NEWs) during normal operation were estimated by reference to the measured doses to workers at the existing UFDSF. The individual doses average 0.6 mSv/y with a maximum of 1.9 mSv/y (OPG 2003b), Table B4-2 and Figure B4-2. Workers are monitored for exposure to external radiation and to internal exposures by bioassay. Consequently, measured doses implicitly include contributions from all sources to which the workers are exposed.

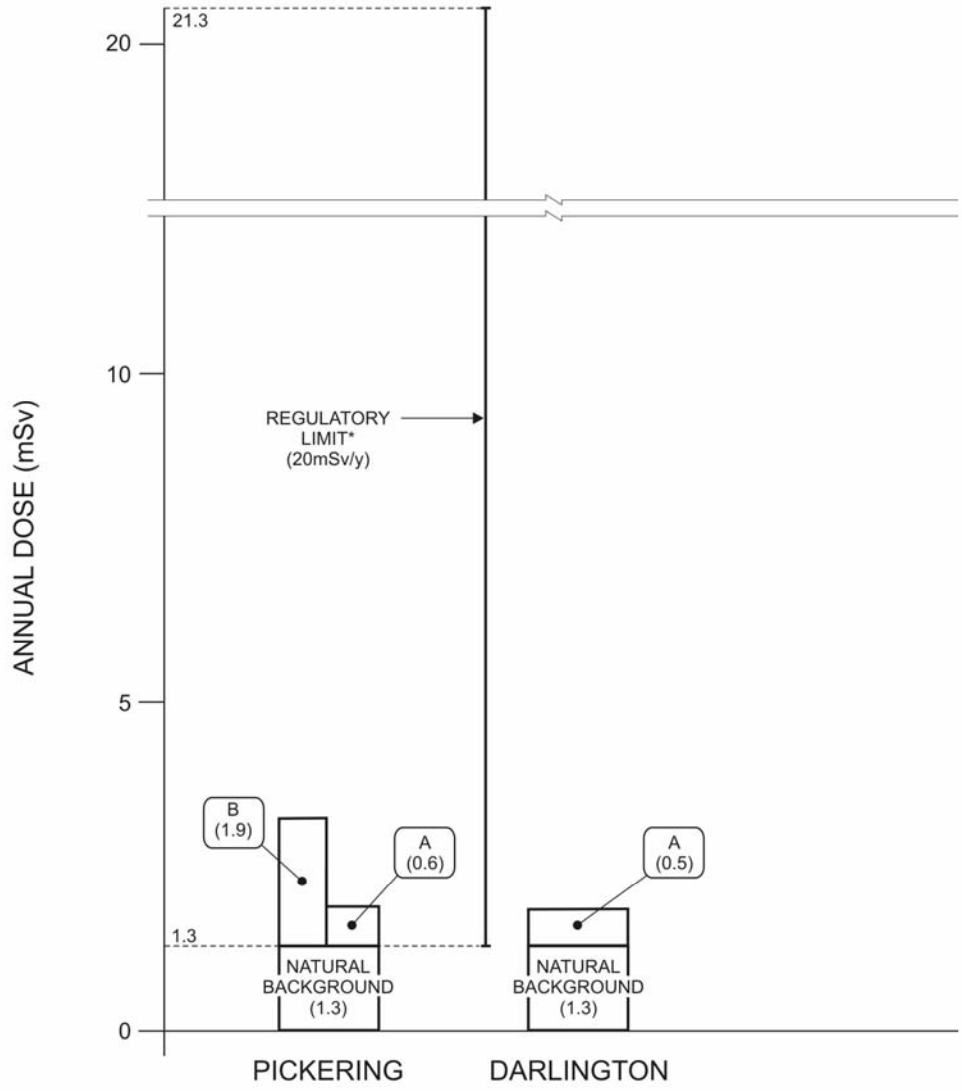
Table B4-2
Annual Worker Dose - NEW (Operation – Normal)

Source	Pickering Average/highest Annual, mSv/y	Darlington Average Annual, mSv/y	Western Average Annual, mSv/y	Regulatory Limit, mSv/y
From UFDSF	0.6/1.9	0.5	nr	20*

