OPG's DEEP GEOLOGIC

REPOSITORY

FOR LOW & INTERMEDIATE LEVEL WASTE

Radiation and Radioactivity Technical Support Document

March 2011

Prepared by: AMEC NSS Ltd.

NWMO DGR-TR-2011-06

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AMEC NSS Ltd.			
Prepared by:	B. Khan, J. Peng, M. Gerchikov		
Reviewed by:	S. Batters		
Approved by:	M. Rawlings (Golder Associates Ltd.)		
Nuclear Waste Management Organization			
Reviewed by:	M. Mayhew, D. Barker		
Accepted by:	A. Castellan		

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EXECUTIVE SUMMARY

ES.1 INTRODUCTION

Ontario Power Generation (OPG) is undergoing a multi-year planning and regulatory approval process for a deep geologic repository (DGR) for the long-term management of low and intermediate level waste (L&ILW). Currently, the L&ILW produced as a result of operation of OPG's nuclear reactors is stored centrally at OPG's Western Waste Management Facility (WWMF) located at the Bruce nuclear site. Although current storage practices are safe and could be continued safely for many decades, OPG's long-term plan is to transfer these wastes to a long-term management facility. Throughout this report, OPG's proposal is referred to as the "DGR Project".

The DGR Project includes the site preparation and construction, operations, decommissioning, and abandonment and long-term performance of the DGR. The DGR will be constructed in competent sedimentary bedrock beneath the Bruce nuclear site near the existing WWMF. The underground facilities will include access-ways (shafts and tunnels), emplacement rooms and various underground service areas and installations. The surface facilities include the underground access and ventilation buildings, Waste Package Receiving Building (WPRB) and related infrastructure.

An environmental assessment (EA) of the proposed DGR Project is required under the provisions of the *Canadian Environmental Assessment Act* (CEAA) because the proponent (OPG) will be required to obtain a licence from the Canadian Nuclear Safety Commission (CNSC) to allow the project to proceed. The findings of the EA are presented in the Environmental Impact Statement (EIS) and Technical Support Documents (TSDs).

ES.2 APPROACH

The approach used for assessing effects of the DGR Project supports the philosophy of EA as a planning tool and decision-making process. The assessment characterizes and assesses the effects of the DGR Project in a thorough, traceable, step-wise manner. The approach used in the assessment includes the following steps:

- describe the project;
- describe the existing environment;
- screen potential project-environment interactions to focus the assessment;
- predict and assess effects, apply mitigation measures to reduce or eliminate the effects and identify residual adverse effects;
- determine significance of residual adverse effects; and
- propose a follow-up program to confirm mitigation measures are effective and the DGR Project effects are as predicted.

The assessment of effects considers direct and indirect affects from the DGR Project, effects of the environment on the project, climate change considerations, and effects of the project on renewable and non-renewable resources. An assessment of the cumulative effects associated with the DGR Project, taking into account past, existing and planned projects, is presented in Section 10 of the EIS. Effects are predicted in the context of temporal and spatial boundaries.

The temporal boundaries for the EIS establish the timeframes for which the effects are assessed. Four temporal phases were identified for the DGR Project:

- site preparation and construction phase;
- operations phase;
- decommissioning phase; and
- abandonment and long-term performance phase.

The timeframes adopted for the EA are intended to be sufficiently flexible to capture the effects of the DGR Project. The assessment presented in this TSD focuses on the effects of the DGR Project on radiation and radioactivity during the first three phases. Given that the long half-life of some radionuclides associated with the L&ILW will extend into the abandonment and long-term performance phase, there is a potential for radiation and radioactivity effects after the abandonment of the DGR facility. Those effects are described in Section 9 of the EIS.

Spatial boundaries define the geographical extents within which environmental effects are considered. As such, these boundaries become the study areas adopted for the EA. Four study areas were selected for the assessment of radiation and radioactivity: the Regional Study Area, Local Study Area, Site Study Area and Project Area. The Project Area, although not specified in the EIS Guidelines, was defined to help describe the potential site-specific effects of the DGR Project. Each study area includes the smaller study areas (i.e., they are not geographically separate).

ES.3 VALUED ECOSYSTEM COMPONENTS

While all components of the environment are important, it is neither practicable nor necessary to assess every potential effect of a project on every component. The EA focuses on the components that have the greatest relevance in terms of value and sensitivity, and which are likely to be affected by the project. To achieve this focus, specific Valued Ecosystem Components (VECs) are identified. A VEC is considered to be the ‘receptor’ for both project-specific effects and cumulative effects. A VEC can be represented by a number of ‘indicators’, which are features of the VEC that may be affected by the DGR Project (e.g., eastern white cedar as a species of terrestrial vegetation). Each indicator requires specific ‘measures’ that can be quantified and assessed (e.g., doses to indicators). In essence, the nature and magnitude of the effects of the DGR Project on these VECs has been studied and their significance determined.

The following VECs are used in assessing the effects of the DGR Project on the radiation and radioactivity environment:

- humans;
- benthic invertebrates;
- aquatic vegetation;
- benthic fish;
- pelagic fish;
- aquatic birds;
- aquatic mammals;
- terrestrial invertebrates;

- terrestrial vegetation;
- terrestrial mammals; and
- amphibians and reptiles.

ES.4 RESULTS

Project-environment interactions are identified and assessed for potential measurable changes. No residual adverse effects associated with radiation and radioactivity are likely as a result of the DGR Project and its associated activities. This TSD assesses the direct and indirect effects of the DGR Project as a result of normal conditions. Credible malfunctions, accidents and malevolent acts, and their consequences in the event that they occur, are discussed in the Malfunctions, Accidents and Malevolent Acts TSD.

ES.4.1 Human Exposure

Based on the conservative assessment undertaken, the following results are provided:

- With regard to worker dose (Nuclear Energy Workers [NEWs]), inhalation, immersion and external radiation doses as a result of the DGR Project are all expected to be much lower than OPG's occupational dose target of 10 mSv/a for workers. The predicted project-related dose is also less than that received for existing NEWs at the Bruce nuclear site. However, some potentially higher dose rate locations were identified where worker occupancy may be limited. This is considered further within the context of ALARA (As Low As Reasonably Achievable).
- For non-NEWs, the project-related external dose rate is well below the compliance dose limit of 0.5 µSv/h; for the members of the public, the external dose rate is less than the Bruce nuclear site boundary dose target of 10 µSv/a.
- Project-related doses to members of the public due to airborne and waterborne emissions from the DGR are predicted to be well below the regulatory limit of 1 mSv/a for members of the public.

ES.4.2 Non-Human Biota Exposure

Based on the conservative assessment undertaken, doses to aquatic and terrestrial biota are expected to be less than the Estimated No Effect dose rate Values (ENEVs) that range from approximately 0.6 to 5.0 mGy/d for different species. The bounding dose to non-human biota as a result of the activities of the DGR Project is calculated to be 8 µGy/d for the white-tailed deer (0.8% of the relevant ENEV).

ES.4.3 Other Effects

Based on the assessment of the effect of the DGR Project on renewable (e.g., air and water bodies) and non-renewable resources (e.g., radioactive materials), it was found that, from the radiation and radioactivity perspective, the DGR Project will not have any adverse effects on renewable and non-renewable resources.

ES.5 PRELIMINARY FOLLOW-UP PROGRAM

The follow-up monitoring program is required to:

- verify the predictions of the EA studies; or
- confirm the key effectiveness of mitigation measures, and in so doing, determine if alternative mitigation strategies are required.

The following program has been proposed as part of the DGR Project EA follow-up monitoring plan:

- Radiological analysis of air: Air samples will be periodically collected to monitor radioactivity in vent exhaust air, including the measurement of radon concentrations in underground facilities during site preparation and construction, operations, and decommissioning phases, as appropriate, to ensure that worker exposure to radiation is limited.
- External radiation monitoring: An external radiation monitoring program will be carried out during the site preparation and construction phase, the operations phase, and the decommissioning phase, respectively. The monitoring program during the site preparation and construction phase is to ensure that the exposure of DGR construction workers (non-NEWs) attributable to operations at the WWMF, which is in the vicinity of the DRG Project site, is properly managed. This program can be coordinated with the existing WWMF monitoring network. During the operations and the decommissioning phases, gamma radiation can be monitored using thermoluminescent dosimeters (TLD) along the boundary of the DGR Project Area to ensure that dose rates at the DGR boundary meet the specific requirement.
- Radiological analysis of groundwater: Throughout the site preparation and construction, operations, and decommissioning phases, radiological analysis will be carried out for samples collected from monitoring wells around the DGR boundary to monitor any changes to groundwater radionuclide concentrations in the DGR Project Area, especially tritium levels. The changes could be a result of the migration of contaminants from facilities in the immediate vicinity, such as the WWMF. This program will likely be similar to the groundwater monitoring program currently carried out for the WWMF.
- Radiological analysis of surface water: Water samples collected from the stormwater management system will be analyzed to determine radionuclide concentrations in surface water during the site preparation and construction phase, the operations phase, and the decommissioning phase. Water analysis during the site preparation and construction phase is to monitor the potential effect resulting from the operations at the WWMF and other nuclear facilities in the Site Study Area and establish a stormwater management system baseline for the operations and decommissioning phases.
- Dose to workers: A dose monitoring program will be carried out throughout the operations and decommissioning phases to determine worker exposure to radiation and radioactivity.

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1. INTRODUCTION

Ontario Power Generation (OPG) is undergoing a multi-year planning and regulatory approvals process for a deep geologic repository (DGR) for the long-term management of low and intermediate level waste (L&ILW). Currently, the L&ILW produced as a result of the operation of OPG-owned nuclear reactors is stored centrally at OPG's Western Waste Management Facility (WWMF) located at the Bruce nuclear site. Although current storage practices are safe and could be continued safely for many decades, OPG's long-term plan is to manage these wastes in a long-term management facility.

A key element of the regulatory approvals process is an environmental assessment (EA), the findings of which are presented in an Environmental Impact Statement (EIS). The EA considers the long-term management of L&ILW currently in interim storage at the WWMF, as well as that produced by OPG-owned or operated nuclear generating stations, in a DGR at the Bruce nuclear site in the Municipality of Kincardine, Ontario. The DGR Project location is shown on Figure 1-1. Throughout this report, OPG's proposal is referred to as the "DGR Project". The DGR Project includes the site preparation and construction, operations, decommissioning, and abandonment and long-term performance of the DGR.

The DGR will be constructed in competent sedimentary bedrock beneath the Bruce nuclear site near the existing WWMF. The underground facilities will include access-ways (shafts and tunnels), emplacement rooms and various underground service areas and installations. The surface facilities include the underground access and ventilation buildings, Waste Package Receiving Building (WPRB) and related infrastructure. All surface and underground facilities will be located within the boundaries of the OPG-retained lands near the WWMF at the Bruce nuclear site.

OPG is the proponent for the DGR Project. OPG will own, operate and be the licensee for the DGR. The regulatory approvals phase of the DGR Project, including the EA process and the site preparation and construction licensing, has been contracted to the Nuclear Waste Management Organization (NWMO). The NWMO is responsible, with support from OPG, for completing the EA, preparing the EIS and obtaining the site preparation and construction licences.

1.1 EA PROCESS AND REGULATORY CONTEXT

The EA process was initiated by the submission of a Project Description for the DGR by OPG to the Canadian Nuclear Safety Commission (CNSC) on December 2, 2005. The site preparation and construction licence application for the DGR was submitted by OPG to the CNSC on August 13, 2007. An EA of the proposed DGR Project is required under the provisions of the *Canadian Environmental Assessment Act* (CEAA) because the proponent (OPG) will require a licence from the CNSC to allow the project to proceed. Under the CEAA, the CNSC is identified as the Responsible Authority (RA); however, the Canadian Environmental Assessment Agency also has statutory responsibilities.

Under the CEAA, this type of project is identified in the Comprehensive Study List Regulations. The CNSC issued draft guidelines for a comprehensive study EA of the DGR Project, which were the subject of a public hearing held in Kincardine on October 23, 2006. Following the hearing, CNSC Commission members recommended to the Minister of the Environment that the

DGR Project be referred to a review panel given the public concerns, possibility of adverse environmental effects, the first-of-a-kind nature of the project and concerns regarding the comprehensive study's ability to address all the questions raised [1].

The Minister of the Environment referred the EA of the DGR Project to a joint review panel on June 29, 2007. Draft guidelines for the preparation of the EIS were issued by the Canadian Environmental Assessment Agency and the CNSC for public review on April 4, 2008. The EIS Guidelines, a copy of which is included in the EIS as Appendix A, were finalized on January 26, 2009. The scope of the EA for the DGR Project includes the site preparation, construction, operations and decommissioning of the above- and below-ground facilities for the long-term management of L&ILW. The EA also addresses the abandonment and long-term performance of the DGR Project.

An EA is a tool to provide an effective means of integrating environmental factors into the planning and decision-making processes in a manner that promotes sustainable development and minimizes the overall effect of a project. The methods used in the EA and presented in the EIS are consistent with the final EIS Guidelines, and are based on systematic and detailed considerations of the systems, works, activities and events comprising the DGR Project.

1.2 EA REPORTING STRUCTURE

The EA for the DGR Project is documented in an EIS, which is based on the final EIS Guidelines and the work detailed in a series of technical support documents (TSDs). In addition, there are parallel technical studies, information from which is also used in preparing the EIS and TSDs. Finally, the findings are summarized in the EIS Summary. Figure 1.2-1 illustrates the relationships between the EIS and summary report, its supporting documents, and the independent technical studies for the DGR Project.

The EIS comprises the following volumes:

- **Volume 1** consolidates and summarizes all aspects of the EIS studies. It includes a description of the EA methods, a description of the DGR Project, a description of the existing environment, an assessment of likely environmental effects, including cumulative effects, a discussion of the proposed follow-up program, and a discussion of the communication and consultation program.
- **Volume 2** contains a series of appendices that support the material in Volume 1, including a copy of the EIS Guidelines and human health assessment. It also contains a summary of the community engagement and consultation program along with copies of supporting materials.

The TSDs present information on the existing environment and describes processes used to assess the direct and indirect effects of the DGR Project on the environment. The TSDs, on which the EIS is based, are as follows:

- Atmospheric Environment;
- Hydrology and Surface Water Quality;
- Geology;
- Aquatic Environment;

- Terrestrial Environment;
- Socio-economic Environment;
- Aboriginal Interests;
- Radiation and Radioactivity; and
- Malfunctions, Accidents and Malevolent Acts.

The above TSDs assess the direct and indirect effects of the DGR Project as a result of normal conditions, with the exception of the Malfunctions, Accidents and Malevolent Acts TSD. The EIS Guidelines require an identification of credible malfunctions and accidents, and an evaluation of the effects of the DGR Project in the event that these accidents or malfunctions occur. All of these effects are discussed and assessed in the Malfunctions, Accidents and Malevolent Acts TSD regardless of the element of the environment that is affected. The reasoning for this is that a single accident is likely to affect multiple elements of the environment.

It is important to note that the assessment of potential radiation and radioactivity effects of the DGR Project are documented in this Radiation and Radioactivity TSD, regardless of the physical media through which they are transported (e.g., air or water). This was done because of the special importance placed on radiation and radioactivity, and the combined effects to the receiving environment regardless of the path of exposure.

The independent parallel technical study reports used in preparing the EIS include the following:

- Postclosure Safety Assessment [2];
- Geosynthesis [3]; and
- Preliminary Safety Report [4].

This TSD considers the radiological effects of the DGR Project during the site preparation and construction, operations, and decommissioning phases. The abandonment and long-term performance phase is considered in Section 9 of the EIS. An assessment of the cumulative effects associated with the DGR Project, taking into account past, existing and planned projects, is presented in Section 10 of the EIS. To facilitate this assessment, a description of the existing environmental features is also provided.

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0 5 10 20 30 40 50

Kilometres

LEGEND

- City
- Highway
- Provincial Highway
- Secondary Highway

REFERENCE

Base Data - MNR NRVIS, obtained 2004, CANMAP v7.3 2003
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2005
Datum: NAD 83 Projection: UTM Zone 17N

PROJECT

RADIATION AND RADIOACTIVITY
TECHNICAL SUPPORT DOCUMENT

TITLE

LOCATION OF THE DGR PROJECT

Golder Associates
Mississauga, Ontario

PROJECT NO. 06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	17 Oct. 2007	FIGURE 1-1	
GIS	BC	14 Apr. 2010		
CHECK	BC	14 Apr. 2010		
REVIEW	MAR	14 Apr. 2010		

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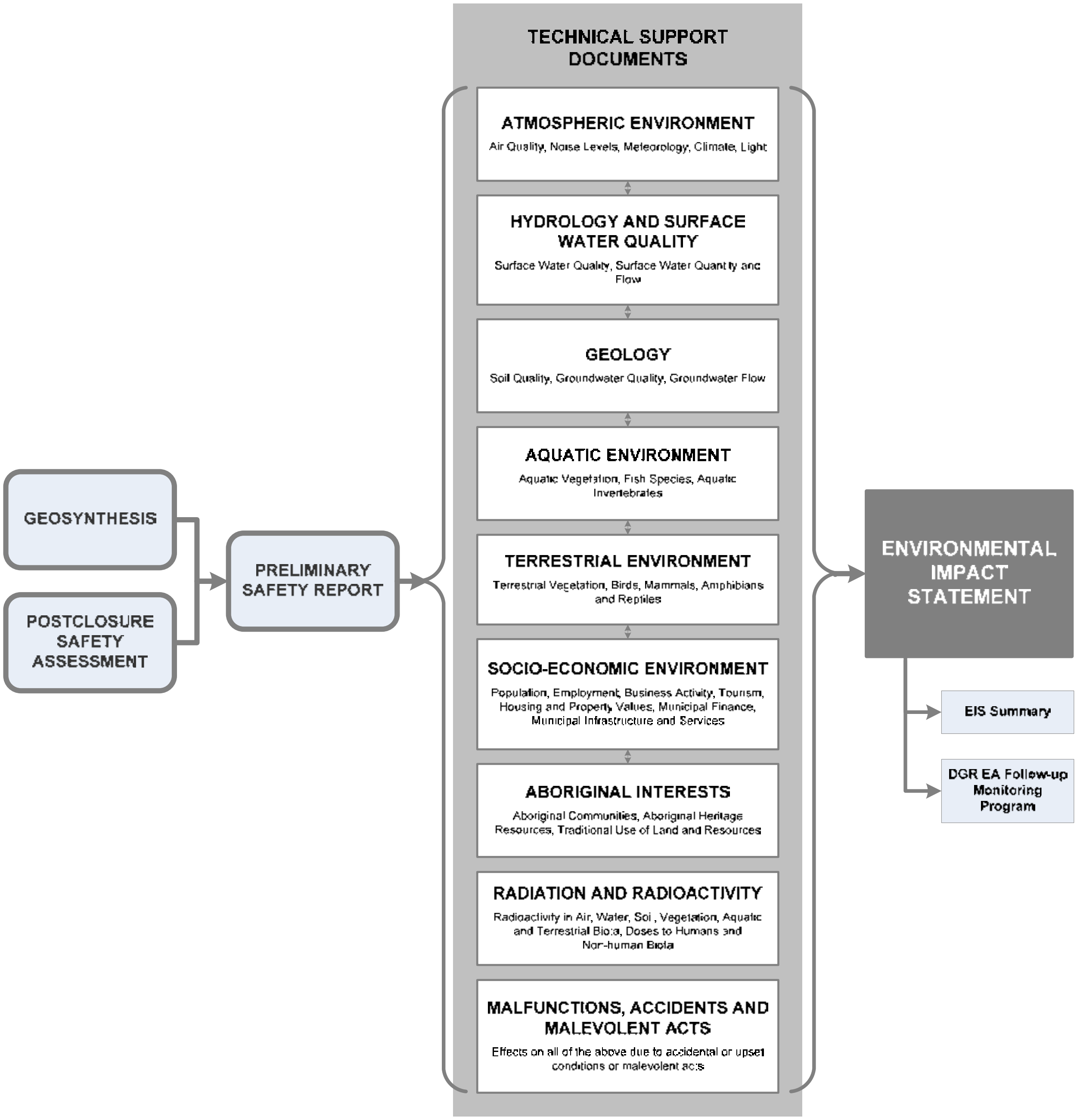

Figure 1.2-1: Organization of EA Documentation

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2. APPROACH

2.1 GENERAL SUMMARY OF EA APPROACH

The approach used for assessing the DGR Project, and documented in this TSD, supports the philosophy of EA as a planning and decision-making process. The assessment characterizes and assesses the effects of the DGR Project in a thorough, traceable, step-wise manner. The approach used in the assessment is illustrated on Figure 2.1-1, and includes the following steps:

- **Describe the Project.** As summarized in Section 3, the DGR Project is described as a number of works and activities that could affect the surrounding environment.
- **Describe the Existing Environment.** The existing environment is characterized using available information and field studies, as described in Section 5. The description of the existing environment reflects the cumulative effects of past and existing projects on the environment.
- **Screen to Focus the Assessment.** Two screening steps, firstly for potential interactions and secondly for measurable change, allow the assessment to focus on where effects are likely to occur. These steps are completed using professional judgment; if there is uncertainty, the interaction is advanced for assessment. The screening steps are completed in Sections 6 and 7.
- **Assess Effects.** Where there is likely to be a measurable change, the effects on the environment are predicted and assessed as to whether or not they are adverse, as described in Section 8. If adverse effects are predicted, mitigation measures to reduce or eliminate the effect are proposed, and residual adverse effects, if any, are identified. Any residual adverse effects are then assessed in Section 10 of the EIS to determine whether they are likely to combine with the effects of other past, present or reasonably foreseeable future projects and activities in the surrounding region to produce cumulative effects.
- **Determine Significance.** All residual adverse effects are then assessed in Section 11 to determine whether the effect is significant, or not, taking into account the magnitude, extent, duration, frequency and irreversibility of the effect.
- **Propose Follow-up Programs.** Finally, follow-up monitoring is proposed to confirm that mitigation measures are effective and the effects are as predicted. Monitoring activities are described in Section 13.

The assessment of effects of the DGR Project focuses on Valued Ecosystem Components (VECs), which are elements of the environment considered to be important for cultural or scientific reasons. Radiation and radioactivity VECs are defined and described in detail in Section 4. Criteria for determining measurable changes and adverse effects are defined for each individual VEC. The detailed methods for each of these steps, including how they are applied to this particular TSD, are described at the beginning of each of the respective sections.

The screening and assessment steps described above follow a source-pathway-receptor approach. The DGR Project works and activities represent the source of a change, a measurable change to the environment represents a pathway, and the VEC represents the receptor. In some cases, VECs may act as both pathways and receptors.

Effects from the DGR Project may occur either directly or indirectly. A direct interaction occurs when the VEC is affected by a change resulting from a project work and activity (e.g., gamma radiation exposure to workers). An indirect interaction occurs when the VEC is affected by a change in an environmental pathway resulting in an indirect exposure to a VEC (e.g., inhalation exposure resulting from radiaological changes in air quality).

There are many linkages and connections between aspects of the physical, biophysical and human environments in an integrated EA. As described in Section 1.2, this TSD considers potential effects on VECs resulting from radiation exposures regardless of the physical media through which the exposure occurs (e.g., radionuclides in air, water or soil). The approach accounts for combined effects, if any, to the receiving environment irrespective of the path of exposure. Potential effects to multi-feature VECs (e.g., Lake Huron, human health) are addressed in Section 7 of the EIS. An assessment of the cumulative effects associated with the DGR Project is addressed in Section 10 of the EIS. Section 9 of the EIS discusses the potential for radiation and radioactivity effects after the abandonment of the DGR facility.

The assessment is completed within the framework of defined temporal and spatial boundaries, and takes into account a precautionary approach and Aboriginal traditional knowledge, where available. These are described in further detail in the following sections.

2.2 PRECAUTIONARY APPROACH

The EA, as a forward-looking planning tool used in the early stages of project development, is based on a precautionary approach. This approach is guided by judgement, based on values and intended to address uncertainties in the assessment. This approach is consistent with Principle 15[1] of the 1992 Rio Declaration on Environment and Development and the Canadian government's framework for applying precaution in decision-making processes [5].

Throughout the EA, the DGR Project has been conservatively considered in a thorough and traceable manner. For example, at each of the screening stages, potential DGR Project-related effects are advanced if they cannot be systematically removed from consideration through application of rigorous, sound and credible scientific evidence. In addition, with the exception of malfunctions, accidents and malevolent acts, all identified residual adverse effects are assumed to occur (i.e., probability of occurrence is assumed to be 1), and are assessed for significance.

A further precautionary feature incorporated into the assessment method is that the evaluation of potential effects is based on changes to the existing environment and not solely on regulatory compliance. This captures and assesses changes to the existing environment that may fall outside or below applicable regulatory frameworks.

The precautionary approach adopted for the EA of the DGR Project is described further in Section 1 of the EIS, and a summary of how precaution has been taken into account in the assessment of radiation and radioactivity is provided at the end of the assessment section (Section 8.4.1).

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[1] Principle 15 of the 1992 Rio Declaration on Environment and Development states that "Where there are threats of serious or irreversible damage, lack of full scientific certainty must not be used as a reason for postponing cost-effective measures to prevent environmental degradation".

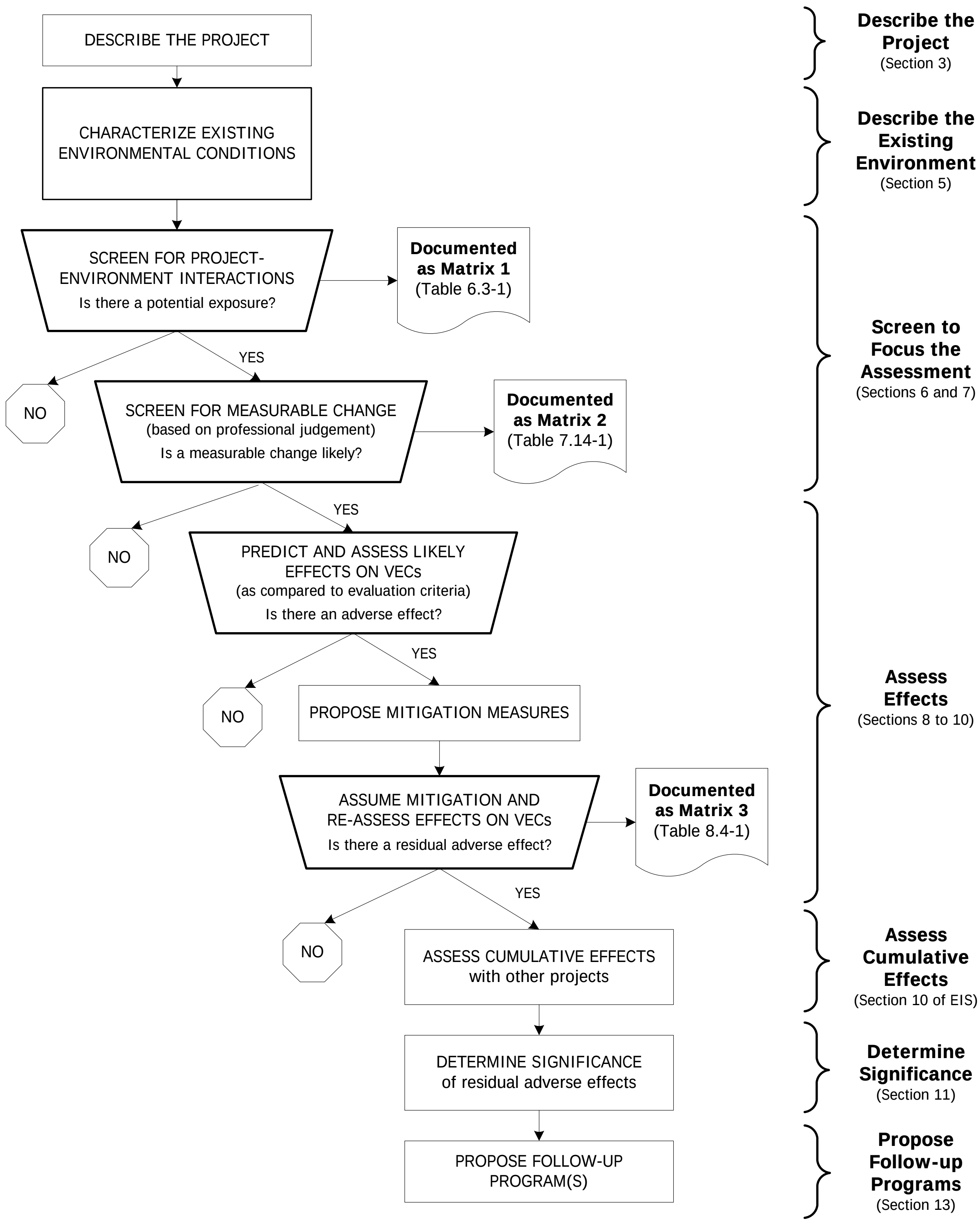

Figure 2.1-1: Methods for Assessment of Effects

2.3 ABORIGINAL TRADITIONAL KNOWLEDGE

This EA considers both western science and traditional and local knowledge, where that information is available. Guidance provided by the Canadian Environmental Assessment Agency describes Aboriginal traditional knowledge as knowledge that is held by, and unique to, Aboriginal peoples [6]. Aboriginal traditional knowledge is a body of knowledge built up by a group of people through generations of living in close contact with nature. It is cumulative and dynamic and builds upon the historic experiences of a people and adapts to social, economic, environmental, spiritual and political change.

Traditional ecological knowledge is a subset of Aboriginal traditional knowledge. Traditional ecological knowledge "refers specifically to all types of knowledge about the environment derived from the experience and traditions of a particular group of people" [7]. There are four traditional ecological knowledge categories:

- knowledge about the environment;
- knowledge about the use of the environment;
- values about the environment; and
- the foundation of the knowledge system.

In this EA, specific traditional knowledge, where available, is incorporated through the characterization of the existing environment and assessment of effects. Issues of historical importance to Aboriginal communities were identified as part of the Aboriginal Interests TSD through examination of available information pertaining to general ecological, socio-economic and cultural heritage interests for Ojibway and Métis peoples in Ontario. This examination identified a range of interests raised by Aboriginal communities that can be used to focus this EA relative to potential effects on residents of the Aboriginal communities in the study areas. This examination included the following:

- interests raised by Aboriginal communities in regards to previous studies;
- interests raised by Aboriginal communities in the context of dialogue for the DGR Project; and
- insight into traditional knowledge, and interests of general importance to Ojibway and Métis peoples.

Throughout this TSD, it is highlighted where Aboriginal traditional knowledge and traditional ecological knowledge was available, and has influenced the assessment.

2.4 TEMPORAL AND SPATIAL BOUNDARIES

The assessment of the DGR Project works and activities on the environment is conducted within the framework of temporal and spatial boundaries that are common to all of the environmental components (with some modifications). The particular temporal and spatial boundaries used in the assessment of radiation and radioactivity are described in the following sections.

2.4.1 Temporal Boundaries

The temporal boundaries for the EA establish the timeframes for which the direct, indirect and cumulative effects are assessed. Four temporal phases were identified for the DGR Project:

- **Site Preparation and Construction Phase**, which includes site preparation and all activities associated with the construction of the DGR Project, up until operations commence with the placement of waste. All of the construction activities at the DGR Project will occur during this phase. The site preparation and construction phase is expected to last approximately five to seven years.
- **Operations Phase**, which covers the period during which waste is emplaced in the DGR, as well as a period of monitoring prior to the start of decommissioning. Activities include receipt and on-site handling of waste packages, transfer underground and emplacement of L&ILW in rooms in the DGR, and activities necessary to support and monitor operations. The operations phase is expected to last approximately 40 to 45 years with waste being emplaced for the first 35 to 40 years. The length of the monitoring period would be decided at some future time in consultation with the regulator.
- **Decommissioning Phase**, which begins immediately after the operations phase for the DGR. Activities include preparation for decommissioning, decommissioning and may include monitoring following decommissioning. The decommissioning activities, including dismantling surface facilities and sealing the shaft, are expected to take five to six years.
- **Abandonment and Long-term Performance Phase**, which begins once decommissioning activities are completed. This period will include institutional controls for a period up to three hundred years.

These timeframes are intended to be sufficiently flexible to capture the effects of the DGR Project. Throughout this TSD, the assessment focuses on the effects of the DGR Project on radiation and radioactivity during the first three phases. Given that the long half-life of some radionuclides associated with the L&ILW will extend into the abandonment and long-term performance phase, there is a potential for radiation and radioactivity effects after the abandonment of the DGR facility. These effects are the subject of the Postclosure Safety Assessment [2], the results of which are summarized in Section 9 of the EIS.

2.4.2 Spatial Boundaries

Spatial boundaries define the geographical extents within which environmental effects are considered. As such, these boundaries become the study areas adopted for the EA.

The EIS Guidelines require that the study areas encompass the environment that can reasonably be expected to be affected by the DGR Project, or which may be relevant to the assessment of cumulative effects. Specific study areas are defined by boundaries to encompass all relevant components of the environment including the people, land, water, air and other aspects of the natural environment.

Four study areas were selected for the assessment of the radiation and radioactivity effects: the Regional Study Area, Local Study Area, Site Study Area, and Project Area. The Project Area, although not specified in the EIS Guidelines, was defined to help describe the potential site-specific effects of the DGR Project. Each study area includes the smaller study areas (i.e., they are not geographically separate). These areas are described in the following sections.

2.4.2.1 Regional Study Area

The Regional Study Area for radiation and radioactivity is shown on Figure 2.4.2-1, and includes the area which could be potentially affected by the release of radioactive materials resulting from the operation of the proposed DGR facility. The Regional Study Area includes Bruce County with the exception of the peninsula communities of the Town of South Bruce Peninsula and the Township of Northern Bruce Peninsula.

To the north, east and south, the Regional Study Area extends to Southampton, Chesley and Teeswater, respectively. To the west, the Regional Study Area includes the nearshore region of Lake Huron between Southampton and Point Clark. It extends a few kilometres offshore based on the transport of tritium in the waste heat outflows from the existing nuclear generating stations at the Bruce nuclear site by currents running parallel to the shore. The northern and southern limits have been selected to ensure that the municipal water supply intakes for the communities of Port Elgin, Southampton and Kincardine are included.

2.4.2.2 Local Study Area

The Local Study Area is shown on Figure 2.4.2-2, and generally corresponds to the 10 km emergency planning zone (centred at the Bruce nuclear site), as identified by Emergency Management Ontario. The Local Study Area covers the Bruce nuclear site and immediate vicinity.

2.4.2.3 Site Study Area

The Site Study Area, which is shown on Figure 2.4.2-3, corresponds to the property boundary of the Bruce nuclear site, including the exclusion zones on land and in Lake Huron. The Site Study Area includes the sources of radioactivity releases to air and water, for example Bruce A, Bruce B, the WWMF and the Central Maintenance and Laundry Facility (CMLF).

2.4.2.4 Project Area

The Project Area (Figure 2.4.2-3) corresponds to the boundary of the OPG-retained lands at the centre of the Bruce nuclear site where the DGR Project is being proposed. The Project Area includes all facilities, buildings and infrastructure at the WWMF. In this report, the potential effects of the DGR Project on the Site Study Area and Project Area will be collectively discussed because the conditions in the Project Area are estimated to be similar to the Site Study Area.

LEGEND

- Municipal Water Supply
- Site Study Area [1]
- Local Study Area
- Regional Study Area
- County Boundary
- First Nations' Lands

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007.
Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m,
Datum: NAD 83 Projection: UTM Zone 17N

PROJECT

RADIATION AND RADIOACTIVITY
TECHINCAL SUPPORT DOCUMENT

TITLE

REGIONAL STUDY AREA

Golder Associates
Mississauga, Ontario

PROJECT NO. 06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	17 Oct. 2007	FIGURE 2.4.2-1	
GIS	BC	14 Apr. 2010		
CHECK	AB	14 Apr. 2010		
REVIEW	MAR	14 Apr. 2010		

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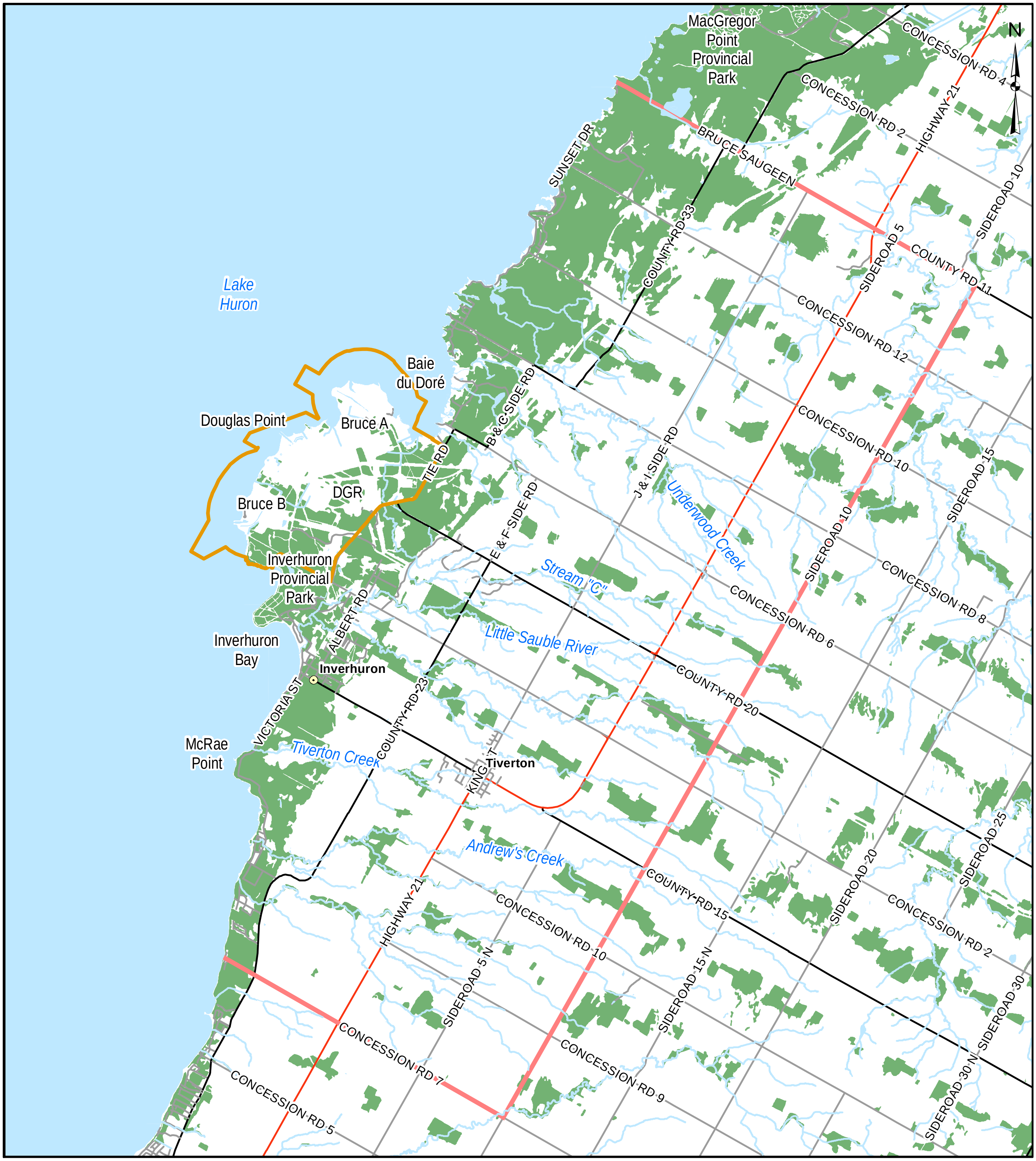

LEGEND

- Site Study Area [1]
- Local Study Area

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007.
Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m, Datum: NAD 83 Projection: UTM Zone 17N

PROJECT

RADIATION AND RADIOACTIVITY
TECHINCAL SUPPORT DOCUMENT

TITLE

LOCAL STUDY AREA

Golder Associates
Mississauga, Ontario

PROJECT NO. 06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	17 Oct 2007	FIGURE 2.4.2-2	
GIS	BC	14 Apr. 2010		
CHECK	AB	14 Apr. 2010		
REVIEW	MAR	14 Apr. 2010		

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LEGEND

- Project Area (OPG-retained lands that encompass the DGR Project)
- Site Study Area [1]

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007.
Imagery and Topo Collected and Processed by Terrapoint Canada Inc.,
Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m,
Datum: NAD 83 Projection: UTM Zone 17N

PROJECT

RADIATION AND RADIOACTIVITY
TECHINCAL SUPPORT DOCUMENT

TITLE

SITE STUDY AREA

Golder Associates
Mississauga, Ontario

PROJECT NO. 06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	17 Oct. 2007	FIGURE 2.4.2-3	
GIS	BC	14 Apr. 2010		
CHECK	AKB	14 Apr. 2010		
REVIEW	MAR	14 Apr. 2010		

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3. PROJECT DESCRIPTION

The assessment of effects requires a detailed description of the DGR Project. The individual works and activities are the physical structures, buildings, systems, components, activities and events comprising the DGR Project. These are collectively referred to as the project works and activities. This section provides an overview of the DGR Project. The specific works and activities required for the DGR Project are summarized in the Basis for the EA in Appendix B. Further details on the DGR Project design can be found in Section 4 of the EIS and in Chapter 6 of the Preliminary Safety Report [4].

3.1 OVERVIEW

The DGR Project will receive L&ILW currently stored in interim facilities at the WWMF, as well as that produced from OPG-owned or operated nuclear generating stations. Low level waste consists of industrial items and materials such as clothing, tools, equipment, and occasional large objects such as heat exchangers, which have become contaminated with low levels of radioactivity. Intermediate level waste consists primarily of used reactor components and resins used to clean the reactor water circuits. The capacity of the DGR is a nominal 200,000 m^3 of "as-disposed" waste.

The DGR Project comprises two shafts, a number of emplacement rooms, and support facilities for the long-term management of L&ILW (Figure 3.1-1). The DGR will be constructed over a period of 5 to 7 years. The DGR Project design is the result of a thorough comparison and evaluation of different alternative methods of implementing the project. This includes considerations such as the layout of the DGR and construction methods. The evaluation compared each of the alternative means using technical, safety, environmental and economic factors to identify the preferred alternative. This evaluation is presented in Section 3 of the EIS. This TSD assesses the effects of the preferred alternative means (i.e., the DGR Project) on the radiation and radioactivity environment.

3.2 SITE DESCRIPTION AND PROJECT LAYOUT

3.2.1 Surface Facilities

The surface DGR facilities will be located on vacant OPG-retained land to the north of the existing WWMF. A new crossing will be constructed over the abandoned rail bed to provide access to the proposed DGR Project site from the WWMF (Figure 3.2.1-1). The surface structures will be grouped in relatively close proximity to facilitate operations and maintenance activities, and provide a compact footprint.

The Waste Package Receiving Building (WPRB) will receive all radioactive waste packages and transfer them to the main shaft cage for transfer underground. A maintenance workshop and stores for essential shaft-related spares and materials will be attached to the WPRB. An office, main control room and amenities building will also form part of the main shaft complex for administrative purposes, control and monitoring of the DGR, and receiving visitors to the DGR. An electrical sub-station will provide power to the entire facility, both surface and underground, and an emergency power supply will maintain critical systems in the event of an outage.

Waste rock piles for the complete excavated volume of rock will be accommodated to the north-east of the two shafts. A stormwater management system of ditches and a pond will be provided to control the outflow of surface runoff and sump discharge water from the site before release into an existing drainage ditch at the Bruce nuclear site, and ultimately Lake Huron (Figure 3.2.1-1). The discharge will also be monitored to confirm it meets certificate of approval water quality requirements.

3.2.2 Underground Facilities

The underground DGR facilities will be constructed in limestone bedrock (Cobourg Formation) at a nominal depth of 680 m beneath the OPG-retained lands in the centre of the Bruce nuclear site (Figure 3.1-1). The overall underground arrangement enables infrastructure to be kept in close proximity to the main shaft, while keeping the L&ILW emplacement areas away from normally occupied and high use areas.