* Regulatory limits are 100 mSv over 5 consecutive years, and 50 mSv in any given year
nr not reported in the environmental assessments

FIGURE B4-2

ANNUAL WORKER DOSE (NEW)
(Operation - Normal)



NOTE:

A) Average annual dose from normal operations
B) Highest annual dose from normal operations

* Regulatory Limits are 100 mSv/ over 5 consecutive calendar years and 50 mSv in any single year

Workers (non-NEWs) who work outside the protected areas of the UFDSF and the NGS will be exposed to gamma radiation from the UFDSF, and are subject to regulatory limits on annual dose of 1 mSv. The gamma dose rate at the perimeter of the UFDSF will be maintained at levels below the OPG target of ≤ 0.5 μSv/h (1 mSv for a 2,000 hour work year). Therefore, the doses to workers (non-NEWs) from normal operation are expected to be below the regulatory limit on annual dose (i.e., 1 mSv/y), Table B4-3 and Figure B4-3.

Table B4-3
Annual Worker Dose – Non-NEW (Operation – Normal)

Source	Pickering Average/highest Annual, mSv/y	Darlington Average Annual, mSv/y	Western Average Annual, mSv/y	Regulatory Limit, mSv/y
From UFDSF	< 1	< 1	< 1	1
From other licensed activities	0.004	0.003	nr	1

nr not reported in the environmental assessments

Darlington

Doses to Darlington UFDSF workers (NEWs) during normal operation were estimated by reference to the measured doses to workers at the Pickering UFDSF. At the time the EA was prepared, the best estimate of average annual worker dose was 0.5 mSv from both internal and external radiation (OPG 2002a), Table B4-2 and Figure B4-2.

Non-NEWs who work outside the Darlington UFDSF and NGS protected areas will be exposed to gamma radiation from the UFDSF, and are subject to regulatory limits on annual dose of 1 mSv. A preliminary dose assessment indicates that the gamma dose rate at the perimeter of the UFDSF will be well below the OPG target of 0.5 μSv/h (1 mSv for a 2,000 hour work year), Table B4-3 and Figure B4-3.