The DGR will have two vertical shafts (main and ventilation shafts) in an islanded arrangement with a services area in which offices, a workshop, wash bay, refuge stations, lunch room and geotechnical laboratory will be provided. From this centralized area, the two panels of emplacement rooms are connected via access tunnels. A main access tunnel will be driven from the main shaft station to the east, passing the ventilation shaft and then proceeding towards the emplacement room panels. The main access tunnel will continue straight into the Panel 1 access tunnel, while a branch tunnel to the south will lead to the Panel 2 access tunnel. The length of the rooms is nominally 250 m. End walls may be erected once the rooms are filled.

The emplacement rooms will all be aligned with the assumed direction (east-northeast) of the major principal horizontal stresses of the rock mass to minimize the risks of any rock fall in the emplacement rooms.

A ventilation supply system will supply air at a controlled range of temperatures to ensure that freezing does not occur in the main shaft and the atmosphere is kept in a reasonably steady and dry state that is suitable for workers and limits corrosion of structures and waste packages.

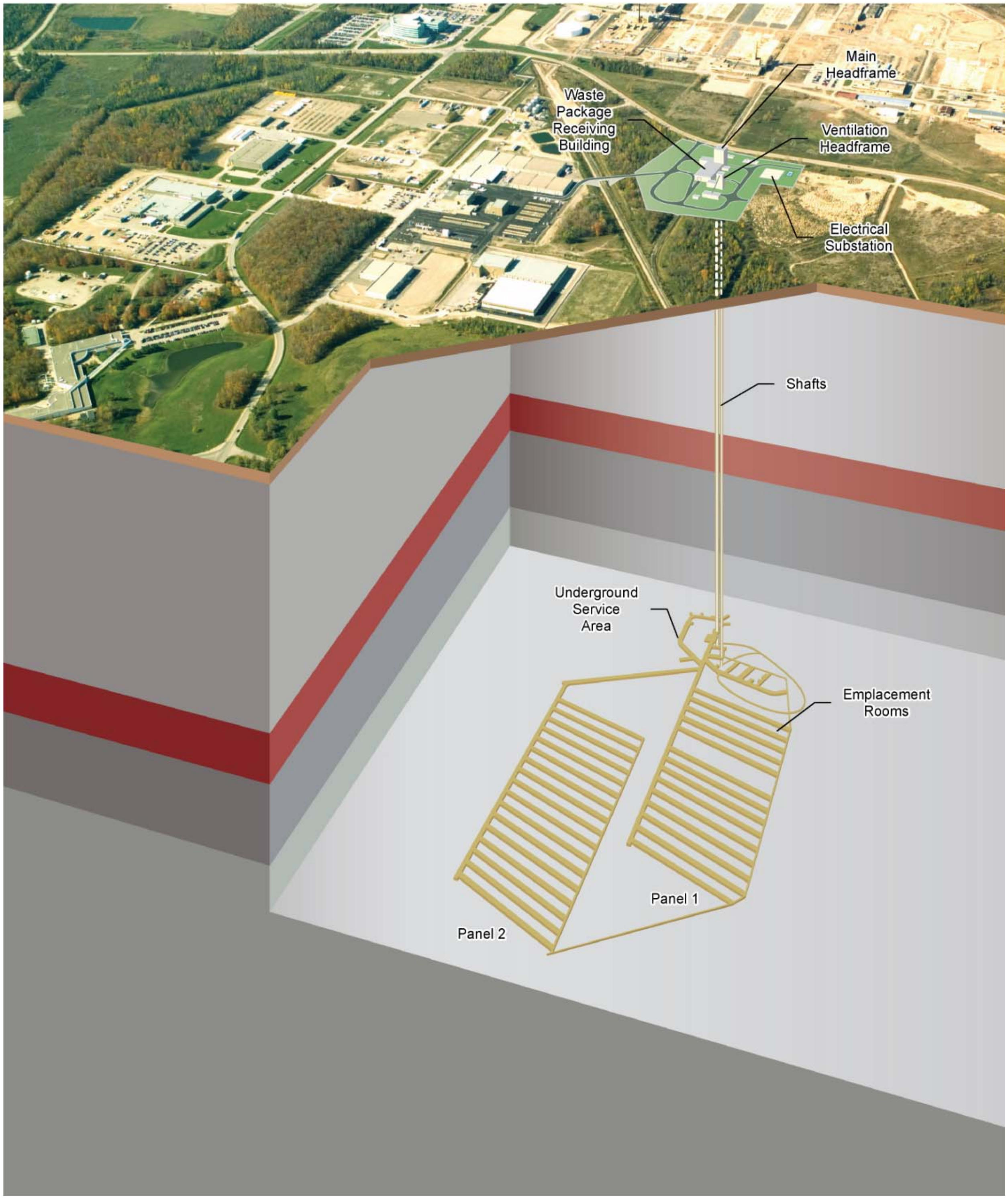

Figure 3.1-1: Schematic of DGR Project

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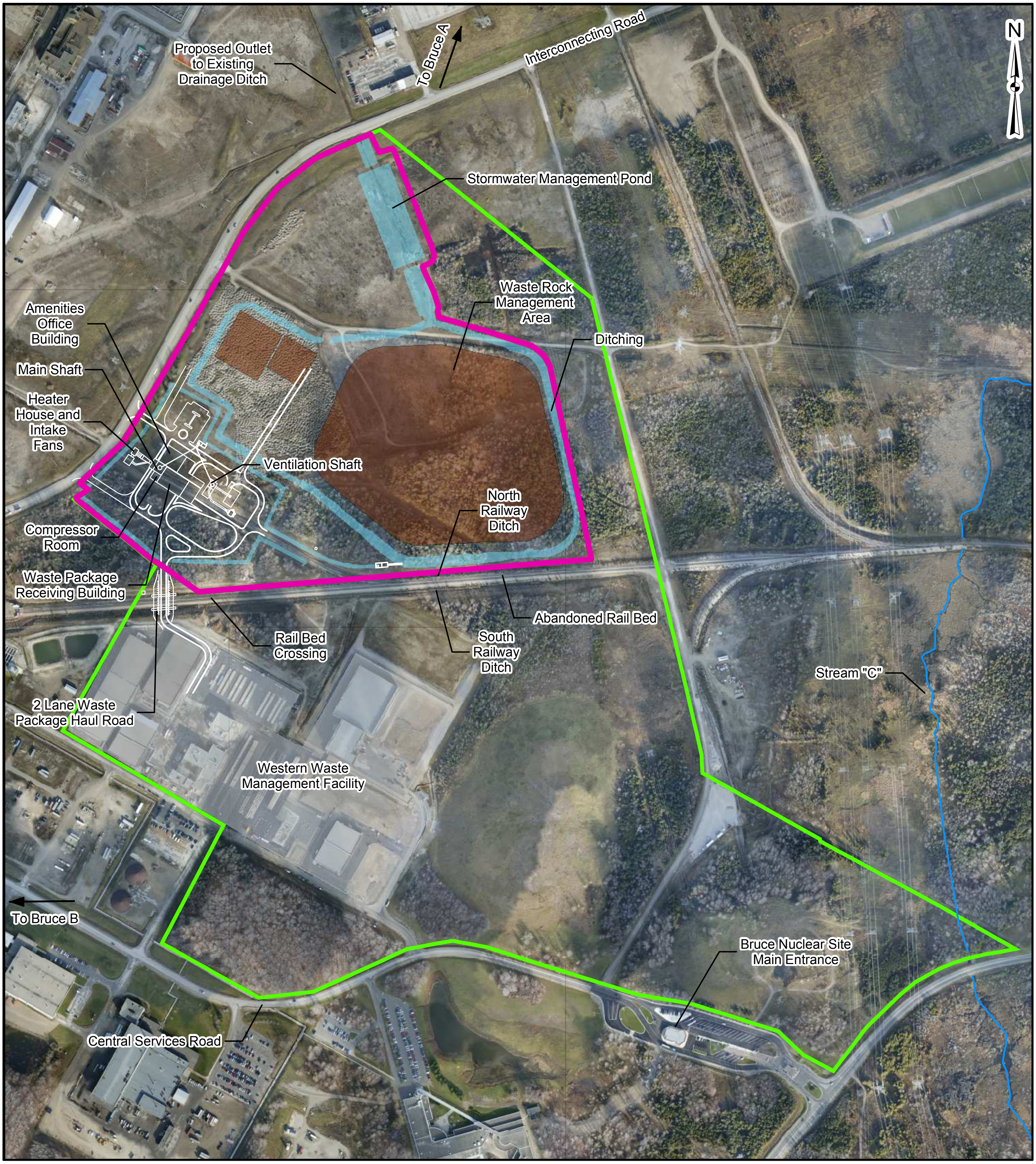

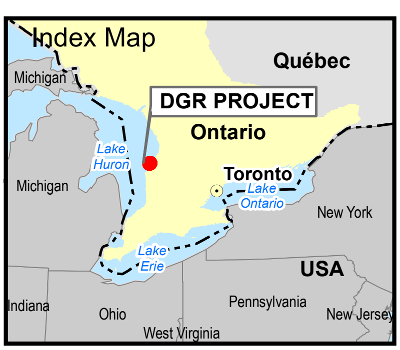

LEGEND

- DGR Project Site
- Project Area (OPG-retained lands that encompass the DGR Project)
- Soils and Rock Stockpile
- Stormwater Management System

0 125 250 500
Metres

REFERENCE

Base Data Provided by 4DM, Nov 2007.
Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m, Datum: NAD 83 Projection: UTM Zone 17N

PROJECT

RADIATION AND RADIOACTIVITY TECHNICAL SUPPORT DOCUMENT

TITLE

LAYOUT OF DGR SURFACE INFRASTRUCTURE

Golder Associates
Mississauga, Ontario

PROJECT NO. 06-1112-037			SCALE: AS SHOWN	R000
DESIGN	AB	16 Mar. 2010		
GIS	BC	25 Nov. 2010		
CHECK	KC	25 Nov. 2010		
REVIEW	AB	25 Nov. 2010		

FIGURE 3.2.1-1

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4. SELECTION OF VECS

While all components of the environment are important, it is neither practicable nor necessary to assess every potential effect of a project on every component of the environment. The EA focuses on the components that have the greatest relevance in terms of value and sensitivity, and which are likely to be affected by the project. To achieve this focus, specific Valued Ecosystem Components (VECs) are identified. The Canadian Environmental Assessment Agency states that VECs are "*Any part of the environment that is considered important by the proponent, public, scientists and government involved in the assessment process"* [8]. Importance may be determined on the basis of cultural values or scientific concerns. VECs can be an individual valued component of the environment or a collection of components that represent one aspect of the environment (e.g., water quality).

From an ecological perspective, VECs can represent features or elements of the natural environment (e.g., a local wetland or stream) considered to be culturally or scientifically important. Such features may be complex, comprising several ecological aspects, and affected by a range of pathways (i.e., routes of exposure or effect). In essence, these ecological feature VECs would encompass a number of individual VECs such as:

- an aspect of the physical environment (e.g., air or water);
- an individual wildlife species (e.g., mallard duck or creek chub); or
- a range of species that serve as a surrogate for species that interact similarly with the environment (e.g., benthic invertebrates).

A VEC is considered to be the receptor for both project-specific effects and cumulative effects. A VEC can be represented by a number of indicators. Indicators are features of the VEC that may be affected by the DGR Project (e.g., eastern white cedar as a species of terrestrial vegetation). Each indicator requires specific 'measures' that can be quantified and assessed (e.g., changes in dose).

The VECs are identified using the expertise of the technical specialists with input from regulators and members of the public. The VECs for the DGR Project were available for discussion and comment at the open houses held in October 2007, November 2008, November 2009 and late summer/fall 2010. At the November 2008 open houses, the public was encouraged to add VECs to the list and to identify the VECs that were most important to them. The public also had the opportunity to provide input with regard to the list of VECs during the public review of the draft guidelines.

Eleven VECs (Table 4-1) are used in assessing the effects of the DGR Project on the radiation and radioactivity environment. These VECs were selected to be representative of radiation and radioactivity and were likely to be important and susceptible to effects within the spatial context of the DGR Project. The rationale for selection of the VECs and the indicators used in the assessment is described in the following sections and summarized in Table 4-1.

Table 4-1: VECs Selected for Radiation and Radioactivity

VEC	Rationale	Indicators	Measures
Humans	• Nuclear Energy Workers (NEWs)[2] are expected to receive radiation doses as a result of the DGR Project	• NEWs	• Dose to NEWs
	• Other workers at the Bruce nuclear site (non-NEWS) are expected to receive minimal radiation doses during site preparation and construction, operations and decommissioning phases as a result of the DGR Project	• Other workers (non-NEWs)	• Dose to non-NEWs
	• Members of the public living and working in the vicinity of the DGR Project site are expected to be exposed to very low doses of radiation from the DGR Project	• Members of the public including Aboriginals	• Dose to members of the public
Benthic Invertebrates	• There is a potential that aquatic species will be exposed to radiation as a result of the DGR Project	• Burrowing crayfish	• Dose to aquatic indicator species
Aquatic Vegetation		• Variable leaf pondweed	
Benthic Fish		• Lake whitefish • Redbelly dace • Creek chub	
Pelagic Fish		• Spottail shiner • Smallmouth bass • Brook trout	
Aquatic Birds		• Double-crested cormorant • Mallard	
Aquatic Mammals		• Muskrat	

2 Nuclear Energy Worker (NEW) is defined as a person who is required, in the course of the person's business or occupation in connection with a nuclear substance or nuclear facility, to perform duties in such circumstances that there is a reasonable probability that the person may receive a dose of radiation that is greater than the prescribed limit for the general public [61].

Table 4-1: VECs Selected for Radiation and Radioactivity (continued)

VEC	Rationale	Indicators	Measures
Terrestrial Invertebrates	• There is a potential that terrestrial species will be exposed to radiation as a result of the proposed DGR Project	• Earthworm	• Dose to terrestrial indicator species
Terrestrial Vegetation		• Eastern white cedar Common cattail • Heal-all	
Terrestrial Birds		• Bald eagle • Yellow warbler • Wild turkey • Red-eyed vireo	
Terrestrial Mammals		• White-tailed deer • Northern short-tailed shrew • Red fox	
Amphibians and Reptiles		• Midland painted turtle • Northern leopard frog	

The following sections identify and justify the selection of the above VECs for assessing the effects of the DGR Project on radiation and radioactivity.

4.1 VALUED ECOSYSTEM COMPONENTS

The VECs were selected to represent different trophic levels, and hence different exposure pathways. For example, benthic invertebrates are likely to be exposed to radionuclides in sediment, while terrestrial birds may be exposed to radionuclides in air, water, soil and food.

4.1.1 Humans

NEWs are expected to receive radiation as a result of the DGR Project. To a lesser degree, non-NEWs and members of the public including Aboriginals are also expected to receive radiation doses during the implementation of the DGR Project. During operations, DGR workers will be NEWs. However, during the site preparation and construction and decommissioning phases, the construction workers will not be considered NEWs.

4.1.2 Benthic Invertebrates

Benthic invertebrates are commonly used as a VEC to identify effects in the aquatic environment for a number of reasons. Benthic invertebrates live in close contact with the sediment and are relatively immobile; therefore, they are highly exposed to the contaminants present therein. Furthermore, benthic invertebrates have short life spans, and thus their response to stressors is expressed relatively rapidly. Finally, benthic invertebrates are an important food source for higher trophic organisms such as fish.

4.1.3 Aquatic Vegetation

Aquatic plants were selected for many of the same reasons given for benthic invertebrates (e.g., immobility, rapid response to stress, serving as a food source). In addition to being exposed to radionuclides in sediment, aquatic plants are also exposed to radionuclides in the water column.

4.1.4 Benthic and Pelagic Fish

Fish have the proven ability to bio-accumulate some radionuclides, and their predatory feeding habits may lead to bio-magnification [9]. Therefore, they have been extensively used as ecological receptors to assess the effect of radiation and radioactivity on the aquatic environment.

4.1.5 Birds

Both aquatic and terrestrial birds have been selected as VECs since they are receptors for DGR Project–related radiological effects and represent different feeding habits and exposure locations within the study areas.

4.1.6 Mammals

Both aquatic and terrestrial mammals were selected as VECs to represent a range of feeding habits and exposure locations.

4.1.7 Terrestrial Invertebrates

Terrestrial invertebrates are relatively immobile and therefore they are highly exposed to the contaminants present in their habitat. Furthermore, terrestrial invertebrates have short life spans, and thus their response to stressors is expressed relatively rapidly. Finally, terrestrial invertebrates are an important food source for higher trophic organisms such as birds and smaller mammals.

4.1.8 Terrestrial Vegetation

Terrestrial plants are considered in this assessment since they are an important component of terrestrial habitat, and serve as a food source for many terrestrial species. Also, they are selected because of their ability to intercept a large proportion of aerially deposited radionuclides, which may lead to acute exposure effects.

4.1.9 Amphibians and Reptiles

The early life stages of amphibians are aquatic and, therefore, they are exposed to radionuclides through surface water and sediment pathways. During the adult life stage, amphibians may be highly exposed to radionuclides in sediment during hibernation or aestivation, as well as surface water and air. Reptiles are exposed through pathways similar to those of adult amphibians. Both reptiles and amphibians may prey on aquatic and terrestrial organisms, and may be, in turn, prey themselves. In addition, they may be more highly exposed to some radionuclides as a result of the accumulation of some elements in their bodies.

4.2 INDICATORS

The species selected as indicators for the assessment of radiological effects are representative of the species of non-human biota present in the study areas. Species' sensitivity to radiation, or "radio-sensitivity", was also considered during the selection process.

4.2.1 Humans

In this TSD, NEWs, non-NEWs, and members of the public including Aboriginals are used as the indicators for humans.

4.2.2 Benthic Invertebrates

Burrowing crayfish, which are found in ditches and wetlands in the Site Study Area and Project Area, are used as an indicator for benthic invertebrates.

4.2.3 Aquatic Vegetation

Variable leaf pondweed is used an indicator for aquatic vegetation in this study.

4.2.4 Benthic and Pelagic Fish

In the context of this assessment, fish species have been broadly divided into benthic fish and pelagic fish. Benthic fish spend the majority of their time at the bottom of lakes (i.e., in close proximity to sediments) and are thus exposed to radionuclides in both water and sediment. Lake whitefish (*Coregonus clupeaformis*) is selected as an indicator of benthic fish in this study as it is important for commercial and First Nations' fisheries. Redbelly dace (*Chrosmus eos*) and creek chub (*Semotilus atromaculatus*) with preferred habitat in streams, have been recorded in Stream C and the South Railway Ditch and are also considered in this study.

Pelagic fish include species that do not spend a large amount of time at the bottom, but rather are free-swimming in the water column. Thus, they are not typically exposed to radionuclides in the sediment. Smallmouth bass (*Micropterus dolomieui*), spottail shiner (*Notropis hudsonius*) and brook trout (*Salvelinus fontinalis*) are used as indicators for pelagic fish in this assessment.

4.2.5 Birds

The double-crested cormorant (*Phalacrocorax auritus*) and the mallard (*Anas platyrhynchos*) are representatives of birds that inhabit the shoreline of Lake Huron (i.e., aquatic birds). Their feeding on sediment invertebrates could maximize possible internal exposure to particle reactive radionuclides. The wading habit of mallard will maximize external exposure to beta gamma emitters in sediments. The yellow warbler (*Dendroica petechia*) and red-eyed vireo (*Vireo olivaceus*) are representatives of insectivores that inhabit deciduous forests in the study areas. The wild turkey (*Meleagris gallopavo*) is representative of omnivorous birds, which prefer eating hard mast and occasionally consume small vertebrates like snakes, frogs or salamanders. Finally, the bald eagle (*Haliaeetus leucocephalus*) is representative of carrion-eating birds that feed on dead fish, mammals and other birds, although bald eagle also take live fish, ducks, and other available prey.

4.2.6 Terrestrial Invertebrates

The earthworm (*Lumbricus terrestris*), which can be found in the Site Study Area and Project Area, was selected as the indicator for determining potential effects of radionuclides on terrestrial invertebrates.

4.2.7 Terrestrial Vegetation

The eastern white cedar (*Thuja occidentalis*), common cattail (*Typha latifolia*) and heal-all (*Prunella vulgaris*) were selected as indicators for determining potential effects of radionuclides on terrestrial vegetation. These indicators represent long-lived tree species, emergent macrophytes, and common groundcover, respectively.

4.2.8 Mammals

The white-tailed deer (*Odocoleus virginianus*) was selected as a representative of herbivorous mammals feeding on terrestrial vegetation living within the study areas. The northern short-tailed shrew (*Blarina brevicauda*) was selected as a representative of short-lived small mammal species with a varied diet including insects, small reptiles, frogs and some plants. They are radio-sensitive and could accumulate less mobile radionuclides in tissues such as the liver. The muskrat (*Ondatra zibethicus*), likely to be radiosensitive, was selected as a mammalian species feeding on aquatic vegetation and exposed to radionuclides in water and sediment. The predatory mammal red fox (*Vulpes vulpes*) was also selected as an indicator. Red fox prey extensively on small mammals (including mice, shrews and voles), insects, birds, and occasionally seeds, berries, and fruits.

4.2.9 Amphibians and Reptiles

The midland painted turtle (*Chrysemys picta marginata*) was selected as an indicator for reptiles that do not live exclusively on land and hibernate in sediment during the winter. Turtles may also aestivate during hot, dry summer conditions. Turtles may be more highly exposed to some radionuclides because of the accumulation of some elements within their shells (e.g., strontium-90). In addition, there is a potential that they may be exposed to elevated radioactivity in sediment during hibernation or aestivation in the unlikely event that its living habitat during these periods is contaminated by radionuclides released from the DGR Project. This assessment also considers the northern leopard frog (*Rana pipiens*), an amphibian, which exhibits high radiosensitivity similar to the midland painted turtle.

4.3 MEASURES

The doses to the indicators are used to measure the potential project-related effects on the VECs.

5. DESCRIPTION OF THE EXISTING ENVIRONMENT

This section describes the existing ionizing radiation and radioactivity conditions in the environment. These environmental conditions reflect the baseline situation of the area where the DGR Project will be implemented and the status of other nuclear facilities at the Bruce nuclear site, including OPG's WWMF, and Bruce Power operated nuclear power generating stations Bruce A and Bruce B, and the Central Maintenance and Laundry Facility (CMLF). This characterization of the existing environment serves as the baseline condition against which the potential environmental effects of the DGR Project are assessed.

5.1 EXISTING ENVIRONMENT METHODS

The description of the existing environment focuses on VECs identified in Section 4. Information is presented for the study areas with emphasis placed on the areal extents most likely to be affected by the DGR Project. The description of the existing environment for radiation and radioactivity presents the following:

- a compilation and review of existing information; and
- the results of modelling used to characterize the existing environment.

The literature review carried out for this work has indicated that the existing information on radiation and radioactivity is sufficient from an EA perspective. Therefore, no further field studies were warranted for this TSD.

The year 2009 is used as the baseline year for describing the existing conditions. Where available, data for years prior to 2009 are provided in the report to show how levels of ambient radioactivity in the study areas have changed over time. The effects assessment (Section 8) evaluates the potential effects of the DGR Project relative to the existing environment conditions (i.e., baseline). The methods used to gather information on which to base the description of radiation and radioactivity are explained in the following sections.

5.1.1 Sources of Existing Data

For the purposes of characterizing radiation and radioactivity, the following key documents are included in the compilation and review of existing information:

- Bruce Power Reports on Annual Summary and Assessment of Environmental Radiological Data for 2001 through 2009 [10;11;12;13;14;15;16;17;18];
- Radiation and Radioactivity Technical Support Document for the WWMF Refurbishment Waste Storage EA [19];
- Radiation and Radioactivity Technical Support Document for the Bruce A Units 1&2 Refurbishment and Continued Operations Project EA [20]; and
- Ontario Power Generation Quarterly Technical Reports, 2006 to 2009 [21;22;23;24;25;26;27;28;29;30;31;32;33;34;35;36].

5.1.2 Modelled Existing Environment

Existing doses to non-human biota VECs were also estimated using an ecological risk assessment model. Modelling methods are described in Section 8.1.4.

5.2 TRADITIONAL KNOWLEDGE

As described in the Aboriginal Interests TSD, concerns with regards to radiation and radioactivity historically raised by local Aboriginal communities include the following:

- radiological effects on health, animals and plants;
- potential health and safety implications for the natural environment, and future generations resulting from the potential for damage to traditional lands and Aboriginal way of life;
- level of contaminants in fish;
- effects on the food web and on all parts of the environment; and
- safety of Aboriginal communities.

The description of the existing radiation and radioactivity environment includes a presentation of the existing doses to both humans and non-human biota. In addition, available information on Aboriginal dietary surveys in relation to the local fishery has been included (Section 5.7.3).

5.3 BACKGROUND SOURCES OF RADIATION AND RADIOACTIVITY

This section describes radiation and radioactivity that is present in the environment from natural and anthropogenic sources such as the fallout from nuclear weapons testing. As noted, baseline conditions are those existing in 2009, to the extent that information is available.

The following discussion is based on the data from provincial and national areas that are not influenced by releases of radiation and radioactivity from nuclear facilities at the Bruce nuclear site. Nevertheless, the background levels are expected to apply equally to the Regional, Local and Site Study Areas defined for this work.

5.3.1 Dose from Natural Radiation

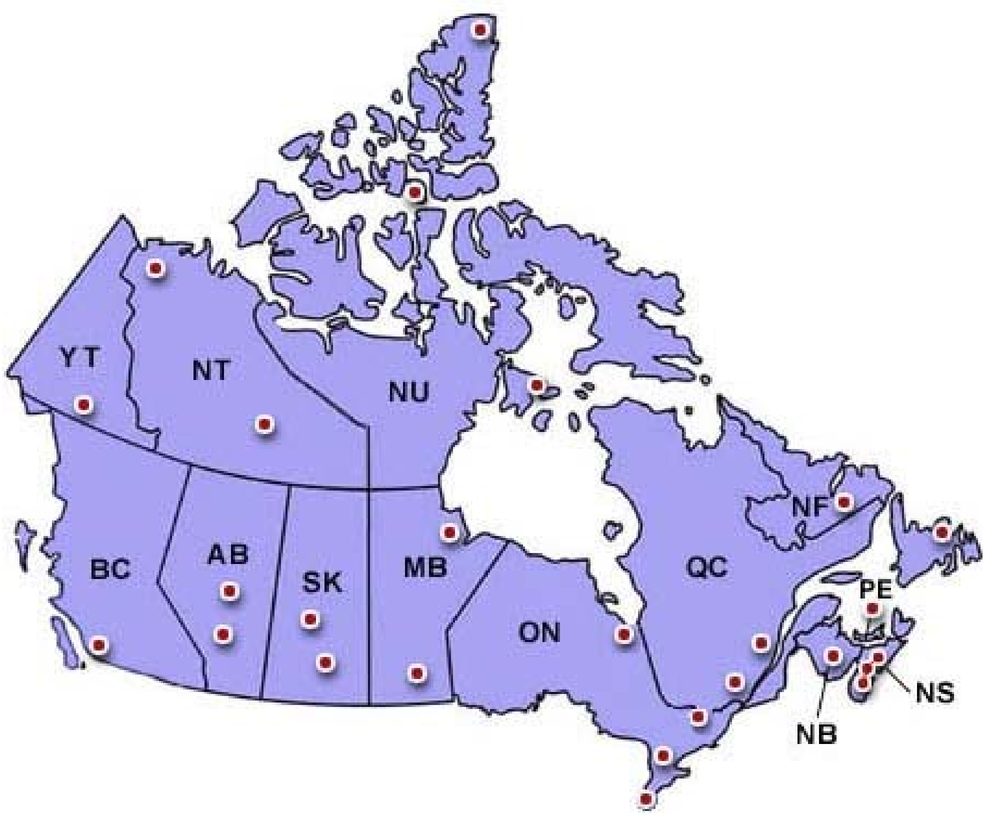
The magnitudes of radiation dose from natural sources vary greatly, both spatially and temporally, and are mainly attributable to the following:

- ionizing radiation from cosmic rays;
- naturally occurring radionuclides in air, water, and food; and
- naturally occurring radionuclides in the soil, rocks, and building materials used in homes.

Cosmic rays are high-energy particles from the sun and other galactic sources, which deliver radiation doses to people at all latitudes. Cosmogenic radionuclides, such as carbon-14, are formed in the atmosphere as a result of cosmic rays. The average annual dose from cosmic radiation in Canada is approximately 300 microSieverts per year (µSv/a). However, the dose can range up to approximately 400 µSv/a to those living at higher elevations (for instance, cities in Western Canada located about 1 km above sea-level) because of reduced shielding by the smaller mass of air above [37].

Naturally occurring radionuclides, such as potassium-40, and other isotopes from the decay chains of uranium and thorium, are present in soils, rocks and building materials used in homes. They contribute to the external gamma radiation dose. The average annual dose from external gamma radiation from the ground is estimated to be approximately 350 µSv/a [37].

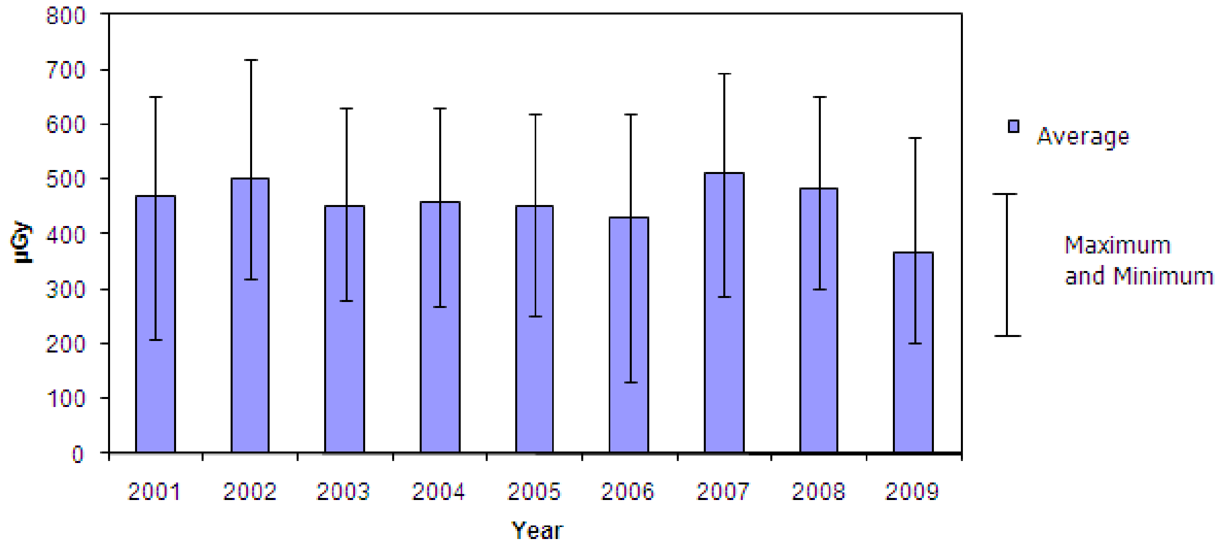
Therefore, the total external gamma dose from cosmic rays and radionuclides on the Earth's surface is about 650 µSv/a. Health Canada measured total external dose rates in 26 cities across Canada, as shown on Figure 5.3.1-1 [38]. The mean value and range of observed external gamma dose rates for the period of 2001 to 2009[3] are illustrated in Figure 5.3.1-2 [39;40]. The monitoring data show the variability of external gamma dose across the country and indicates that, at a given location, the external gamma dose rate can be up to 60% higher than the national average. For example, a recent measurement in 2009 [40] showed that the annual dose at 26 stations across Canada ranged from 201 µSv in Resolute, Nunavut to 578 µSv in Montreal, Quebec and Yellowknife, Northwest Territories, with a mean of 365 µSv (assuming 1 Sievert = 1 Gray). In Ontario, the external gamma dose measured at four stations in 2009 ranged from 272 µSv to 569 µSv.



Source: [38]

Figure 5.3.1-1: Radiation Monitoring Network in Canada

3 For year 2009, only the first quarter data were available when the report was prepared.



Note: For year 2009, only the first quarter data were available when the report was prepared.
Source: [39;40]

Figure 5.3.1-2: Annual External Gamma Dose at Cities Across Canada

Uranium and thorium decay chains and potassium-40 enter the body through the ingestion of food, the consumption of water and the inhalation of air. These media all contain naturally occurring radioactivity that was incorporated from surrounding soils and rock. The average internal dose from this source in a typical human body is 350 µSv/a [37].

Radon gas and its radioactive decay products often contribute the highest annual dose from naturally occurring radioactivity. Based on approximately 14,000 measurements across Canada, the annual effective inhalation dose related to radon-222 and radon-220 was calculated at 926 µSv/a. Radon gas is a product of the decay of uranium series radionuclides in soil. The three-month summer average has been measured at 5 to 103 Becquerels per cubic metre (Bq/m^3) in outdoor air in cities across Canada [41]. Radon gas also passes through foundation walls into building basements and accumulates to higher levels on all floors indoors. Average dose from radon and its radioactive decay products in the air of houses in different Canadian cities ranges from approximately 200 to 2,200 µSv/a [37], depending on the concentration of radionuclides in soil, rock and groundwater, as well as building ventilation rates.

The total population-weighted average annual effective dose to Canadians from all sources of natural background radiation was estimated to be 1,769 µSv/a [42]. However, there are wide variations in radioactivity concentrations in soil and surrounding materials and in external gamma fields. As a result of these factors, a wide range of annual doses from natural sources is observed, which could be up to 3,000 µSv/a [37].

5.3.2 Background Levels of Tritium

Tritium is produced in the atmosphere by the interaction of cosmic radiation and elements in the atmosphere. Tritium is also present in the environment as a result of the atmospheric testing of nuclear weapons and as a by-product of nuclear power generation.

Annual average tritium concentrations in air at background sites in Ontario were reported as less than the detection limit in 2009 [18].

Tritium concentrations in precipitation have been measured in the Ottawa Valley since 1953. The concentration of tritium in precipitation peaked in 1963 at a value of almost 350 Becquerels per litre (Bq/L) [43] and has gradually decreased over time through radioactive decay and dilution by evaporation from the oceans. Measurements in the early 1990s at this location ranged from 2.6 to 4.6 Bq/L. In 2006, the average tritium concentration in precipitation at background sites across Canada was found to be less than 3.7 Bq/L in Calgary, Alberta and Saskatoon, Saskatchewan and 6.8 Bq/L in Fredericton, New Brunswick [15]. Precipitation is potentially a source of drinking water via surface water and shallow groundwater systems. In 2009, the tritium concentration in drinking water supplies at background sites across Ontario averaged 3.0 Bq/L [18].

The mean concentrations of tritium in water in vegetation samples collected in 2009 at background sites in Ontario (i.e., Sarnia, Picton and Bancroft) ranged from 3.0 Bq/L at Sarnia to 6.7 Bq/L at Picton [18]. These concentrations of tritium in vegetation are expected to be typical of the values across Ontario because of long-term and long-range mixing in the atmosphere.

Fallout from weapons testing has historically been a source of tritium loading to Lake Huron. In 1966, the measured concentrations in Lake Huron were 21.5 Bq/L, all of which was attributable to fallout. Cosmogenic tritium in Lake Huron is estimated at a constant value of 0.47 Bq/L. Tritium in Lake Huron from fallout and cosmogenic sources has gradually decreased with time to a level of 2.0 Bq/L in 2009 [18].

5.3.3 Background Levels of Carbon-14

Carbon-14, present in air as carbon dioxide, is ubiquitous in the atmosphere because of the interaction of cosmic radiation and nitrogen, oxygen and carbon in the atmosphere. It may also be produced by atmospheric testing of nuclear weapons. Carbon-14 can be incorporated into all living tissues (e.g., plants, terrestrial organisms and aquatic organisms) through photosynthetic uptake by plants and subsequently through the food web.

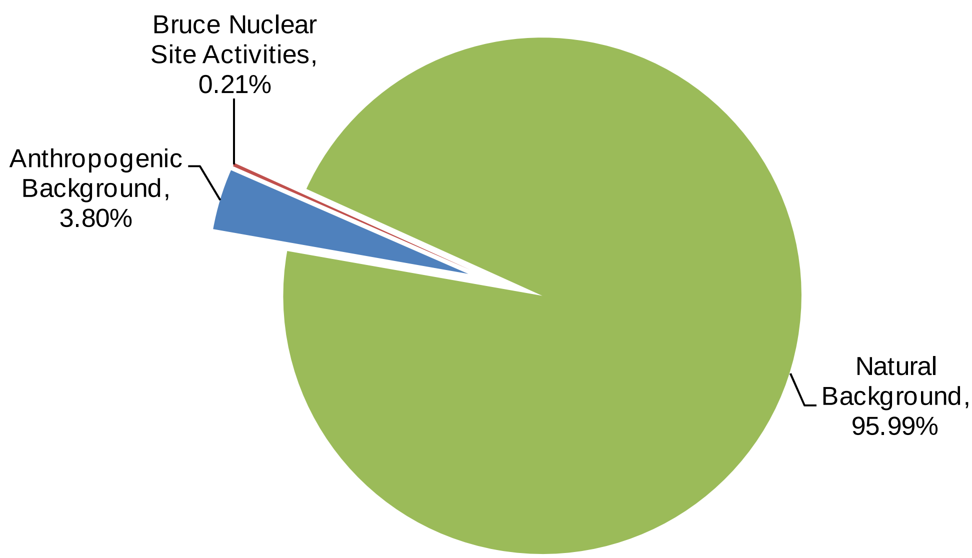
Levels of carbon-14 in biota were determined in 2009 at several Ontario background sites. The current background level of carbon-14 in Ontario vegetation at these sampling sites ranged from 222 Becquerels per kilogram carbon (Bq/kg-C) in Picton to 232 Bq/kg-C in Bancroft [18]. Prior to atmospheric testing of atomic weapons, background carbon-14 levels were measured at 226 Bq/kg-C [44]. Given the relatively long half life of carbon-14 (~5,700 years), these data indicate weapons testing did not produce noteworthy amounts of this radionuclide across Ontario.

5.3.4 Other Sources of Human Exposure

Other sources of human exposure include the following:

- radionuclides in atmosphere, soil and water from global fallout from open-air nuclear weapons testing, the Chernobyl accident, and satellite accidents;
- consumer products (e.g., cigarettes, smoke detectors, and cathode ray tube type colour televisions and computer monitors);
- waste from human activities concentrating and/or releasing naturally occurring radionuclides (e.g., operating coal power plants, abstracting oil and gas, smelting metals, manufacturing fertilizer and building materials);
- medical procedures involving exposure (e.g., diagnostics and radiotherapy); and
- exposure to cosmic rays during long-haul flights as a result of the lack of protection from the atmosphere.

Figure 5.3.4-1 compares the dose to humans (represented by the critical group identified in Bruce Power's REMP report) as a result of all activities at the Bruce nuclear site in relation to background doses in Ontario, Canada. The total dose represented by this figure is approximately 2,100 μSv/a [18].



Source: [18]

Figure 5.3.4-1: Public Dose Due to Bruce Nuclear Site in Relation to Background Doses in Ontario

5.4 RADIOACTIVE RELEASES TO THE ENVIRONMENT

There are no anthropogenic sources of radiation and radioactivity that result in significant (non-medical) exposures to members of the public and non-human biota within the Regional Study Area, except the nuclear facilities at the Bruce nuclear site. Therefore, this section focuses on the radioactive releases from facilities at the Bruce nuclear site, including Bruce A, Bruce B, the WWMF and the CMLF. As stated previously, 2009 is considered the baseline year for this EA. For comparison, data for the period of 2001 to 2008 are also provided.

5.4.1 Releases to Air

The total annual radiological releases to air from four facilities at the Bruce nuclear site during the period of 2001 to 2009 are shown in Table 5.4.1-1, and are illustrated graphically on Figure 5.4.1-1.

Bruce A and Bruce B are the major contributors of airborne emissions at the Bruce nuclear site. In 2009, radionuclide emissions to air from these two facilities were 1.54×10^{15} Bq, which amounts to about 97% of the total release to air from the Bruce nuclear site [18] .

Releases from Bruce A and Bruce B generally followed trends that can be related to their operations, maintenance and lay up activities. For example, tritium, noble gases and iodine-131 releases from Bruce A followed a generally decreasing trend throughout the period of operation and maintenance from 1991 to late 1995. During this period, the tritium removal program was underway. The decreasing trend in releases of tritium, noble gases and iodine-131 continued as the four units were shut down and put into lay up condition. Following the restart of Units 3 and 4 in 2004 and 2003, respectively, increased airborne emissions, including gaseous radionuclides and radioactive particulates, have been observed [20].

Airborne emissions from the WWMF account for a small portion of the total releases from the Bruce nuclear site. For example, as shown in Table 5.4.1-1 and Figure 5.4.1-2, the airborne emissions of tritium from the WWMF in 2009 were 4.95×10^{13} Bq, which represented only 3.44% of the total tritium releases to air from the Bruce nuclear site [18]. As shown in Table 5.4.1-2, all these releases were far less than the corresponding annual Derived Release Limits (DRLs) for the WWMF. The DRL is the limit at which the release of a radionuclide occurring from a nuclear facility will not result in doses to individual members of the public exceeding the dose limits set by the CNSC.

5.4.2 Releases to Water

Treated effluents are discharged to Lake Huron via the Condenser Cooling Water (CCW) duct. The total annual releases of radioactivity to water from facilities at the Bruce nuclear site during the period of 2001 to 2009 are shown in Table 5.4.2-1, and are illustrated graphically on Figure 5.4.2-1[4].

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[4] Elevated levels of waterborne tritium and gross gamma were observed in 2007 due to a small leak at Bruce B. The leak was repaired in November 2007 [16].

Bruce A and Bruce B are the major contributors of waterborne emissions at the Bruce nuclear site. In 2009, the emission of radioactivity to water from these two facilities was 6.28×10^{14} Bq, over 99.98% of the total waterborne emissions from the Bruce nuclear site [18].

Waterborne emissions from the WWMF account for a small portion of the total releases from the Bruce nuclear site. Water collected from structures at the WWMF, such as sumps in the Low Level Storage Buildings (LLSBs) and some of the in-ground containers, are transferred to the Bruce A Active Liquid Waste System for treatment and discharge. As shown in Table 5.4.2-1 and Figure 5.4.2-2, waterborne emissions of tritium from the WWMF in 2009 were 8.83×10^{10} Bq, which was less than 0.01% of the total releases of tritium to water from the Bruce nuclear site [18]. As shown in Table 5.4.1-2, all these releases were far less than the corresponding annual DRLs. However, it was observed that the action level for the emission of Gross beta, 1.0×10^{-7} Bq/month, was exceeded in 2009 [33;35;36]. Initial investigations indicated that there was no evidence of an operational occurrence to cause the exceedance, and the exceedances were due to the use of road salt as a de-icing compound on the asphalt surfaces at the WWMF and the lab techniques, which could lead to overestimating the gross beta concentration [33;36].

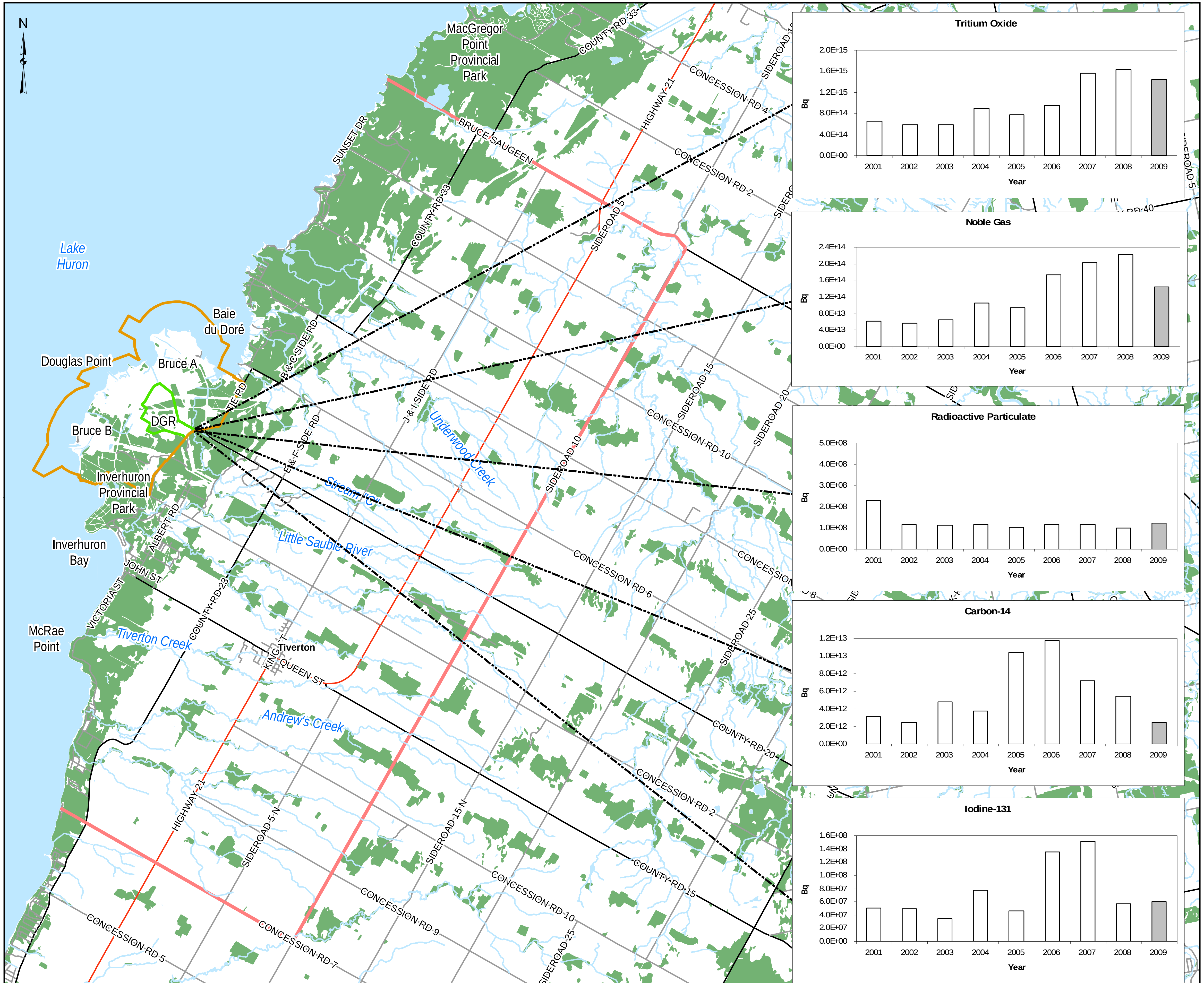
Table 5.4.1-1: Annual Releases to Air in Gaseous Effluent from Bruce Nuclear Site [c]

	2001	2002	2003	2004	2005	2006	2007	2008	2009
Tritium Oxide (Bq)									
WWMF emission	1.50×10^{12}	4.08×10^{9}	2.56×10^{13}	3.29×10^{13}	5.06×10^{13}	5.49×10^{13}	1.34×10^{13}	2.72×10^{13}	4.95×10^{13}
Total emission	6.50×10^{14}	5.81×10^{14}	5.81×10^{14}	8.97×10^{14}	7.82×10^{14}	9.51×10^{14}	1.57×10^{15}	1.63×10^{15}	1.44×10^{15}
Ratio of emission (WWMF/Total, %)	0.23	0.0007	4.41	3.67	6.47	5.77	0.85	1.67	3.44
Noble Gas (Bq)									
WWMF emission [a]	—	—	—	—	—	—	—	—	-
Total emission	6.10×10^{13}	5.63×10^{13}	6.53×10^{13}	1.06×10^{14}	9.44×10^{13}	1.73×10^{14}	2.03×10^{14}	2.22×10^{14}	1.44×10^{14}
Ratio of emission (WWMF/Total, %)	—	—	—	—	—	—	—	—	-
Iodine-131 (Bq)									
WWMF emission	2.10×10^{7}	2.86×10^{4}	3.91×10^{5}	1.26×10^{5}	1.20×10^{5}	1.13×10^{4}	7.02×10^{4}	5.96×10^{4}	6.45×10^{4}
Total emission	5.00×10^{7}	4.93×10^{7}	3.42×10^{7}	7.70×10^{7}	4.63×10^{7}	1.35×10^{8}	1.51×10^{8}	5.64×10^{7}	6.04×10^{7}
Ratio of emission (WWMF/Total, %)	42.00 [b]	0.06	1.14	0.16	0.26	0.008	0.046	0.11	0.11
Radioactive Particulate (Bq)									
WWMF emission	8.10×10^{7}	5.01×10^{4}	2.90×10^{5}	1.70×10^{5}	2.45×10^{6}	5.03×10^{5}	4.70×10^{4}	7.23×10^{4}	4.08×10^{4}
Total emission	2.30×10^{8}	1.16×10^{8}	1.13×10^{8}	1.18×10^{8}	1.05×10^{8}	1.17×10^{8}	1.16×10^{8}	1.00×10^{8}	1.22×10^{8}
Ratio of emission (WWMF/Total, %)	35.22 [b]	0.04	0.26	0.14	2.33	0.43	0.04	0.07	0.03

Table 5.4.1-1: Annual Releases to Air in Gaseous Effluent from Bruce Nuclear Site (continued)

	2001	2002	2003	2004	2005	2006	2007	2008	2009
Carbon-14 (Bq)									
WWMF emission	1.00×10^{9}	—	1.72×10^{9}	3.97×10^{8}	2.84×10^{8}	1.12×10^{9}	4.67×10^{9}	4.81×10^{9}	3.92×10^{9}
Total emission	3.10×10^{12}	2.49×10^{12}	4.77×10^{12}	3.80×10^{12}	1.04×10^{13}	1.18×10^{13}	7.17×10^{12}	5.41×10^{12}	2.45×10^{12}
Ratio of emission (WWMF/Total, %)	0.03	—	0.04	0.01	0.00	0.01	0.07	0.09	0.16

Notes:
a Noble gases are not released from the WWMF
b Higher emission ratios for iodine-131 and particulate were observed in 2001 but the reason is not clear.
c Fugitive emission is not included in WWMF emission data.
— Not available
Source: [10;11;12;13;14;15;16;17;18]



LEGEND

- Project Area (OPG-retained lands that encompass the DGR Project)
- Site Study Area [1]
- Local Study Area

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

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Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m, [10;11;12;13;14;15;16;17;18]
Datum: NAD 83 Projection: UTM Zone 17N

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PROJECT
RADIATION AND RADIOACTIVITY TECHNICAL SUPPORT DOCUMENT

TITLE
ANNUAL RELEASES TO AIR FROM THE BRUCE NUCLEAR SITE

Golder Associates
Mississauga, Ontario

PROJECT No.06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	03 Aug. 2006		
GIS	BC	14 Apr. 2010		
CHECK	AB	14 Apr. 2010		
REVIEW	MAR	14 Apr. 2010		

FIGURE 5.4.1-1

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Table 5.4.1-2: WWMF Emissions as % of DRL

	DRL (Bq/a)	2001		2002		2003		2004		2005		2006		2007		2008		2009	
		Emission (Bq)	% of DRL	Emission (Bq)	% of DRL	Emission (Bq)	% of DRL	Emission (Bq)	% of DRL	Emission (Bq)	% of DRL	Emission (Bq)	% of DRL	Emission (Bq)	% of DRL	Emission (Bq)	% of DRL	Emission (Bq)	% of DRL
Air [a]																			
Tritium Oxide	1.39×10^{17}	1.50×10^{12}	0.0011	4.08×10^{9}	0	2.56×10^{13}	0.0184	3.29×10^{13}	0.0237	5.06×10^{13}	0.0364	5.49×10^{13}	0.0395	1.34×10^{13}	0.0096	2.72×10^{13}	0.0196	$4. 95\times0^{13}$	0.036
Iodine-131	7.16×10^{12}	2.10×10^{7}	0.0003	2.86×10^{4}	0	3.91×10^{5}	0	1.26×10^{5}	0	1.20×10^{5}	0	1.13×10^{4}	0	7.02×10^{4}	0	5.96×10^{4}	0	6.45×10^{4}	0
Radioactive Particulate	2.93×10^{12}	8.10×10^{7}	0.0028	5.01×10^{4}	0	2.90×10^{5}	0	1.70×10^{5}	0	2.45×10^{6}	0.0001	5.03×10^{5}	0	4.70×10^{4}	0	7.23×10^{4}	0	4.08×10^{4}	0
Carbon-14	4.64×10^{15}	1.00×10^{7}	0 [c]	—	—	1.72×10^{9}	0	3.97×10^{8}	0	2.84×10^{8}	0	1.12×10^{9}	0	4.67×10^{9}	0	4.81×10^{9}	0	3.92×10^{9}	0
Water [b]																			
Tritium Oxide	2.10×10^{15}	7.30×10^{10}	0.0035	2.94×10^{10}	0.0014	3.68×10^{10}	0.0018	2.05×10^{10}	0.001	3.26×10^{10}	0.0016	4.38×10^{10}	0.0021	8.08×10^{10}	0.0038	8.74×10^{10}	0.0042	8.83×10^{10}	0.004
Gross beta-gamma activity	1.16×10^{11}	8.00×10^{6}	0.0069	1.06×10^{7}	0.0091	9.27×10^{6}	0.008	6.19×10^{6}	0.0053	8.26×10^{6}	0.0071	1.35×10^{7}	0.0116	3.13×10^{7}	0.027	5.16×10^{7}	0.0445	1.23×10^{8}	0.106

Notes:
a Noble gases are not released from the WWMF
b Carbon-14 is not released to water from the WWMF
c Zeros are shown when the emission is less than 0.0001% of the DRL
— Not available
Source: [10;11;12;13;14;15;16;17;18]

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LEGEND

- Project Area (OPG-retained lands that encompass the DGR Project)
- Site Study Area [1]
- Local Study Area

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

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Datum: NAD 83 Projection: UTM Zone 17N

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PROJECT
RADIATION AND RADIOACTIVITY TECHNICAL SUPPORT DOCUMENT

TITLE
ANNUAL RELEASES TO AIR FROM THE WWMF

Golder Associates
Mississauga, Ontario

PROJECT NO. 06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	03 Aug. 2006		
GIS	BC	15 Apr. 2010		
CHECK	AB	15 Apr. 2010		
REVIEW	MAR	15 Apr. 2010		

FIGURE 5.4.1-2

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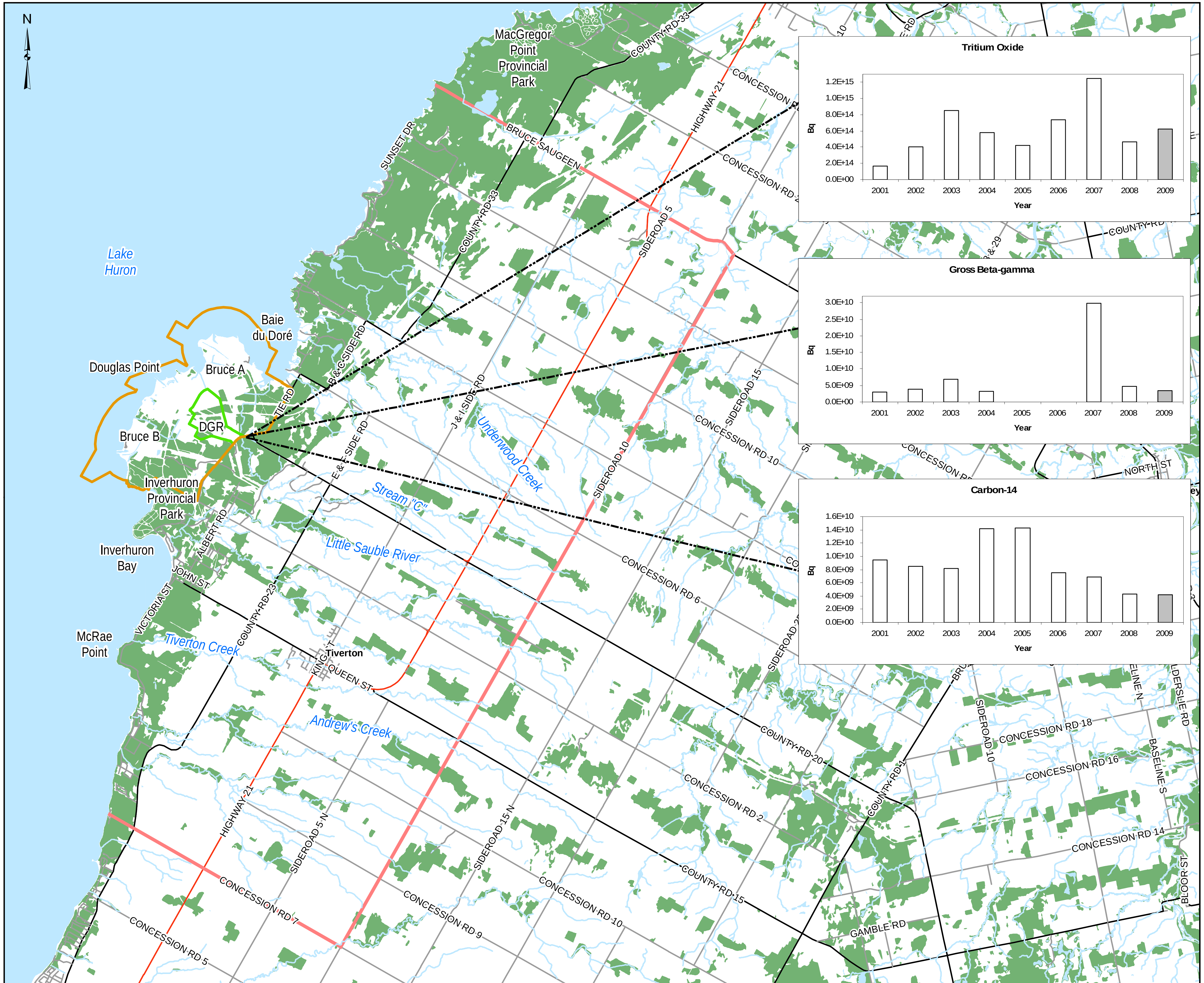

LEGEND

- Project Area (OPG-retained lands that encompass the DGR Project)
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- Local Study Area

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[10;11;12;13;14;15;16;17;18]
Datum: NAD 83 Projection: UTM Zone 17N

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Kilometres

PROJECT
RADIATION AND RADIOACTIVITY TECHNICAL SUPPORT DOCUMENT

TITLE
ANNUAL RELEASES TO WATER FROM THE BRUCE NUCLEAR SITE

Golder Associates
Mississauga, Ontario

PROJECT No.06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	03 Aug. 2006		
GIS	BC	15 Apr. 2010		
CHECK	AB	15 Apr. 2010		
REVIEW	MAR	15 Apr. 2010		

FIGURE 5.4.2-1

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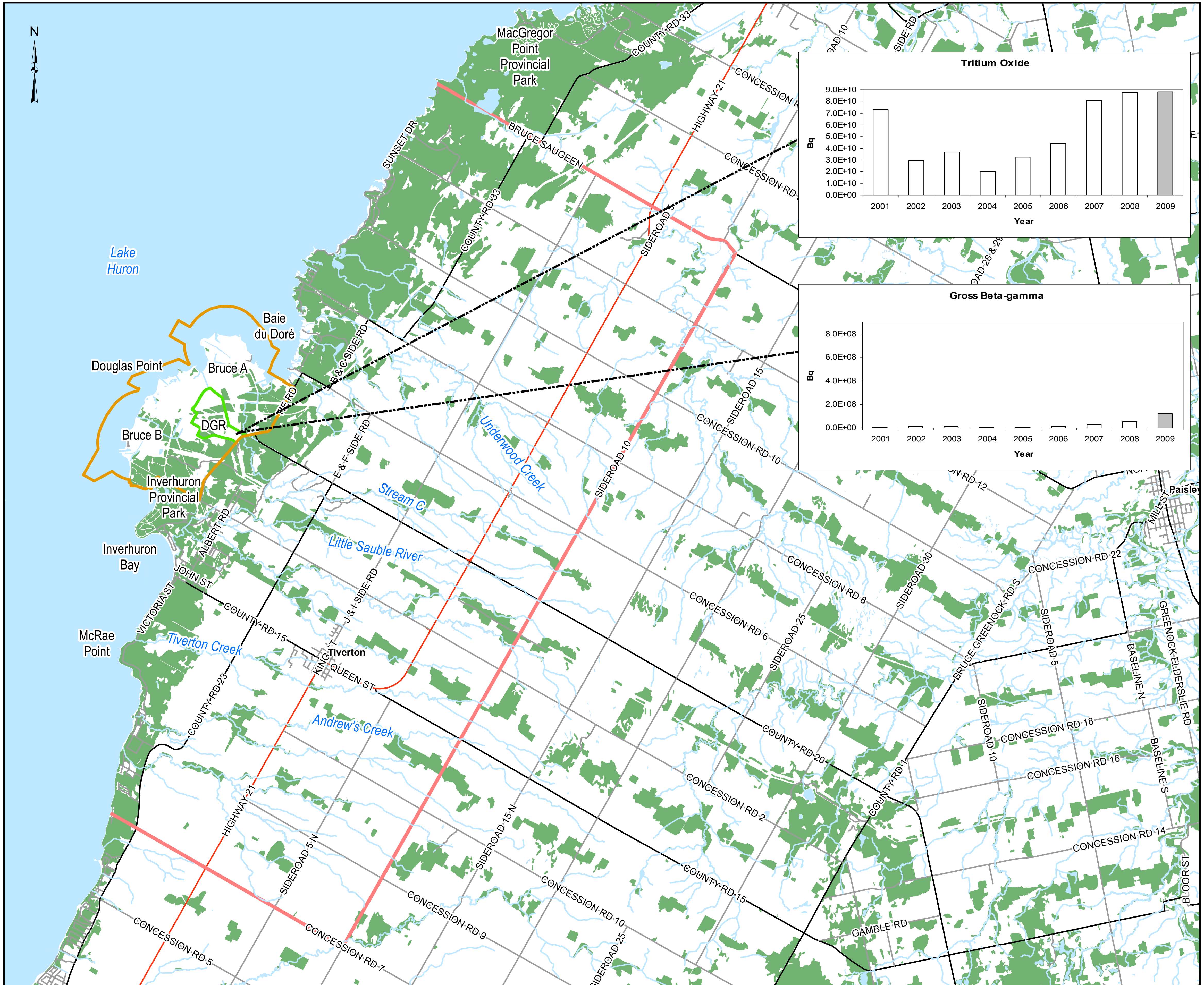

LEGEND

- Project Area (OPG-retained lands that encompass the DGR Project)
- Site Study Area [1]
- Local Study Area

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[10;11;12;13;14;15;16;17;18]
Datum: NAD 83 Projection: UTM Zone 17N

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PROJECT

RADIATION AND RADIOACTIVITY TECHNICAL SUPPORT DOCUMENT

TITLE

ANNUAL RELEASES TO WATER FROM THE WWMF

Golder Associates
Mississauga, Ontario

PROJECT No.06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	03 Aug. 2006	**FIGURE 5.4.2-2**	
GIS	BC	15 Apr. 2010		
CHECK	AB	15 Apr. 2010		
REVIEW	MAR	15 Apr. 2010		

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Table 5.4.2-1: Annual Releases to Water in Liquid Effluent from Bruce Nuclear Site [a]

	2001	2002	2003	2004	2005	2006	2007[b]	2008	2009
Tritium Oxide (Bq)									
WWMF emission	7.30×10^{10}	2.94×10^{10}	3.68×10^{10}	2.05×10^{10}	3.26×10^{10}	4.38×10^{10}	8.08×10^{10}	8.74×10^{10}	8.83×10^{10}
Total Bruce nuclear site emission	1.70×10^{14}	4.01×10^{14}	8.55×10^{14}	5.84×10^{14}	4.26×10^{14}	7.34×10^{14}	1.25×10^{15}	4.68×10^{14}	6.28×10^{14}
Ratio of emission (WWMF/Total, %)	0.04	0.01	0.004	0.004	0.01	0.01	0.01	0.02	0.01
Gross beta-gamma Activity (Bq)									
WWMF emission	8.00×10^{6}	1.06×10^{7}	9.27×10^{6}	6.19×10^{6}	8.26×10^{6}	1.35×10^{7}	3.13×10^{7}	5.16×10^{7}	1.23×10^{8}
Total Bruce nuclear site emission	3.10×10^{9}	3.83×10^{9}	6.96×10^{9}	3.30×10^{9}	—	—	2.99×10^{10}	4.78×10^{9}	3.49×10^{9}
Ratio of emission (WWMF/Total, %)	0.26	0.28	0.13	0.19	—	—	0.10	1.08	3.52

Notes:

a The waterborne emission of carbon-14 is not provided in this table as there is no direct release of carbon-14 to water from the WWMF.

b Elevated levels of waterborne tritium and gross gamma were observed in 2007 due to a small leak at Bruce B. The leak was repaired in November 2007 [16].

— Gross beta-gamma emission data for Bruce A and Bruce B are not available in the Annual Summary and Assessment of Environmental Radiological Data reports for 2005 and 2006 [14;15]

Source: [10;11;12;13;14;15;16;17;18]

5.5 RADIOACTIVITY IN THE ATMOSPHERIC ENVIRONMENT

Bruce Power and Health Canada routinely measure the concentrations of selected radionuclides in the atmosphere at designated locations in the study areas and across the province. These measurements reflect the concentrations of natural background and anthropogenic radioactivity as described previously, and the concentrations of radioactivity attributable to releases from nuclear facilities at the Bruce nuclear site, most notably Bruce A and Bruce B. Sampling locations in the Local and Regional Study Areas are shown on Figures 5.5-1 and 5.5-2, respectively. Monitoring results, including tritium in air, tritium in precipitation, radioactive particulate, carbon-14 in air and radioactive noble gas, for the period of 2001 to 2009 are summarized.

5.5.1 Tritium in Air

Airborne tritium release takes place in the form of gaseous tritiated water (HTO) and elemental tritium. There are no specific regulatory limits on tritium concentrations in air against which the measured data can be compared. However, the airborne tritium concentration is limited implicitly by the regulatory limits on annual dose to the member of the most highly exposed group in the public and by the constraints on doses to non-human biota.

Tritium concentrations in air are measured[5] on a regular basis by Bruce Power at locations in the vicinity of the Bruce nuclear site and at a number of more distant locations, including Paisley approximately 30 km to the east of the Bruce nuclear site. The tritium concentrations in air measured by an active sampling method are summarized in Table 5.5.1-1, and illustrated on Figures 5.5-1 and 5.5-2. In general, tritium concentrations in air decrease with distance from the sources because of atmospheric dispersion. The concentration of tritium in air also varies with direction, with the highest concentration being measured in the direction down gradient of the prevailing wind.

During 2009, the average concentrations of airborne tritium in the Local Study Area ranged from 0.82 Bq/m^3 at Site B11 to 3.08 Bq/m^3 at Site B4 (shown on Figure 5.5-1). The corresponding average concentrations of airborne tritium in the Regional Study Area ranged from 0.2 Bq/m^3 in Paisley (Site B6) to 0.36 Bq/m^3 in Kincardine (Site B9, as shown on Figure 5.5-2)[6] [18]. These concentrations are substantively higher than the provincial average level of 0.03 to 0.05 Bq/m^3 measured at Nanticoke and Lambton [14] (shown on Figure 5.5-2).

---

5 Currently only gaseous tritiated water (HTO) is measured by Bruce Power. Elemental tritium, although possibly released from the Bruce nuclear site, is not measured as the dose resulting from this form of tritium is negligible compared to the dose due to the emission of HTO. Elemental tritium emissions are measured at Darlington Nuclear Generating Station where they currently contribute 0.0006% of the total dose to members of the public due to tritium [45].

6 Bruce A recorded high levels of airborne tritium due to Vault Vapour Recovery not performing to its design capabilities. Procedures and processes are being improved to reduce emissions and preventative maintenance and monitoring are being enhanced to identify maintenance requirements.

LEGEND

- Monitoring Locations
- Site Study Area [1]
- Project Area (OPG-retained lands that encompass the DGR Project)
- Local Study Area

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

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[10;11;12;13;14;15;16;17;18]
Datum: NAD 83 Projection: UTM Zone 17N

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PROJECT
RADIATION AND RADIOACTIVITY
TECHNICAL SUPPORT DOCUMENT

TITLE
ANNUAL AVERAGE TRITIUM CONCENTRATIONS
IN AIR IN THE LOCAL STUDY AREA

Golder Associates
Mississauga, Ontario

PROJECT No.06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	03 Aug. 2006		
GIS	BC	15 Apr. 2010		
CHECK	AB	15 Apr. 2010		
REVIEW	MAR	15 Apr. 2010		

FIGURE 5.5-1

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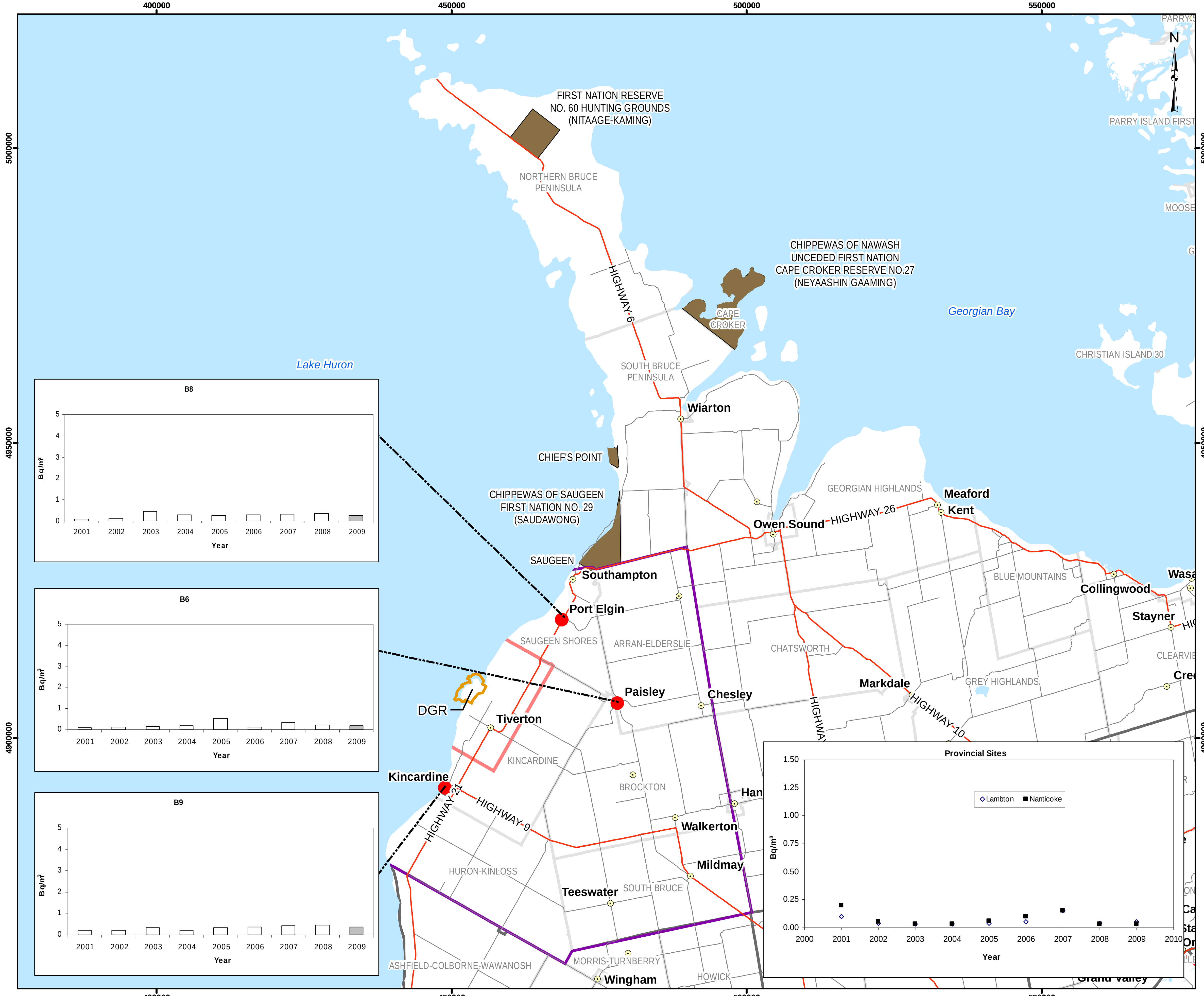

LEGEND

- Monitoring Locations
- Site Study Area [1]
- Local Study Area
- Regional Study Area
- County Boundary
- First Nations' Lands

NOTES

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Datum: NAD 83 Projection: UTM Zone 17N

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PROJECT
RADIATION AND RADIOACTIVITY
TECHNICAL SUPPORT DOCUMENT

TITLE
ANNUAL AVERAGE TRITIUM CONCENTRATIONS IN AIR IN THE REGIONAL STUDY AREA

Golder Associates
Mississauga, Ontario

PROJECT No.06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	03 Aug. 2006		
GIS	BC	15 Apr. 2010		
CHECK	AB	15 Apr. 2010		
REVIEW	MAR	15 Apr. 2010		

FIGURE 5.5-2

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Table 5.5.1-1: Annual Average Tritium Concentrations in Air (Bq/m^3)

Monitoring Locations	2001	2002	2003	2004	2005	2006	2007	2008	2009
Local Study Area									
B2	1.7	1.6	1.48	1.57	1.87	2.29	3.14	4.59	2.80
B3	1.5	3.1	2.17	2.05	1.78	2.11	3.78	3.51	2.18
B4	1.7	2.0	1.37	1.73	1.94	2.17	2.86	2.72	3.08
B5	1.5	1.3	1.63	1.04	1.28	1.51	1.98	2.39	1.35
B7	0.6	0.64	0.42	0.82	0.97	1.08	2.03	3.98	2.49
B10	0.7	0.49	0.59	1.16	0.89	1.44	1.55	2.03	1.31
B11	0.5	0.29	—	0.43	0.43	0.62	1.21	1.20	0.82
Regional Study Area									
B6	0.1	0.14	0.15	0.19	0.52	0.14	0.34	0.23	0.20
B8	0.1	0.14	0.45	0.29	0.25	0.29	0.33	0.35	0.27
B9	0.2	0.20	0.33	0.21	0.35	0.38	0.44	0.46	0.36
Provincial Locations									
Lambton	0.10	0.04	0.03	0.03	0.04	0.05	<0.15	0.04	0.05
Nanticoke	0.20	0.05	0.03	0.03	0.06	0.10	<0.15	0.03	0.03

Note:
— No measurement taken
Source: [10;11;12;13;14;15;16;17;18]

5.5.2 Tritium in Precipitation

Tritium levels observed in precipitation are related to the concentration of tritium in air, as rain or snow scavenge the tritium and fall to the ground. Precipitation can be a significant component in the recharge of shallow groundwater aquifers, which may be used as a source of drinking water in the region. This is a potential pathway for human exposure. For this reason, the tritium concentration in precipitation is compared to the limit for tritium found in the current Ontario Drinking Water Quality Standards (ODWQS) [46], which is 7,000 Bq/L. It should be noted that the current standard (the tritium concentration of 7000 Bq/L in drinking water) is consistent with guidance from the International Commission on Radiation Protection (ICRP) and the World Health Organization (WHO) [47]. The tritium in drinking water at this level is equivalent to a dose of 0.1 mSv/a, representing 10% of the dose limit for members of the public (1 mSv/a).

Recently, the Ontario Drinking Water Advisory Committee to the Ministry of the Environment has issued a report recommending changing the current standard of 7000 Bq/L in drinking water down to 20 Bq/L on a rolling annual average [47]. This constraint, if implemented, would be the most restrictive drinking water standard in the world. In a hypothetical case in which members of potential critical groups consume all their drinking water from a source with a tritium concentration of 20 Bq/L, it would represent a dose of 0.3 µSv/a or 0.03% of the annual dose limit for members of the public (1 mSv/a).

At the time of writing, this recommendation has not been accepted by the Ontario Ministry of the Environment and, as noted, the limit for tritium in drinking water is 7,000 Bq/L. This value is also used for comparison purposes.

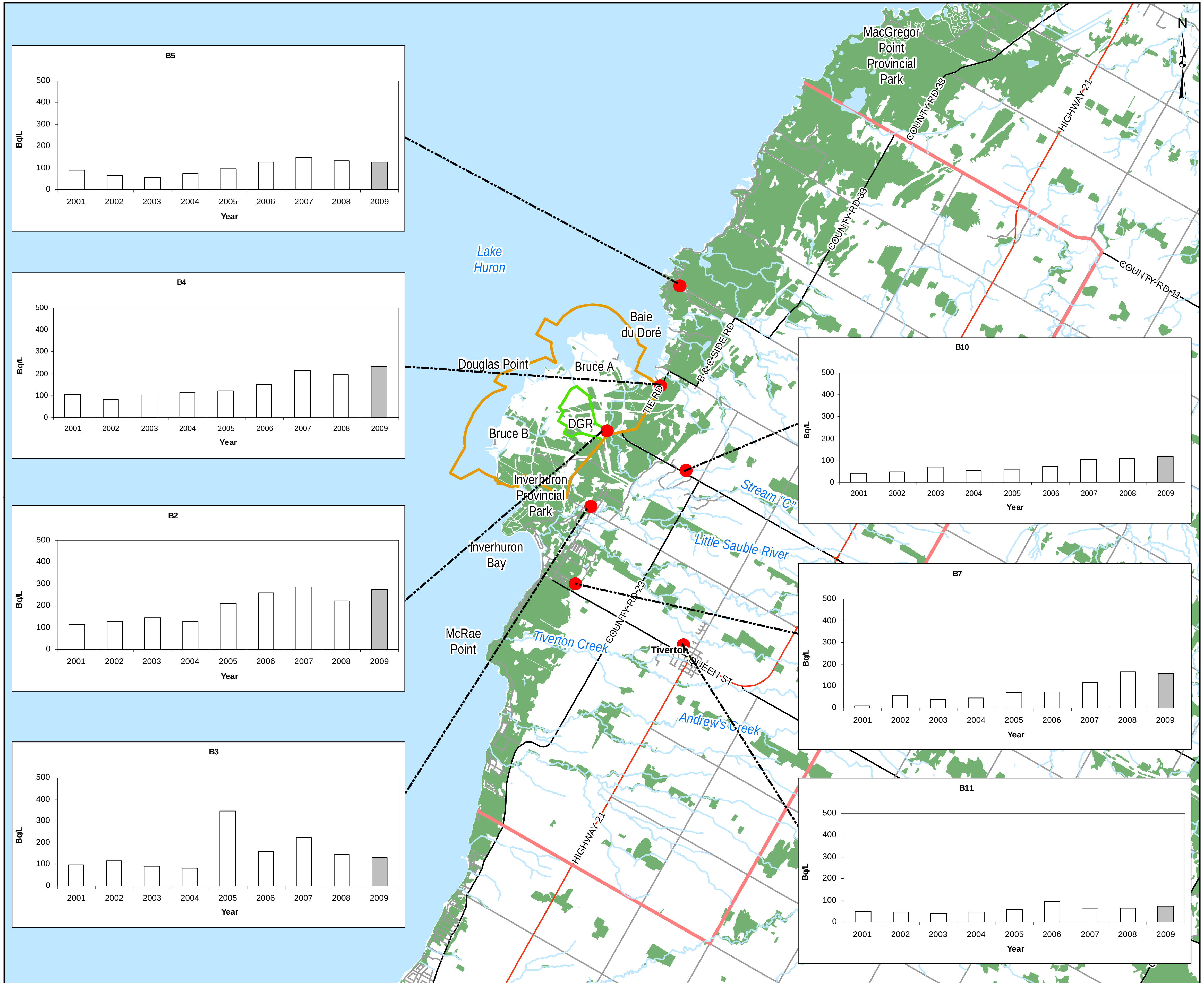
Within the Regional and Local Study Areas, precipitation is collected continuously at monitoring locations and samples are taken for the analysis of tritium on a monthly basis by Bruce Power. Annual average tritium concentrations in precipitation for the period of 2001 to 2009 are shown in Table 5.5.2-1, and on Figures 5.5.2-1 and 5.5.2-2. Within the Site Study Area, tritium in precipitation was monitored at the WWMF during the period of 2000 to 2002. The monitoring data for this period are summarized in Table 5.5.2-2 [48].

It was found that tritium concentrations in precipitation generally decrease with distance from the Bruce nuclear site, following similar decreasing trends as tritium concentration in air. For example, during 2009, the average concentration of tritium in precipitation in the Local Study Area ranged from 75.3 Bq/L at Site B11 to 274.6 Bq/L at Site B2 (shown on Figure 5.5.2-1). In remote monitoring locations in the Regional Study Area, the average concentrations of tritium in precipitation ranged from 14.3 Bq/L at Paisley (Site B6, shown on Figure 5.5.2-2) to 21.6 Bq/L at Port Elgin (Site B8). They were well below the ODWQS of 7,000 Bq/L for drinking water [46]. Some values are above the 20 Bq/L concentration that has been proposed by the Ontario Drinking Water Advisory Council (ODWAC).

Table 5.5.2-1: Annual Average Tritium Concentrations in Precipitation (Bq/L)

Monitoring Location	2001	2002	2003	2004	2005	2006	2007	2008	2009
Local Study Area									
B2	114	131	143.7	130.9	209.9	258.0	285.6	222.4	274.6
B3	97	118	90.5	83.8	346.4	159.5	223.1	146.9	132.0
B4	106	84	102.2	115.8	120.6	150.0	215.2	197.1	235.2
B5	88	66	54.4	74.6	95.2	125.9	149.5	133.7	125.8
B7	10	58	40.3	46.6	71.3	73.7	116.6	165.6	158.3
B10	41	47	70.1	54.4	58.8	72.8	106.3	109.2	119.3
B11	50	46	41.5	46.7	59.4	95.2	63.4	65.2	75.3
Regional Study Area									
B6	10	9.8	9.6	6.3	17.5	10.0	17.3	14.6	14.3
B8	13	16	12.1	14.8	16.6	25.0	23.0	20.9	21.6
B9	12	13	28	18.1	10.2	26.1	137.2	16.0	14.8
National Locations									
Calgary, AB	1.8	1.5	1.3	<4.8	<3.7	<3.7	—	—	—
Saskatoon, SK	8.0	2.6	2.3	<4.8	<3.7	<3.7	—	—	—
Fredericton, NB	3.3	3.5	1.8	<4.8	<3.7	6.8	—	—	—

Note:
— No measurement taken
Source: [10;11;12;13;14;15;16;17;18]



LEGEND

- Monitoring Locations
- Site Study Area [1]
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PROJECT
RADIATION AND RADIOACTIVITY TECHNICAL SUPPORT DOCUMENT

TITLE
ANNUAL AVERAGE TRITIUM CONCENTRATIONS IN PRECIPITATION IN THE LOCAL STUDY AREA

Golder Associates
Mississauga, Ontario

PROJECT No.06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	03 Aug. 2006		
GIS	BC	15 Apr. 2010		
CHECK	AB	15 Apr. 2010		
REVIEW	MAR	15 Apr. 2010		

FIGURE 5.5.2-1

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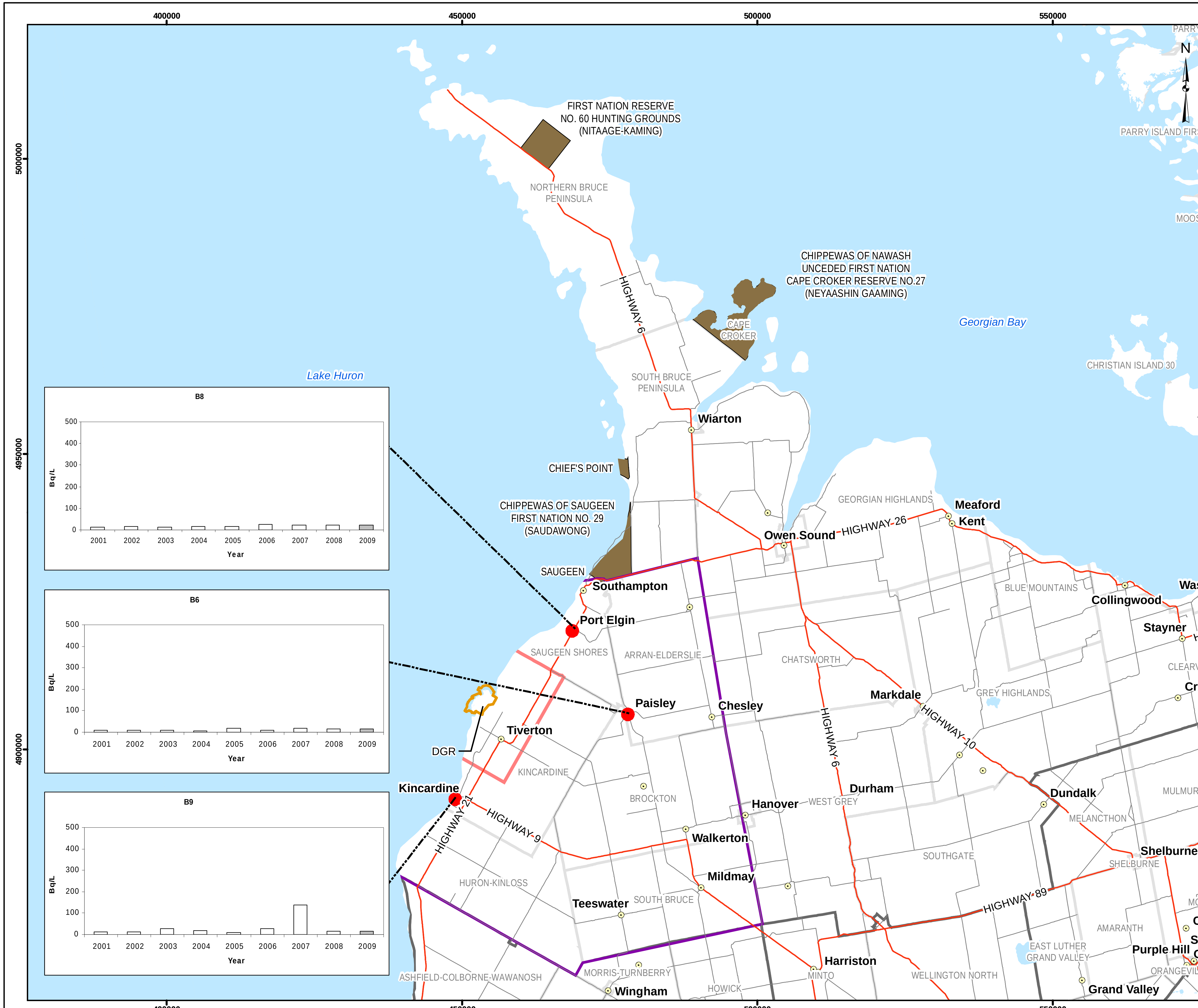

LEGEND

- Monitoring Locations
- Site Study Area [1]
- Local Study Area
- Regional Study Area
- County Boundary
- First Nations' Lands

Index Map

Québec, Michigan, DGR PROJECT, Ontario, Lake Huron, Toronto, Lake Ontario, New York, USA, Lake Erie, Indiana, Ohio, Pennsylvania, New Jersey, West Virginia

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007.
Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m, [10;11;12;13;14;15;16;17;18]
Datum: NAD 83 Projection: UTM Zone 17N

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FIGURE 5.5.2-2

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Table 5.5.2-2: Tritium in Precipitation in the Site Study Area

Site Study Area	2000	2001	2002
Number of measurements	2	35	7
Mean tritium concentration (Bq/L)	586	371	1,440
Range of tritium concentration (Bq/L)	273 to 899	12 to 1,380	195 to 6,620

Source: [48]

5.5.3 Radioactive Particulate

The deposition of radioactive particulate can result in the long-term accumulation of long-lived radionuclides onto the surfaces of vegetation and the ground. This can contribute to the external gamma dose to humans and other terrestrial biota. Also, these radionuclides can enter the food web by deposition onto plants and uptake from the soil.