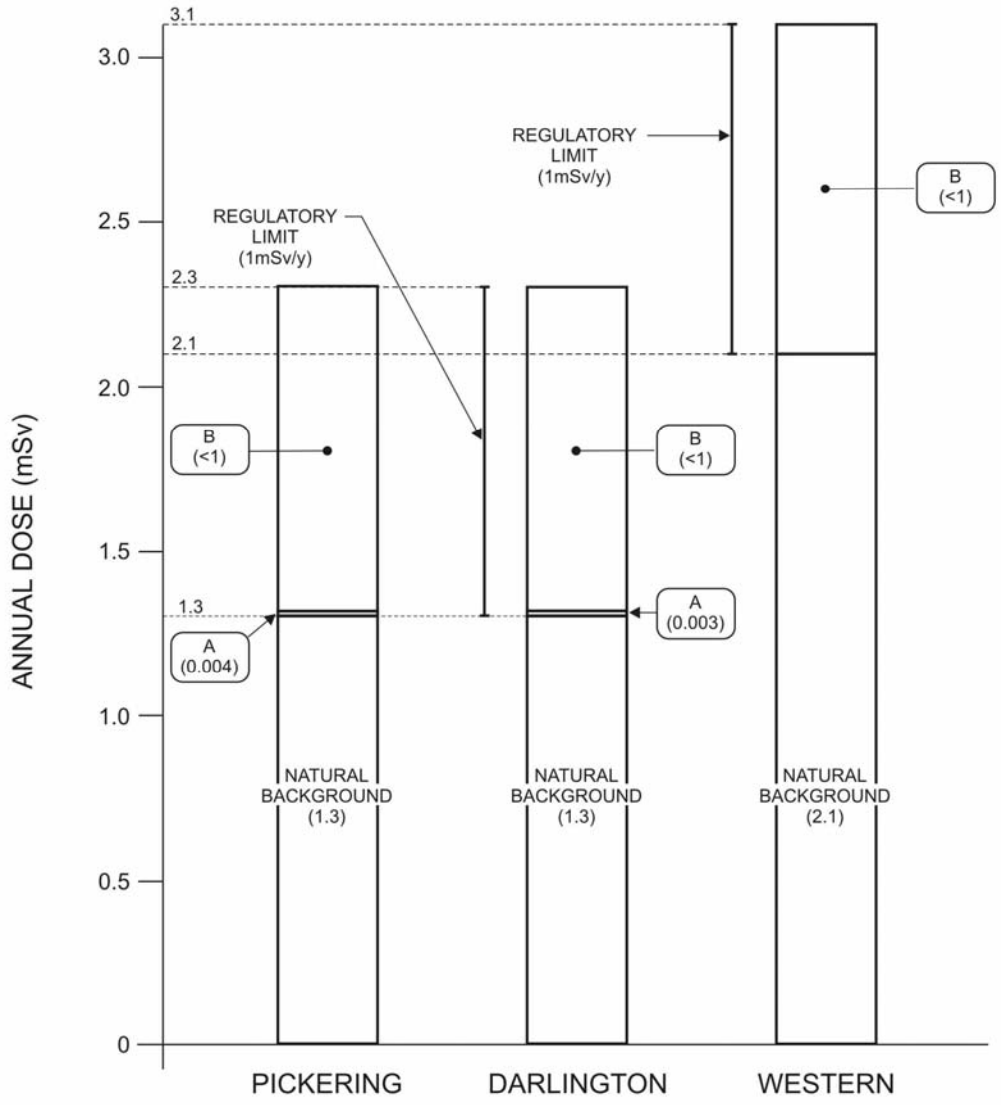
Western

Worker doses (to NEWs) were not addressed in the Western UFDSF EA (OH 1997).

Bruce Power and OPG workers (non-NEWs) who work outside the perimeter of the Western UFDSF will be exposed to gamma radiation from loaded DSCs, and are subject to regulatory limits on annual dose of 1 mSv. A dose assessment indicated that the gamma dose rate at the UFDSF perimeter will be below the OPG target of 0.5 μSv/h (1 mSv for a 2,000 hour work year), Table B4-3 and Figure B4-3.

FIGURE B4-3

ANNUAL WORKER DOSE (non-NEW) (Operation - Normal)



NOTE:

A) Average annual dose from normal operation of other licensed nuclear facilities.
B) Annual dose from normal operation of UFDSFs.

B4.1.3 Non-Human Biota

Pickering

The preliminary assessment of the gamma radiation levels from loaded DSCs in Storage Buildings 3 and 4 predicted a dose rate of 0.13 μSv/h at the perimeter of the UFDSF. The absorbed dose rate to terrestrial flora and fauna was estimated at 0.00013 mGy/h (OPG 2003b). The corresponding daily dose rate to terrestrial flora and fauna at the perimeter of the UFDSF is approximately 0.003 mGy/d, and is a small fraction of the no-effects level of 1 mGy/d reported by UNSCEAR (1996). Also, the predicted dose rate is expected to be within the range of natural background, 0.004 to 0.02 mGy/d reported by UNSCEAR (1996), Table B4-4 and Figure B4-4.

Table B4-4
Daily Dose to Non-Human Biota (Operation – Normal)

Source	Pickering Average Annual, mGy/d	Darlington Average Annual, mGy/d	Western Average Annual, mGy/d	UNSCEAR Guideline, mGy/d
From UFDSF	0.003	0.008	0.11	1
From natural background and other licensed activities	0.004-0.02	0.004-0.02	nr	1