There are no specific regulatory limits on radioactive particulate deposition against which the measured data can be compared. However, radioactive particulate deposition is limited implicitly by the regulatory limits on annual dose to the average member of the most highly exposed group of the public.

Bruce Power measures radioactive particulate deposition rates at the same locations used for sampling tritium in air. Precipitation and dust fall is collected in open containers on a continuous basis for a period of 30 days. The containers are collected each month and a gross beta measurement is made on each sample. The data for the period 2001 to 2009 can be found in Table 5.5.3-1 and on Figures 5.5.3-1 and 5.5.3-2.

Table 5.5.3-1: Annual Average Gross Beta Deposition Rate (Bq/m^2/month)

Monitoring Location	2001	2002	2003	2004	2005	2006	2007	2008	2009
Local Study Area									
B2	24.3	27.0	29.5	20.7	16.6	21.2	20.6	28.4	19.0
B3	17.7	17.0	17.5	15.6	14.2	19.3	19.0	23.0	18.6
B4	19.9	22.0	23.2	17.7	17.9	20.5	23.6	31.5	18.9
B5	19.7	21.0	21.7	17.0	20.1	22.1	22.1	25.9	17.4
B7	17.4	22.0	22.3	16.4	19.3	22.7	23.1	28.8	18.7
B10	21.0	21.0	23.7	20.0	19.2	22.7	22.5	28.3	19.5
B11	16.2	18.0	18.7	14.4	14.6	17.9	17.4	22.6	15.7
Regional Study Area									
B6	17.4	18.0	18.6	15.1	14.9	17.8	19.6	24.0	15.3
B8	22.4	18.0	22.3	14.6	15.7	18.6	19.4	24.3	14.9
B9	18.8	19.0	20.7	17.2	17.8	18.8	19.4	22.7	16.0

Source: [10;11;12;13;14;15;16;17;18]

During 2009, the average gross beta deposition rate of radioactive particulate in the Regional Study Area ranged from 14.9 Becquerels per square metre per month (Bq/m²/month) at Port Elgin (Site B8) to 16 Bq/m²/month at Kincardine (Site B9) [18]. For the same year, the corresponding average gross beta deposition rate in the Local Study Area ranged from 15.7 Bq/m²/month at Tiverton (Site B11) to 19.5 Bq/m²/month at the Bruce Power Visitors' Centre (Site B10). These deposition rates are within the range of gross beta in fallout in North America, which normally averages from 5 to 100 Bq/m²/month on an annual basis [14].

Within the Site Study Area, OPG measured the radioactive particulates during the period of 2000 to 2002 by analyzing gross beta of precipitation samples collected at the WWMF. The gross beta concentrations calculated for this period are shown in Table 5.5.3-2. The mean gross beta concentrations in precipitation ranged from 0.10 to 0.22 Bq/L [48].

Table 5.5.3-2: Gross Beta in Precipitation in the Site Study Area

Site Study Area	2000	2001	2002
Number of measurements	14	11	4
Mean gross beta concentration (Bq/L)	0.10	0.13	0.22
Range of gross beta concentration (Bq/L)	0.04-0.18	0.04-0.28	0.09-0.56

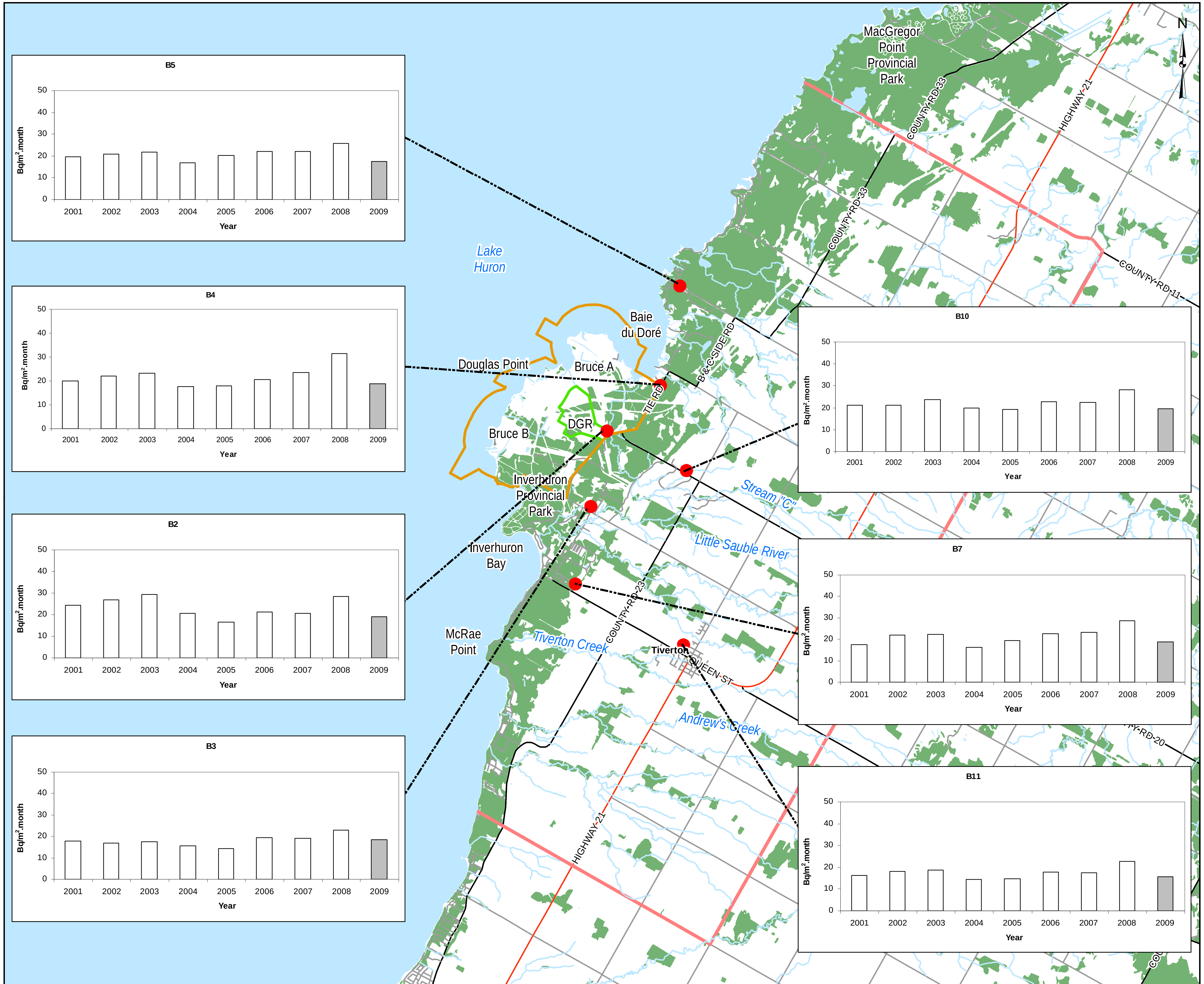
Source: [48]

5.5.4 Carbon-14 in Air

There are no specific regulatory limits on carbon-14 concentrations in air against which the measured data can be compared. However, the airborne carbon-14 concentration is limited implicitly by the regulatory limits on annual dose to members of the public.

In recent years, carbon-14 concentrations in air have been measured by Bruce Power on a regular basis. Two methods have been employed since 1999. One method (active sampling) passes air through a molecular sieve at a continuous steady rate for a 30-day period. The sieve is collected and CO_2 is analyzed by liquid scintillation counting. The other method (passive sampling) uses samplers containing mixed hydroxide pellets to absorb CO_2 from air at a controlled rate. The CO_2 is released from the pellets in the laboratory and analyzed by liquid scintillation counting. Passive samples are analysed on a quarterly basis. Bruce Power discontinued the use of active samplers after January 2008.

Annual average carbon-14 concentrations in air in the Local Study Areas for 2001 to 2009 are shown in Table 5.5.4-1, along with the data obtained at provincial monitoring locations. During 2009, the carbon-14 content of air within the Local Study Area was found to range from 223 Bq/kg-C at the Bruce Eco-Industrial Park Sewage Treatment Plant (Site B3) to 258 Bq/kg-C at Site BR11 (by the passive sampling method) [18]. Some of these values are higher than those reported for the provincial background locations, which averaged at 245 Bq/kg-C, but not by a statistically significant amount [18]. It is reasonable to conclude that any increased carbon-14 concentrations in air in the Local Study Area are a result of the emission of carbon-14 from the Bruce nuclear site.



LEGEND

- Monitoring Locations
- Site Study Area [1]
- Project Area (OPG-retained lands that encompass the DGR Project)
- Local Study Area

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

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Datum: NAD 83 Projection: UTM Zone 17N

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PROJECT
RADIATION AND RADIOACTIVITY TECHNICAL SUPPORT DOCUMENT

TITLE
ANNUAL AVERAGE GROSS BETA DEPOSITION RATE IN THE LOCAL STUDY AREA

Golder Associates
Mississauga, Ontario

PROJECT No.06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	03 Aug. 2006		
GIS	BC	15 Apr. 2010		
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FIGURE 5.5.3-1

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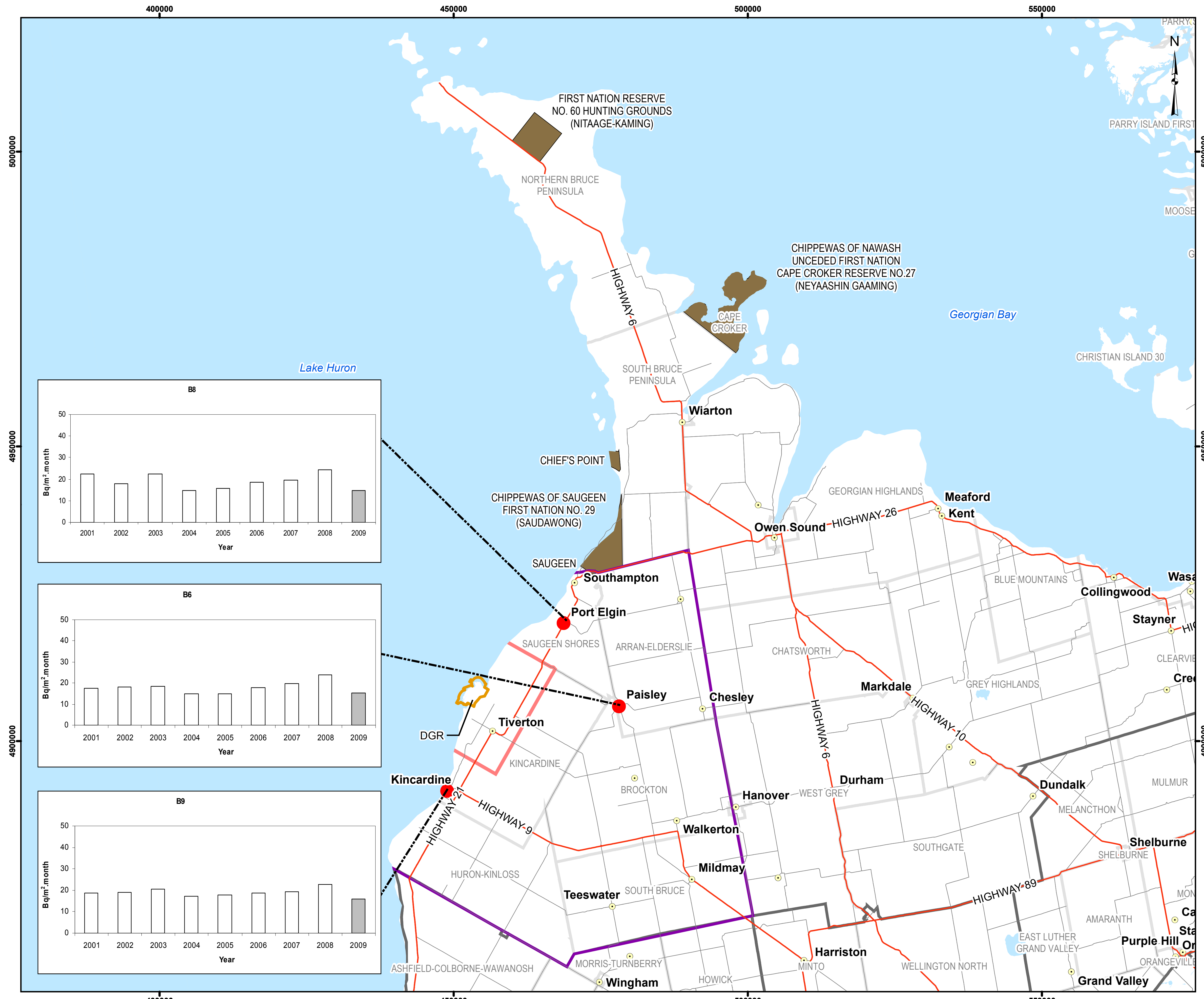

LEGEND

- Monitoring Locations
- Site Study Area [1]
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Golder Associates
Mississauga, Ontario

PROJECT No.06-1112-037			SCALE: AS SHOWN	R000
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GIS	BC	15 Apr. 2010		
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Table 5.5.4-1: Carbon-14 Activity in Air (Bq/kg-C)

Monitoring Location	2001	2002	2003	2004	2005	2006	2007	2008	2009
Local Study Area *(locations defined in [18])*									
B3	306	238	257	269	319	331	266	277	223
B5	304	241	251	255	278	307	273	266	246
B11	271	246	236	246	265	265	246	251	231
BR1	264	246	253	243	285	301	274	273	244
BR11	277	235	247	262	297	392	284	264	258
BF1	251	245	240	249	284	307	251	254	242
BF14	265	257	252	249	288	306	254	275	258
BDF11	256	240	240	247	263	261	249	254	231
Provincial Locations									
Lambton	—	—	248	—	242	230	224	221	239
Lakefield	—	—	236	231	234	231	224	236	232
Bancroft	242	213	228	236	230	231	228	213	246
Barrie	236	192	223	240	222	235	233	215	266
Belleville	244	195	227	232	246	233	225	220	242
Picton	—	—	229	233	228	227	230	234	248
Provincial Average	237	216	232	235	234	231	227	223	245

Note:
— No measurement taken
Source: [10;11;12;13;14;15;16;17;18]

Bruce Power's carbon-14 emissions have been increasing since 2003 as a result of the restart of Bruce A Units 3 and 4, and continuous purging of the moderator cover gas at Bruce B [18]. In 2008, the moderator cover gas oxygen addition system was returned to service at Bruce B, reducing the frequency of moderator cover gas purging and carbon-14 emissions. The moderator cover gas oxygen addition systems at Bruce A have been upgraded during refurbishment, which are expected to result in lower emissions once the Bruce A units are back on-line.

The concentration of carbon-14 in air within the Site Study Area was also investigated. It was reported that airborne carbon-14 inside LLSB1 and LLSB6, storage structures located at the WWMF, was measured at the range of 2,000 to 67,000 Bq/m^3 during 1997 and 1998. In 1999, airborne carbon-14 was measured at 14 outdoor locations on the WWMF property. The average concentrations ranged from <3,000 Bq/kg-C in the vicinity of the LLSBs to 20,000 Bq/kg-C in the vicinity of the in-ground containers and quadricells. For comparison, the carbon-14 concentration in air at locations outside the WWMF site ranged from 350 to 3,500 Bq/kg-C [48].

5.5.5 Radioactive Noble Gas

There are no specific regulatory limits for noble gas concentrations against which the measured data can be compared. However, external gamma radiation is limited implicitly by the regulatory limit on annual dose (from all human-made sources) to members of the public.

Noble gas in the environment is conservatively estimated using actual stack releases and a calculated atmospheric dilution factor. The estimated annual noble gas concentrations at the locations occupied by the potential critical groups within the Local Study Area are provided in Table 5.5.5-1. As shown in the table, the estimated noble gas concentration at these locations in 2009 ranged from 0.06 to 0.34 Becquerel MegaElectron volt per cubic metre (Bq-MeV/m^3). Radioactive noble gases have historically accounted for a significant portion of the calculated dose to members of the public from the operation of nuclear facilities on the Bruce nuclear site. However, the reported dose to the public from noble gas emissions has been gradually decreasing over the past two decades. Bruce Power estimates the maximum individual dose to the public from noble gases from the Bruce nuclear site in 2009 was 0.482 µSv [18]. This can be compared with the estimated dose of 3.8 µSv in 1991 [20]. Details of the calculation are provided in the Annual Summary and Assessment of Environmental Radiological Data for 2009 [18].

Table 5.5.5-1: Estimated Noble Gas Concentrations (Bq-MeV/m³)

Local Study Area (locations defined in [18])	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
BR1	0.18	0.12	0.13	0.33	0.31	0.37	0.29
BR11	0.11	0.05	0.20	0.48	0.33	0.55	0.34
BR27	0.11	0.15	0.17	0.32	0.25	0.19	0.14
BR22	0.06	0.09	0.11	0.19	0.18	0.17	0.15
BR32	0.05	0.09	0.12	0.20	0.26	0.55	0.25
BDF11	0.02	0.03	0.03	0.06	0.10	0.03	0.06
BF1	0.08	0.07	0.08	0.14	1.64	0.17	0.12
BF14	0.08	0.01	0.13	0.24	0.28	0.30	0.18
Bruce Energy Centre [a]	0.07	0.13	0.17	0.26	0.20	0.28	0.13

Notes:
a Bruce Energy Centre has been renamed to Bruce Eco-Industrial Centre. Historically it is refered to as Bruce Energy Centre.
Data not available for 2001 and 2002
Source: [10;11;12;13;14;15;16;17;18]

5.6 RADIOACTIVITY IN SURFACE WATER

Liquid wastes generated at the Bruce nuclear site are discharged to Lake Huron after treatment. In this section, existing levels of radioactivity in surface water are discussed.

5.6.1 Tritium and Gross Beta in Surface Water

Bruce Power has historically reported drinking water monitoring data for three water supply plants in the Regional Study Area (i.e., Kincardine, Port Elgin and Southampton), where Lake Huron serves as a source of drinking water for these three communities. In 2008, the Port Elgin water supply was taken out of service, and the community is now supplied by the Southampton water supply plant.

Grab samples of treated water are collected twice a day at the water supply plants. Weekly composites are analyzed for tritium, and monthly composites are analyzed for gross beta activity. The annual average concentrations of tritium and gross beta in treated water are shown in Tables 5.6.1-1 and 5.6.1-2 and are illustrated on Figures 5.6.1-1 and 5.6.1-2.

Table 5.6.1-1: Area Drinking Water Tritium Levels (Bq/L)

Drinking Water Supply Plant	2001	2002	2003	2004	2005	2006	2007	2008	2009
Kincardine	6.3	5.7	5.0	5.4	6.4	6.4	7.3	3.6	6.1
Port Elgin	7.3	10.2	11.7	11.7	12.5	17.4	16.8	7.1	n/a
Southampton	6.9	8.8	8.9	8.4	9.8	12.0	14.4	6.4	8.8

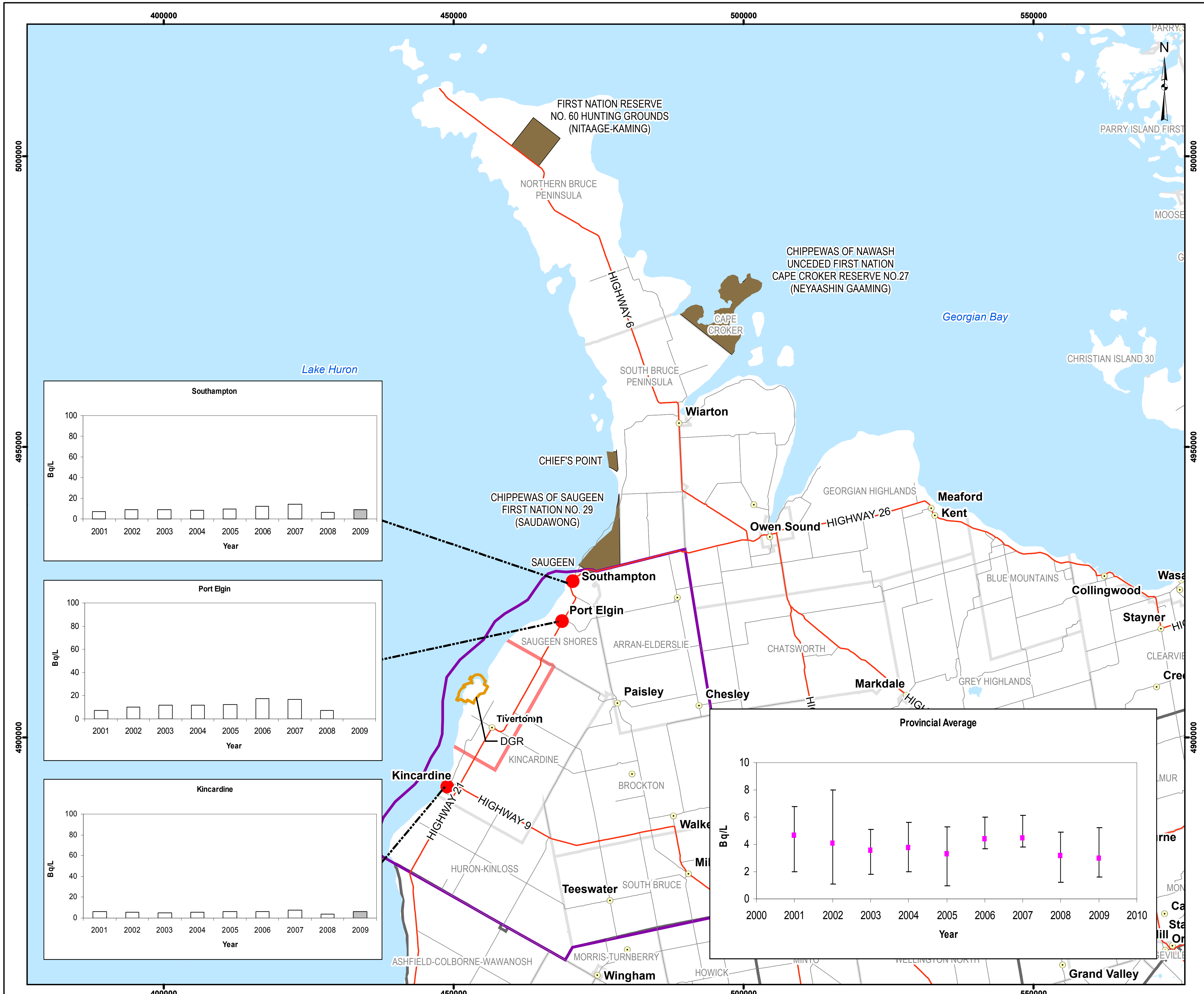
Note:
n/a Not applicable. The Port Elgin water supply plant was taken out of service in 2008; Port Elgin is now supplied by the Southampton water supply plant.
Source: [10;11;12;13;14;15;16;17;18]

Table 5.6.1-2: Area Drinking Water Gross Beta Levels (Bq/L)

Drinking Water Supply Plant	2001	2002	2003	2004	2005	2006	2007	2008	2009
Kincardine	0.08	0.07	0.07	0.07	0.07	0.08	0.07	0.08	0.07
Port Elgin	0.08	0.07	0.07	0.06	0.07	0.08	0.07	0.07	n/a
Southampton	0.09	0.08	0.08	0.07	0.08	0.08	0.07	0.08	0.07

Note:
n/a Not applicable. The Port Elgin water supply plant was taken out of service in 2008; Port Elgin is now supplied by the Southampton water supply plant.
Source: [10;11;12;13;14;15;16;17;18]

During 2009, the average concentration of tritium in water from the water supply plants ranged from 6.1 Bq/L in Kincardine to 8.8 Bq/L in Southampton, which was higher than the tritium concentration measured at provincial monitoring locations (averaged at 3.0 Bq/L) but well below the Maximum Acceptable Concentration (MAC) for tritium in drinking water (7,000 Bq/L) listed in the ODWQS (see Tables 5.6.1-3). This value is also below 20 Bq/L, which was recently recommended by the ODWAC as a revised limit for tritium concentrations in drinking water [47], but has not been accepted by the Ontario Ministry of the Environment at the time of writing. During the same year, the average concentrations of gross beta radioactivity in water from the water supply plants are 0.07 Bq/L in both Kincardine and Southampton. The 2009 gross beta concentrations at the Southampton and Kincardine water supply plants in the Regional Study Area were similar to the provincial average value of 0.05 Bq/L at sample locations across the province, as shown in Table 5.6.1-4 [18]. Over the last nine years, the gross beta levels have remained relatively constant and are essentially at the same level as the provincial background level. Gross beta activities in the range of 0.005 to 0.2 Bq/L in drinking water are normal and result from naturally occurring radionuclides and fallout from atmospheric nuclear weapons tests [18].



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PROJECT
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TITLE
ANNUAL AVERAGE TRITIUM LEVELS IN DRINKING WATER IN THE REGIONAL STUDY AREA

Golder Associates
Mississauga, Ontario

PROJECT No.06-1112-037			SCALE: AS SHOWN	R000
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FIGURE 5.6.1-1

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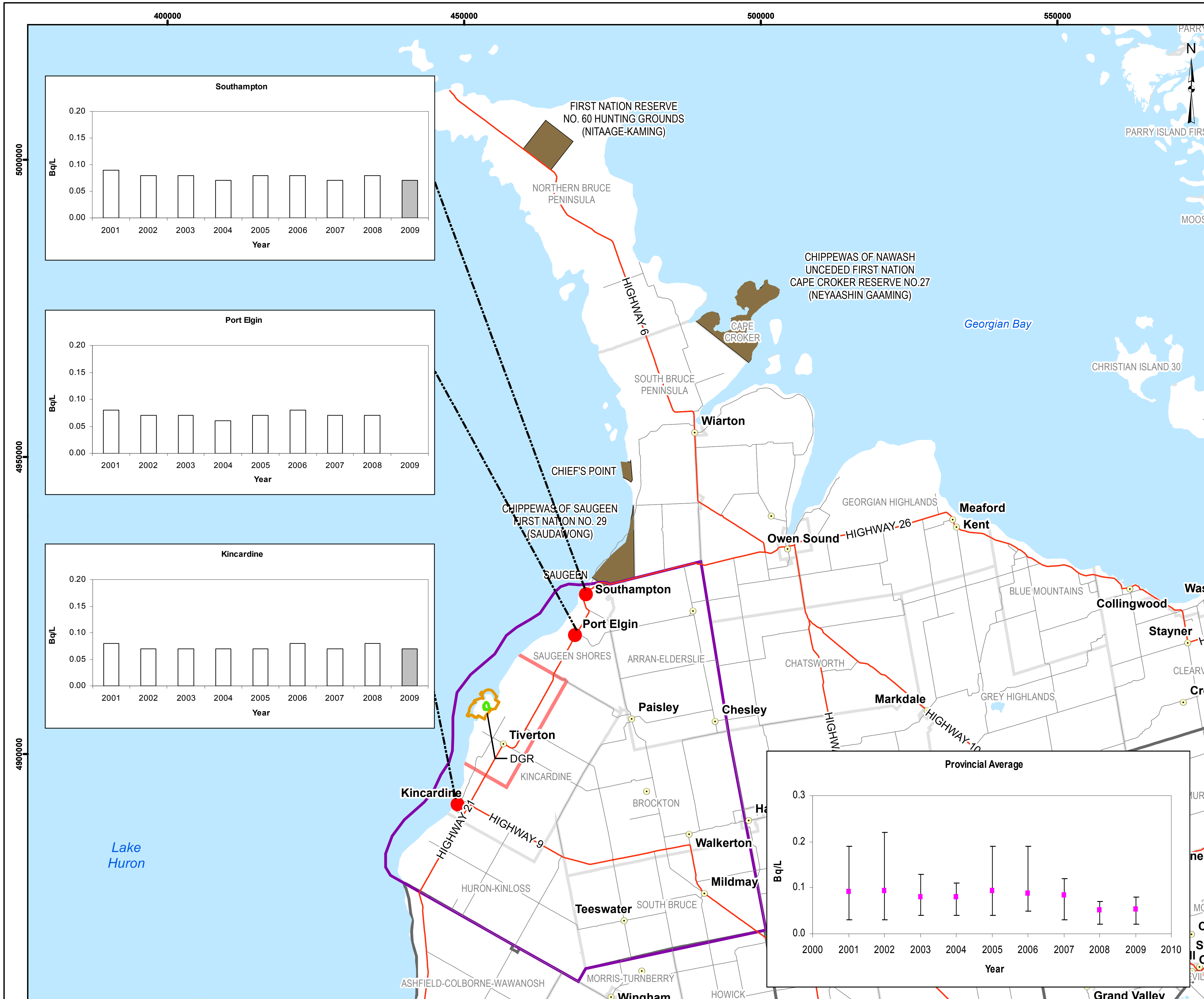

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FIGURE 5.6.1-2

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Table 5.6.1-3: Annual Average Tritium Levels in Drinking Water - Provincial Sites (Bq/L)

Provincial Sites	2001	2002	2003	2004	2005	2006	2007	2008	2009
Bancroft	2.0	2.7	2.1	3.5	2.9	<3.7	4.0	2.8	1.6
Belleville	3.8	2.9	2.9	3.3	2.2	4.2	5.9	3.6	2.4
Brockville	5.8	5.0	4.2	4.8	3.7	4.6	3.9	4.5	4.0
Coburg	6.3	8.0	5.1	4.8	4.1	5.3	5.6	4.9	3.7
Burlington	5.7	6.9	4.4	4.6	4.4	6.0	5.1	4.6	5.2
London	6.7	4.5	4.0	5.6	5.3	3.7	6.1	4.0	2.9
St. Catherines	4.3	3.8	2.9	3.7	2.5	3.7	<3.8	2.5	2.4
North Bay	2.8	2.3	3.0	2.4	1.6	<3.7	5.1	1.6	1.7
Orangeville	3.3	2.2	2.9	2.0	1.7	<3.7	<3.8	1.5	2.3
Goderich	6.5	5.1	3.0	5.1	4.8	5.2	5.0	3.4	4.0
Parry Sound	4.6	3.5	3.5	3.9	3.7	<3.7	4.4	3.6	2.8
Kingston	6.8	4.9	4.5	4.0	3.6	4.6	<3.8	3.8	4.5
Sudbury	2.4	2.6	3.3	2.0	2.4	5.8	<3.8	1.8	1.7
Thunder Bay	2.1	1.1	1.8	2.7	1.0	<3.7	<3.8	1.2	1.7
Niagara Falls	5.4	4.1	4.0	3.5	3.0	4.1	4.1	2.9	2.4
Sarnia	5.1	5.0	5.0	4.7	4.7	4.0	4.1	3.5	3.9
Windsor	5.7	4.3	4.0	3.1	4.4	5.2	<3.8	3.0	3.2

Source: [10;11;12;13;14;15;16;17;18]

Table 5.6.1-4: Annual Average Gross Beta Levels in Drinking Water – Provincial Sites (Bq/L)

Provincial Sites	2001	2002	2003	2004	2005	2006	2007	2008	2009
Bancroft	0.03	0.06	0.07	0.05	0.19	0.05	0.06	0.03	0.03
Belleville	0.07	0.08	0.09	0.10	0.08	0.07	0.09	0.06	0.05
Brockville	0.09	0.11	0.10	0.10	0.10	0.11	0.11	0.06	0.07
Coburg	0.12	0.16	0.09	0.10	0.16	0.11	0.12	0.07	0.07
Burlington	0.13	0.12	0.09	0.11	0.11	0.11	0.11	0.06	0.06
London	0.08	0.08	0.07	0.08	0.08	0.07	0.08	0.05	0.05
St. Catherines	0.09	0.09	0.09	0.08	0.09	0.09	0.10	0.06	0.06
North Bay	0.07	0.06	0.07	0.06	0.07	0.07	0.08	0.04	0.04
Orangeville	0.10	0.03	0.04	0.09	0.11	0.08	0.09	0.06	0.08
Goderich	0.08	0.22	0.08	0.09	0.08	0.19	0.08	0.06	0.05
Parry Sound	0.06	0.05	0.05	0.05	0.06	0.07	0.05	0.04	0.04
Kingston	0.10	0.09	0.10	0.10	0.11	0.10	0.10	0.06	0.06

Table 5.6.1-4: Annual Average Gross Beta Levels in Drinking Water – Provincial Sites (Bq/L) (continued)

Provincial Sites	2001	2002	2003	2004	2005	2006	2007	2008	2009
Sudbury	0.05	0.04	0.06	0.04	0.04	0.05	0.03	0.02	0.02
Thunder Bay	0.04	0.10	—	0.06	0.05	0.05	0.07	0.03	0.04
Niagara Falls	0.10	0.11	0.08	0.09	0.10	0.11	0.10	0.06	0.06
Sarnia	0.16	0.09	0.06	0.07	0.08	0.08	0.08	0.05	0.06
Windsor	0.19	0.09	0.13	0.07	0.07	0.09	0.07	0.06	0.05

Note:
— No measurement taken
Source: [10;11;12;13;14;15;16;17;18]

Within the Site Study Area, surface water samples were collected from two monitoring locations, Stream C and BEC (renamed to Bruce Eco-Industrial Park) steam condensate. The monitoring results for the period of 2001 to 2009 are summarized in Tables 5.6.1-5 and 5.6.1-6. The annual average tritium concentrations in 2009 ranged from 12.5 to 152.5 Bq/L, which is above the provincial background location average tritium concentrations of 3.0 Bq/L but well below the ODWQS of 7,000 Bq/L. The annual average gross beta concentration in water samples collected in these two locations is 0.16 Bq/L at Stream C and less than Method Detection Limit (MDL) at BEC steam condensate. The concentration at Stream C is higher than concentrations measured at the provincial background locations.

Table 5.6.1-5: Tritium Levels in Surface Water (Bq/L)

Site Study Area	2001	2002	2003	2004	2005	2006	2007	2008	2009
BEC Steam Condensate	12.1	12.6	20.7	16.8	17.1	20.7	23.3	29.8	12.5
Stream C (inside Bruce nuclear site boundary)	128.2	99.1	109.1	101.1	100.8	101.0	108.2	148.9	152.5

Source: [10;11;12;13;14;15;16;17;18]

Table 5.6.1-6: Gross Beta Levels in Surface Water (Bq/L)

Site Study Area	2001	2002	2003	2004	2005	2006	2007	2008	2009
BEC Steam Condensate	0.01	0.01	0.01	<4.8	<4.9	0.01	0.01	0.01	Ld
Stream C (inside Bruce nuclear site boundary)	0.18	0.17	0.20	0.16	0.14	0.13	0.13	0.18	0.16

Note: Ld = Lower than method detection limit
Source: [10;11;12;13;14;15;16;17;18]

An integrated EA follow-up monitoring program has been completed at the WWMF, which provides data for the Site Study Area. Radioactivity in surface water samples was monitored as part of the monitoring program [49]. Tritium activities ranged from <18.5 to 37 Bq/L at the control sites and from 289 to 1,850 Bq/L at the WWMF sites. Tritium levels at the WWMF sites are at least 3.7-fold lower than the ODWQS of 7,000 Bq/L [46], but are still much higher than those observed at the control sites.

5.6.2 Other Radionuclides in Surface Water

The concentrations of cesium-137, cesium-134 and potassium-40 (naturally occurring) were measured in grab samples of water taken from Lake Huron in the vicinity of Bruce nuclear site beginning in 1991. It was reported that the concentrations of cesium-137 and cesium-134 in Regional Study Area and background samples are all less than the MDL of 0.001 to 0.002 Bq/L and therefore such measurements ended in 2000 [50]. The concentrations of potassium-40 in water samples are within the expected range [50].

In the Project Area, surface water samples collected from the railway ditches were also monitored for other radionuclides including cobalt-60, cesium-134, cesium-137, potassium-40, strontium-90, iodine-129, technetium-99 and chlorine-36. It was reported that concentrations of these radionuclides in water samples were all less than corresponding MDLs [19]. However, it was found that carbon-14 concentrations in water samples from the North and South Railway Ditches and from the Little Sauble River (Local Study Area) were slightly above the MDL (0.1 Bq/kg).

5.7 RADIOACTIVITY IN THE AQUATIC ENVIRONMENT

This section presents the results of measurements of radioactivity in sediments and fish in Lake Huron, shoreline gamma scans in the vicinity of Bruce A and B, and a discussion of radiation doses to aquatic biota.

5.7.1 Radioactivity in Sediments

Sediment samples are collected annually by Bruce Power from Lake Huron in the Regional and Local Study Areas. Sediment samples are analyzed for radionuclides including cesium-137, cesium-134, cobalt-60 and potassium-40 and the results are expressed as Becquerels per kilogram (Bq/kg) of dry sediment.

The major portion of the activity in the sediments is attributable to the existence of potassium-40, a naturally occurring radionuclide. In the Regional Study Area, potassium-40 concentrations in sediment samples collected near Southampton in 2009 ranged from 246.6 to 250.5 Bq/kg [18]. In the Local Study Area, concentrations ranged from 276.1 (Inverhuron) to 590 Bq/kg (Scott Point).

Cesium-137, a product of both global fallout and reactor operation, was detected in all sediment samples. For sediment samples collected in the Regional Study Area (Southampton), the concentration of cesium-137 was in the range of 0.21 to 0.23 Bq/kg in 2009. The corresponding values for samples from the Local Study Area ranged from 0.19 Bq/kg at Scott Point to 8.90 Bq/kg at Baie du Doré [18].

Cobalt-60 and cesium-134 are mainly present in the environment because of reactor operation. Cobalt-60 was detected in all lake bottom sediment samples collected in the Bruce A and Bruce B discharge channels (Site Study Area) in 2009, ranging from 0.50 to 0.76 Bq/kg. For sediment samples collected from the locations in the Local Study Area, cobalt-60 was in the range of less than 0.20 Bq/kg to 0.85 Bq/kg. Concentrations of cobalt-60 in samples collected in the Regional Study Area were all below the detection limit. In 2009, the concentrations of cesium-134 in all sediment samples collected from all locations were below the MDL [18].

As part of an integrated EA follow-up monitoring program implemented at the WWMF [49], radioactivity in sediments in the Project Area was measured during the period from 2000 to 2004. The sediment samples were collected from the North and South Railway Ditches using a Ponar Dredge and/or shovel. Each sediment sample consisted of 1 kg of materials for the radionuclide analysis. Sediment samples collected from all WWMF ditch sites and control sites had concentrations of cesium-134 below the MDL. The mean sediment concentrations of cesium-137 ranged from <1.1 to 25.5 Bq/kg. The maximum sediment concentration of cesium-137 (27 Bq/kg) is lower than that reported for the pre-construction phase (37 Bq/kg). For gross comparative purposes, the maximum concentration of cesium-137 is considerably lower than the guideline value of 450 Bq/kg suggested by the United States' National Council on Radiation Protection and Measurement (NCRP) for contaminated soil [51]. The highest tritium activity in sediment was measured to be 2,368 Bq/kg at one location in the South Railway Ditch. This compares to a concentration of less than 18.5 Bq/kg at the Goderich control site, and below 600 Bq/kg at all other sampling sites. It should be noted that there is no NCRP suggested guideline level for sediment contamination.

5.7.2 Shoreline Gamma Survey

In the fall of 2000, a ground gamma survey was carried out along a 15 km stretch of shoreline from Inverhuron Provincial Park, south of Bruce B, to Scott Point, north of the Bruce nuclear site [44]. Cobalt-60 was not detected during the scans. The highest cesium-137 activity, of around 50 Bq/kg, was found on the Bruce nuclear site shoreline in the area of Bruce A and Baie du Doré [50].

A follow-up survey was conducted by Bruce Power in 2002. Three samples from Baie du Doré had cesium-137 activities of approximately 50 Bq/kg. Cobalt-60 was present in the samples at a low level (<4 Bq/kg). These results confirmed that past emissions from the Bruce nuclear site have contributed to observed levels as cobalt-60 is not a product of global fallout and is not naturally occurring [10].

5.7.3 Radioactivity in Fish

The fish living in Lake Huron are potentially exposed to radioactive emissions to water from operations at the Bruce nuclear site. Samples of fish are collected annually by Bruce Power from Lake Huron adjacent to the Bruce nuclear site (i.e., Baie du Doré) and from the background sampling locations (the opposite side of Lake Huron). The fish target species are white sucker (*Catostomus commersoni*) with brown bullhead (*Ameiurus nebulosus)* as the backup species, and lake whitefish (*Coregonus clupeaformis)*, with round whitefish (*Prosopium cylindraceum)* as the backup species. Throughout the period 2001 to 2009, fish were caught and analyzed for carbon-14, gamma emitters (e.g., cesium-137, cesium-134 and potassium-40) and tritium, including tritiated water (HTO) and organically bound tritium (OBT).

The major portion of the activity in fish is naturally occurring potassium-40 and carbon-14. In 2009, the potassium-40 concentrations ranged from 125 to 146 Bq/kg, consistent with the range measured in other years. In the same year, the concentration of carbon-14 was found at levels above the provincial background (in the range of 225 to 270 Bq/kg-C) in all fish caught in the immediate vicinity of the Bruce nuclear site [18]. The data for the past seven years (from 2003 to 2009) indicate a decreasing trend in carbon-14 concentrations. This parallels the waterborne emissions trend, which indicates a decrease in waterborne carbon-14 emissions of approximately 50% from 2002 levels.

Low concentrations of cesium-137 are usually present as a result of global fallout and reactor operation. During 2009, cesium-137 was detected in all fish caught in the immediate vicinity of the Bruce nuclear site. The concentrations ranged from 0.18 to 0.43 Bq/kg, similar to the background sampling conducted at provincial sites [18]. The overall decreasing trend is likely due to the declining levels of radioisotopes from historical weapons testing [18].

Tritium (as Tissue-Free Water Tritium, TFWT) levels measured in fish taken from the immediate vicinity of the Bruce nuclear site were reported in the range of 7.6 to 30.5 Bq/L (water). The average tritium concentration in fish showed an increasing trend from 2003 to 2006, which parallels the increase in waterborne tritium emissions from the Bruce nuclear site. The trend has been decreasing since 2006. Although 2009 data shows an increase in tritium in fish as a result of waterborne emissions released during 2009, a decrease of approximately 45% has occurred since 2006 [18].

In 2009, OBT measurements were carried out on fish samples collected from the immediate vicinity of the Bruce nuclear site. The OBT in whitefish and sucker samples are 9.6 and 10.5 Bq/L, respectively, showing a decreasing trend since 2006. This is consistent with the measurement results of TFWT in fish samples.

The presence of cesium-134 and cobalt-60, which are indicative of reactor operation, was not detected in any fish samples taken from the Local Study Area, or from the fish samples taken from the background areas.

In 2002, some samples were collected from fish caught in the Bruce B forebay (Site Study Area). Radionuclide concentrations in those samples were dominated by activity because of potassium-40 and carbon-14, which ranged from 103 to 147 Bq/kg and 250 to 412 Bq/kg-C, respectively. Similar to the fish samples collected from Baie du Doré (within the Site Study Area), the cesium-137 concentrations in all fish caught in the Bruce B forebay were above the detection limit; however, cesium-134 and cobalt-60 were not detected in any of the fish samples [48].

In addition, a diet survey of the Chippewas of Nawash Unceded First Nation (Neyaashiinigmiing, at Cape Croker ON, on Georgian Bay, approximately 80 km to the northeast of the Bruce nuclear site) was also conducted in November 2000 and June 2002 [50]. It was found that fish caught in Georgian Bay had:

- carbon-14 concentrations close to the Ontario background of 240 to 250 Bq/kg-C (258 and 259 Bq/kg-C for whitefish and lake trout, respectively);
- low cesium-137 levels (1.5 and 2.0 Bq/kg for whitefish and lake trout, respectively);
- low strontium-90 levels (14% of whitefish sampled had detectable levels of strontium-90, while none of the lake trout sampled had detectable levels of strontium-90); and
- tritium levels lower than those at provincial background locations (4.1 and 3.5 Bq/L for whitefish and lake trout, respectively).

The dose to the persons who ate the most locally caught fish was calculated to be 1.5 µSv/a, less than 0.2% of the dose limit to members of the public.