nr not reported in the environmental assessments

Darlington

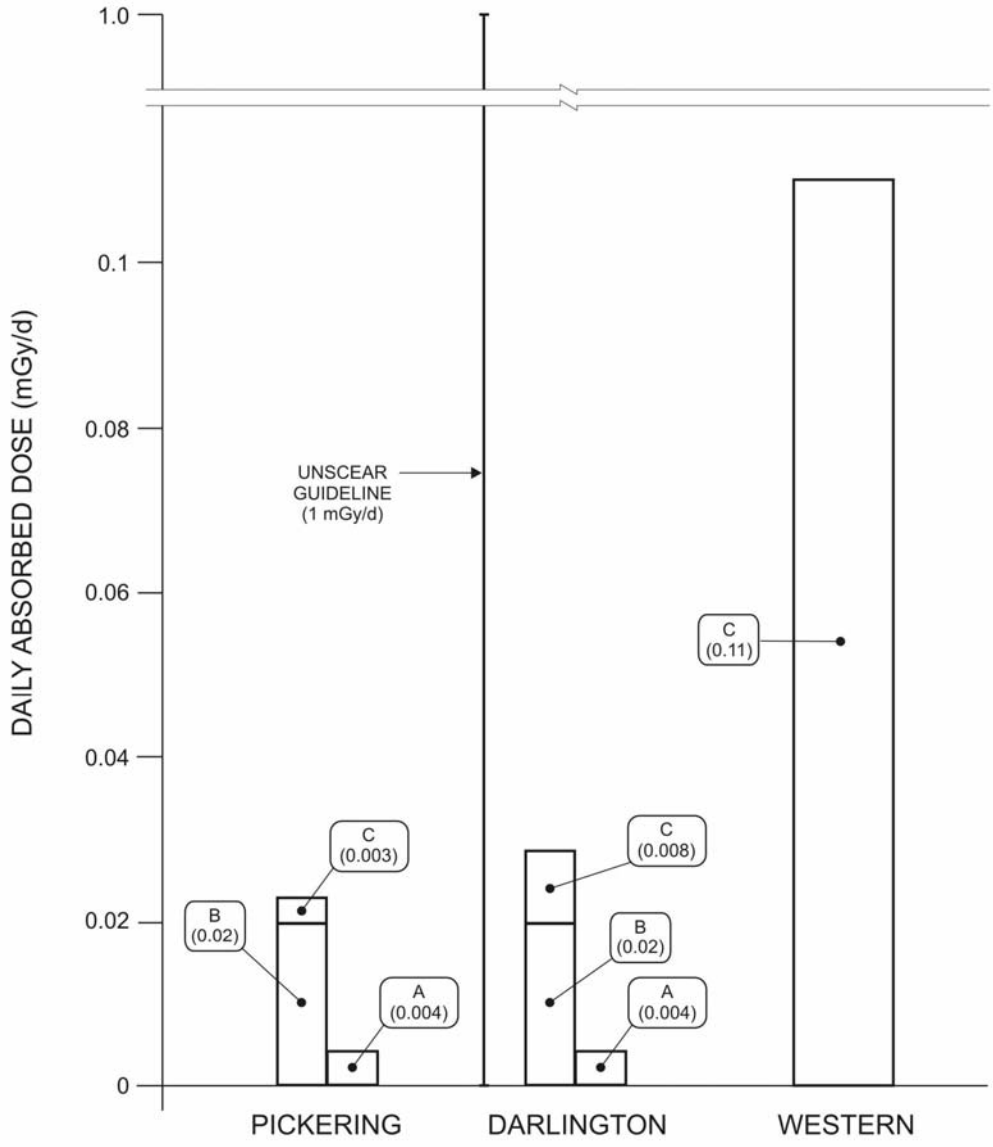
The preliminary assessment of the gamma radiation levels from the full complement of loaded DSCs in the Storage Buildings predicted a dose rate of 0.345 μSv/h at the UFDSF perimeter, 18 m from the wall of the Storage Buildings (OPG 2002a). The corresponding absorbed dose rates to tissue were conservatively estimated at 0.35 μGy/h. The estimated daily dose rate to terrestrial flora and fauna at the UFDSF perimeter is approximately 0.008 mGy/d, and is a small fraction of the guideline recommended by UNSCEAR (1996), 1 mGy/d, Table B4-4 and Figure B4-4.

Western

The preliminary assessment of the gamma radiation levels at 20 m from loaded DSCs (the distance at which biota may be present) predicted a dose rate of 0.11 mGy/d (OH 1997). The estimated daily dose rate to terrestrial flora and fauna is a small fraction of the guideline recommended by UNSCEAR (1996), 1 mGy/d, Table B4-4 and Figure B4-4.

FIGURE B4-4

DAILY DOSE TO NON-HUMAN BIOTA (Operation - Normal)



NOTE:

A) Low end of range of daily dose from natural background.
B) High end of range of daily dose from natural background.
C) Average daily dose from normal operation at UFDSF.