5.7.4 Radiation Doses to Aquatic Biota

Radioactive releases to water may result in a measurable dose to aquatic biota. Currently, there are no internationally agreed criteria that explicitly address protection of aquatic biota from ionizing radiation, although many international agreements and statutes call for protection against pollution, including radiation [52]. At present, there are various benchmarks available in the literature, typically in the range of 0.6 to 10 mGy/day [53;54].

A series of calculations were carried out to estimate the doses to aquatic biota in the vicinity of the Bruce nuclear site under existing conditions. A variety of ecological receptors were used in the assessment, including the aquatic environment VECs identified for the DGR Project. Detailed descriptions of the methodology used to estimate radiation doses in this work and calculation results are provided in Section 8 and Appendix C.

5.8 RADIOACTIVITY IN THE TERRESTRIAL ENVIRONMENT

Airborne and waterborne emissions may result in a measurable change to the terrestrial environment. This section summarizes the baseline levels of radioactivity in vegetation, milk and radiation from soil. It also discusses radiation doses to terrestrial biota under existing conditions.

5.8.1 Vegetation

Bruce Power collects samples of garden vegetables and agricultural plants in the vicinity of the Bruce nuclear site on an annual basis. The vegetation collected includes apples, leafy vegetables, above-ground vegetables, root vegetables, tomatoes, soy beans, and corn among others. For comparison, fruit and vegetable samples are collected at a variety of provincial background locations. The samples are analyzed for carbon-14 and tritium in water in the plant material, which is distinguished from organically bound tritium that has been incorporated into the organic component of plant tissues.

For grain samples, the concentrations of tissue-free water tritium in samples collected during 2009 ranged from 18.1 to 123.8 Bq/L in soy beans [18]. The concentrations of carbon-14 in grains were in the range of 205 to 240 Bq/kg-C.

For apples, Figures 5.8.1-1 and 5.8.1-2 present the tritium and carbon-14 values measured in samples collected in some monitoring locations for 2001 through 2009. The results are also summarized in Tables 5.8.1-1 and 5.8.1-2.

The results of routine monitoring of tritium and carbon-14 in vegetation show that, in general, the tissue-free water tritium and carbon-14 concentrations in vegetation decrease with distance from the Bruce nuclear site. The concentrations of tritium and carbon-14 in vegetation also vary with direction. This is expected since the concentration of tritium and carbon-14 in vegetation is directly related to the concentration of tritium and carbon-14 in air.

The HTO activity in vegetation has shown an increasing trend, and can be attributed to an increase in emissions resulting from the restart of Bruce A Units 3 and 4. The carbon-14 activity in vegetation has shown a decreasing trend in the last five years (from 2005 to 2009). The return to service of the oxygen addition system to the moderator cover gas system at Bruce B in

2008 resulted in a decrease in moderator cover gas purging, and therefore resulted in a reduction of carbon-14 emissions.

Within the Site Study Area, four replicated terrestrial vegetation samples were collected at two locations during a 2000 monitoring program. It was reported that the concentrations of cesium-137, cesium-134 and cobalt-60 in vegetation samples were all below detection limits. The levels of naturally-occurring potassium-40 in the vegetation samples were detectable, with a maximum concentration of 350 Bq/kg measured at one of the locations within the Site Study Area. However, the same concentration (350 Bq/kg) was also measured at the control location [48].

Table 5.8.1-1: Tritium Concentrations in Apples in the Local Study Area (Bq/L)

Monitoring Location [a]	2001	2002	2003	2004	2005	2006	2007	2008	2009
BG1	56.8	48.0	96.4	72.9	94.8	84.4	97.5	164.6	214.4
BG 3	45.1	35.9	82.5	44.6	49.7	63.2	58.7	151	131.4
BG 4	41.8	18.2	34.3	23.7	34.1	39.6	37.1	—	45.2
BG 5	26.9	17.3	35.2	21.6	33.3	25.5	36.0	—	41.1
BG 7	24.1	24.1	33.5	31.3	30.5	34.1	41.5	49	42.3
BG 10	44.3	39.5	61.1	48.6	83.0	122.7	75.8	95	99.8
BG 16	35.2	29.4	54.3	38.9	45.3	47.3	49.6	75.7	66.3

Notes:
a Locations are shown on Figure 5.8.1-1
— No measurement taken
Source: [10;11;12;13;14;15;16;17;18]

Table 5.8.1-2: Carbon-14 Concentrations in Apples in the Local Study Area (Bq/kg-C)

Monitoring Location [a]	2001	2002	2003	2004	2005	2006	2007	2008	2009
BG1	246	256	246	246	409	351	279	259	283
BG 3	255	234	227	223	291	299	266	287	262
BG 4	242	232	227	223	285	281	251	—	238
BG 5	247	243	235	228	347	280	246	—	263
BG 7	256	224	224	258	254	287	261	254	244
BG 10	239	241	252	258	331	355	341	264	267
BG 16	249	244	246	243	313	332	280	267	252

Notes:
a Locations are shown on Figure 5.8.1-2
— No measurement taken
Source: [10;11;12;13;14;15;16;17;18]

5.8.2 Milk

Airborne emissions from nuclear facilities at the Bruce nuclear site may affect the concentrations of radionuclides in animal products (e.g., milk, egg, meat, honey). This represents a potential internal pathway for human exposure. In the following section, milk is used as an example to illustrate the activities of radionuclides in animal products.

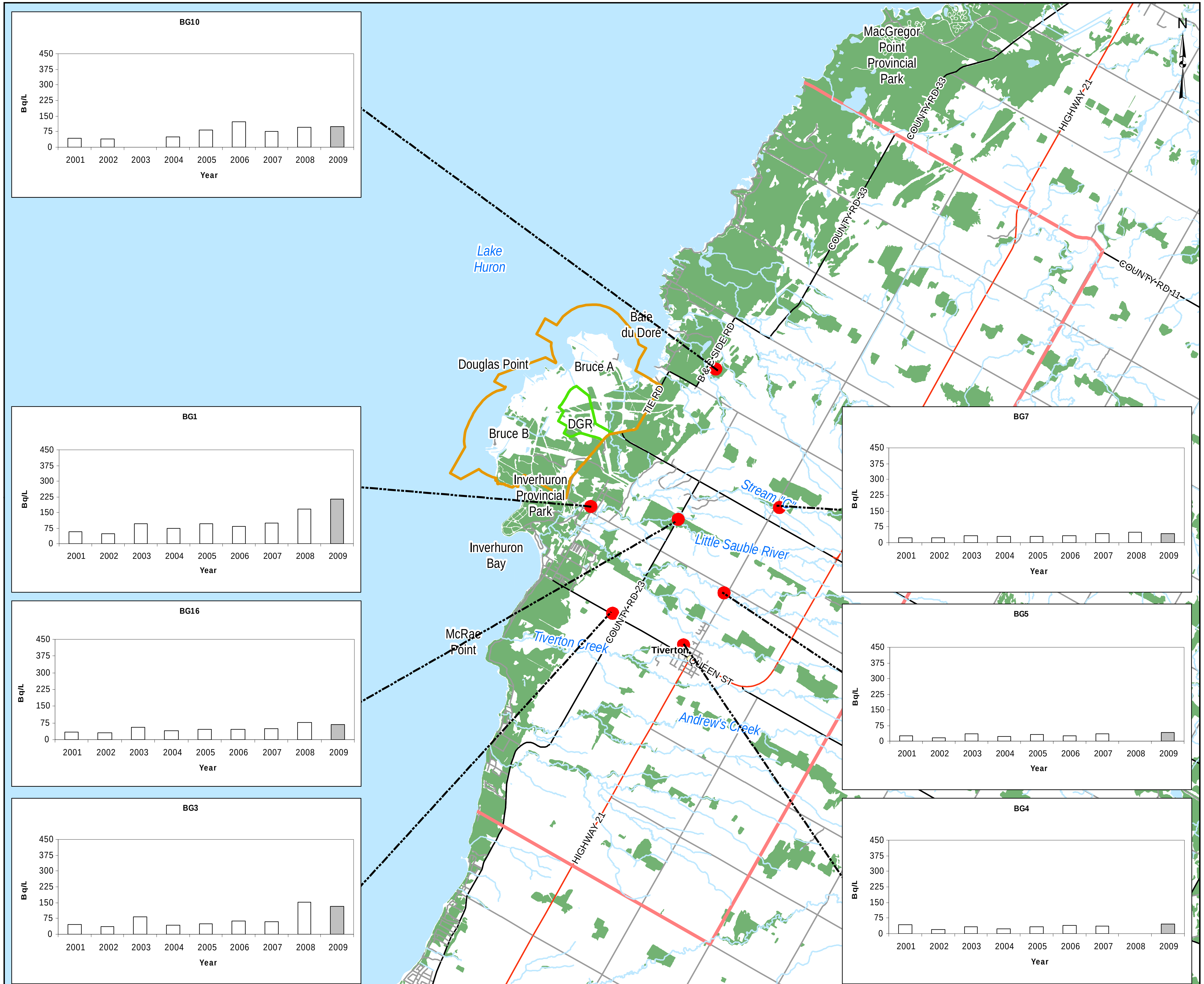
Bruce Power collects milk samples weekly from dairy farms within the Local and Regional Study Areas. Weekly samples from each farm are composited into monthly samples, and are analyzed for tritium, carbon-14 and iodine-131. Other radionuclide emissions to air are not monitored because they are not considered to be significant contributors to exposures to humans and biota. The approximate locations of monitoring sites, as well as the respective tritium and carbon-14 levels, in the Local/Regional Study Area for milk are shown on Figures 5.8.2-1 and 5.8.2-2. For comparison, milk samples are also collected from more distant farms in Belleville and London, Ontario. The monitoring results for the period of 2001 to 2009 are summarized in Tables 5.8.2-1 and 5.8.2-2.

During 2009, the tritium concentrations in milk were reported to range from 7.9 to 13.9 Bq/L [18], depending upon the distance and direction from the Bruce nuclear site. The average tritium concentration in milk in the vicinity of the Bruce nuclear site has increased since 2005, approaching 11 Bq/L in 2009. Meanwhile, the carbon-14 concentrations in milk were 237 Bq/kg-C at two monitoring locations in 2009 [18]. Carbon-14 concentrations in milk have decreased from over 300 Bq/kg-C in 1991 to natural background levels of 240 to 250 Bq/kg-C in recent years. Variations between levels measured at provincial background locations and locations near the Bruce nuclear site show a variance that is statistically insignificant. Iodine-131 was detected at a concentration of less than 0.2 Bq/L in milk samples from the Bruce Power sampling locations in 2009, similar to the results from the provincial background sites [18].

Table 5.8.2-1: Tritium Concentrations in Milk (Bq/L)

Monitoring Location [a]	2001	2002	2003	2004	2005	2006	2007	2008	2009
Local/Regional Study Area									
BDF9	6.5	5.3	6.8	4.8	9.8	8.4	7.3	8.8	7.9
BDF1	4.7	5.1	4.3	7.0	7.5	8.7	7.6	9.2	13.9
BDF11	5.9	4.5	6.5	5.7	7.3	8.2	—	—	—
Provincial Locations									
Belleville	3.2	4.1	4.0	4.3	3.1	<3.7	4.7	3.0	3.9
London	0.4	1.8	0.6	1.9	0.5	<3.7	<4.5	1.0	<3.3-4.5

Notes:
a Sample locations are shown on Figure 5.8.2-1
— No measurement taken (the production of milk at this location ceased after 2006)
Source: [10;11;12;13;14;15;16;17;18]



LEGEND

- Monitoring Locations
- Site Study Area [1]
- Project Area (OPG-retained lands that encompass the DGR Project)
- Local Study Area

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007.
Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m, [10;11;12;13;14;15;16;17;18]
Datum: NAD 83 Projection: UTM Zone 17N

0 0.5 1 2 3 4 5
Kilometres

PROJECT
RADIATION AND RADIOACTIVITY TECHNICAL SUPPORT DOCUMENT

TITLE
ANNUAL TRITIUM CONCENTRATIONS IN APPLES IN THE LOCAL STUDY AREA

Golder Associates
Mississauga, Ontario

PROJECT No.06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	03 Aug. 2006		
GIS	BC	15 Apr. 2010		
CHECK	AB	15 Apr. 2010		
REVIEW	MAR	15 Apr. 2010		

FIGURE 5.8.1-1

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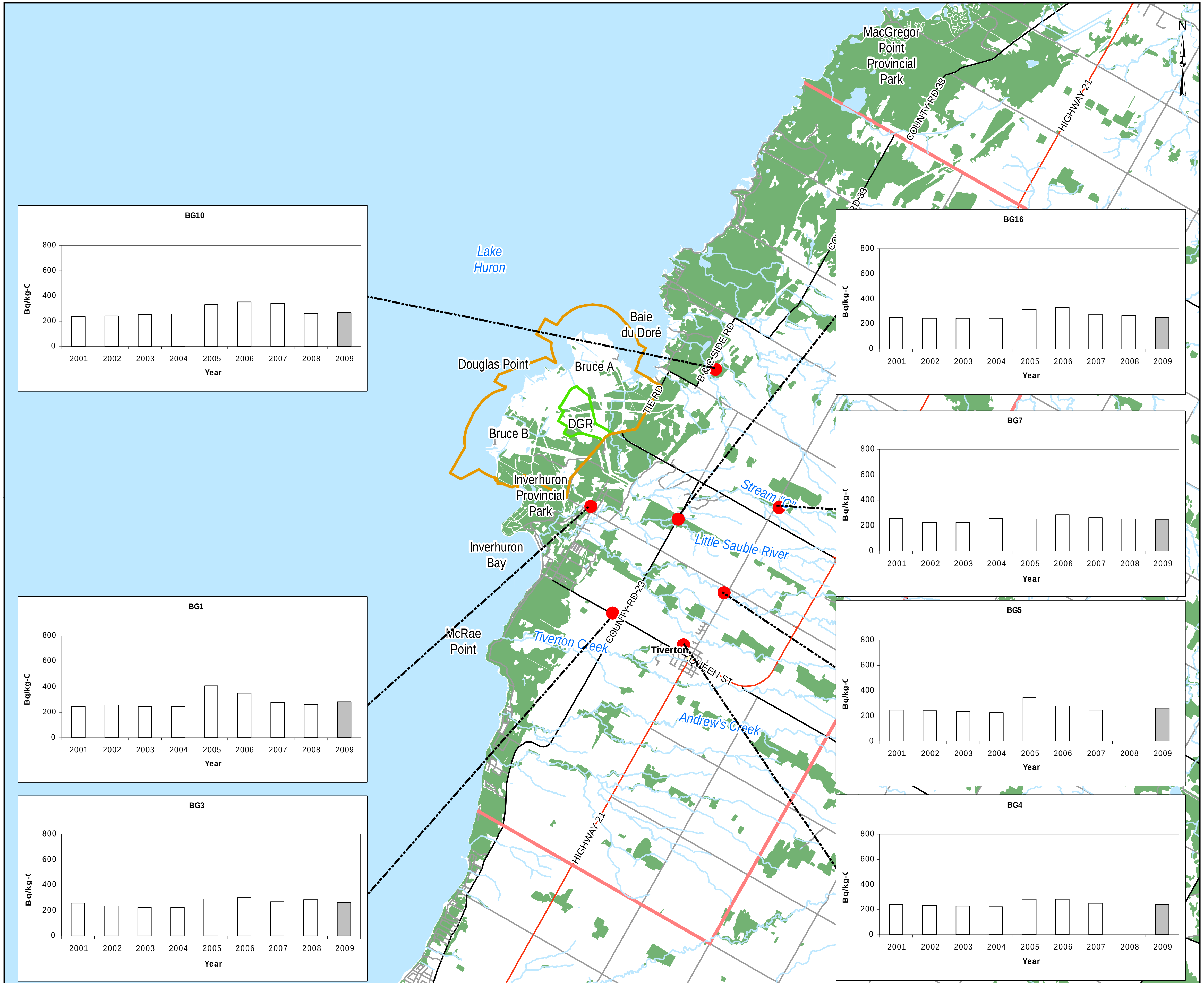

LEGEND

- Monitoring Locations
- Site Study Area [1]
- Project Area (OPG-retained lands that encompass the DGR Project)
- Local Study Area

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007.
Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m,
[10;11;12;13;14;15;16;17;18]
Datum: NAD 83 Projection: UTM Zone 17N

0 0.5 1 2 3 4 5
Kilometres

PROJECT

RADIATION AND RADIOACTIVITY TECHNICAL SUPPORT DOCUMENT

TITLE

ANNUAL CARBON-14 CONCENTRATIONS IN APPLES IN THE LOCAL STUDY AREA

Golder Associates
Mississauga, Ontario

PROJECT No.06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	03 Aug. 2006		
GIS	BC	15 Apr. 2010		
CHECK	AB	15 Apr. 2010		
REVIEW	MAR	15 Apr. 2010		

FIGURE 5.8.1-2

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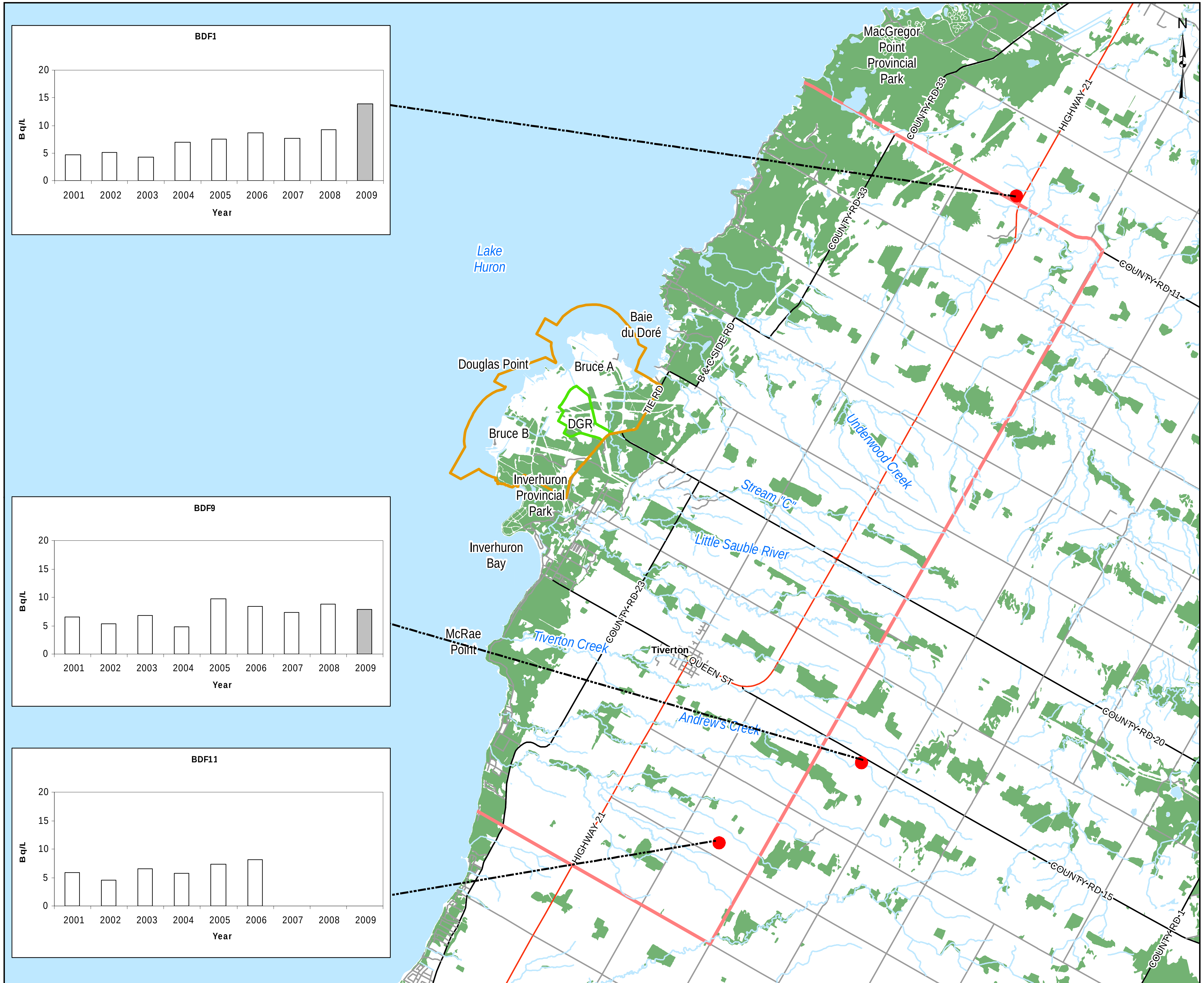

LEGEND

- Monitoring Locations
- Site Study Area [1]
- Project Area (OPG-retained lands that encompass the DGR Project)
- Local Study Area

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007.
Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m,
[10;11;12;13;14;15;16;17;18]
Datum: NAD 83 Projection: UTM Zone 17N

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Kilometres

PROJECT

RADIATION AND RADIOACTIVITY
TECHNICAL SUPPORT DOCUMENT

TITLE

ANNUAL AVERAGE TRITIUM LEVELS
IN MILK IN THE LOCAL/REGIONAL STUDY AREA

Golder Associates
Mississauga, Ontario

PROJECT No.06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	03 Aug. 2006	FIGURE 5.8.2-1	
GIS	BC	15 Apr. 2010		
CHECK	AB	15 Apr. 2010		
REVIEW	MAR	15 Apr. 2010		

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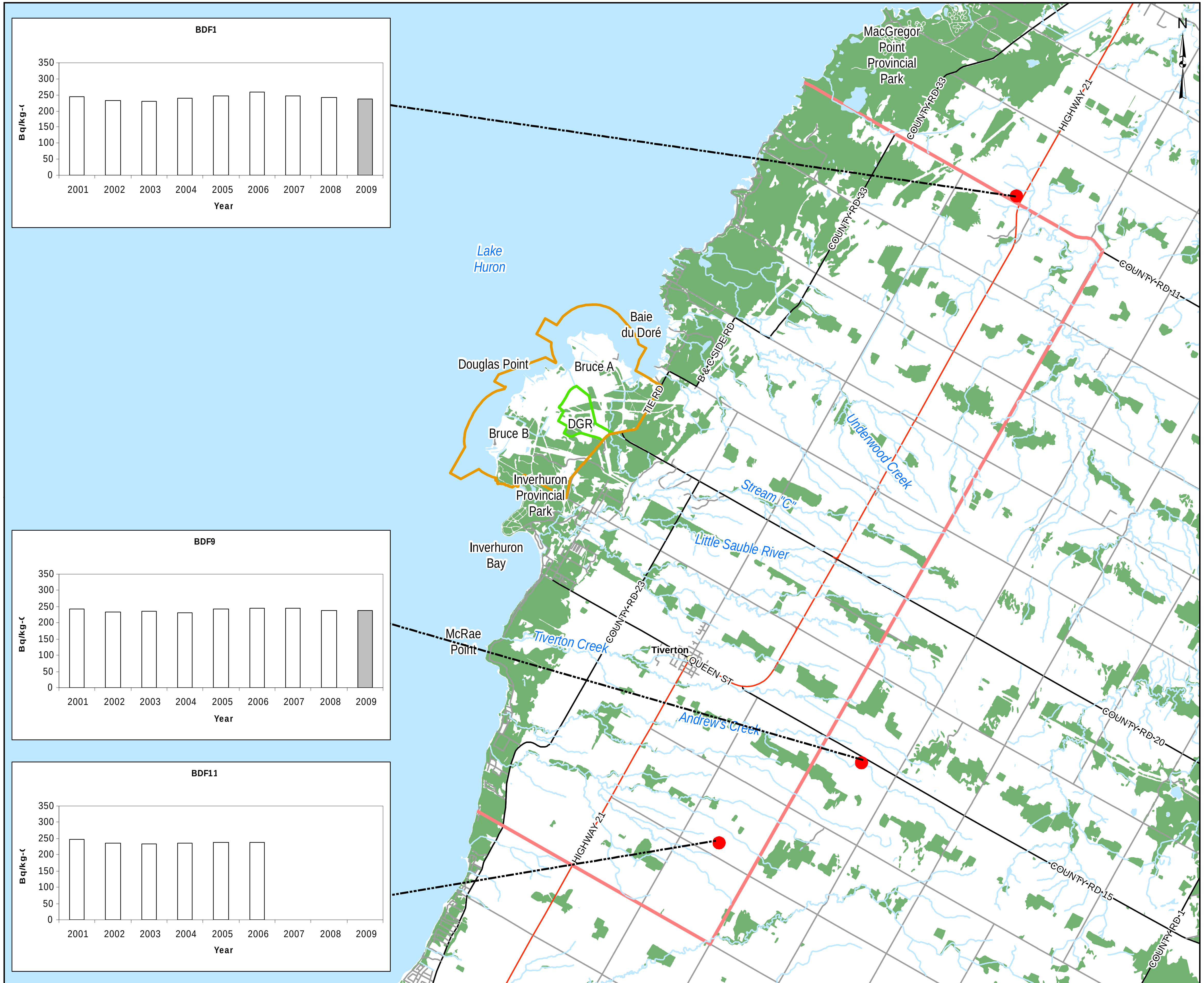

LEGEND

- Monitoring Locations
- Site Study Area [1]
- Project Area (OPG-retained lands that encompass the DGR Project)
- Local Study Area

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007.
Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m,
[10;11;12;13;14;15;16;17;18]
Datum: NAD 83 Projection: UTM Zone 17N

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Kilometres

PROJECT
RADIATION AND RADIOACTIVITY
TECHNICAL SUPPORT DOCUMENT

TITLE
ANNUAL AVERAGE CARBON-14 LEVELS
IN MILK IN THE LOCAL/REGIONAL STUDY AREA

Golder Associates
Mississauga, Ontario

PROJECT NO. 06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	03 Aug. 2006	FIGURE 5.8.2-2	
GIS	BC	15 Apr. 2010		
CHECK	AB	15 Apr. 2010		
REVIEW	MAR	15 Apr. 2010		

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Table 5.8.2-2: Carbon-14 Concentrations in Milk (Bq/kg-C)

Monitoring Location [a]	2001	2002	2003	2004	2005	2006	2007	2008	2009
Local/Regional Study Area									
BDF9	242	233	235	232	243	245	244	238	237
BDF1	244	232	230	240	246	260	247	241	237
BDF11	248	235	233	236	238	239	—	—	—
Provincial Locations									
Belleville	252	222	234	245	240	234	226	220	231
London	234	238	237	239	241	231	226	234	222

Notes:
a Sample locations are shown on Figure 5.8.2-2
— No measurement taken (the production of milk at this location ceased after 2006)
Source: [10;11;12;13;14;15;16;17;18]

5.8.3 External Gamma Radiation

Emissions of noble gases, radioactive particulate and iodine-131 from the Bruce nuclear site have the potential to contribute to external gamma radiation levels observed in the study areas. This section discusses the external gamma radiation by Thermoluminescent Dosimeter (TLD) measurements, a flyover gamma survey and a ground gamma survey of selected locations.

External gamma radiation doses are measured on a continuous basis in the Regional and Local Study Areas by Bruce Power. The TLDs used for these measurements are sensitive to gamma radiation from the surrounding soil and air, but not to cosmic radiation. The annual doses from external gamma radiation reported by Bruce Power are shown in Table 5.8.3-1, and are illustrated on Figures 5.8.3-1 and 5.8.3-2.

Table 5.8.3-1: Annual Average External Gamma Dose Rate in Air (nGy/h)

Monitoring Location	2001	2002	2003	2004	2005	2006	2007	2008	2009
Local Study Area									
B2	43.0	43.8	44.5	45.6	44.4	48.0	52.9	53.4	53.7
B3	40.1	40.6	42.6	45.2	42.8	40.7	49.7	51.1	50.6
B4	34.6	39.1	40.0	40.7	40.0	40.5	47.6	46.1	46.6
B5	35.2	34.3	35.0	38.7	36.7	38.2	45.7	44.1	44.0
B7	30.4	34.4	36.3	37.8	35.8	38.9	43.5	44.3	45.0
B10	45.5	48.3	49.0	53.0	48.0	50.5	57.7	59.3	63.6
B11	42.9	42.7	43.1	43.0	41.6	45.3	52.7	54.5	56.4

Table 5.8.3-1: Annual Average External Gamma Dose Rate in Air (nGy/h) (continued)

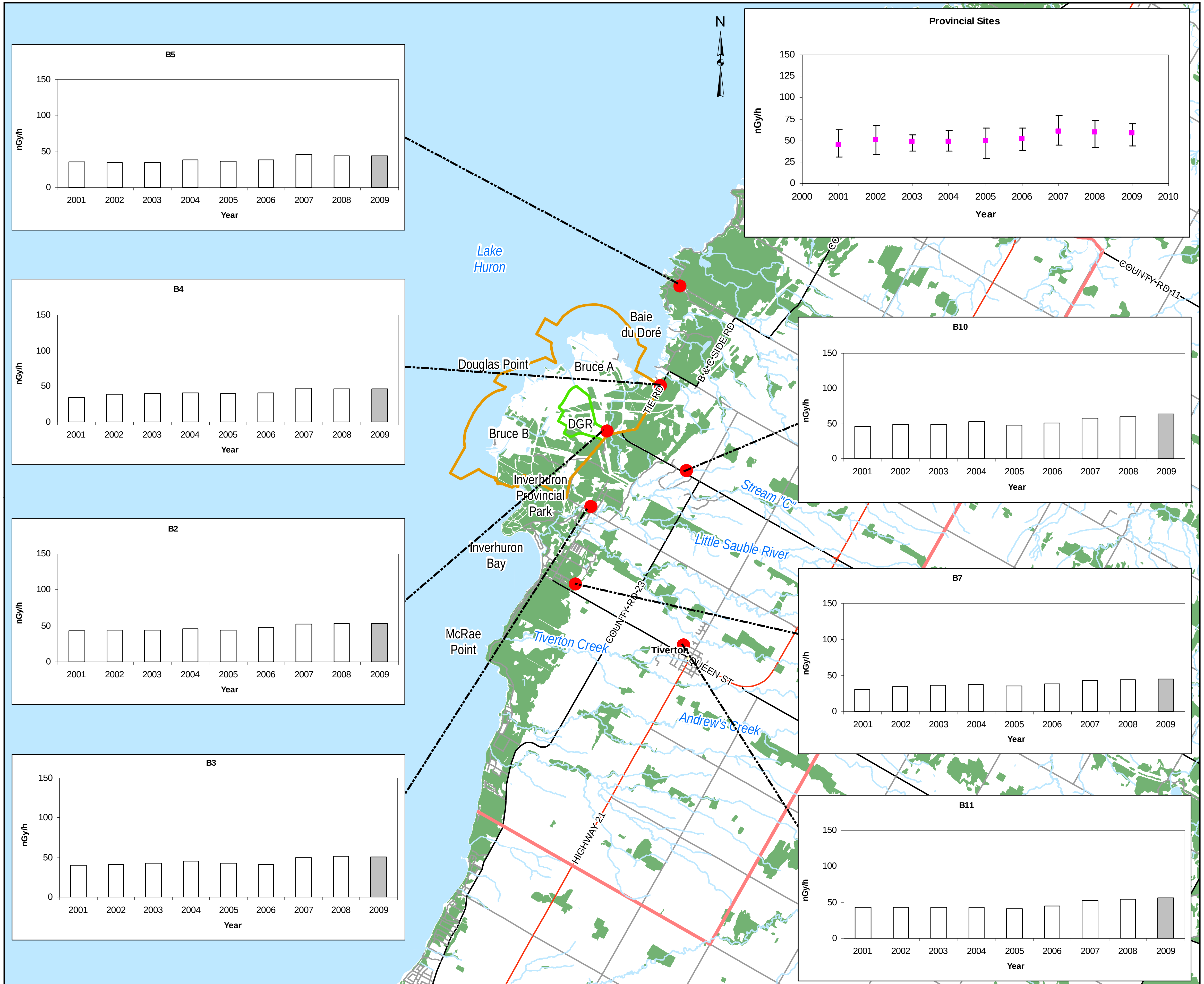
Monitoring Location	2001	2002	2003	2004	2005	2006	2007	2008	2009
Regional Study Area									
B6	35.9	36.7	37.4	38.7	35.3	37.3	44.6	45.8	45.6
B8	34.2	43.3	31.9	38.0	36.1	40.2	42.9	43.8	44.1
B9	41.4	36.5	41.7	39.7	36.8	38.8	42.9	45.2	44.8
Provincial Locations									
Bancroft	40.2	60.4	56.5	54.6	54.6	57.1	65.8	64.5	63.4
Belleville	47.6	48.8	50.9	55.0	52.1	56.32	66.6	59.0	44.8
Barrie	—	—	—	—	58.9	54.4	61.9	65.0	61.1
Lakefield	43.4	57.9	56.7	56.4	55.7	61.8	64.8	65.3	65.6
Windsor	37.5	51.9	40.8	41.7	42.0	44.9	52.9	71.1	69.1
Niagara Falls	37.7	33.9	38.0	37.8	34.9	39.1	45.0	63.1	65.7
North Bay	50.2	44.7	46.5	49.0	52.3	53.5	57.9	47.9	44.2
Ottawa	41.0	41.7	43.7	40.7	40.3	44.4	54.0	59.8	59.0
Parry Sound	30.4	44.7	38.1	45.7	29.1	39.0	51.7	49.4	53.0
Sudbury	52.9	50.2	55.9	45.7	59.0	51.4	61.5	74	52.7
Thunder Bay	62.9	67.5	55.5	61.1	64.7	64.8	79.1	41.4	61.8

Note:
— No measurement taken
Source: [10;11;12;13;14;15;16;17;18]

During 2009, the external gamma dose rates in the Regional Study Area ranged from 44.1 to 45.6 nanoGray per hour (nGy/h) and 44.0 to 63.6 nGy/h in the Local Study Area. The results are within the range of dose rates observed at sites across Ontario (44.2 to 69.1 nGy/h), suggesting that air emissions from the Bruce nuclear site are not contributing to higher than normal gamma radiation levels [18].

In the Site Study Area, OPG routinely measures ambient radiation dose rate at various monitoring locations within and along the WWMF perimeter fence. In 2009, the quarterly gamma dose rates ranged from <0.04 to 0.16 µGy/h, below the OPG target of 0.5 µGy/h [33;34;35;36].

In October 1995, an airborne gamma survey was conducted over the Bruce nuclear site and surrounding land areas covering most of the Regional Study Area to identify the distribution of natural and man-made emitting isotopes and to examine the variability of gamma radiation from various sources. The results of the airborne survey indicated that gamma radiation produced at the Bruce nuclear site is localized to the containment structures of Bruce A, Bruce B, the Douglas Point Nuclear Generating Station, and the Radioactive Waste Operations Site (RWOS) 1 and RWOS 2 (now part of the WWMF) [55].



LEGEND

- Monitoring Locations
- Site Study Area [1]
- Project Area (OPG-retained lands that encompass the DGR Project)
- Local Study Area

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007.
Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m,
[10;11;12;13;14;15;16;17;18]
Datum: NAD 83 Projection: UTM Zone 17N

0 0.5 1 2 3 4 5
Kilometres

PROJECT

RADIATION AND RADIOACTIVITY TECHNICAL SUPPORT DOCUMENT

TITLE

ANNUAL AVERAGE DOSE RATE IN AIR IN THE LOCAL STUDY AREA

PROJECT No.06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	03 Aug. 2006		
GIS	BC	15 Apr. 2010		
CHECK	AB	15 Apr. 2010		
REVIEW	MAR	15 Apr. 2010		

Golder Associates
Mississauga, Ontario

FIGURE 5.8.3-1

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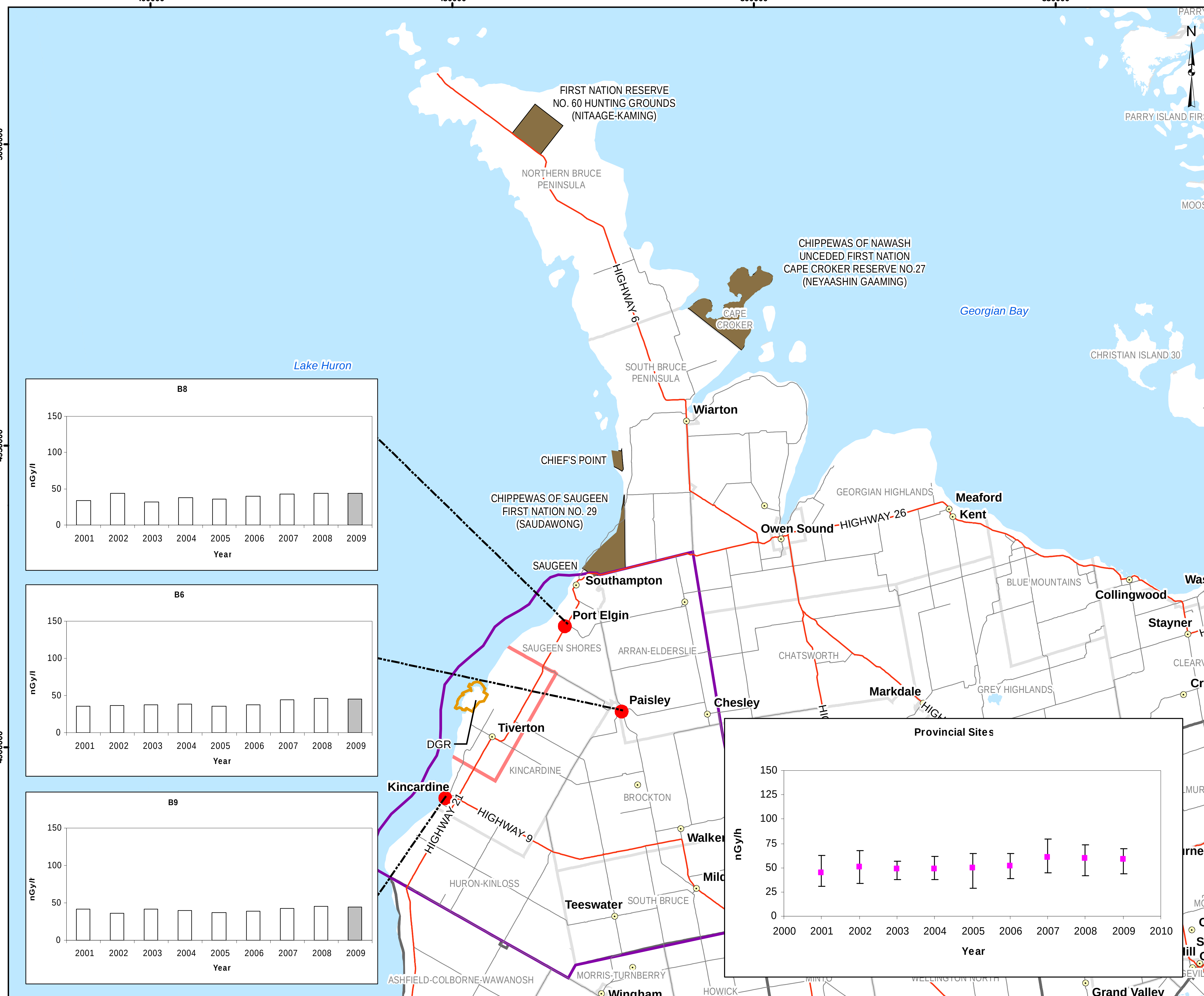

LEGEND

- Monitoring Locations
- Site Study Area [1]
- Local Study Area
- Regional Study Area
- County Boundary
- First Nations' Lands

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007.
Imagery and Topo Collected and Processed by Terrapoint Canada Inc., Acquisition Date: Nov. 12, 14, and 15, 2006, Ground Resolution: 0.25m,
[10;11;12;13;14;15;16;17;18]
Datum: NAD 83 Projection: UTM Zone 17N

0 5 10 20 30 40 50
Kilometres

PROJECT
RADIATION AND RADIOACTIVITY
TECHNICAL SUPPORT DOCUMENT

TITLE
ANNUAL AVERAGE DOSE RATE IN
AIR IN THE REGIONAL STUDY AREA

Golder Associates
Mississauga, Ontario

PROJECT No.06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	03 Aug. 2006		
GIS	BC	15 Apr. 2010		
CHECK	AB	15 Apr. 2010		
REVIEW	MAR	15 Apr. 2010		

FIGURE 5.8.3-2

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There were no fugitive sources or leaks of gamma emitting radioactive materials from reactors or waste storage at the Bruce nuclear site detected in the surrounding communities. Radiation exposure rates throughout the rest of the Bruce nuclear site and the surrounding communities are at natural levels.

5.8.4 Radioactivity in Soil

Bruce Power collects soil samples at monitoring locations in the Local Study Area and at the provincial background locations on an annual basis. These samples are analyzed for cesium-137, cesium-134, cobalt-60 and potassium-40.

As found in previous years, the dominant radionuclide measured in the soil samples in 2009 was the naturally occurring potassium-40 [18]. For the soil samples collected in the Local Study Area, potassium-40 concentrations ranged from 294.5 to 626.0 Bq/kg (dry weight), compared to the concentrations of 446.0 to 500.0 Bq/kg measured from samples collected at the provincial background locations. Cesium-137 concentrations in soils samples collected in the Local Study Area ranged from 0.91 to 8.02 Bq/kg, compared with concentrations ranging from 2.68 to 3.94 Bq/kg measured at provincial background locations. The concentrations of cobalt-60 and cesium-134 in all soil samples were negligible.

Within the Site Study Area, soil samples were collected from 18 locations at the WWMF in 2000 [48]. The soil samples were collected using a 100 cm long tube with a diameter of 3.8 cm. The top 30 cm of each soil core was used for the radionuclide analysis. It was reported that cobalt-60, cesium-134, along with carbon-14 concentration in the majority of samples, were below their method detection limits. Tritium concentrations ranged from approximately 40 to 120 Bq/kg, which is three to five orders of magnitude below OPG's screening limit of 3×10^6 Bq/kg. Also, it was found that the mean concentrations for the Western Used Fuel Dry Storage Facility (WUFDSF) sampling locations and the remaining WWMF locations for each radionuclide were within the corresponding radionuclide concentrations at the control sites, except for cesium-137. The cesium-137 concentrations on the WUFDSF site and the remainder of the WWMF sampling locations averaged 6.9 and 3.2 Bq/kg, respectively. The corresponding values at Goderich and the Bruce nuclear site main gate are 5.7 and <2.3 Bq/kg, respectively. However, it should be noted that cesium-137 is a product of both global fallout and all reactor operations, and its concentration varies widely in the environment.

5.8.5 Radiation Doses to Terrestrial Biota

Radioactive releases to water and the atmosphere may result in a measurable dose to terrestrial biota. As with aquatic biota, there are currently no internationally agreed criteria that explicitly address protection of the terrestrial biota from ionizing radiation, although many international agreements and statutes call for protection against pollution, including radiation [52]. At present, there are various benchmarks available in the literature, typically in the range of 0.6 to 10 mGy/day [53;54].

Radiation dose to terrestrial biota under existing conditions was estimated for the terrestrial VECs identified for the DGR Project (see Section 4). A detailed description of the methodology used to estimate radiation doses and calculation results are provided in Section 8 and Appendix C. All doses are less than the most restrictive benchmark (i.e., 0.6 mGy/d).

5.9 RADIOACTIVITY IN GROUNDWATER

There is a possibility that groundwater, a potential pathway for human exposure, is radioactively contaminated as a result of the various activities at the Bruce nuclear site. To investigate the radiation and radioactivity level in groundwater, routine groundwater monitoring programs are being carried out by Bruce Power and OPG.

Within the Local Study Area, Bruce Power collects samples of well water from a number of deep wells and shallow wells for tritium. Monitoring for gross beta at all deep wells has been discontinued as any small contribution by releases from the stations is expected to be negligible compared to natural background levels. Monitoring results of tritium in the deep well water for the period of 2001 to 2009 are provided in Table 5.9-1.

During 2009, tritium concentrations in the majority of the deep wells continued to be at a very low level. One exception is a newly built monitoring well at a resident location close to Inverhuron Bay with a measured concentration of 22.8 Bq/L. This well is not behaving as a deep well and appears to be under the influence of Lake Huron. In the same year, the shallow water wells had tritium levels in the range of 18.3 to 94.7 Bq/L, which are elevated relative to provincial background levels. The source of tritium can be attributed to tritium emissions from the Bruce nuclear site [18].

Bruce Power also monitors groundwater around the Bruce A and Bruce B stations for tritium, a program initiated as a result of a reconnaissance level groundwater quality study [18]. Groundwater samples from ten multi-level wells installed into the bedrock around the Bruce A and Bruce B are collected twice per year. The monitoring results are present in Table 5.9-2.

It was found, based on 2009 data, that tritium activities in groundwater in these monitoring wells around the Bruce A and Bruce B stations are orders of magnitude lower than the generic screening criteria of 3×10^6 Bq/L for non-potable groundwater. Also, it was observed that tritium concentrations decreased with depth. This study concluded that the operations of Bruce A and Bruce B have a negligible effect on groundwater quality [18].

A routine groundwater monitoring program was established at the WWMF to detect both temporal and spatial trends in groundwater quality that may be a result of the storage of low level radioactive waste. The long-term monitoring results of three groundwater monitoring wells at the WWMF, the locations of which are shown on Figure 5.9-1, are illustrated on Figures 5.9-2 through 5.9-4 [36]. As shown on Figure 5.9-2, the tritium concentration in groundwater taken from Well 231, which was built on the Middle Sand Aquifer[7], exceeded the operating limit of 4.0×10^4 Bq/L in recent years. In 2009, the tritium concentrations in Well 231 reached a maximum value of approximately 8.0×10^4 Bq/L. This is still far less (i.e., orders of magnitude) than the generic screening criteria of 3×10^6 Bq/L for non-potable groundwater. Currently, Well 231 is sampled twice a month, compared with the quarterly sampling frequency at other WWMF monitoring wells. It is believed, based on the understanding of the site hydrogeology that the trends in tritium concentration correspond to the trends in the mass loadings of tritium in the LLSB foundation drains. Precipitation is also a factor influencing trends in tritium concentration. Additional information on the groundwater regime in the Project Area is provided in the Geology TSD.

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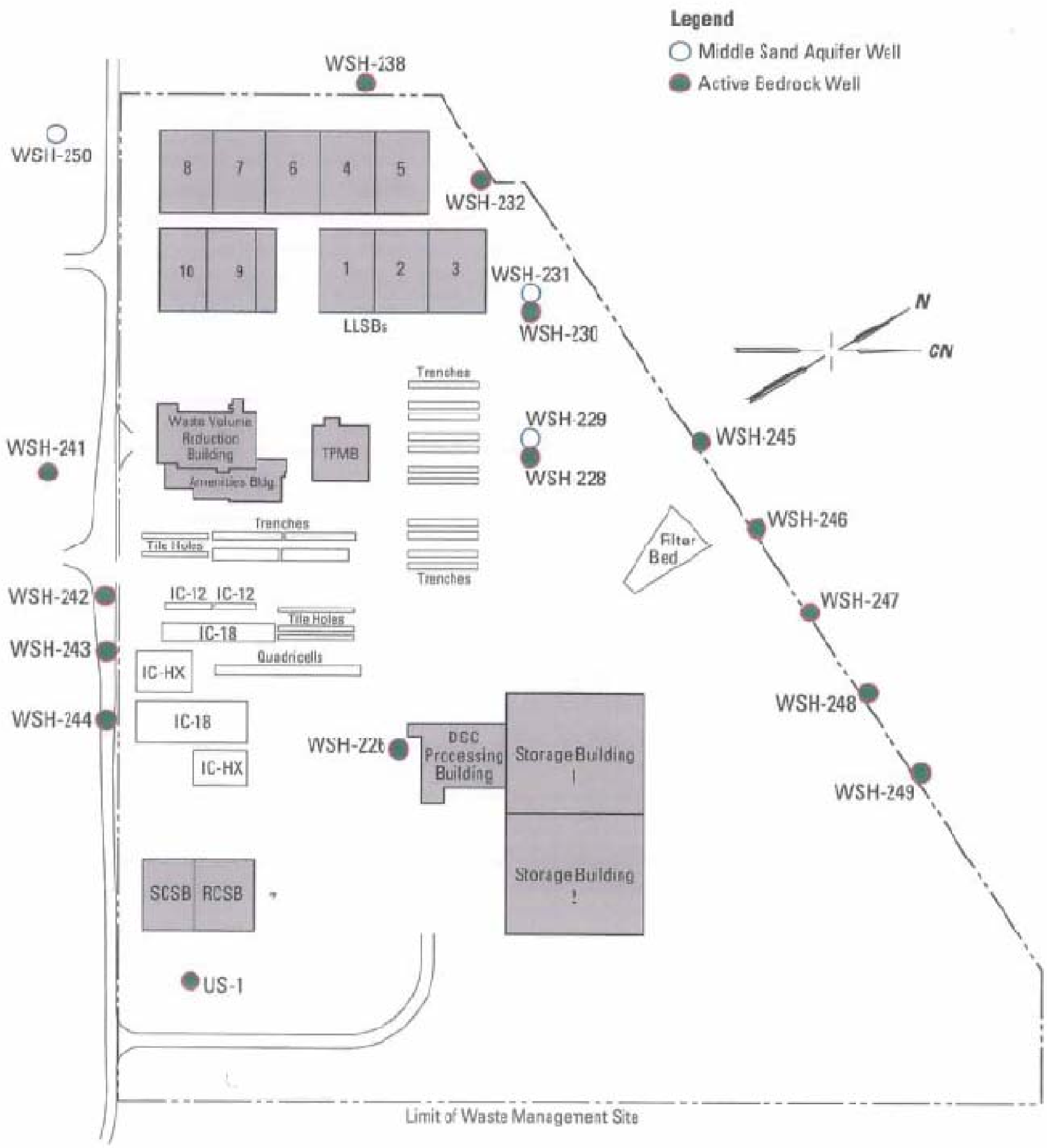
[7] The Middle Sand Aquifer is a localized layer of relatively high permeability located beneath the WWMF. A full description of the Middle Sand Aquifer and its influence on groundwater flow is provided in the Geology TSD.



Source: [56]

Figure 5.9-1: WWMF Groundwater Monitoring Well Locations

Table 5.9-1: Annual Average Tritium Activity in Deep Well Water (Bq/L)

Local Study Area	2001	2002	2003	2004	2005	2006	2007	2008	2009
BM 12 and 13	<3.7	<3.7	<3.7	<4.8	<4.9	<5.9	<5.7	Ld	Ld
BM6	<3.7	<3.7	<3.7	<4.8	<4.9	<5.9	<5.7	Ld	Ld
BR27	<3.7	<3.7	<3.7	<4.8	6.4	<5.9	<5.7	—	—
BM2	<3.7	<3.7	<3.7	<4.8	<4.9	<5.9	<5.7	Ld	Ld
BM9	<3.7	<3.7	<3.7	<4.8	<4.9	<5.9	<5.7	0.3	Ld
BR1	<3.7	<3.7	<3.7	<4.8	<4.9	<5.9	<5.7	Ld	Ld
BR8	<3.7	<3.7	<3.7	<4.8	<4.9	<5.9	<5.7	Ld	Ld
BR25	<3.7	<3.7	<3.7	<4.8	<4.9	<5.9	<5.7	Ld	Ld
BR39	22.8	18.3	20.5	19.2	19.0	19.1	—	—	—
BR37 [a]	—	—	—	—	—	—	—	25.1	22.8
BF1	<3.7	<3.7	<3.7	<4.8	<4.9	<5.9	<5.7	2.8	Ld
BF14	<3.7	<3.7	<3.7	<4.8	<4.9	<5.9	<5.7	0.3	Ld
BDF11	<3.7	<3.7	<3.7	<4.8	<4.9	<5.9	<5.7	Ld	Ld

Notes:
— No measurement taken
a Sample collection at location BR37 was initiated in year 2008. This location is close to Inverhuron Bay and well water appears to be under the influence of water from Lake Huron.
Ld Lower than detection limit
Source: [10;11;12;13;14;15;16;17;18]

Table 5.9-2: Tritium Level in Bruce A and B Groundwater Monitoring Wells (Bq/L)

Monitoring Location	2001		2002		2003		2004		2005		2006		2007		2008		2009	
	June	Nov.	May [a]	Nov [b]	Aug.	Nov.	June	Dec.	June	Dec.	June	Dec.	June	Dec.	June	Dec.	June	Dec.
Bruce A																		
1-Jan	94.4	101.6	130	43.6	550	481	415	249.3	235	157.7	214.9	201.1	246.1	138.3	240.4	165.8	153.9	82.9
2-Jan	258.5	277.4	401	100.1	660	614	596	320	409	252.8	430	375.5	483	267.4	487	334.2	351.4	200
1-Feb	<3.7	<3.7	<23.5	<3.7	13.3	4.8	<4.3	<5.9	<4.4	<4.9	<5.1	<5.0	<5.2	<4.6	1.4	1.4	Ld	Ld
2-Feb	<3.7	<3.7	<23.5	<3.7	383.7	268.8	83.2	34.6	21.3	11.9	12.5	89.1	8.3	6.2	24.5	6.4	Ld	Ld
3-Feb	474	762.2	692	364.3	1,707	1817	1271	807	977	667	840	1499	783	527	763	544	462	499
1-Mar	<3.7	<3.7	<23.5	<3.7	<3.7	<3.7	<4.3	<5.9	<4.4	<4.9	<5.1	<5.0	<5.2	<4.6	0	0	Ld	Ld
2-Mar	<3.7	<3.7	<23.5	<3.7	8.6	11.2	4.7	<5.9	<4.4	<4.9	<5.1	<5.0	<5.2	<4.6	1.4	1.2	Ld	Ld
3-Mar	516.8	645.5	704	318	1,252	1,092	985	526	7.53	522	778	585	682	429.0	570	536	493	506
1-Apr	<3.7	<3.7	<23.5	<3.7	<3.7	<3.7	<4.3	<5.9	<4.3	<4.9	14.8	<5.0	<5.2	<4.6	3	1.1	Ld	Ld
2-Apr	1,466.4	1,303.3	1,590	594.6	450	433	250.3	231.2	190.7	167.7	188.9	176.2	350	114.9	221.5	171.6	176.6	131.6
1-May	<3.7	<3.7	<23.5	<3.7	<3.7	<3.7	5.2	<5.9	<4.4	3.8	<5.1	5.7	<5.2	<4.6	0.4	2.6	Ld	Ld
2-May	<3.7	<3.7	<23.5	<3.7	<3.7	<3.7	<4.3	<5.9	<4.4	<4.9	<5.1	<5.0	<5.2	<4.6	0	0	Ld	Ld
Bruce B																		
1-Jan	16.3	18.2	—	19.8	27.8	21	23.4	22.9	22.6	23.9	19.7	19.5	18.9	23.9	21.8	0	17.6	21.1
2-Jan	233.2	149	—	213.7	252.2	409	308.4	310.8	215.8	312.8	191	213.2	214.5	285.7	321.9	324.9	265.6	226.6
3-Jan	463.7	215.3	—	185	890	1,686	2,784	739	429	226.1	373.4	286.6	695	209.2	1116	389	436	270.6
1-Feb	156.4	143.8	—	147.6	177.6	164.7	163.1	160.6	109	140.9	221.2	167.9	219.8	226.1	202.3	257.2	142	272.8
2-Feb	155.4	161.1	—	191.2	262	278.8	277.8	323	301.4	279	390.8	407.0	444	400	597	650	763	754
1-Mar	<3.7	<3.7	—	4.9	<3.7	<3.7	4.6	<5.9	<4.4	<4.9	<5.1	<5.0	<5.2	<4.6	3.5	4.4	Ld	Ld
2-Mar	50.6	46.7	—	55.4	45.5	42.5	39.9	50.4	48.6	81.8	52.3	33.9	87.0	201.9	106.8	72.2	48.2	59.7
3-Mar	400.9	381.1	—	440.6	385.6	387.7	372.6	598	467	369.7	547	397.7	437	451	474	537	724	659
1-Apr	72.4	69.1	—	73.1	56.6	63.4	66.5	63.8	55.6	53.4	52	48.8	50.3	43.1	48.6	49.8	47.5	47
2-Apr	551.4	500.4	—	318.3	419	802	508	366	364	616	513	583	506	589	504	669	685	421
3-Apr	1,204.3	1341	—	899.3	1,089	1,552	1,600	1,406	1,649	1,593	1,895	2,042	2,153	1,979	2,769	3,012	3,082	3,161
1-May	258.5	252.6	—	288.9	265.7	287.6	288	267	240.9	257.8	253.1	233	249.4	234.6	262.7	263.3	288.9	245.3
2-May	354	361.6	—	388	392.6	450	468	445	370.9	390.3	467	462	505	470	604	610	621	619
3-May	469.3	454.5	—	431.5	619	742	534	460	559	449	656	613	1,024	650	1,250	945	766	599

Notes:
a Modification to the security fencing around Bruce B made access to the groundwater wells impractical during the first half of 2002.
b Samples were collected on November 13 for wells in Bruce A and November 19 for wells in Bruce B.
— No measurement taken
Ld Lower than detection limit
Source: [10;11;12;13;14;15;16;17;18]

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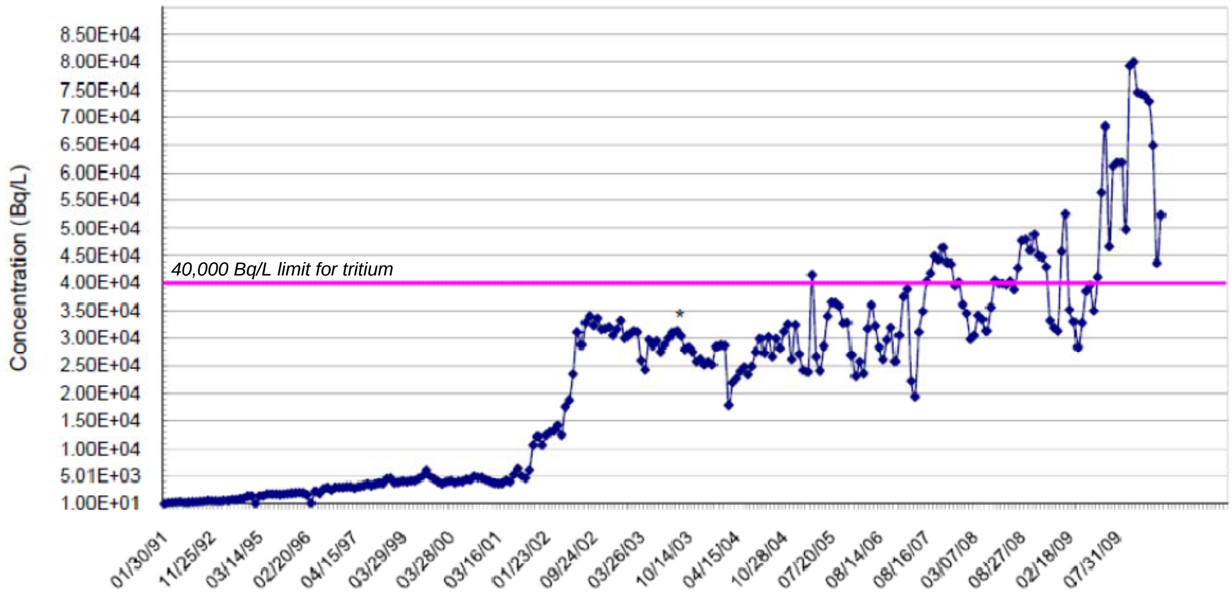
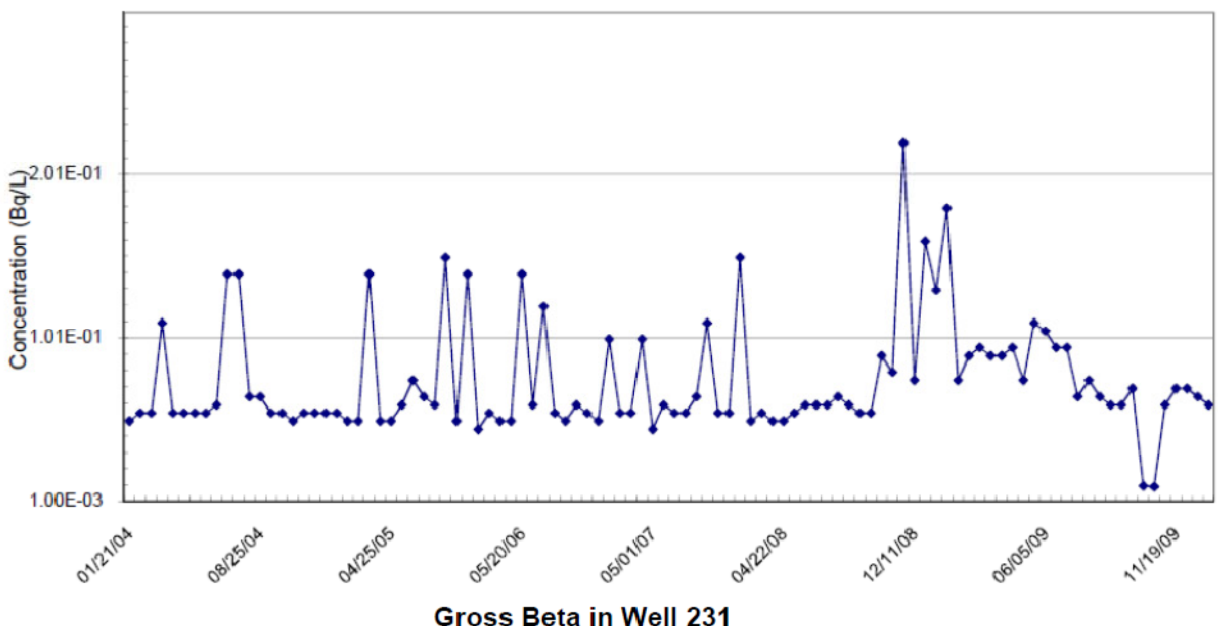


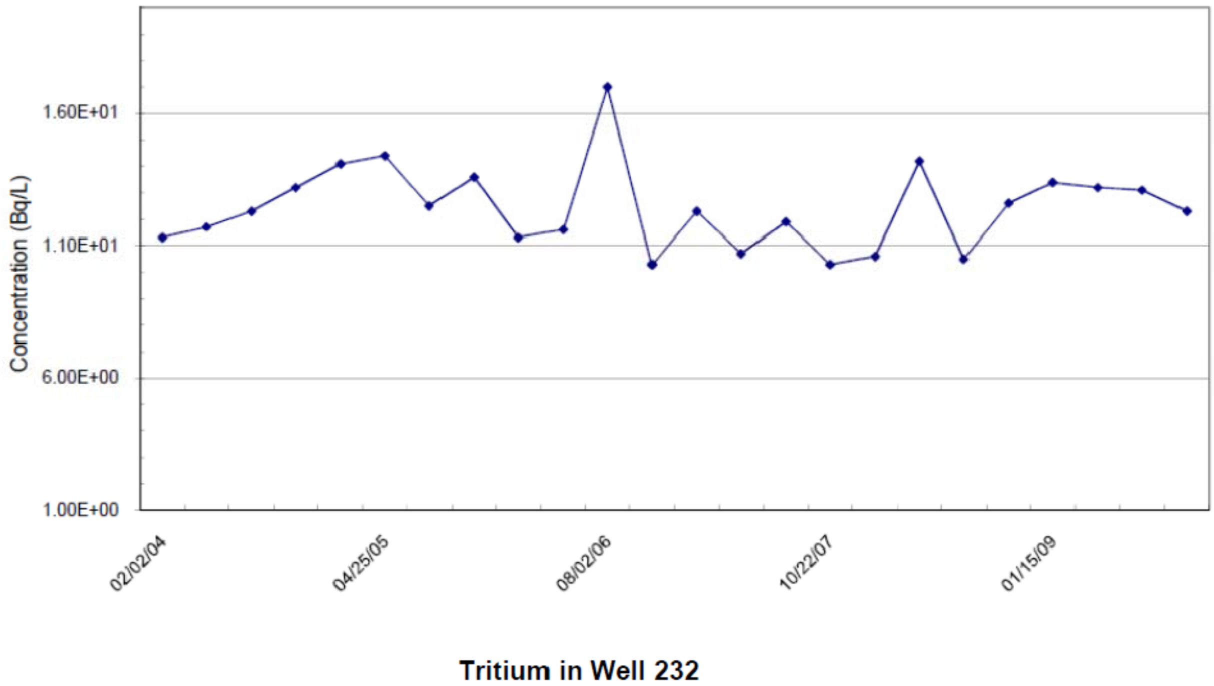
Tritium in Well 231

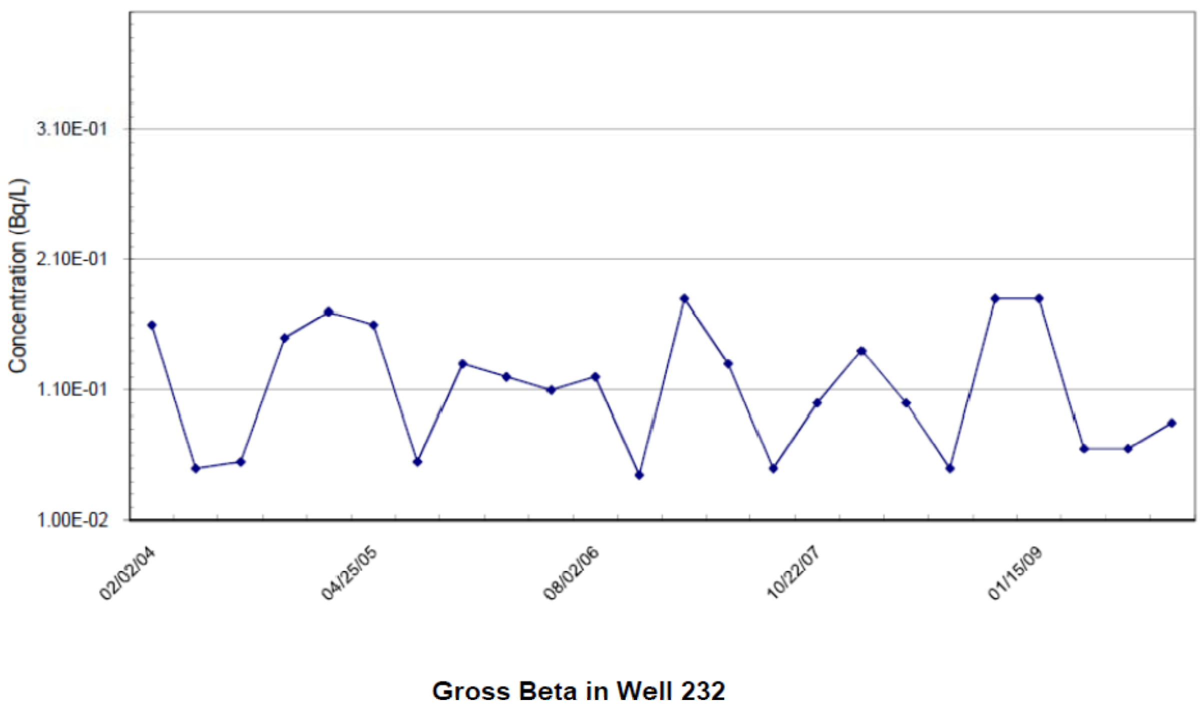


Gross Beta in Well 231

Source: [36]

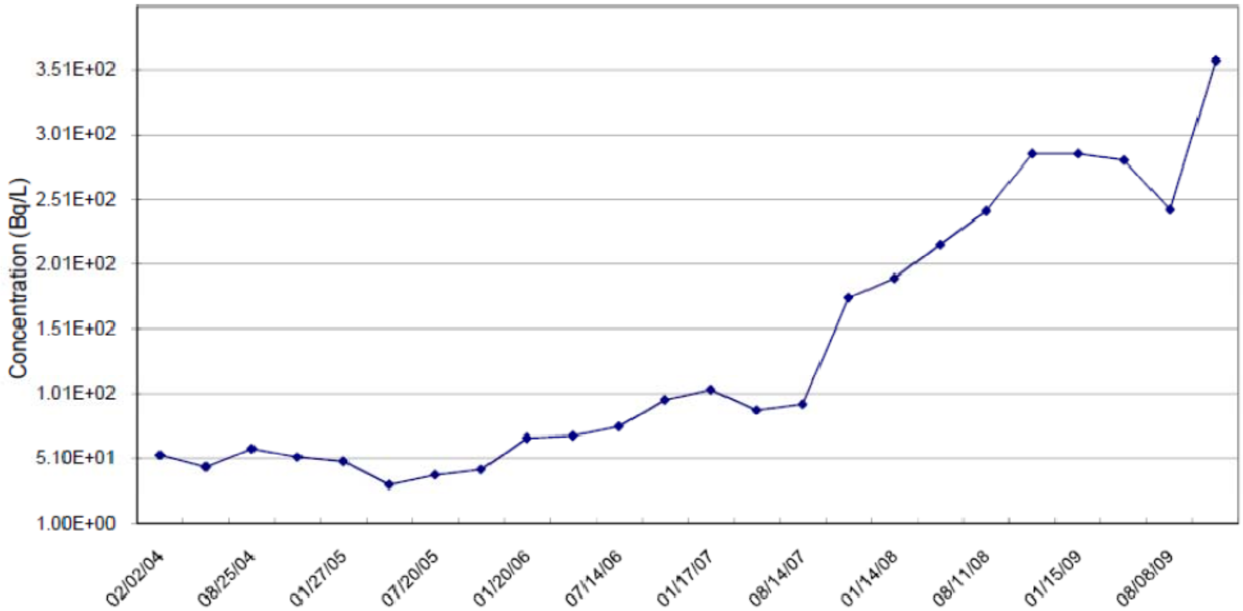
Figure 5.9-2: Tritium and Gross Beta Concentrations Measured at WWMF Groundwater Monitoring Well 231



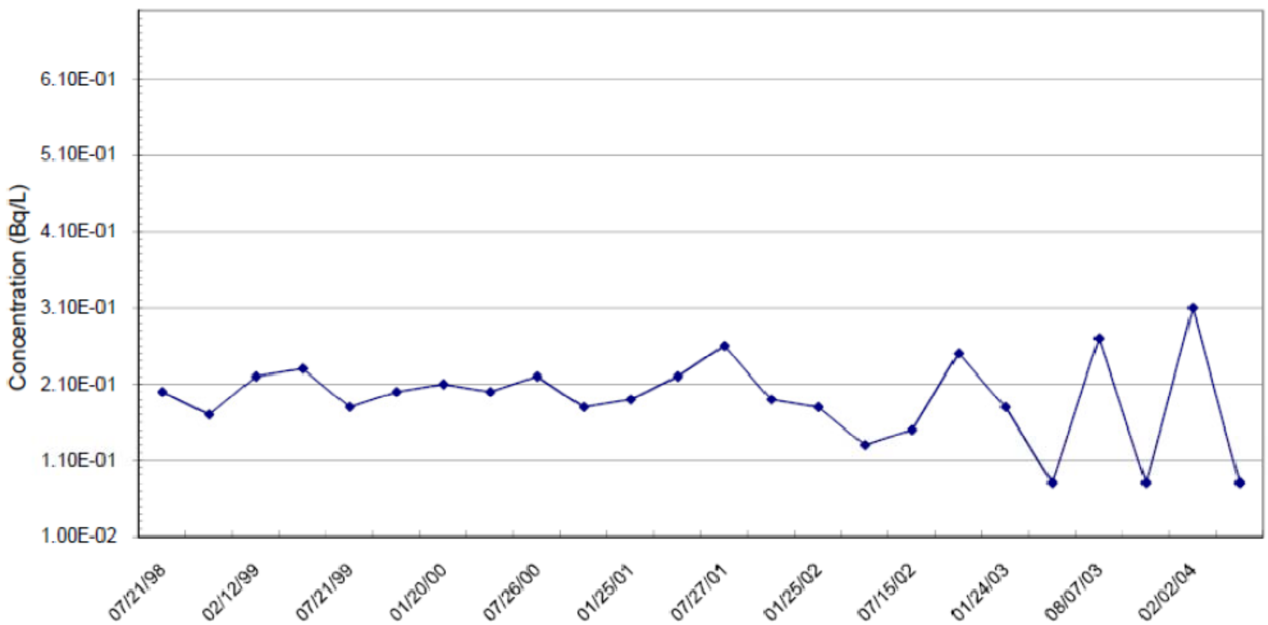


Source: [36]

Figure 5.9-3: Tritium and Gross Beta Concentrations Measured at WWMF Groundwater Monitoring Well 232



Tritium in Well 243



Gross Beta in Well 243

Source: [36]

Figure 5.9-4: Tritium and Gross Beta Concentrations Measured at WWMF Groundwater Monitoring Well 243

5.10 RADIATION DOSES TO MEMBERS OF THE PUBLIC

This section provides a description of the baseline radiation dose to members of the public that is attributable to radiation and radioactivity releases from the Bruce nuclear site.

For the purpose of the EA, critical groups are used to estimate the maximum realistic effects of emissions. According to the Canadian Standards Association (CSA) N288.1 Standard [57], the critical group is "*a fairly homogeneous group of people whose location, habits, diet, etc., cause them to receive doses higher than the average received by typical people in all other groups in the exposed population*". Compared with the concept of hypothetical group, which was employed previously by Bruce Power, the method to calculate the doses to members of a critical group produces more realistic results of the effects of radioactive emissions for the following reasons:

- The hypothetical individual dose calculation assumes infants and adults live just outside the site boundary 24 hours per day; eat only local fruit, vegetables and milk; ingest only locally caught fish; and drink local water. This approach is intentionally conservative and is thought to result in an estimate of public doses that should be at the high end of the range of possible doses. The critical group dose calculations encompass more realistic receptor characteristics and thus give rise to more realistic doses.
- The hypothetical individual dose calculation did not include some of the minor pathways such as ingestion of animal products such as meat and eggs, which are included in the critical group dose calculations.
- The critical group calculations make use of known contaminated ingestion fractions.
- The critical group calculations include all known pathways of exposure.
- Critical group doses from OBT in foodstuffs are calculated by conservatively assuming the OBT dose is 50% of the tritium oxide dose.
- Other minor differences between the two dose calculation methods are designed to remove unnecessary conservatism in the critical group calculations.

A survey conducted in 2007 [58] (previous ones in 1997 and 2003) in the area surrounding the Bruce nuclear site gathered information regarding land usage, population distribution, meteorology, hydrology, water sources, water uses and food sources. As a result of the information accumulated during the survey, three types of potential critical groups were identified and their characteristics were defined [18]. The three types of potential critical groups are: 1) non-farm resident, 2) farm resident, and 3) dairy farm resident. Eight candidate groups representing these three types of residents were defined for the purpose of estimating radiation doses to determine which group is the most highly exposed group (the critical group)[8]. A worker employed at the Bruce Eco-Industrial Park (formerly Bruce Energy Centre) was also identified representing another potential critical group. The general characteristics of these nine candidate groups are summarized in Table 5.10-1 and their locations are illustrated on Figure 5.10-1.

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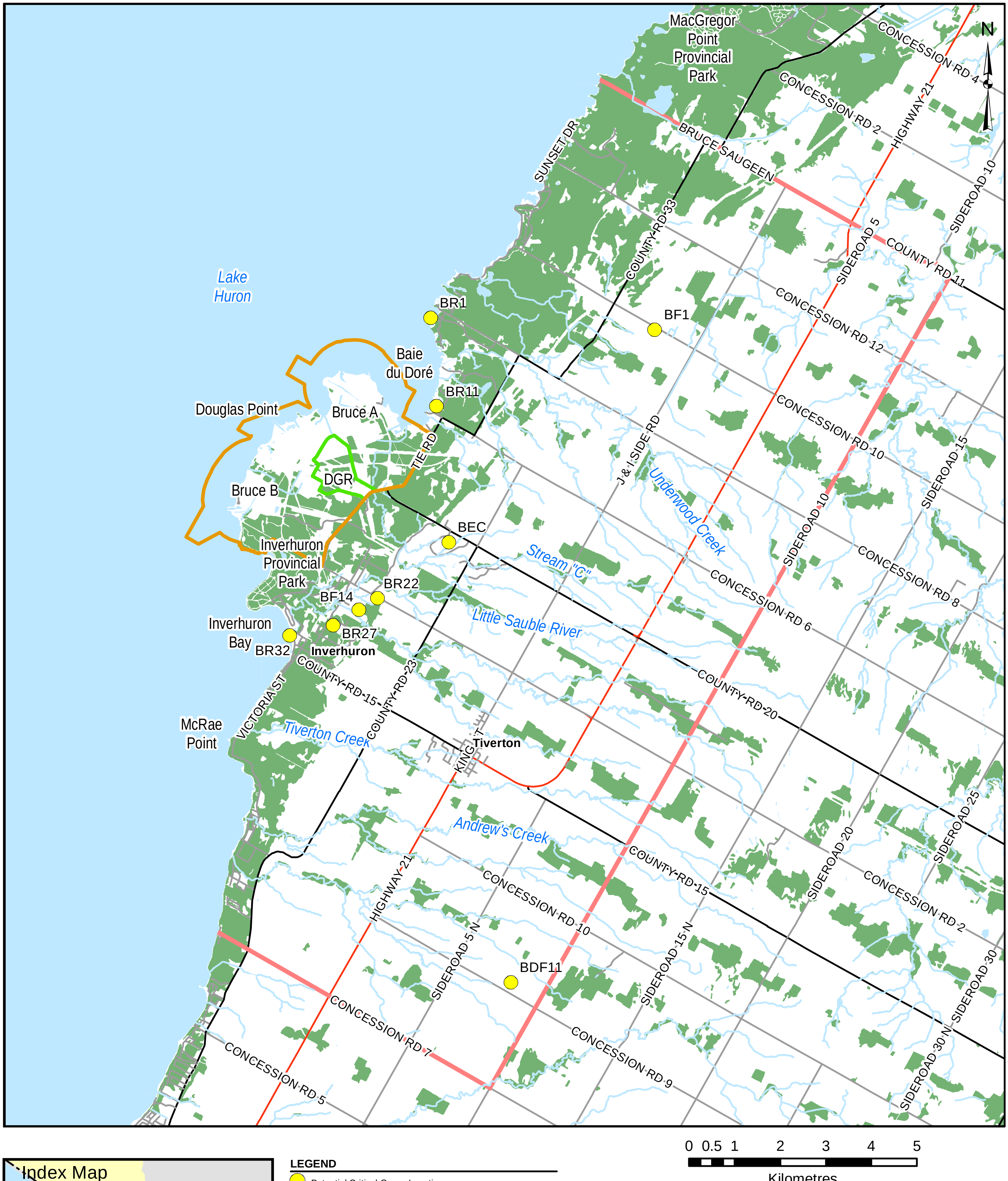
[8] Aboriginals are not identified as a specific candidate group in Bruce Power's REMP program. Their locations, traditional activities/lifestyle or traditional dietary habits mean they will not be exposed to a higher dose than those candidate groups identified here. This is supported by the results of the diet survey of Chippewas of Nawash First Nation (Neyaashiinigmiing, at Cape Croker ON, on Georgian Bay) as discussed in Section 5.7.3.



LEGEND

- Potential Critical Group Location
- Project Area (OPG-retained lands that encompass the DGR Project)
- Site Study Area [1]
- Local Study Area

NOTES

1. Site Study Area is defined by EIS Guidelines as: "includes the facilities, buildings and infrastructure at the Bruce nuclear site, including the existing licensed exclusion zone for the site on land and within Lake Huron, and particularly the property where the Deep Geologic Repository is proposed.

REFERENCE

Base Data Provided by 4DM, November 2007.
Bruce Power. 2008. Annual Summery and Assessment of Environmental Radiological Data for 2007. B-REP-03419-00008-R00. April 2008
Datum: NAD 83 Projection: UTM Zone 17N

PROJECT

RADIATION AND RADIOACTIVITY
TECHINCAL SUPPORT DOCUMENT

TITLE

LOCATIONS OF
POTENTIAL CRITICAL GROUPS

Golder Associates
Mississauga, Ontario

PROJECT NO. 06-1112-037			SCALE: AS SHOWN	R000
DESIGN	ASB	17 Oct 2007	FIGURE 5.10-1	
GIS	BC	14 Apr. 2010		
CHECK	AB	14 Apr. 2010		
REVIEW	MAR	14 Apr. 2010		

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Table 5.10-1: General Characteristics of Potential Critical Groups

Group Name	General Characteristics and Location of Group
BR1	Non-farm resident, Lakeshore Scott Point, Located north of the Bruce nuclear site
BR11	Non-farm resident, Inland Baie du Doré, Located to the northeast of the Bruce nuclear site
BR32	Non-farm resident, Lakeshore Inverhuron Bay, south-southeast of Bruce B
BR22	Non-farm resident, Inland Northeast of Inverhuron, Located to the south of the Bruce nuclear site
BR27	Non-farm resident, Trailer Park Northeast of Inverhuron, Located to the south of the Bruce nuclear site
BF1	Agricultural, Non-dairy farm resident Located to the northeast of the Bruce nuclear site
BF14	Agricultural, Non-dairy farm resident Located to the southeast of the Bruce nuclear site
BDF11	Agricultural, Dairy farm resident Located to the southeast of the Bruce nuclear site near Tiverton.
BEC	Worker in Bruce Eco-Industrial Park (formerly Bruce Energy Centre [BEC]) Located to the east of the Bruce nuclear site

Source: [16]

These potential critical groups were defined on the basis of proximity to the sources of emissions at the Bruce nuclear site, and on the basis of lifestyle characteristics to ensure that the homogeneity criterion could be satisfied.

The doses to each candidate critical group are calculated for the radionuclides shown in Table 5.10-2 via each of the pathways shown in the same table [14].

Table 5.10-2: Radionuclides and Pathways to Critical Groups

Parameter	Details
Radionuclides	• Tritiated water • Noble gases • Iodine • Particulates [a] • Carbon-14 • Organically bound tritium
Pathways	• Air inhalation/skin absorption • Air immersion (external exposure) • Water ingestion • Water immersion (via swimming or bathing) • Soil external exposure (soil groundshine) • Terrestrial plant ingestion • Terrestrial animal ingestion

Table 5.10-2: Radionuclides and Pathways to Critical Groups (continued)

Parameter	Details
Pathways (continued)	• Aquatic plant ingestion • Aquatic animal ingestion • Sediment external exposure (beach groundshine)

Note:
a Refers to the remaining group of particulates not otherwise identified in this table.
Source: [14]

The human attributes, which determine the degree of exposure to, or intake of, radionuclides present in environmental media, were drawn from the default values in the Derived Release Limit (DRL) guidance document [59] used by both OPG and Bruce Power. The default rates in the DRL guidance document represent the 90th percentile values for the population.

These rates were purposely chosen for the DRL document [59] to introduce conservatism in release limit calculations. The intent of this TSD is to provide a more realistic assessment of doses and therefore the default food consumption rates used were adjusted to reference the caloric intake requirements of each age group, as outlined in the International Commission on Radiation Protection (ICRP) document [60] and shown in the DRL guidance document [59]. Values for some of the more prominent parameters, from the perspective of performing dose calculations, are outlined in Table 5.10-3.

Table 5.10-3: Human Attributes

Parameter	Units	Adult	1 Year Infant	1 Year Infant at Dairy Farm
Inhalation Rate	m^3/a	8,103	1,883	1,883
Water Ingestion Rate	L/a	840	292	76
Grain Intake	kg/a	231	59	59
Fruit & Berry Intake	kg/a	174	66	66
Vegetable Intake	kg/a	234	44	44
Mushrooms Intake	kg/a	1.5	0.2	0.2
Beef Intake	kg/a	66.3	10.6	10.6
Lamb Intake	kg/a	0.7	0	0
Poultry Intake	kg/a	19.7	4.6	4.6
Egg Intake	kg/a	30	8.4	8.4
Deer Intake	kg/a	5.6	1.5	0.6
Milk Intake	kg/a	265	0	371
Total Animal Ingestion Rate	kg/a	417	28	398
Fish Ingestion Rate	kg/a	7.9	1.6	0.3

Source: [18]

When performing the dose calculations for the potential critical groups, the consumption rates are modified to take into account the local attributes of the critical groups obtained during the course of conducting the site specific survey. Plant and animal ingestion rates are modified by taking into account information regarding the fraction of plant and animal products obtained from sources affected by emissions from the Bruce nuclear site (i.e., local attributes). For example, an adult living in the vicinity of the Bruce nuclear site might consume 400 kg of fruits and vegetables in a year but only 10% of these fruits and vegetables might come from local sources. Fish ingestion rates are estimated directly from the site specific survey.

As part of its Radiological Environmental Monitoring Program (REMP), Bruce Power calculates annual doses to members of the public in the vicinity of the Bruce nuclear site, based on the measured concentrations of radionuclides in different media, and estimated values where monitoring data are not available. It should be noted that the reported doses to members of the public exclude contributions from naturally occurring or anthropogenic radioactivity, which are not attributable to the facility. The estimated doses to members of the public are then compared to current regulatory limits specified in the Regulations under the *Nuclear Safety and Control Act* [61], specifically the annual dose limit of 1 mSv/a (1,000 µSv/a) for members of the public.

Based on the calculation results, Bruce Power has determined that for 2009, the critical group receiving the highest doses among all nine potential critical groups of adults, children and infants, was an adult in Group BF14 located to the southeast of the Bruce nuclear site [18]. As shown in Table 5.10-4, the critical group individual dose during 2009 was 4.41 µSv/a to the adult [18]. The predicted dose to members of the public includes the consumption of country foods. It should be noted that the doses to the public presented here include the contribution from Bruce Power's facilities (Bruce A, Bruce B and the CMLF) and OPG's WWMF, which are currently operated at the Bruce nuclear site. It is impossible to distinguish doses associated with the operation of OPG's facilities from those associated with the operation of Bruce Power's facilities, and the doses are reported collectively for the entire Bruce nuclear site.

As shown in Table 5.10-4, the estimated doses are considerably less than 1% of the regulatory limit of 1 mSv/a for members of the public. The values are also quite small compared to the variation in background radiation from natural sources. Also, it is noteworthy that the baseline dose is less than the *de minimis* dose level of 10 µSv/a recommended by the Canadian Advisory Committee on Radiological Protection (ACRP) and the Advisory Committee on Nuclear Safety (ACNS) [62] for the 18^{th} consecutive year. The *de minimis* dose rate is based on a risk level that would generally be regarded as negligible in comparison to other, non-nuclear risks.

Table 5.10-4: Doses from Radionuclides to Members of Public

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009
Critical group	Infant at BR1	Infant at BR1	Infant at BR1	Infant at BR1	Infant at BR1	Infant at BR1	Adult at BF14	Adult at BR11	Adult at BF14
Dose (µSv/a)	2.0	2.26	2.08	1.58	1.98	2.45	2.07	2.70	4.41
Percentage of the dose limit (%)	0.20	0.23	0.21	0.16	0.20	0.25	0.21	0.27	0.44

Source: [10;11;12;13;14;15;16;17;18]

5.11 RADIATION DOSES TO WORKERS

5.11.1 Radiation Doses to Nuclear Energy Workers

The occupational doses received by Nuclear Energy Workers (NEWs) at the WWMF and other nuclear facilities at the Bruce nuclear site are closely monitored by comprehensive personal dosimetry programs. Radiation doses to workers at the WWMF are monitored by OPG. Radiation doses to workers at Bruce A, Bruce B and the CMLF are monitored by Bruce Power, which operates those facilities. Doses to workers at the Douglas Point Nuclear Generating Station are monitored by Atomic Energy of Canada Limited (AECL).

Under these programs, radiation doses from external gamma radiation, neutron radiation and from internal radioactivity (inhaled and transferred across the skin) are measured, recorded and reported. The following paragraphs describe the existing radiation doses to workers at licensed nuclear facilities at the Bruce nuclear site.

5.11.1.1 NEWs at the WWMF

The collective annual whole body dose and the maximum individual annual whole body doses received by NEWs at the WWMF for the period of 2001 to 2009 are summarized in Table 5.11.1-1. During 2009, the maximum individual annual whole body dose was 2.8 mSv, which was well below the current regulatory limit of a maximum of 50 mSv in a single year and 100 mSv over any five years [63]. Meanwhile, the collective annual whole body doses received by workers at the WWMF were estimated to be 6.5 person-mSv. This value is much less than OPG's Action Level of 40 person-mSv/a for the WWMF [48].