B4.2 OPERATION (MALFUNCTIONS AND ACCIDENTS)

Malfunctions and accidents at UFDSFs have the potential for release of free radionuclide inventory from failed fuel elements. Specifically within the period from 10 years to several decades after removal from the reactor core, tritium and krypton-85 are available for release. The assessment of potential effects of malfunctions and accidents first identified potential events that could result in a release. The identified events were:

Internal events:

- DSC drop during on-site transfer;
- Transfer vehicle failure;
- Accidents during DSC handling and storage;
- DSC seal-weld failure during storage (chronic release):
- DSC Processing Building fire;
- DSC Storage Building fire;
- DSC Storage Building structural collapse:
- Loss of Irradiated Fuel Bay cooling;
- Loss of Reception Bay water inventory;
- Fuel module drop in the Irradiated Fuel Bay;
- Drop of a module inside a DSC;
- Drop of a loaded DSC in the Irradiated Fuel Bay;
- Drop of a loaded DSC on the concrete floor (before draining);
- Slapdown impact of a DSC on the concrete floor (after draining);
- Turbine break-up;
- Fires; and
- Criticality.

External events (natural hazards):

- Earthquakes;
- Thunderstorms;
- Floods; and
- Tornadoes and tornado-generated missiles.

External events arising from human activities:

- Fires and explosions;
- Toxic corrosive chemical rail line accident;
- Tritium Removal Facility/Heavy Water Management Building failures; and
- Small aircraft crash.

Events that are not underlined above, were identified as either incredible or releases from them were less than releases from one or more of the underlined events. Therefore, it was concluded that dose assessments of the underlined events determined the envelope of effects of all credible malfunctions and accidents. Radiation doses to off-site members of the public were estimated for each of the underlined scenarios, and the DSC drop during on-site transfer was identified as the bounding malfunction/accident potentially resulting in the highest dose to the public. The potential doses from the bounding malfunction/accident were addressed in the respective environmental assessments and are summarized in the following section.

B4.2.1 Public

Pickering

The assessment of the effects of the release of tritium and Kr-85 following the bounding accident was based on releases of 1.45×10^{12} Bq of tritium and 7.77×10^{12} Bq of Kr-85 (OPG 2003). For perspective, the inventory of tritium released from the bounding accident, should it occur, is less than the amount of tritium released from PN to air during an average day in 2001.

During an accident, tritium is expected to be released in the oxide form. If a fire should occur during the release, the tritium will be carried aloft in the thermal plume. To be conservative, dose estimates were made assuming that the plume is dispersed at ground level. The public dose at the PN site boundary from a bounding malfunction/accident was conservatively estimated at 0.001 mSv (OPG 2003b), Table B4-5 and Figure B4-5. The dose from a malfunction/accident would be in addition to doses from normal UFDSF operations and from other licensed activities on the Pickering site. During the year in which a bounding malfunction/accident occurs, the sum of these doses is a small fraction of the regulatory limit on public dose in a year - 1 mSv.

Table B4-5
Public Dose During the Year in Which a – Bounding Malfunction/Accident Occurs (Operation)

Source	Pickering, mSv	Darlington, mSv	Western, mSv	Regulatory Limit, mSv
UFDSF Malfunction/Accident	0.001	0.005	0.005	-
UFDSF (normal)	< 0.01	0.000032	< 0.001	-
other licensed activities	0.005	0.002	0.002	-
Total in the year	≤ 0.016	≤ 0.007	≤ 0.008	1

nr not reported in the environmental assessments.

Darlington

The assessment of the effect of the release of tritium and Kr-85 following the bounding accident was based on releases of 3.32×10^{12} Bq of tritium and 1.85×10^{13} Bq of Kr-85 and was evaluated in a conservative manner. For perspective, the inventory of tritium released from the bounding accident is approximately equal to the amount of tritium released from the DNGS to air over an average three-day period during 2001.

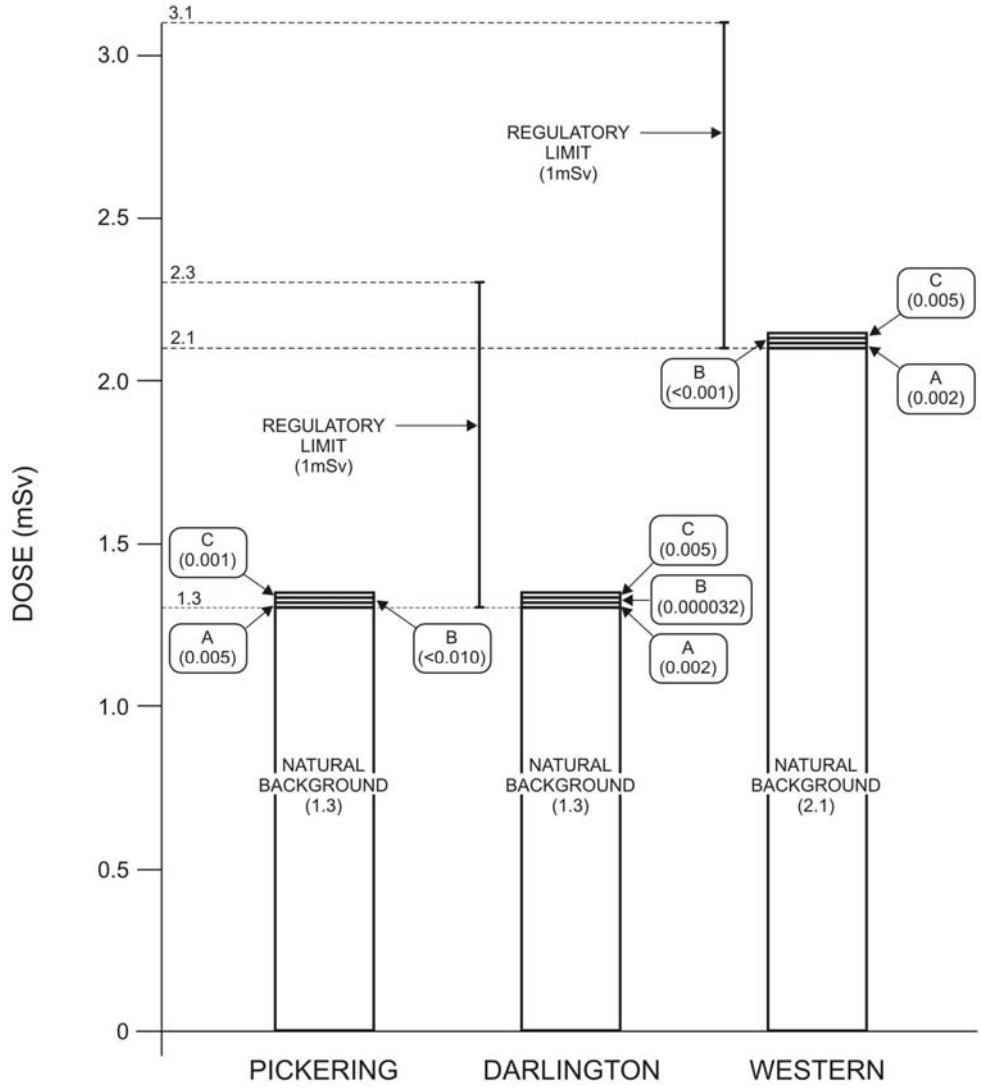
As in the assessment of malfunction/accident at Pickering, tritium was assumed to be in the oxide form, and calculations were made assuming that the plume is transported at ground level. A preliminary estimate of the dose to members of the public at the NGS site boundary was conservatively calculated at 0.005 mSv (OPG 2002). Most of the dose would be attributable to tritium oxide. During the year in which a bounding malfunction/accident occurs, the estimated dose from the malfunction/accident and from normal UFDSF operations and other licensed activities on the Darlington site is a small fraction of the regulatory limit on dose to members of the public (1 mSv) in a year, Table B4-5 and Figure B4-5.

Western

As in the assessment of malfunction/accident at Pickering, tritium was assumed to be in the oxide form, and calculations were made assuming that the plume is transported at ground level. A preliminary estimate of the dose to members of the public at the Bruce site boundary was conservatively calculated at 0.005 mSv (OPG 2001). Most of the dose would be attributable to tritium oxide. During the year in which a bounding malfunction/accident occurs, the estimated dose from the malfunction/accident and from normal UFDSF operations and other licensed activities on the Bruce site is a small fraction of the regulatory limit on dose to members of the public (1 mSv) in a year, Table B4-5 and Figure B4-5.