5.11.1.2 NEWs at Other Nuclear Facilities at the Bruce Nuclear Site

As at the WWMF, the designated NEWs at other nuclear facilities at the Bruce nuclear site such as Bruce A and Bruce B are monitored for radiation dose. In 2006, the maximum individual dose and collective whole body dose received by workers at Bruce A were 10.2 mSv and 2.0 person-Sv, respectively [64]. For the same year, the maximum individual dose and collective dose received by workers at Bruce B were 12.3 mSv and 3.8 person-Sv, respectively [64]. In 2009, the collective doses received by workers at Bruce A and B were 2.7 person-Sv and 4.3 person-Sv, respectively. The data in Table 5.11.1-1 were based on publically available data. No publically available data on maximum individual whole body doses were available for either Bruce A or Bruce B during the period from 2007 to 2009.

5.11.2 Radiation Dose to Non-NEWs

For those workers who are working at the Bruce nuclear site but are not designated as NEWs, the regulatory dose limit of 1 mSv/a is applied [63]. The activities of non-NEWs, including access and movement, in the Site Study Area and the Project Area (OPG-retained land) are controlled by Bruce Power and OPG, respectively. Radiation doses to these workers from licensed nuclear activities are strictly monitored and controlled.

Table 5.11.1-1: Radiation Dose to NEWs

Facility	Dose	2001	2002	2003	2004	2005	2006	2007	2008	2009
WWMF	Collective whole body dose (Person-mSv) [b]	3.98	11	9.1	8.96	23.05	19.44	16.25	21.72	6.52
	Maximum individual whole body dose (mSv)	1.65	3.5	2.3	1.76	4.57	5.28	2.83	5.82	2.84
Bruce A [a]	Collective whole body dose (Person-mSv)	400	3,100	2,177	1,479	2,343	2022	4,689	4,240	2,743
	Maximum individual whole body dose (mSv)	8.3	21.9	13.4	9.7	15.2	10.2	*	*	*
Bruce B	Collective whole body dose (Person-mSv)	*	*	4,276	2,706	6,342	3,804	4,212	6,652	4,307
	Maximum individual whole body dose (mSv)	18.8	18.7	15.2	12	18.2	12.3	*	*	*

Notes:
- * Data not publically available
- a The total collective dose for Bruce A for the period of 2004 to 2009 is for Units 3 and 4, which were in operation during this period.
- b Collective whole body dose includes internal dose and external dose.

Source: [65;34;66;50;48;67;68;64;21;22;23;24;25;26;27;28;29;30;31;32;33;35;36]

In 2009, the highest dose rate measured at the RWOS1 and WWMF perimeter fences was 0.16 µSv/h [33;34;35;36]. This is below the perimeter dose rate limit of 0.5 µSv/h based on maximum 2,000 hours per year occupancy for non-NEWs as described in the WWMF operating licence documentation [33;34;35;36].

If there is any likelihood that the dose to workers may exceed 100 µSv/a (0.1 mSv/a), then such activities are carried out by NEWs. Therefore, current doses to non-NEWs do not exceed 100 µSv/a, which represents 10% of the annual dose limit to the general public.

Each year, some individuals or groups visit the Bruce nuclear site. Radiation doses to these visitors are monitored and strictly controlled by OPG and Bruce Power. For example, TLDs are used to measure external doses to visitors on tours in zoned areas to ensure the regulatory limit of 1 mSv/a is not exceeded.

5.12 SUMMARY OF EXISTING ENVIRONMENT

Table 5.12-1 provides a summary of the existing radiation and radioactivity environment by VEC. All numerical values are based on 2009 data, which is considered the baseline year for describing the existing conditions.

Table 5.12-1: Summary of Existing Radiation and Radioactivity

VEC	Existing Environment [a]
Human	• The highest dose among nine potentially critical groups of public studied was an adult in Group BF14 located to the southeast of the Bruce nuclear site, with dose during 2009 being 4.41 µSv/a. • For NEWs at the WWMF, the collective annual whole body doses and the maximum individual whole body dose were 6.5 person-mSv, and 2.8 mSv, respectively. • For non-NEWs, the current doses do not exceed 100 µSv/a, which represents 10% of the annual dose limit to general public.
Benthic Invertebrates	• The major portion of the activity in the sediments is attributable to naturally occurring potassium-40. • The concentrations of cesium-137 ranged from 0.21 to 0.23 Bq/kg in the sediments in the Regional Study Area and from 0.19 to 8.90 Bq/kg in the Local Study Area. • Cobalt-60 concentrations in sediments ranged from 0.20 to 0.85 Bq/kg in the Local Study Area and concentrations in Regional Study Area samples were all below the detection limit.
Aquatic Vegetation	• Modelled baseline doses are well below established benchmarks (see dose assessment presented in Section 8).

Table 5.12-1: Summary of Existing Radiation and Radioactivity (continued)

VEC	Existing Environment [a]
Benthic Fish Pelagic Fish	• Potassium-40 concentrations ranged from 125 to 146 Bq/kg. • Carbon-14 concentrations ranged from 225 to 270 Bq/kg-C. • Cesium-137 concentrations ranged from 0.18 to 0.43 Bq/kg, similar to background levels. • Tritium concentrations ranged from 7.6 to 30.5 Bq/L (water). • The OBT concentrations in whitefish and sucker were 9.6 and 10.5 Bq/L, respectively. • Cesium-134 and cobalt-60 were not detected in any fish samples collected from the Local Study Area. • Refer also to dose assessment presented in Section 8.
Aquatic Birds	• Modelled baseline doses are well below established benchmarks (see dose assessment presented in Section 8).
Aquatic Mammals	• Modelled baseline doses are well below established benchmarks (see dose assessment presented in Section 8).
Terrestrial Invertebrates	• Modelled baseline doses are well below established benchmarks (see dose assessment presented in Section 8).
Terrestrial Vegetation	• Tritium concentrations ranged from 18.1 to 123.8 Bq/L in soy beans. • The concentrations of carbon-14 in grains ranged from 205 to 240 Bq/kg-C. • For apples, tritium concentrations ranged from 41.1 to 214.4 Bq/L and carbon-14 concentrations ranged from 238 to 283 Bq/kg-C in listed monitoring locations. • Tritium and carbon-14 concentrations in vegetation decreased with distance from the Bruce nuclear site, and also vary with direction. • Refer also to dose assessment presented in Section 8.
Terrestrial Birds	• Modelled baseline doses are well below established benchmarks (see dose assessment presented in Section 8).
Terrestrial Mammals	• Modelled baseline doses are well below established benchmarks (see dose assessment presented in Section 8).
Amphibians and Reptiles	• Modelled baseline doses are well established benchmarks (see dose assessment presented in Section 8).

Note:

a All numerical values presented in this table are for year 2009 unless otherwise indicated.

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6. INITIAL SCREENING OF PROJECT-ENVIRONMENT INTERACTIONS

The first screening considers whether there is a potential for the DGR Project to interact with the radiation and radioactivity VECs.

6.1 INITIAL SCREENING METHODS

Following the description of the DGR Project, identification of VECs, and description of the existing environment, the project works and activities are screened to determine those with the potential exposures to the radiation and radioactivity VECs. The screening was conducted based on the general description of the existing environmental conditions. This allowed the EA to focus on issues of key importance where the potential interactions between the DGR Project and radiation and radioactivity are likely. The analyses are based on qualitative data, as well as the professional judgement and experience of the EA team. This screening is conducted by VEC for site preparation and construction, operations, and decommissioning phases of the DGR Project.

Radiation and radioactivity VECs interact with the DGR Project either via a direct exposure (e.g., external radiation dose to humans) or an indirect exposure (e.g., inhalation dose as a result of changes in air quality). Both potential direct and indirect exposures are carried forward through this assessment. Where a mechanism for exposures is identified, the individual project work or activity is advanced for further consideration of measurable changes. Where no potential exposures are identified, no further screening or assessment is conducted.

With regard to direct exposures, the screening was based on the general understanding of the project works and activities with regard to the physical and operational features of the DGR Project. With regard to indirect exposures, the screening was based on the general understanding of what physical processes and potential interactions with the environment could affect the VEC considered.

For the purpose of this TSD, direct exposures refer to external exposure to radiation resulting from being in its immediate vicinity, while indirect exposures refer to exposures via pathways such as air, water and soil where the dose is received through ingestion, inhalation or immersion in radioactive matter.

The results of the screening are documented in an interaction matrix. A potential project-VEC interaction was marked with a '•' on Matrix 1 (Table 6.3-1).

If, following the evaluation of project-environment interactions, there are no potential interactions between a VEC and a project work and activity or other VEC, the VEC may not be considered further.

6.2 IDENTIFICATION OF DGR PROJECT-ENVIRONMENT INTERACTIONS

In the initial screening, all works and activities associated with the DGR Project are identified and analyzed for possible interactions with the radiation and radioactivity VECs. As shown in the Basis for the EA (Appendix B), the DGR Project includes the following project works and activities:

- site preparation;
- construction of surface facilities;
- excavation and construction of underground facilities;
- above-ground transfer of waste;
- underground transfer of waste;
- decommissioning of the DGR Project;
- abandonment of the DGR facility;
- presence of the DGR Project;
- waste management;
- support and monitoring of DGR life cycle; and
- workers, payroll and purchasing.

The abandonment of the DGR facility work and activity is considered in this TSD as being at the end of the decommissioning phase. The abandonment and long-term performance phase is not considered in the assessment as no activities are expected to occur during this phase. It is considered in Section 9 of the EIS.

This TSD considers normal operations and radiological effects only. As noted, effects of the DGR Project in the abandonment and long-term performance phase are considered in Section 9 of the EIS. Abnormal conditions are considered in the Malfunctions, Accidents and Malevolent Acts TSD.

6.2.1 Humans

There are three indicators for humans, that is, NEWs, non-NEWs, and members of the public including Aboriginals. In this section, the potential interactions between the DGR Project and humans are screened for these groups.

6.2.1.1 Potential Direct Exposures

As described in the Basis for the EA (Appendix B), no radioactive waste packages will be involved during the following project works and activities:

- site preparation;
- construction of surface facilities;
- excavation and construction of underground facilities;
- abandonment of the DGR facility;
- presence of the DGR Project; and
- workers, payroll and purchasing.

There is no potential mechanism through which these works and activities may directly interact with this VEC from the radiation and radioactivity perspective. Accordingly, further assessment of the direct effects of these works and activities on humans is not warranted.

The interactions between other project works and activities and humans, including construction workers that are not categorized as NEWs are discussed below. The potential effect from operation of the other nuclear facilities at the Bruce nuclear site on these workers is assessed in Section 10 of the EIS as part of the cumulative effects assessment.

Above-ground Transfer of Waste

Above-ground transfer of waste will include receipt of L&ILW from the WWMF at the DGR Project Waste Package Receiving Building (WPRB) and on-site transfer to the main shaft. Some waste packages may require additional shielding for safe handling. Therefore, there is a potential mechanism through which this work and activity may directly interact with this VEC from the radiation and radioactivity perspective, and further assessment of the direct effects of this work and activity on humans is warranted. This interaction is advanced to Section 7 for a second screening. The related cell in Table 6.3-1 is therefore marked with a "•".

Underground Transfer of Waste

Underground transfer of waste will include receipt of waste packages underground via the main shaft, transfer from the shaft to underground waste transport vehicles and placement into the final emplacement rooms. Once an emplacement room has been completely filled, end walls may be installed to close it from the rest of the repository. Therefore, there is a potential mechanism through which this work and activity may directly interact with this VEC from the radiation and radioactivity perspective, and further assessment of the direct effects of this work and activity on humans is warranted. This interaction is advanced to Section 7 for a second screening. The related cell in Table 6.3-1 is therefore marked with a "•".

Decommissioning of the DGR Project

Decommissioning of the DGR Project will include all activities required to seal the shafts and remove surface facilities. This includes dismantling the equipment, sealing the repository and access ways and decontaminating and demolishing the surface facilities. Therefore, there is a potential mechanism through which this work and activity may directly interact with this VEC from the radiation and radioactivity perspective, and further assessment of the direct effects of this work and activity on humans is warranted. This interaction is advanced to Section 7 for a second screening. The related cell in Table 6.3-1 is therefore marked with a "•".

Waste Management

Waste management represents all activities required to manage wastes during the first three DGR Project phases. During site preparation and construction, waste management will include managing the waste rock along with conventional and hazardous waste management, but no radioactive wastes will be present. During operations, waste management would include managing conventional and radioactive wastes generated by the underground and above-ground operations. Decommissioning waste management may include management of conventional and construction wastes, along with management of project-related materials that may have become contaminated with radioactive materials over the course of operations.

Therefore, there are potential mechanisms through which this work and activity may directly interact with this VEC during the operations and decommissioning phases from the radiation and radioactivity perspective, and further assessment of the direct effects of this work and activity on humans is warranted. This interaction is advanced to Section 7 for a second screening. The related cells in Table 6.3-1 is therefore marked with a "•".

Support and Monitoring of DGR Life Cycle

Support and monitoring of DGR life cycle will include all activities to support the safe site preparation and construction, operation and decommissioning of the DGR Project. This includes operation of the ventilation systems, monitoring air and water quality, electricity and lighting, communication, fire protection and safety, site security, and groundwater and surface water management. Radioactive wastes are not present during the site preparation and construction phase; however, there is a potential mechanism through which this work and activity may directly interact with this VEC during the operations and decommissioning phases from the radiation and radioactivity perspective, and further assessment of the direct effects of this work and activity on humans is warranted. This interaction is advanced to Section 7 for a second screening. The related cells in Table 6.3-1 is therefore marked with a "•".

6.2.1.2 Potential Indirect Exposures

Naturally occurring radioactive material (NORM), in particular radon, may be a cause for concern. As a result, the exposure of workers to radon cannot be precluded, specifically during the construction and operations phases. In addition, worker exposure to radioactive particulate matter from the waste packages cannot be precluded during the operations and decommissioning phases.

Releases of radionuclides from the DGR Project during the operations and decommissioning phases are possible and could lead to human exposure via different pathways such as ingestion or immersion in contaminated surface water (in addition to air, as described above). Although there is no direct release to groundwater, groundwater contamination is possible through precipitation, which is another pathway through which humans could be exposed to radiation and radioactivity.

Therefore, further assessment of the indirect exposures on humans resulting from exposures through various environmental pathways is warranted, and these interactions are advanced to Section 7 for a second screening. The related cells in Table 6.3-1 are therefore marked with a "•".

Consumption of food that might be contaminated is also considered a mechanism through which the DGR Project potentially interacts with humans and therefore is advanced to Section 7 for a second screening. The related cells in Table 6.3-1 are therefore marked with a "•".

6.2.2 Benthic Invertebrates

In this assessment, burrowing crayfish, found in ditches and wetlands in the Site Study Area and Project Area, is used as the indicator for the benthic invertebrates for determining the potential effects of radionuclides released from the DGR Project.

6.2.2.1 Potential Direct Exposures

All project works and activities associated with the DGR Project, as described in Appendix B, have been reviewed. There is no mechanism through which these project works and activities could result in the direct exposure of this VEC to radioactive waste packages. All exposures are

expected to be through indirect pathways (described in Section 6.2.2.2). Therefore, further assessment of potential direct effects of the DGR Project on benthic invertebrates is not warranted.

6.2.2.2 Potential Indirect Exposures

Burrowing crayfish utilize habitat provided by the ditches and the wetland areas in the Site Study Area and Project Area. Burrowing crayfish excavate burrows below the groundwater table, and therefore spend considerable time as adults immersed in groundwater. Therefore, changes to the radiological quality of surface water, groundwater and soil/sediment where burrowing crayfish live (i.e., the changes in radioactivity levels in these environmental media) could have effects on this VEC. As burrowing crayfish spend the majority of their time in water and soil/sediment, the change to radioactivity levels in air would have negligible effects on this VEC and this pathway can be screened out. A screening is carried out below to identify if the VEC could be indirectly affected during each phase of the DGR Project.

During the site preparation and construction phase, there are no project-related radiological emissions to the environment. Therefore, the quality of surface water, groundwater and soil/sediment will not be affected from the radiation and radioactivity perspective, and indirect effects of the site preparation and construction phase on benthic invertebrates are not possible. No further consideration is warranted.

During the operations phase, there could be radioactive airborne and waterborne emissions from the DGR Project. As a result, the radioactivity levels in surface water, groundwater, and soil/sediment could be changed from existing levels. The increased radioactivity levels in these environmental media where burrowing crayfish live could result in incremental doses to this benthic invertebrate. Therefore, indirect effects on benthic invertebrates due to project-related changes in the quality of surface water, groundwater and soil/sediment may occur, and these interactions are advanced for a second screening in Section 7. The related cells in Table 6.3-1 are therefore marked with a "•".

During the decommissioning phase, the quality of surface water, groundwater and soil/sediment could be affected by the airborne and waterborne emissions resulting from the decommissioning of the facilities. The increased radioactivity levels in these environmental media where burrowing crayfish live could result in some incremental doses to this benthic invertebrate. Therefore, indirect effects on benthic invertebrates due to radiological changes in quality of surface water, groundwater and soil/sediment may occur, and these interactions are advanced for a second screening. The related cells in Table 6.3-1 are therefore marked with a "•".

6.2.3 Aquatic Vegetation

In this assessment, variable leaf pondweed is used as an indicator for aquatic vegetation for determining the potential effects of radionuclides released from the DGR Project.

6.2.3.1 Potential Direct Exposures

All project works and activities associated with the DGR Project, as described in Appendix B, have been reviewed. There is no mechanism through which these project works and activities could result in the direct exposure of this VEC to radioactive waste packages. All exposures are

expected to be through indirect pathways (described in Section 6.2.3.2). Therefore, further assessment of potential direct effects of the DGR Project on aquatic vegetation is not warranted.

6.2.3.2 Potential Indirect Exposures

Variable leaf pondweed is found in surface water bodies in the Site Study Area and Project Area. It is not in direct contact with air and groundwater and therefore it is unlikely that changes to radioactivity levels in air and groundwater could have effects on this VEC. Therefore, indirect effects on aquatic vegetation due to the radiological changes to air quality and groundwater quality warrant no further assessment.

Changes to the radiological quality of surface water and soil/sediment where variable leaf pondweed is found could have effects on aquatic vegetation. A screening is carried out below to identify if the VEC could be indirectly affected during each phase of the DGR Project.

During the site preparation and construction phase, there are no project-related radiological emissions to the environment. Therefore, surface water quality and soil/sediment quality will not be affected from the radiation and radioactivity perspective. Since, indirect effects of the site preparation and construction phase on aquatic vegetation are not possible, further consideration is not warranted.

During the operations phase, there could be radioactive airborne and waterborne emissions. As a result, the radioactivity levels in soil/sediment and surface water could be changed from existing levels. The increased radioactivity levels in soil/sediment and water could result in incremental doses to aquatic vegetation. Therefore, indirect effects on this VEC resulting from project-related changes in soil/sediment quality and surface water quality may occur, and these interactions are advanced for a second screening. The related cells in Table 6.3-1 are therefore marked with a "•".

During the decommissioning phase, soil/sediment quality and surface water quality could be affected by the airborne and waterborne emissions resulting from the decommissioning of the facilities. The increased radioactivity levels in soil/sediment and water could result in incremental doses to this VEC. Therefore, indirect effects on aquatic vegetation resulting from changes in soil/sediment quality and surface water quality may occur, and these interactions are advanced for a second screening. The related cells in Table 6.3-1 are therefore marked with a "•".

6.2.4 Benthic Fish

In this assessment, lake whitefish, redbelly dace and creek chub are used as the indicators for benthic fish for determining the potential effects of radionuclides released from the DGR Project.

6.2.4.1 Potential Direct Exposures

All project works and activities associated with the DGR Project, as described in Appendix B, have been reviewed. There is no mechanism through which these project works and activities could result in the direct exposure of this VEC to radioactive waste packages. All exposures are

expected to be through indirect pathways (described in Section 6.2.4.2). Therefore, further assessment of the potential direct effects of the DGR Project on benthic fish is not warranted.

6.2.4.2 Potential Indirect Exposures

Benthic fish (as indicated by lake whitefish, redbelly dace and creek chub) are found at the bottom of surface water bodies in the Site Study Area and Project Area. It is unlikely that radiological changes to air quality and groundwater quality could have effects on this VEC. Therefore, indirect effects on benthic fish resulting from the radiological changes to air quality and groundwater quality warrant no further assessment.

Changes to the radiological quality of surface water and soil/sediment could have effects on benthic fish. A screening is carried out below to identify if the VEC could be indirectly affected during each phase of the DGR Project.

During the site preparation and construction phase, there are no project-related radiological emissions to the environment. Therefore, surface water quality and soil/sediment quality will not be affected from the radiation and radioactivity perspective. Because indirect effects on benthic fish during the site preparation and construction phase are not possible, further consideration is not warranted.

During the operations phase, there could be radioactive airborne and waterborne emissions from the DGR Project. As a result, the radioactivity levels in soil/sediment and surface water could be changed from existing levels. The increased radioactivity levels in soil/sediment and water could result in incremental doses to this VEC. Therefore, indirect effects on benthic fish resulting from radiological changes in soil/sediment quality and surface water quality may occur, and these interactions are advanced for a second screening. The related cells in Table 6.3-1 are therefore marked with a “•”.

During the decommissioning phase, soil/sediment quality and surface water quality could be affected by the airborne and waterborne emissions resulting from the decommissioning of the facilities. The increased radioactivity levels in soil/sediment and water could result in some incremental doses to this VEC. Therefore, indirect effects on benthic fish resulting from radiological changes in soil/sediment quality and surface water quality may occur, and these interactions are advanced for a second screening. The related cells in Table 6.3-1 are therefore marked with a “•”.

Consumption of food that might be contaminated is considered a mechanism through which the DGR Project potentially interacts with this VEC and therefore is advanced to Section 7 for a second screening. The related cells in Table 6.3-1 are therefore marked with a “•”.

6.2.5 Pelagic Fish

In this assessment, smallmouth bass, spottail shiner and brook trout are used to represent pelagic fish for determining the potential effects of radionuclides released from the DGR Project.

6.2.5.1 Potential Direct Exposures

All project works and activities associated with the DGR Project, as described in Appendix B, have been reviewed. There is no mechanism through which these project works and activities could result in the direct exposure of this VEC to radioactive waste packages. All exposures are expected to be through indirect pathways (described in Section 6.2.5.2). Therefore, further assessment of the direct effects of the DGR Project on pelagic fish is not warranted.

6.2.5.2 Potential Indirect Exposures

Pelagic fish use surface water bodies in the Local and Regional Study Area. As noted, pelagic fish do not spend a large amount of time near the sediment layer in lakes and rivers. As a result, it is unlikely that radiological changes to air quality, groundwater quality and soil/sediment quality could have effects on this VEC. Therefore, potential indirect effects on pelagic fish resulting from potential radiological changes to air quality, groundwater quality and soil/sediment quality warrant no further assessment.

Project-related changes to the radiological quality of surface water could have effects on pelagic fish. A screening is carried out below to identify if the VEC could be indirectly affected during each phase of the DGR Project.

During the site preparation and construction phase, there are no project-related radiological emissions to the environment. Therefore, surface water quality will not be affected from the radiation and radioactivity perspective. Since indirect effects on pelagic fish during the site preparation and construction phase are not possible, further consideration is not warranted.

During the operations phase, there could be radioactive airborne and waterborne emissions from the DGR Project. As a result, the radioactivity levels in surface water could be changed from existing levels. The increased radioactivity levels in surface water could result in incremental doses to this VEC. Therefore, indirect effects on pelagic fish resulting from project-related radiological changes in surface water quality may occur, and this interaction is advanced for a second screening. The related cell in Table 6.3-1 is therefore marked with a "•".

During the decommissioning phase, surface water quality could be affected by the airborne and waterborne emissions resulting from decommissioning activities. The increased radioactivity levels in surface water could result in incremental doses to this VEC. Therefore, indirect effects on pelagic fish resulting from project-related radiological changes in surface water quality may occur, and this interaction is advanced for a second screening. The related cell in Table 6.3-1 is therefore marked with a "•".

Consumption of food that might be contaminated is considered a mechanism through which the DGR Project potentially interacts with this VEC and therefore is advanced to Section 7 for a second screening. The related cells in Table 6.3-1 are therefore marked with a "•".

6.2.6 Aquatic Birds

In this assessment, double-crested cormorant and mallard are used to represent aquatic birds for determining the potential effects of radionuclides released from the DGR Project.

6.2.6.1 Potential Direct Exposures

The DGR Project could result in the direct exposure of aquatic birds to radiation. For example, aquatic birds, which may use marshy areas or woodland pools in the Project Area, could be exposed to gamma radiation from the waste packages during above-ground transfer of waste, and while being handled within the WPRB. Therefore, there is a potential mechanism through which the DGR Project may directly interact with this VEC from the radiation and radioactivity perspective. Further assessment of the direct effects of the above-ground transfer of waste on aquatic birds is warranted, and this interaction is advanced to Section 7 for a second screening. The related cell in Table 6.3-1 is therefore marked with a "•".

6.2.6.2 Potential Indirect Exposures

Aquatic birds spend large fractions of their time at least partially immersed in water bodies (i.e., diving/dabbling). It is unlikely that the changes of radioactivity level in groundwater could affect this VEC. Therefore, potential indirect effects on aquatic birds resulting from changes to groundwater quality warrant no further assessment.

Project-related changes to the radiological quality of air, surface water and soil/sediment could have effects on aquatic birds. A screening is carried out below to identify if the VEC could be indirectly affected during each phase of the DGR Project considered in this TSD.

During the site preparation and construction phase, there are no project-related radiological emissions to the environment. Therefore, air quality, surface water quality and soil/sediment quality will not be affected from the radiation and radioactivity perspective. Since indirect effects on aquatic birds during the site preparation and construction phase are not possible, no further consideration is warranted.

During the operations phase, there could be radioactive airborne and waterborne emissions from the DGR Project. As a result, the radioactivity levels in air, soil/sediment and surface water could be changed from existing levels. The increased radioactivity levels in air, soil/sediment and water could result in incremental doses to this VEC. Therefore, indirect effects on aquatic birds resulting from radiological changes in air quality, soil/sediment quality and surface water quality may occur, and these interactions are advanced for a second screening. The related cells in Table 6.3-1 are therefore marked with a "•".

During the decommissioning phase, air quality, soil/sediment quality and surface water quality could be affected by the airborne and waterborne emissions resulting from the decommissioning of the DGR. The increased radioactivity levels in air, soil/sediment and water could result in incremental doses to this VEC. Therefore, indirect effects on aquatic birds resulting from radiological changes in air quality, soil/sediment quality and surface water quality may occur, and these interactions are advanced for a second screening. The related cells in Table 6.3-1 are therefore marked with a "•".

Consumption of food (such as invertebrates) that might be contaminated is considered a mechanism through which the DGR Project potentially interacts with this VEC and therefore is advanced to Section 7 for a second screening. The related cells in Table 6.3-1 are therefore marked with a "•".

6.2.7 Aquatic Mammals

In this assessment, muskrat is used to represent aquatic mammals for determining the potential effects of radionuclides released from the DGR Project.

6.2.7.1 Potential Direct Exposures

The DGR Project could result in the direct exposure of aquatic mammals to radiation. For example, aquatic mammals such as muskrat, which have been recorded close to the location where the abandoned rail bed crossing from the WWMF is proposed, could be exposed to gamma radiation from the waste packages during above-ground transfer of waste and while being handled within the WPRB. Therefore, there is a potential mechanism through which the DGR Project may directly interact with this VEC from the radiation and radioactivity perspective, and further assessment of the direct effects of the above-ground transfer of waste on aquatic mammals is warranted. This interaction is advanced to Section 7 for a second screening. The related cell in Table 6.3-1 is therefore marked with a "•".

6.2.7.2 Potential Indirect Exposures

Aquatic mammals spend large fractions of their time immersed in water (e.g., wetted ditches and wetland areas). In general, it is unlikely that the radiological changes in groundwater quality could have effects on this VEC, although occasionally groundwater seeps might provide a source of drinking water. Therefore, indirect effects on aquatic mammals resulting from potential radiological changes to groundwater quality warrant no further assessment.

Project-related changes to the radiological quality of air, surface water and soil/sediment could affect aquatic mammals. A screening is carried out below to identify if the VEC could be indirectly affected during each phase of the DGR Project.

During the site preparation and construction phase, there are no project-related radiological emissions to the environment. Therefore, air quality, surface water quality and soil/sediment quality will not be affected from the radiation and radioactivity perspective. Because, indirect effects on aquatic mammals during the site preparation and construction phase are not possible, no further consideration is warranted.

During the operations phase, there could be radioactive airborne and waterborne emissions from the DGR Project. As a result, the radioactivity levels in air, soil/sediment and surface water could be changed from existing levels. The increased radioactivity levels in air, soil/sediment and water could result in incremental doses to this VEC. Therefore, indirect effects on aquatic mammals resulting from project-related radiological changes in air quality, soil/sediment quality and surface water quality may occur, and these interactions are advanced for a second screening. The related cells in Table 6.3-1 are therefore marked with a "•".

During the decommissioning phase, air quality, soil/sediment quality and surface water quality could be affected by airborne and waterborne emissions resulting from the decommissioning of the DGR Project. The increased radioactivity levels in air, soil/sediment and water could result in incremental doses to this VEC. Therefore, indirect effects on aquatic mammals because of project-related radiological changes in air quality, soil/sediment quality and surface water quality may occur, and these interactions are advanced for a second screening. The related cells in Table 6.3-1 are therefore marked with a "•".

Consumption of food (such as aquatic vegetation) which might be contaminated is considered a mechanism through which the DGR Project could potentially interact with this VEC and therefore is advanced to Section 7 for a second screening. The related cells in Table 6.3-1 are therefore marked with a "•".

6.2.8 Terrestrial Invertebrates

In this assessment, earthworm is used as the indicator for the terrestrial invertebrates for determining the potential effects of radionuclides released from the DGR Project.

6.2.8.1 Potential Direct Exposures

The DGR Project could result in the direct exposure of terrestrial invertebrates to radiation. For example, terrestrial invertebrates could be exposed to gamma radiation from the waste packages during above-ground transfer of waste and while being handled within the WPRB. Therefore, there is a potential mechanism through which the DGR Project may directly interact with this VEC from the radiation and radioactivity perspective, and further assessment of the direct effects of the DGR Project on terrestrial invertebrates is warranted. This interaction is advanced to Section 7 for a second screening. The related cell in Table 6.3-1 is therefore marked with a "•".

6.2.8.2 Potential Indirect Exposures

Earthworms are found in soil and also come into regular contact with groundwater. Therefore, changes to the radiological quality of soil and groundwater where earthworms live (i.e., the changes in radioactivity levels in these environmental media) could have effects on this VEC. As earthworms spend the vast majority of their time in soil and groundwater, the change to radioactivity levels in air and surface water has negligible effects on this VEC and these pathways can be screened out. A screening is carried out below to identify if the VEC could be indirectly affected during each phase of the DGR Project.

During the site preparation and construction phase, there is no project-related radiological emission to the environment. Therefore, the quality of groundwater and soil will not be affected from the radiation and radioactivity perspective. Thus, indirect effects of the site preparation and construction phase on terrestrial invertebrates are not possible, and no further consideration is warranted.

During the operations phase, there could be radioactive airborne and waterborne emissions from the DGR Project. As a result, the radioactivity levels in groundwater and soil could be changed from existing levels. The increased radioactivity levels in these environmental media where earthworms live could result in incremental doses to this terrestrial invertebrate. Therefore, indirect effects on terrestrial invertebrates due to project-related changes in the quality of groundwater and soil may occur, and these interactions are advanced for a second screening in Section 7. The related cells in Table 6.3-1 are therefore marked with a "•".

During the decommissioning phase, the quality of groundwater and soil could be affected by the airborne and waterborne emissions resulting from the decommissioning of the facilities. The increased radioactivity levels in these environmental media where earthworm lives could result in some incremental doses to this terrestrial invertebrate. Therefore, indirect effects on terrestrial invertebrates due to radiological changes in quality of groundwater and soil may occur, and these interactions are advanced for a second screening. The related cells in Table 6.3-1 are therefore marked with a "•".

6.2.9 Terrestrial Vegetation

In this assessment, eastern white cedar, common cattail and heal-all are selected as the indicators of terrestrial vegetation for determining potential effects of radionuclides released from the DGR Project.

6.2.9.1 Potential Direct Exposures

The DGR Project could result in the direct exposure of terrestrial vegetation to radiation. For example, terrestrial vegetation could be exposed to gamma radiation from the waste packages during above-ground transfer of waste and while being handled within the WPRB. Therefore, there is a potential mechanism through which the DGR Project may directly interact with this VEC from the radiation and radioactivity perspective. Thus, further assessment of the direct effects of the above-ground transfer of waste on terrestrial vegetation is warranted, and this interaction is advanced to Section 7 for a second screening. The related cell in Table 6.3-1 is therefore marked with a "•".

6.2.9.2 Potential Indirect Exposures

The radiological changes to the quality of air, soil/sediment, and surface water could have effects on terrestrial plants. A screening is carried out below to identify if the VEC could be indirectly affected during each phase of the DGR Project. It is unlikely that radiological changes in groundwater quality, if any, will interact with terrestrial plants since root water uptake by plants is considered through changes to surface water quality[9]. No further consideration of the groundwater pathway is warranted.

During the site preparation and construction phase, there are no project-related radiological emissions to the environment. Therefore, air quality, soil/sediment quality, and surface water quality will not be affected from the radiation and radioactivity perspective. Because indirect effects on terrestrial plants during the site preparation and construction phase are not possible, further consideration is not warranted.

During the operations phase, there could be radioactive airborne and waterborne emissions from the DGR Project. As a result, the radioactivity levels in air, soil/sediment, and surface water could be changed from existing levels. The increased radioactivity levels in air, soil, and surface water could result in incremental doses to this VEC. Therefore, indirect effects on terrestrial plants because of project-related radiological changes in air quality, soil quality and

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[9] In this work, root water is considered surface water, not ground water. Note that groundwater is less likely to be contaminated by the DGR Project.

surface water quality may occur, and these interactions are advanced for a second screening. The related cells in Table 6.3-1 are therefore marked with a "•".

During the decommissioning phase, air quality, soil quality, and surface water quality could be affected by the airborne and waterborne emissions resulting from the decommissioning of the DGR. The increased radioactivity levels in air, soil, and surface water could result in some incremental doses to this VEC. Therefore, indirect effects on terrestrial plants because of project-related changes in air quality, soil quality, and surface water quality may occur, and these interactions are advanced for a second screening. The related cells in Table 6.3-1 are therefore marked with a "•".

6.2.10 Terrestrial Birds

In this assessment, yellow warbler, red-eyed vireo, wild turkey and bald eagle are selected as indicators for terrestrial birds for determining potential effects of radionuclides released from the DGR Project.

6.2.10.1 Potential Direct Exposures

The DGR Project could result in the direct exposure of terrestrial birds to radiation. For example, terrestrial birds could be exposed to gamma radiation from the waste packages during above-ground transfer of waste and while being handled within the WPRB. Therefore, there is a potential mechanism through which the DGR Project may directly interact with this VEC from the radiation and radioactivity perspective, and further assessment of the direct effects of the above-ground transfer of waste on terrestrial birds is warranted. This interaction is advanced to Section 7 for a second screening. The related cell in Table 6.3-1 is therefore marked with a "•".

6.2.10.2 Potential Indirect Exposures

In general, terrestrial birds do not intake groundwater, although occasionally groundwater seeps could provide a source of drinking water for this VEC. Therefore, it is unlikely that the potential changes of radioactivity levels in groundwater could have effects on this VEC. Thus, indirect effects on terrestrial birds resulting from the radiological changes to groundwater quality warrant no further assessment.

The radiological changes to the quality of air, surface water and soil could have effects on terrestrial birds. A screening is carried out below to identify if the VEC could be indirectly affected during each phase of the DGR Project.

During the site preparation and construction phase, there are no project-related radiological emissions to the environment. Therefore, air quality, surface water quality and soil quality will not be affected from the radiation and radioactivity perspective. Because indirect effects on terrestrial birds during the site preparation and construction phase are not possible, no further consideration is warranted.

During the operations phase, there could be both radioactive airborne and waterborne emissions from the DGR Project. As a result, the radioactivity levels in air, soil and surface water could be changed from existing levels. The increased radioactivity levels in air, soil and surface water could result in incremental doses to this VEC. Therefore, indirect effects on terrestrial birds caused by project-related radiological changes in air quality, soil quality and surface water quality may occur, and these interactions are advanced for a second screening. The related cells in Table 6.3-1 are therefore marked with a "•".

During the decommissioning phase, air quality, soil quality and surface water quality could be affected by the airborne and waterborne emissions resulting from decommissioning of the DGR Project. The increased radioactivity levels in air, soil and surface water could result in incremental doses to this VEC. Therefore, indirect effects on terrestrial birds because of project-related radiological changes in air quality, soil quality and surface water quality may occur, and these interactions are advanced for a second screening. The related cells in Table 6.3-1 are therefore marked with "•".

Consumption of food (such as terrestrial invertebrates), which might be contaminated is considered a mechanism through which the DGR Project potentially interacts with this VEC and therefore is advanced to Section 7 for a second screening. The related cells in Table 6.3-1 are therefore marked with a "•".

6.2.11 Terrestrial Mammals

In this assessment, white-tailed deer, the northern short-tailed shrew and red fox are selected as the representative terrestrial mammals for determining the potential effects of radionuclides released from the DGR Project.

6.2.11.1 Potential Direct Exposures

The DGR Project could result in the direct exposure of terrestrial mammals to radiation. For example, terrestrial mammals could be exposed to gamma radiation from the waste packages during above-ground transfer of waste and while being handled within the WPRB. Therefore, there is a potential mechanism through which the DGR Project may directly interact with this VEC from the radiation and radioactivity perspective, and further assessment of the direct effects of the above-ground transfer of waste on terrestrial mammals is warranted. This interaction is advanced to Section 7 for a second screening. The related cell in Table 6.3-1 is therefore marked with a "•".

6.2.11.2 Potential Indirect Exposures

In general, terrestrial mammals do not intake groundwater although occasionally groundwater seeps may provide a source of drinking water for this VEC. Therefore, it is unlikely that the radiological changes to groundwater quality, if any, could have effects on this VEC. Thus, indirect effects on terrestrial mammals due to the radiological changes to groundwater quality warrant no further assessment.

The radiological changes to the quality of air, surface water and soil could have effects on terrestrial mammals. A screening is carried out below to identify if the VEC could be indirectly affected during each phase of the DGR Project.

During the site preparation and construction phase, there are no project-related radiological emissions to the environment. Therefore, air quality, surface water quality and soil quality will not be affected from the radiation and radioactivity perspective. Because indirect effects on terrestrial mammals during the site preparation and construction phase are not possible, no further consideration is warranted.

During the operations phase, there could be radioactive airborne and waterborne emissions from the DGR Project. As a result, the radioactivity levels in air, soil and surface water could be changed from existing levels. The increased radioactivity levels in air, soil and surface water could result in incremental doses to this VEC. Therefore, indirect effects on terrestrial mammals because of project-related radiological changes in air quality, soil quality and surface water quality may occur, and these interactions are advanced for a second screening. The related cells in Table 6.3-1 are therefore marked with "•".

During the decommissioning phase, air quality, soil quality and surface water quality could be affected by the airborne and waterborne emissions resulting from the decommissioning of the DGR. The increased radioactivity levels in air, soil and surface water could result in incremental doses to this VEC. Therefore, indirect effects on terrestrial mammals because of project-related radiological changes in air quality, soil quality and surface water quality may occur, and these interactions are advanced for a second screening. The related cells in Table 6.3-1 are therefore marked with a "•".

Consumption of food that might be contaminated is considered a mechanism through which the DGR Project potentially interacts with this VEC and therefore is advanced to Section 7 for a second screening. The related cells in Table 6.3-1 are therefore marked with a "•".

6.2.12 Amphibians and Reptiles

In this assessment, northern leopard frog and midland painted turtle are selected as the representative amphibians and reptiles for determining the potential effects of radionuclides released from the DGR Project.

6.2.12.1 Potential Direct Exposures

The DGR Project could result in the direct exposure of amphibians and reptiles to radiation. For example, amphibians and reptiles inhabiting the North and South Railway Ditches could be exposed to gamma radiation from the waste packages during above-ground transfer of waste and while being handled within the WPRB. Therefore, there is a potential mechanism through which the DGR Project may directly interact with this VEC from the radiation and radioactivity perspective, and further assessment of the direct effects of the above-ground transfer of waste on amphibians and reptiles is warranted. This interaction is advanced to Section 7 for a second screening. The related cell in Table 6.3-1 is therefore marked with a "•".

6.2.12.2 Potential Indirect Exposures

Amphibians and reptiles would intake groundwater under extremely rare circumstances. It is unlikely that the changes of radioactivity level in groundwater quality, if any, could have effects on this VEC. Therefore, potential indirect effects on amphibians and reptiles due to radiological changes to groundwater quality warrant no further assessment.

Radiological changes to the quality of air, surface water and soil/sediment could have effects on amphibians and reptiles. A screening is carried out below to identify if the VEC could be indirectly affected during each phase of the DGR Project.

During the site preparation and construction phase, there are no project-related radiological emissions to the environment. Therefore, air quality, surface water quality and soil/sediment quality will not be affected from the radiation and radioactivity perspective. Because indirect effects on amphibians and reptiles during the site preparation and construction phase are not possible, further consideration is not warranted.

During the operations phase, there could be radioactive airborne and waterborne emissions from the DGR Project. As a result, the radioactivity levels in air, soil/sediment and surface water could be changed from existing levels. The increased radioactivity levels in air, soil/sediment and water could result in incremental doses to this VEC. Therefore, indirect effects on amphibians and reptiles because of project-related radiological changes in air quality, soil/sediment quality and surface water quality may occur, and these interactions are advanced for a second screening. The related cells in Table 6.3-1 are therefore marked with a "•".

During the decommissioning phase, air quality, soil quality and surface water quality could be affected by the airborne and waterborne emissions resulting from the decommissioning of the DGR. The increased radioactivity levels in air, soil/sediment and surface water could result in incremental doses to this VEC. Therefore, indirect effects on amphibians and reptiles because of project-related radiological changes in air quality, soil quality and surface water quality may occur, and these interactions are advanced for a second screening. The related cells in Table 6.3-1 are therefore marked with "•".

Consumption of food that might be contaminated is considered a mechanism through which the DGR Project potentially interacts with this VEC and therefore is advanced to Section 7 for a second screening. The related cells in Table 6.3-1 are therefore marked with a "•".

6.3 SUMMARY OF FIRST SCREENING

Table 6.3-1 provides a summary of the initial screening for the DGR Project. Small dots (•) on this matrix represent potential project-environment interactions involving specific VECs. These interactions are advanced to Section 7 for a second screening to determine those interactions that likely result in a measurable change to the radiation and radioactivity VECs.

Table 6.3-1: Matrix 1 – Summary of the First Screening for Potential Interactions with VECs

Project Work and Activity	Humans			Benthic Invertebrates			Aquatic Vegetation			Benthic Fish		
	C	O	D	C	O	D	C	O	D	C	O	D
Potential Direct Exposures												
Site Preparation		—	—		—	—		—	—		—	—
Construction of Surface Facilities		—	—		—	—		—	—		—	—
Excavation and Construction of Underground Facilities		—	—		—	—		—	—		—	—
Above-ground Transfer of Waste	—	•	—	—		—	—		—	—		—
Underground Transfer of Waste	—	•	—	—		—	—		—	—		—
Decommissioning of the DGR Project	—	—	•	—	—		—	—		—	—	
Abandonment of the DGR Facility	—	—		—	—		—	—		—	—	
Presence of the DGR Project												
Waste Management		•	•									
Support and Monitoring of DGR Life Cycle		•	•									
Workers, Payroll and Purchasing												
Potential Indirect Exposures												
Radiological Changes in Air Quality	•	•	•									
Radiological Changes in Surface Water Quality		•	•		•	•		•	•		•	•
Radiological Changes in Soil/Sediment Quality		•	•		•	•		•	•		•	•
Radiological Changes in Groundwater Quality		•	•		•	•						
Changed Radionuclide Concentrations in Food		•	•								•	•

Notes:
C = Site Preparation and Construction Phase
O = Operations Phase
D = Decommissioning Phase
The matrices are meant to indicate when the effect occurs and do not imply how long the effect will last. The duration of the effect is assessed in Section 11.