FIGURE B4-5

PUBLIC DOSE DURING A HYPOTHETICAL YEAR IN WHICH A BOUNDING MALFUNCTION/ACCIDENT OCCURS AT UFDSF



NOTE:

A) Average annual dose from normal operation of other licensed nuclear facilities on site.
B) Dose from normal operation of UFDSF at year end when malfunction/accident occurs.
C) Dose from bounding malfunction/accident at UFDSF.

B4.2.2 Workers

Pickering

For purposes of estimating dose from the bounding malfunction/accident, the worker was assumed to be present in the vicinity of the accident location wearing no protective clothing or respiratory protection. The worker's response time to exit the accident location was assumed to be two minutes. The dose was calculated assuming a semi-infinite cloud model of 500 m^3. Under the worst credible accident condition, the worker dose was calculated at 6 mSv (OPG 2003). During the year in which a bounding malfunction/accident occurs, this dose could be added to the annual dose from normal operation, Table B4-6 and Figure B4-6. The total dose in a year would be a small fraction of the regulatory limit on dose in a year (50 mSv).

Table B4-6
Worker Dose (NEW) During the Year in Which a Bounding Malfunction/Accident Occurs (Operation)

Source	Pickering Average/highest, mSv	Darlington Average, mSv	Western Average, mSv	Regulatory Limit, mSv
UFDSF Malfunction/Accident	6	15	6	-
UFDSF (normal)	0.6/1.9	0.5	nr	-
Total in the year	6.6/7.9	15.5	-	50*

* Regulatory limits are 100 mSv over 5 consecutive years, and 50 mSv in any given year.
nr not reported.

Darlington

The dose to UFDSF workers from a bounding malfunction/accident was estimated at 15 mSv (OPG 2002a). Should the malfunction/accident occur near the end of a dosimetry year, the estimated dose to a worker could be in addition to a typical annual dose of approximately 0.5 mSv from normal operation. During the year in which a bounding malfunction/accident occurs, the total dose for the year would be approximately 16 mSv, well below the regulatory limit of 50 mSv for any given year, Table B4-6 and Figure B4-6.

Western

The dose to workers at the Western UFDSF from a bounding malfunction/accident was estimated at 6 mSv (OPG 2001). Should the malfunction/accident occur near the end of a dosimetry year, the estimated dose to a worker could be in addition to a typical annual dose from normal operation. During the year in which a bounding malfunction/accident occurs, the total dose for the year would be well below the regulatory limit of 50 mSv for any given year, Table B4-6 and Figure B4-6.

FIGURE B4-6

WORKER DOSE (NEW) DURING A HYPOTHETICAL YEAR IN WHICH A BOUNDING MALFUNCTION/ACCIDENT OCCURS AT UFDSF

NOTE:

A) Average occupational dose at year end when malfunction/accident occurs.
B) Expected dose from malfunction/accident.
n.r.) Not reported

B4.2.3 Non-Human Biota

Pickering

The acute dose to terrestrial flora and fauna within 100 or 200 m of the release of tritium and Kr-85 from a bounding accident was estimated at 9 mGy (OPG 2003b), Table B4-7 and Figure B4-7. Most of the dose is attributable to an assumed exposure to tritium oxide. The total dose from malfunctions and accidents, normal operation of the UFDSF, normal operation of other licensed facilities, and natural background is less than 1 % of the guideline recommended by UNSCEAR (1996) for acute doses.

Table B4-7
Acute Dose to Non-Human Biota (Operation – Malfunction/Accident)

Source	Pickering Average Annual, mGy	Darlington Average Annual, mGy	Western Average Annual, mGy	UNSCEAR Guideline, mGy
UFDSF Malfunction/Accident	9	50	nr	-
From UFDSF	0.003	0.008	0.11	-
From natural background and other licensed activities	0.004-0.02	0.004-0.02	nr	-
Total in a day	9	50	nr	1,000

nr not reported in the environmental assessments

Darlington

The estimated dose to terrestrial flora and fauna within 100 or 200 m of a release of tritium and Kr-85 from a bounding accident was calculated at 50 mGy (OPG 2002), Table B4-7 and Figure B4-7.

Western

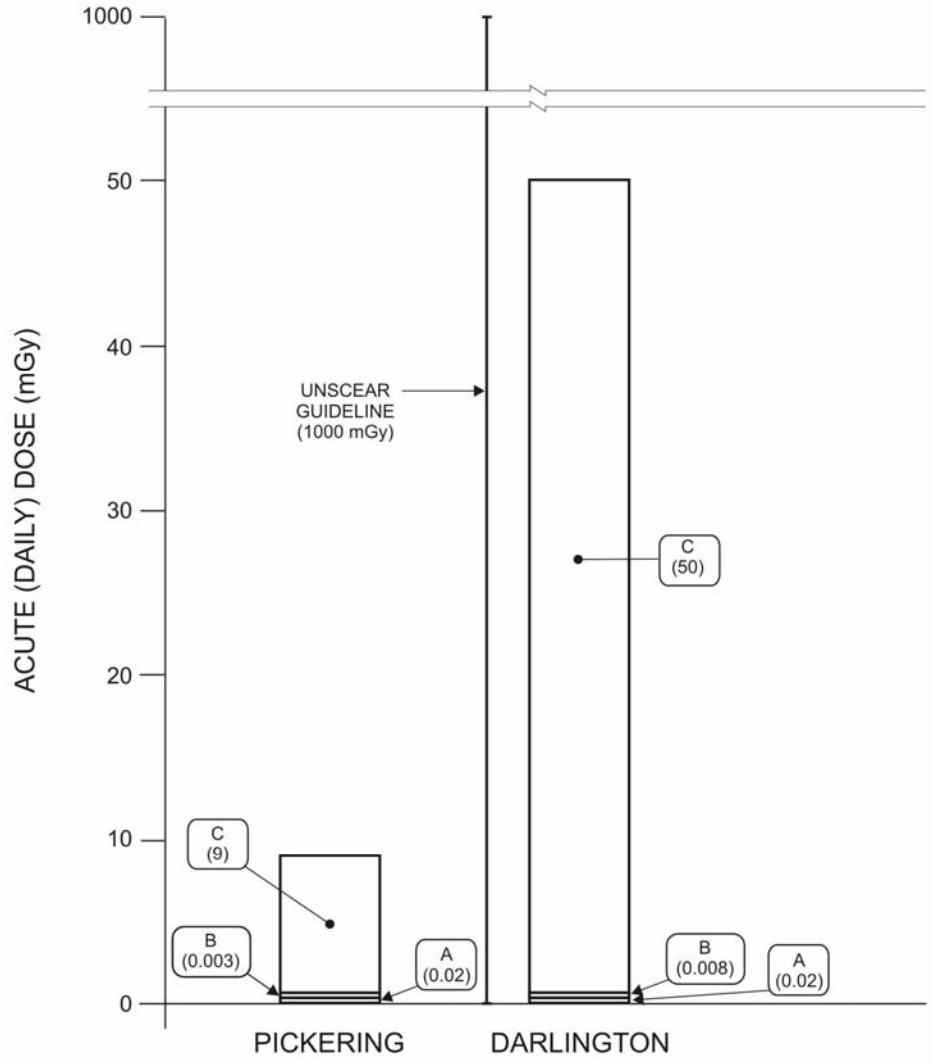
The dose to terrestrial flora and fauna from malfunctions and accidents at the Western UFDSF was not addressed in the Environmental assessment (OH 1997).

B5 DECOMMISSIONING PHASE

To the time of writing, decommissioning of UFDSFs has been addressed in qualitative terms only. Consequently, quantitative estimates of radiation doses to the public, workers and biota during decommissioning at UFDSF were not available.

FIGURE B4-7

DOSE TO NON-HUMAN BIOTA
(Hypothetical - Bounding Malfunction/Accident at UFDSF)



NOTE:

A) High end of range of daily dose from natural background.
B) Average daily dose from normal operation at UFDSF.
C) Acute dose from bounding malfunction/accident at UFDSF.

B6 REFERENCES

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