The abandonment and long-term performance phase is not included in the matrix as no activities occur during this phase. The abandonment of the DGR facility work and activity occurs immediately following decommissioning within the decommissioning phase and does not encompass the entirety of the abandonment and long-term performance phase.

• Potential project-environment interaction
— Activity does not occur during this phase
Blank No potential interaction

Table 6.3-1: Matrix 1 – Summary of the First Screening for Potential Interactions with VECs (continued)

Project Work and Activity	Pelagic Fish			Aquatic Birds			Aquatic Mammals			Terrestrial Invertebrates		
	C	O	D	C	O	D	C	O	D	C	O	D
Potential Direct Exposures												
Site Preparation		—	—		—	—		—	—		—	—
Construction of Surface Facilities		—	—		—	—		—	—		—	—
Excavation and Construction of Underground Facilities		—	—		—	—		—	—		—	—
Above-ground Transfer of Waste	—		—	—	•	—	—	•	—	—	•	—
Underground Transfer of Waste	—		—	—		—	—		—	—		—
Decommissioning of the DGR Project	—	—		—	—		—	—		—	—	
Abandonment of the DGR Facility	—	—		—	—		—	—		—	—	
Presence of the DGR Project												
Waste Management												
Support and Monitoring of DGR Life Cycle												
Workers, Payroll and Purchasing												
Potential Indirect Exposures												
Radiological Changes in Air Quality					•	•		•	•			
Radiological Changes in Surface Water Quality		•	•		•	•		•	•			
Radiological Changes in Soil/Sediment Quality					•	•		•	•		•	•
Radiological Changes in Groundwater Quality											•	•
Changed Radionuclide Concentrations in Food		•	•		•	•		•	•			

Notes:
C = Site Preparation and Construction Phase
O = Operations Phase
D = Decommissioning Phase
The matrices are meant to indicate when the effect occurs and do not imply how long the effect will last. The duration of the effect is assessed in Section 11.

The abandonment and long-term performance phase is not included in the matrix as no activities occur during this phase. The abandonment of the DGR facility work and activity occurs immediately following decommissioning within the decommissioning phase and does not encompass the entirety of the abandonment and long-term performance phase.

• Potential project-environment interaction
— Activity does not occur during this phase
Blank No potential interaction

Table 6.3-1: Matrix 1 – Summary of the First Screening for Potential Interactions with VECs (continued)

Project Work and Activity	Terrestrial Vegetation			Terrestrial Birds			Terrestrial Mammals			Amphibians and Reptiles		
	C	O	D	C	O	D	C	O	D	C	O	D
Potential Direct Exposures												
Site Preparation		—	—		—	—		—	—		—	—
Construction of Surface Facilities		—	—		—	—		—	—		—	—
Excavation and Construction of Underground Facilities		—	—		—	—		—	—		—	—
Above-ground Transfer of Waste	—	•	—	—	•	—	—	•	—	—	•	—
Underground Transfer of Waste	—		—	—		—	—		—	—		—
Decommissioning of the DGR Project	—	—		—	—		—	—		—	—	
Abandonment of the DGR Facility	—	—		—	—		—	—		—	—	
Presence of the DGR Project												
Waste Management												
Support and Monitoring of DGR Life Cycle												
Workers, Payroll and Purchasing												
Potential Indirect Exposures												
Radiological Changes in Air Quality		•	•		•	•		•	•		•	•
Radiological Changes in Surface Water Quality		•	•		•	•		•	•		•	•
Radiological Changes in Soil/Sediment Quality		•	•		•	•		•	•		•	•
Radiological Changes in Groundwater Quality												
Changed Radionuclide Concentrations in Food					•	•		•	•		•	•

Notes:
C = Site Preparation and Construction Phase
O = Operations Phase
D = Decommissioning Phase
The matrices are meant to indicate when the effect occurs and do not imply how long the effect will last. The duration of the effect is assessed in Section 11.

The abandonment and long-term performance phase is not included in the matrix as no activities occur during this phase. The abandonment of the DGR facility work and activity occurs immediately following decommissioning within the decommissioning phase and does not encompass the entirety of the abandonment and long-term performance phase.

• Potential project-environment interaction
— Activity does not occur during this phase
Blank No potential interaction

Following the screening of potential project-environment interactions, all VECs identified could potentially interact with the DGR Project from a radiation and radioactivity perspective. Therefore, as summarized in Table 6.3-2, all of the VECs proposed in Table 4-1 will be carried forward for further assessment.

Table 6.3-2: Advancement of Radiation and Radioactivity VECs

VEC	Retained?	Rationale
Humans	Yes	Direct Exposure: Above-ground/underground waste transfer including waste packages being handled in the WPRB; waste management; DGR decommissioning; support and monitoring Indirect Exposure: Radiological Changes in Quality of Air; Surface Water; Soil; Groundwater Quality; Consumption of contaminated food
Benthic Invertebrates	Yes	Indirect Exposure: Radiological Changes in Quality of Surface Water; Groundwater; Soil/Sediment
Aquatic Vegetation	Yes	Indirect Exposure: Radiological Changes in Quality of Surface Water; Soil/Sediment
Benthic Fish	Yes	Indirect Exposure: Radiological Changes in Quality of Surface Water; Soil/Sediment; Consumption of contaminated food
Pelagic Fish	Yes	Indirect Exposure: Radiological Changes in Quality of Surface Water; Consumption of contaminated food
Aquatic Birds	Yes	Direct Exposure: Above-ground waste transfer including waste packages being handled in the WPRB Indirect Exposure: Radiological Changes in Quality of Air; Surface Water; Soil/Sediment; Consumption of contaminated food
Aquatic Mammals	Yes	Direct Exposure: Above-ground waste transfer including waste packages being handled in the WPRB Indirect Exposure: Radiological Changes in Quality of Air; Surface Water; Soil/Sediment; Consumption of contaminated food
Terrestrial Invertebrates	Yes	Direct Exposure: Above-ground waste transfer including waste packages being handled in the WPRB Indirect Exposure: Radiological Changes in Quality of Groundwater; Soil
Terrestrial Vegetation	Yes	Direct Exposure: Above-ground waste transfer including waste packages being handled in the WPRB Indirect Exposure: Radiological Changes in Quality of Air; Surface Water; Soil
Terrestrial Birds	Yes	Direct Exposure: Above-ground waste transfer including waste packages being handled in the WPRB Indirect Exposure: Radiological Changes in Quality of Air; Surface Water; Soil; Consumption of contaminated food

Table 6.3-2: Advancement of Radiation and Radioactivity VECs (continued)

VEC	Retained?	Rationale
Terrestrial Mammals	Yes	Direct Exposure: Above-ground waste transfer including waste packages being handled in the WPRB Indirect Exposure: Radiological Changes in Quality of Air; Soil; Surface Water; Consumption of contaminated food
Amphibians and Reptiles	Yes	Direct Exposure: Above-ground waste transfer including waste packages being handled in the WPRB Indirect Exposure: Radiological Changes in Quality of Air; Surface Water; Soil/Sediment; Consumption of contaminated food

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7. SECOND SCREENING FOR MEASURABLE CHANGE

The second screening considers the DGR Project works and activities advanced from Section 6 to determine if the identified interactions are likely to cause a measurable change to the radiation and radioactivity VECs. As noted previously, potential effects of radiation and radioactivity during the abandonment and long-term performance phase of the DGR Project are discussed in Section 9 of the EIS.

7.1 SECOND SCREENING METHODS

Each of the potential interactions identified in the first screening is evaluated to determine those likely to result in a measurable change in the environment. For the purposes of the assessment, a measurable change in the environment is defined as change that is real, observable or detectable compared with existing conditions. For the purposes of the Radiation and Radioactivity TSD, if a change in concentration over baseline is likely, the interaction is advanced as a measurable change for detailed assessment. A likely measurable change to a VEC is marked with a '■' on Matrix 2 (Section 7.13). A predicted change that is trivial, negligible or indistinguishable from baseline conditions is not considered measurable.

7.2 HUMANS

7.2.1 Measurable Changes to Direct Exposures

For conservative purposes, any potential human exposure to project-related radiation identified in Section 6.2.1.1 is considered measurable. The direct effects of the DGR Project works and activities on humans will be collectively considered in Section 8.

7.2.2 Measurable Changes to Indirect Exposures

The first screening determined humans could be exposed to radon gas during site preparation and construction phase and operations phase. However, a recent study indicated that there is no significant radon hazard to the workers or general public during development and operation of the DGR resulting from the low concentration of uranium in the host rock, the rock properties and low concentration of radium in the waste [69]. For example, the maximum dose rate attributable to the exposure to radon gas, based on conservative assumptions outlined in the radon assessment document [69], is 0.04 mSv/a to workers located at the leeward side of the waste rock pile and 2.2×10^{-5} mSv/a to the public, far less than the dose criteria for workers and members of the public. Therefore, further assessment of potential interactions related to radon gas exposure is not warranted.

However, the indirect exposures to humans resulting from the changes of radionuclide levels in all environmental media such as air, surface water, groundwater, and soil/sediment as the result of emission of radionuclides from the waste packages are judged to be measurable. Consumption of contaminated food is also considered to result in a measurable change in dose to humans. These indirect exposures will be collectively considered in Section 8.

7.3 BENTHIC INVERTEBRATES

7.3.1 Measurable Changes to Direct Exposures

The first screening determined all project works and activities have no direct effects on benthic invertebrates from the radiation and radioactivity perspective.

7.3.2 Measurable Changes to Indirect Exposures

The first screening determined the following indirect project-related exposures exist for this VEC:

- radiological changes to surface water quality;
- radiological changes to groundwater quality; and
- radiological changes to soil/sediment quality.

The radionuclides released as a result of the DGR Project consist of tritium and carbon-14 [4], which could contaminate surface water, groundwater and soil/sediment. Accordingly, the concentrations of tritium and carbon-14 in surface water, groundwater and sediment could increase, which will result in an incremental dose to benthic invertebrates (indicated by burrowing crayfish). Therefore, a likely measurable change is identified. These interactions are advanced to Section 8 for a detailed calculation of doses to burrowing crayfish to determine the radiological effects, if any, of the DGR Project on benthic invertebrates.

7.4 AQUATIC VEGETATION

7.4.1 Measurable Changes to Direct Exposures

The first screening determined all project works and activities have no direct effects on aquatic vegetation from the radiation and radioactivity perspective.

7.4.2 Measurable Changes to Indirect Exposures

The first screening determined the following indirect project-related exposures exist for this VEC:

- radiological changes to surface water quality; and
- radiological changes to soil/sediment quality.

As noted above, the radionuclides released as a result of the DGR Project consist of tritium and carbon-14 [4], which could be released to surface water and sediment. Accordingly, the concentrations of tritium and carbon-14 in surface water and sediment could increase, which will result in an incremental dose to this VEC. Therefore, a detailed calculation of doses is required to determine the likely radiological effects of the DGR Project on aquatic vegetation. As a result, a likely measurable change is identified, and these interactions are advanced to Section 8 for further consideration.

7.5 BENTHIC FISH

7.5.1 Measurable Changes to Direct Exposures

The first screening determined all project works and activities have no direct effects on benthic fish from the radiation and radioactivity perspective.

7.5.2 Measurable Changes to Indirect Exposures

The first screening has determined that the following indirect exposures exist for this VEC:

- radiological changes to surface water quality;
- radiological changes to soil/sediment quality; and
- radiological changes in food.

The radionuclides released as a result of the DGR Project consist of tritium and carbon-14 [4], which could contaminate surface water and soil/sediment. Accordingly, the concentrations of these radionuclides in surface water and sediment could increase, which will result in an incremental dose to this VEC. Therefore, a detailed calculation of doses is required to determine the likely radiological effects of the DGR Project on benthic fish. As a result, a measurable change is identified, and these interactions are advanced to Section 8 for further consideration.

7.6 PELAGIC FISH

7.6.1 Measurable Changes to Direct Exposures

The first screening determined all project works and activities have no direct effects on pelagic fish from the radiation and radioactivity perspective.

7.6.2 Measurable Changes to Indirect Exposures

The first screening determined the following indirect project-related exposure exists for this VEC:

- radiological changes to surface water quality; and
- radiological changes in food.

The concentrations of tritium and carbon-14 in surface water could increase as a result of project-related releases. The increased radionuclide concentrations will result in an incremental dose to this VEC, warranting a detailed calculation of doses to determine the likely radiological effects of the DGR Project on pelagic fish. Therefore, a likely measurable change is identified, and this interaction is advanced to Section 8 for further consideration.

7.7 AQUATIC BIRDS

7.7.1 Measurable Changes to Direct Exposures

The first screening determined the DGR Project has the potential to directly affect aquatic birds from the radiation and radioactivity perspective. Aquatic birds could be exposed to gamma radiation from the waste packages during above-ground transfer of waste and could also be exposed to radiation emanating from WPRB where the waste packages could be stored temporarily prior to transfer underground.

The maximum allowable dose rate at 2 m from a waste package for transport is 0.1 mSv/h. Assuming the closest distance that an aquatic bird gets to a waste package is 10 m, and the waste package behaves as a point source at this distance, the maximum external exposure rate for the bird would be 0.004 mSv/h. If the waste transfer vehicle would take, conservatively, 1 hour per day passing the small area along the transfer route where the aquatic bird is located, the daily dose received by the aquatic bird would be 0.004 mGy (1 Gy = 1 Sv for gamma radiation), which is three orders of magnitude less than the criterion for this VEC (see Table 8.1.1-1). In addition, it should be noted the effect from exposure to waste packages in transit would be limited to the individual members of populations of aquatic birds in the near vicinity of the transfer route. The overall populations of aquatic birds would remain unaffected, in particular those populations spanning the Local and Regional Study Areas.

It has been estimated that the highest dose rate is less than 0.025 mSv/h at 1 m outside of the WPRB external walls and 0.01 mSv/h on the roof directly above the source(when there are 24 LLW boxes with feeder pipes in the staging area within WPRB). The daily dose received by an aquatic bird at a distance of 10 m outside the WPRB external walls would be, if staying for 1 hour per day, 0.00025 mGy, which is four orders of magnitude less than the criterion for this VEC. If it perches on the roof of the WPRB for one hour per day, the daily dose would be 0.01 mGy, which is two orders of magnitude less than the criterion (Table 8.1.1-1). In addition, it should be noted that the estimated dose would be limited to the individual members of populations of aquatic birds in the near vicinity of the WPRB. The overall populations of aquatic birds would remain unaffected, in particular those populations spanning the Local and Regional Study Areas.

In summary, the direct effects of the DGR Project on aquatic birds are negligible compared with the dose criteria considered in the report. Therefore, further assessment of the direct effects of the DGR Project on aquatic birds is not warranted.

7.7.2 Measurable Changes to Indirect Exposures

The first screening determined the following indirect exposures exist for this VEC:

- radiological changes to air quality;
- radiological changes to surface water quality;
- radiological changes to soil/sediment quality; and
- radiological changes in food.

The radionuclides released as a result of the DGR Project consist of tritium and carbon-14 [4], which could contaminate air, surface water and sediment, causing a change in the concentrations of these radionuclides in the specified media, including food consumed by this VEC. Accordingly, an incremental dose to this VEC could occur, warranting a detailed calculation of doses to determine the likely radiological effects of the DGR Project on aquatic birds. Therefore, a likely measurable change is identified, and these interactions are advanced to Section 8 for further consideration.

7.8 AQUATIC MAMMALS

7.8.1 Measurable Changes to Direct Exposures

The first screening determined the DGR Project has the potential to directly affect aquatic mammals from the radiation and radioactivity perspective. Aquatic mammals in the Project Area could be exposed to gamma radiation from the waste packages during above-ground transfer of waste and could also be exposed to radiation emanating from the WPRB where the waste packages could be stored for a period time in the staging area.

Similar to the discussion in Section 7.7.1, the daily dose to aquatic mammals resulting from direct exposures during above-ground transfer of waste could be 0.004 mGy and 0.00025 mGy due to presence in the vicinity of the WPRB, far less than the criterion for this VEC. In addition, it should be noted the direct effect discussed above would be limited to individual members of populations of aquatic mammals in the Project Area. The overall populations of aquatic mammals would remain unaffected, in particular those populations spanning the Local and Regional Study Areas.

In summary, the direct effects of the DGR Project on the aquatic mammals are negligible compared with the dose criteria considered in the report. Therefore, further assessment of the direct effects of the DGR Project on aquatic mammals is not warranted.

7.8.2 Measurable Changes to Indirect Exposures

The first screening determined the following indirect exposures exist for this VEC:

- radiological changes to air quality;
- radiological changes to surface water quality; and
- radiological changes to soil/sediment quality; and
- radiological changes in food.

The radionuclides released as a result of the DGR Project consist of tritium and carbon-14 [4], which could contaminate air, surface water and soil/sediment. Accordingly, the concentrations of tritium and carbon-14 in air, surface water, soil/sediment and food consumed by this VEC could increase, which will result in an incremental dose to this VEC. This warrants a detailed calculation of doses to determine the likely radiological effects of the DGR Project on aquatic mammals. Therefore, a likely measurable change is identified, and these interactions are advanced to Section 8 for further consideration.

7.9 TERRESTRIAL INVERTEBRATES

7.9.1 Measurable Changes to Direct Exposures

The first screening determined the DGR Project has the potential to directly affect terrestrial invertebrates from the radiation and radioactivity perspective. Terrestrial invertebrates in the Project Area could be exposed to gamma radiation from the waste packages during above-ground transfer of waste and could also be exposed to radiation emanating from WPRB where the waste packages could be stored temporarily in the staging area.

Similar to the discussion in Sections 7.7.1 and 7.8.1, the daily dose to terrestrial invertebrates resulting from direct exposures during above-ground transfer of waste could be 0.004 mGy and 0.00025 mGy, without considering shielding by layers of soil, due to presence in the vicinity of the WPRB, which are far less than the criterion for this VEC. In addition, it should be noted the direct effect discussed above would be limited to individual members of populations of terrestrial invertebrates in the Project Area. The overall populations of terrestrial invertebrates would remain unaffected.

In summary, the direct effects of the DGR Project on terrestrial invertebrates are negligible compared with the dose criteria considered in the report. Therefore, further assessment of the direct effects of the DGR Project on terrestrial invertebrates is not warranted.

7.9.2 Measurable Changes to Indirect Exposures

The first screening determined the following indirect project-related exposures exist for this VEC:

- radiological changes to groundwater quality; and
- radiological changes to soil quality.

The radionuclides released as a result of the DGR Project consist of tritium and carbon-14 [4], which could contaminate groundwater and soil. Accordingly, the concentrations of tritium and carbon-14 in groundwater and soil could increase, which could result in an incremental dose to terrestrial invertebrates (indicated by earthworm). Therefore, a likely measurable change is identified. These interactions are advanced to Section 8 for a detailed calculation of doses to earthworm to determine the radiological effects, if any, of the DGR Project on terrestrial invertebrates.

7.10 TERRESTRIAL VEGETATION

7.10.1 Measurable Changes to Direct Exposures

The first screening determined the DGR Project has the potential to directly affect terrestrial vegetation from the radiation and radioactivity perspective. Terrestrial vegetation could be exposed to gamma radiation from the waste packages during above-ground transfer of waste and could also be exposed to radiation emanating from the WPRB where the waste packages could be stored temporarily in the staging area.

Similar to the previous discussions, the daily dose to terrestrial vegetation resulting from direct exposures during above-ground transfer of waste could be 0.004 mGy, far less than the criterion for this VEC. The daily dose to terrestrial vegetation, due to presence in the vicinity of the WPRB, is estimated to be 0.006 mGy assuming exposure to the highest dose rate for 24 hours. This is three orders of magnitude less than the dose criterion for this VEC.

In summary, the direct effects of the DGR Project on the terrestrial vegetation are negligible compared with the dose criteria considered in the report. Therefore, further assessment of the direct effects of the DGR Project on terrestrial vegetation is not warranted.

7.10.2 Measurable Changes to Indirect Exposures

The first screening determined the following indirect exposures exist for this VEC:

- radiological changes to air quality;
- radiological changes to soil/sediment quality; and
- radiological changes to surface water quality.

As noted, the radionuclides released as a result of the DGR Project consist of tritium and carbon-14 [4], which could contaminate air, surface water and soil/sediment. Accordingly, the concentrations of tritium and carbon-14 in air, soil and surface water could increase, which will result in an incremental dose to this VEC, warranting a detailed calculation of doses to determine the likely radiological effects of the DGR Project on terrestrial vegetation. Therefore, a likely measurable change is identified, and these interactions are advanced to Section 8 for further consideration.

7.11 TERRESTRIAL BIRDS

7.11.1 Measurable Changes to Direct Exposures

The first screening determined the DGR Project has the potential to directly affect terrestrial birds from the radiation and radioactivity perspective. Terrestrial birds in the Project Area could be exposed to gamma radiation from the waste packages during above-ground transfer of waste and could also be exposed to radiation emanating from the WPRB where the waste packages could be stored temporarily in the staging area.

Similar to the discussion in Section 7.7.1, the daily dose to terrestrial birds resulting from direct exposures during above-ground transfer could be 0.004 mGy and 0.00025 mGy due to presence in the vicinity of the WPRB, far less than the criterion for this VEC. The daily dose to terrestrial birds perching on the roof of the WPRB could be 0.01 mGy, which is two orders of magnitude less than the criterion for this VEC. In addition, it should be noted the direct effect discussed above would be limited to the individual members of populations of terrestrial birds in the Project Area. The overall populations of terrestrial birds would remain unaffected, in particular those populations spanning the Local and Regional Study Areas.

In summary, the direct effects of the DGR Project on the terrestrial birds are negligible compared with the dose criteria considered in the report. Therefore, further assessment of the direct effects of the DGR Project on terrestrial birds is not warranted.

7.11.2 Measurable Changes to Indirect Exposures

The first screening determined the following indirect exposures exist for this VEC:

- radiological changes to air quality;
- radiological changes to surface water quality;
- radiological changes to soil quality; and
- radiological changes in food.

The DGR Project may contribute to increased concentrations of tritium and carbon-14 in air, surface water, soil, and food consumed by this VEC. These increased concentrations could, in turn, result in an incremental dose to this VEC, warranting a detailed calculation of doses to determine the likely radiological effects of the DGR Project on terrestrial birds. Therefore, a likely measurable change is identified, and these interactions are advanced to Section 8 for further consideration.

7.12 TERRESTRIAL MAMMALS

7.12.1 Measurable Changes to Direct Exposures

The first screening determined the DGR Project has the potential to directly affect terrestrial mammals from the radiation and radioactivity perspective. Terrestrial mammals in the Project Area could be exposed to gamma radiation from the waste packages during above-ground transfer of waste and could also be exposed to radiation emanating from the WPRB where the waste packages could be stored temporarily in the staging area.

Similar to the discussions involving other VECs, the daily dose to terrestrial mammals resulting from direct exposures during above-ground transfer of waste could be 0.004 mGy and 0.00025 mGy due to presence in the vicinity of the WPRB, far less than the criterion for this VEC. In addition, it should be noted the direct effect discussed above would be limited to the individual members of populations of terrestrial mammals in the Project Area. The overall populations of terrestrial mammals would remain unaffected, in particular those populations spanning the Local and Regional Study Areas.

In summary, the direct effects of the DGR Project on the terrestrial mammals are negligible compared with the dose criteria considered in the report. Therefore, further assessment of the direct effects of the DGR Project on terrestrial mammals is not warranted.

7.12.2 Measurable Changes to Indirect Exposures

The first screening determined the following indirect exposures exist for this VEC:

- radiological changes to air quality;
- radiological changes to surface water quality;
- radiological changes to soil quality; and
- radiological changes in food.

The screening described for terrestrial birds in Section 7.10.2, above, also applies to terrestrial mammals. Accordingly, likely measurable changes to this VEC are identified, and these interactions are advanced to Section 8 for further consideration.

7.13 AMPHIBIANS AND REPTILES

7.13.1 Measurable Changes to Direct Exposures

The first screening determined the DGR Project has the potential to directly affect amphibians and reptiles from the radiation and radioactivity perspective. Amphibians and reptiles in the Project Area could be exposed to gamma radiation from the waste packages during above-ground transfer of waste and could also be exposed to radiation emanating from the WPRB where the waste packages could be stored temporarily in the staging area.

Similar to the discussion in Section 7.7.1, the daily dose to amphibians and reptiles resulting from direct exposures during above-ground transfer of waste could be 0.004 mGy and 0.00025 mGy due to presence in the vicinity of the WPRB, far less than the criterion for this VEC. In addition, it should be noted the direct effect discussed above would be limited to individual members of populations of amphibians and reptiles in the Project Area. The overall populations of amphibians and reptiles would remain unaffected, in particular those populations spanning the Local and Regional Study Areas.

In summary, the direct effects of the DGR Project on amphibians and reptiles are negligible compared with the dose criteria considered in the report. Therefore, further assessment of the direct effects of the DGR Project on amphibians and reptiles is not warranted.

7.13.2 Measurable Changes to Indirect Exposures

The first screening determined the following indirect exposures exist for this VEC:

- radiological changes to air quality;
- radiological changes to surface water quality;
- radiological changes to soil/sediment quality; and
- radiological changes in food.

Tritium and carbon-14 could be released to air, surface water and soil as a result of the DGR Project. Accordingly, the concentrations of these radionuclides in air, surface water and soil/sediment could increase, which could result in an incremental dose to this VEC. These exposures warrant a detailed calculation of doses to determine the likely radiological effects of the DGR Project on amphibians and reptiles. Therefore, a likely measurable change is identified, and these interactions are advanced to Section 8 for further consideration.

7.14 SUMMARY OF SECOND SCREENING

Table 7.14-1 provides a summary of the second screening for the DGR Project. Squares (■) on this matrix represent likely project-environment interactions resulting in a likely measurable change to VECs. These interactions are advanced to Section 8 for a detailed assessment to determine those interactions that may result in a likely adverse effect on radiation and radioactivity VECs.

Table 7.14-1: Matrix 2 – Summary of the Second Screening for Measurable Change on VECs

Project Work and Activity	Humans			Benthic Invertebrates			Aquatic Vegetation			Benthic Fish		
	C	O	D	C	O	D	C	O	D	C	O	D
Measurable Changes from Direct Exposures												
Site Preparation		—	—		—	—		—	—		—	—
Construction of Surface Facilities		—	—		—	—		—	—		—	—
Excavation and Construction of Underground Facilities		—	—		—	—		—	—		—	—
Above-ground Transfer of Waste	—	■	—	—		—	—		—	—		—
Underground Transfer of Waste	—	■	—	—		—	—		—	—		—
Decommissioning of the DGR Project	—	—	■	—	—		—	—		—	—	
Abandonment of the DGR Facility	—	—		—	—		—	—		—	—	
Presence of the DGR Project												
Waste Management		■	■									
Support and Monitoring of DGR Life Cycle		■	■									
Workers, Payroll and Purchasing												
Measurable Changes from Indirect Exposures												
Radiological Changes in Air Quality	•	■	■									
Radiological Changes in Surface Water Quality		■	■		■	■		■	■		■	■
Radiological Changes in Soil/Sediment Quality		■	■		■	■		■	■		■	■
Radiological Changes in Groundwater Quality		■	■		■	■						
Changed Radionuclide Concentrations in Food		■	■								■	■

Notes:
C = Site Preparation and Construction Phase
O = Operations Phase
D = Decommissioning Phase
The matrices are meant to indicate when the effect occurs and do not imply how long the effect will last. The duration of the effect is assessed in Section 11.

The abandonment and long-term performance phase is not included in the matrix as there are no activities during this phase. The abandonment of the DGR facility work and activity occurs immediately following decommissioning within the decommissioning phase and does not encompass the entirety of the abandonment and long-term performance phase.

• Potential project-environment interaction
■ Measurable change
— Activity does not occur during this phase
Blank No potential interaction

Table 7.13-1: Matrix 2 – Summary of the Second Screening for Measurable Change on VECs (continued)

Project Work and Activity	Pelagic Fish			Aquatic Birds			Aquatic Mammals			Terrestrial Invertebrates		
	C	O	D	C	O	D	C	O	D	C	O	D
Measurable Changes from Direct Exposures												
Site Preparation		—	—		—	—		—	—		—	—
Construction of Surface Facilities		—	—		—	—		—	—		—	—
Excavation and Construction of Underground Facilities		—	—		—	—		—	—		—	—
Above-ground Transfer of Waste	—		—	—	•	—	—	•	—	—	•	—
Underground Transfer of Waste	—		—	—		—	—		—	—		—
Decommissioning of the DGR Project	—	—		—	—		—	—		—	—	
Abandonment of the DGR Facility	—	—		—	—		—	—		—	—	
Presence of the DGR Project												
Waste Management												
Support and Monitoring of DGR Life Cycle												
Workers, Payroll and Purchasing												
Measurable Changes from Indirect Exposures												
Radiological Changes in Air Quality					■	■		■	■			
Radiological Changes in Surface Water Quality		■	■		■	■		■	■			
Radiological Changes in Soil/Sediment Quality					■	■		■	■		■	■
Radiological Changes in Groundwater Quality											■	■
Changed Radionuclide Concentrations in Food		■	■		■	■		■	■			

Notes:
C = Site Preparation and Construction Phase
O = Operations Phase
D = Decommissioning Phase
The matrices are meant to indicate when the effect occurs and do not imply how long the effect will last. The duration of the effect is assessed in Section 11.

The abandonment and long-term performance phase is not included in the matrix as there are no activities during this phase. The abandonment of the DGR facility work and activity occurs immediately following decommissioning within the decommissioning phase and does not encompass the entirety of the abandonment and long-term performance phase.

• Potential project-environment interaction
■ Measurable change
— Activity does not occur during this phase
Blank No potential interaction

Table 7.13-1: Matrix 2 – Summary of the Second Screening for Measurable Change on VECs (continued)

Project Work and Activity	Terrestrial Vegetation			Terrestrial Birds			Terrestrial Mammals			Amphibians and Reptiles		
	C	O	D	C	O	D	C	O	D	C	O	D
Measurable Changes from Direct Exposures												
Site Preparation		—	—		—	—		—	—		—	—
Construction of Surface Facilities		—	—		—	—		—	—		—	—
Excavation and Construction of Underground Facilities		—	—		—	—		—	—		—	—
Above-ground Transfer of Waste	—	•	—	—	•	—	—	•	—	—	•	—
Underground Transfer of Waste	—		—	—		—	—		—	—		—
Decommissioning of the DGR Project	—	—		—	—		—	—		—	—	
Abandonment of the DGR Facility	—	—		—	—		—	—		—	—	
Presence of the DGR Project												
Waste Management												
Support and Monitoring of DGR Life Cycle												
Workers, Payroll and Purchasing												
Measurable Changes from Indirect Exposures												
Radiological Changes in Air Quality		■	■		■	■		■	■		■	■
Radiological Changes in Surface Water Quality		■	■		■	■		■	■		■	■
Radiological Changes in Soil/Sediment Quality		■	■		■	■		■	■		■	■
Radiological Changes in Groundwater Quality												
Changed Radionuclide Concentrations in Food					■	■		■	■		■	■

Notes:
C = Site Preparation and Construction Phase
O = Operations Phase
D = Decommissioning Phase
The matrices are meant to indicate when the effect occurs and do not imply how long the effect will last. The duration of the effect is assessed in Section 11.

The abandonment and long-term performance phase is not included in the matrix as there are no activities during this phase. The abandonment of the DGR facility work and activity occurs immediately following decommissioning within the decommissioning phase and does not encompass the entirety of the abandonment and long-term performance phase.

• Potential project-environment interaction
■ Measurable change
— Activity does not occur during this phase
Blank No potential interaction

8. IDENTIFICATION AND ASSESSMENT OF ENVIRONMENTAL EFFECTS

The assessment of effects predicts and describes the likely environmental effects, mitigation measures and residual adverse effects on the VECs that could reasonably be expected as a result of the DGR Project.

8.1 ASSESSMENT METHODS

8.1.1 Identify Likely Environmental Effects

All measurable changes identified in the second screening (Section 7) are advanced for assessment within the framework of the applicable VECs. Consistent with accepted EA practice, quantitative and qualitative methods, including professional expertise and judgement, are used to predict and describe the project-specific effects to allow for a detailed assessment.

If a likely environmental effect is identified, the effect is assessed as being either beneficial or adverse. Any adverse effects on VECs attributable to the DGR Project are advanced for consideration of possible mitigation measures. Beneficial effects, if any, are also identified during this step but are not considered further. The results of the assessment are recorded in Matrix 3 (Table 8.4-1).

For the purposes of the radiation and radioactivity assessment, likely effects were considered adverse, or not, by comparison with regulatory limits for NEWs, non-NEWs and members of the public. For ecological VECs, screening dose criteria for non-human biota are used to determine whether project-related changes are likely to be adverse. As previously noted, effects during the abandonment and long-term performance phase are not assessed in this TSD and are addressed in Section 9 of the EIS.

8.1.1.1 Dose Criteria for Members of the Public and Workers

The CNSC has set the following regulatory limits on the annual dose to members of the public and to workers to ensure that the probability of occurrence of effects is acceptably low [63]:

- nuclear energy worker, including a pregnant nuclear energy worker: 50 mSv for one-year dosimetry period and 100 mSv for a five-year dosimetry period;
- pregnant nuclear energy worker: 4 mSv for the balance of the pregnancy; and
- a person who is not a nuclear energy worker (members of the public and non-NEWs): 1 mSv for one calendar year.

The regulatory limits established to protect members of the public apply to Aboriginal peoples. The DGR Project is expected to result in doses to humans much lower than these established regulatory limits.

The Ontario government has also introduced the regulation limiting the radionuclide concentrations in drinking water [46]. In recognition of the influence radioactive releases from the DGR Project might have on water supply plant operations, predicted concentrations of radionuclides are compared to the limits provided in the provincial regulation [46]. The concentration of tritium in water calculated in the following sections is compared to the accepted and established Ontario Drinking Water Quality Standard (ODWQS) of 7,000 Bq/L. Recently the ODWAC made recommendations to revise the limit of tritium in drinking water to 20 Bq/L [47]; however, the recommendation has not been accepted at the time of writing. This value is also used for the comparison purpose.

8.1.1.2 Dose Criteria for Non-human Biota

For this assessment, the following dose criteria, which are usually expressed as the Estimated No Effect dose-rate Values (ENEVs)[10], were used to assess the potential effect of the DGR Project on non-human biota (Table 8.1.1-1). These benchmarks are consistent with the lowest values in various studies [70] and represent chronic dose rates that were observed not to produce any adverse effects upon populations of biota [53]. It is worth noting that the daily dose rates, rather than annual ones, are proposed to prevent a scenario where the annual dose is received within a few days [53].

Table 8.1.1-1: Chronic Dose Rate Criteria

VEC	Dose rate criteria (mGy/day)
Benthic invertebrates	5.0
Aquatic vegetation	2.4
Pelagic fish	0.6
Benthic fish	0.6
Aquatic bird	1.0
Aquatic mammal	1.0
Terrestrial invertebrates	1.6
Terrestrial vegetation	1.6
Terrestrial bird	1.0
Terrestrial mammal	1.0
Amphibian and reptile	5.0

Source: [54]

8.1.2 Consider Mitigation Measures

If the assessment indicates that an adverse effect on one of the radiation and radioactivity VECs is likely as a result of the DGR Project, technically and economically feasible mitigation measures are proposed to control, reduce, or eliminate the identified effect.

[10] ENEVs are used in ecological risk assessments as a benchmark for population-level impacts on non-human biota. Dose rates below the ENEV have not been observed to produce any adverse impacts upon populations of biota.

8.1.3 Identify Residual Adverse Effects

Once mitigation measures are considered, the likely adverse effect is re-evaluated with the mitigation measures in place to identify any residual adverse effects. If a residual adverse effect on a VEC is identified, it is marked with a '◆' on Matrix 3 (Section 8.4). Any identified residual adverse effects are advanced to Section 11 for an assessment of significance.

8.1.4 Predictive Modelling

8.1.4.1 Calculating Dose to Humans – NEWs

External Radiation Dose

Direct radiation dose calculations were undertaken with MicroShield Version 8.02[11]. Skyshine doses were calculated to receptors at fence line locations using MicroSkyshine Version 2.10. Some of the calculations for underground (i.e., repository level) scenarios were also carried out using Monte Carlo N-Particle (MCNP) code Version 5.1.40[12], in particular to assess the influence of scattering along walls and ceilings. The assessment was carried out for representative LLW and ILW waste packages [4].

Four scenarios[13] were considered to calculate external worker dose during operations:

- Scenario 1 – LLW in WPRB Staging Area;
- Scenario 2 – ILW in WPRB Loading Area;
- Scenario 3 – LLW in Underground Emplacement Room; and
- Scenario 4 – ILW in Underground Emplacement Room.

Inhalation and Immersion Dose

NEWs could be exposed to radiation via inhalation, skin absorption and immersion of radionuclides dispersed in air above ground and underground. The radionuclides of concern include tritium and carbon-14, which are slowly released from waste packages. Radon could be generated from wastes and from surrounding host rock; however, it is not expected to be present in the DGR in significant concentrations on the basis of the measured low uranium/radium content of the rock and wastes [69].

Air concentrations of tritium and carbon-14 in the DGR were estimated using a compartment-based ventilation model, taking into account container offgassing rates and room ventilation rates. Doses to operations phase workers were then calculated. The values of other

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11 Microshield, developed by Grove Software, Inc., is a comprehensive photon/gamma ray shielding and dose assessment program that is widely used for designing shields, estimating source strength from radiation measurements, minimizing exposure to people, and teaching shielding principles.

12 MCNP is a general-purpose Monte Carlo N-Particle code developed by Los Alamos National Laboratory. The code can be used for neutron, photon, electron, or coupled neutron/photon/electron transport. In this work, MCNP modelling was performed to determine the effects of backscattering from the surrounding environment in the underground ILW emplacement room.

13 Dose to workers during waste transfer from the DGR boundary to the WPRB was estimated separately and is presented in Appendix D.

parameters required for dose calculation could be found in literature. For example, the dose coefficients for tritium and carbon-14 were taken from CSA N288.1-08 [57].

NEWs could also be exposed to radiation during the decommissioning phase. However, as no radioactive waste packages will be handled during this phase, it is expected that NEWs will be receiving less dose than those during the operations phase. In other words, doses to workers during operations phase represent bounding values. Therefore, the dose calculation for the operations phase is considered sufficient to assess the project-related radiological effects on NEWs.

A sample of the detailed dose calculation can be found in Appendix D.

8.1.4.2 Calculating Dose to Humans – Members of the Public

External Radiation Dose

External radiation dose to the public was estimated as a result of the direct radiation and skyshine from packages during above-ground handling at the DGR [4].

Dose from Airborne and Waterborne Releases

The radiological effect on the public of any airborne and waterborne releases from the DGR during the operations phase is estimated using two methods [4]:

- derivation of dose is based on the DGR estimated releases in comparison to the Bruce nuclear site releases and dose estimates, which are based on measurements from the Bruce Nuclear Site Radiological Environmental Monitoring Program (REMP); and
- derivation of dose is based on the WWMF pathways model and Annual Reports scaled to DGR release rate estimates.

The REMP method is semi-empirical and therefore more realistic than the theoretical pathways model method. Both methods are conservative and focus on the (potentially) most exposed receptor groups, as described in Section 5.10.

During the decommissioning phase, there may be measurable doses to members of the public. However, as no radioactive waste packages will be handled during this phase, it is expected that members of the public will be receiving less dose than during the operations phase. In other words, doses to members of the public during operations phase represent bounding values. Therefore, the dose calculation for the operations phase is considered sufficient to assess the project-related radiological effects on members of the public.

A sample of the detailed dose calculation can be found in Appendix D.

8.1.4.3 Calculating the Dose to Non-human Biota

The approach used to calculate the dose to non-human biota in this report was adapted from that used for the Ecological Risk Assessment completed for the new nuclear build proposed at the Darlington site [71]. The methods for calculating dose to non-human biota from internally deposited radioactivity and external radiation are generically applied to all VECs. For the key species (Table 8.1.1-1), a literature survey was used to determine the dose coefficients for each radionuclide in each type of organism, transfer factors for each radionuclide in each type of organism, and occupancy factors of each organism for various environments. Species characteristics (e.g., size, weight, food and water intake rates) were also obtained to determine the intake rate for each radionuclide. Further description of the methodology and supporting calculations can be found in Appendix C.

8.1.5 Application of Precautionary Approach in the Assessment

With regard to the Radiation and Radioactivity TSD, conservatism is built into the assessment using a bounding assessment approach. Furthermore, the calculation of doses to humans and non-human biota in this study involved postulating scenarios leading to the highest possible doses, and then comparison with stringent regulatory and literature dose criteria for the assessment of consequences.

8.1.6 Application of Traditional Knowledge in the Assessment

With regard to the Radiation and Radioactivity TSD, Aboriginal traditional knowledge and traditional ecological knowledge has been built into the assessment, where available. The predictions of dose to members of the public are considered to be representative of the dose to Aboriginal community members. Doses to species that are historically known to be important to Aboriginal communities (e.g., lake whitefish and white-tailed deer) were also calculated to ensure that potential effects on fishing or hunting activities are considered.

8.2 HUMANS

8.2.1 Exposure Pathways Analysis

The evaluation of the effects of the DGR Project on humans used the dose to humans to measure direct and indirect DGR Project effects. The assessment considered three receptors, namely:

- NEWs;
- non-NEWs; and
- members of the public.

The above-ground transfer of waste, underground transfer of waste, waste management, support and monitoring of DGR life cycle and decommissioning activities were identified as resulting in a likely direct measurable change to humans during the operations and decommissioning phases of the DGR Project.

Radiological changes in air quality, surface water quality, soil quality and groundwater quality and food consumption were identified as indirect pathways of exposure to humans.

8.2.2 In-design Mitigation

To minimize the radiological effects on humans, mitigation measures have been developed during the design of the DGR and its associated infrastructure (e.g., the WPRB). These in-design mitigation measures include the following features:

- shielding (e.g., appropriate design of waste container, WPRB design, underground emplacement rooms, installation of shielding and end and closure walls when appropriate);
- ventilation;
- sump and stormwater collection and management;
- emission control (airborne and waterborne);
- zoning and monitoring to prevent spread of contamination in the DGR;
- fencing and security; and
- operating procedures and training (ALARA).

These in-design mitigation measures are taken into account in the following assessment, and are described in greater detail in the Preliminary Safety Report and EIS.

8.2.3 Dose to NEWs

8.2.3.1 External Radiation Dose

Direct radiation dose calculations were undertaken as described in Section 8.1.4.1. The results showed that workers can be in most locations without exceeding OPG's occupational dose target (10 mSv/a). However, higher dose rate locations were identified where worker occupancy may be limited, for instance, near the face of an array of LLW or ILW packages in emplacement rooms [4]. Generally, workers would not need to spend much time in these locations, and most packages do not approach the dose rate limits. However, it would be appropriate to monitor the radiation fields in these locations, and if necessary, limit the worker exposure, use shielded forklifts and/or use greater stand-off distances. This was considered further within the context of ALARA [72].

8.2.3.2 Inhalation and Immersion Dose

Air concentrations of tritium and carbon-14 in the DGR were estimated as described in Section 8.1.4.1. The assessment determined air concentrations of tritium and carbon-14 are below the Derived Air Concentration for workers, and inhalation and immersion doses to workers are much lower than OPG's occupational dose target of 10 mSv/a for workers [4].

8.2.4 Dose to non-NEWs On-site

The access and movement of non-NEWs in the Project and Site Study Area are controlled by OPG and Bruce Power. Dose rate measurements at locations around the site where non-NEWs might be located ensure that the received doses do not exceed the non-NEW criterion value of 1 mSv/a. Based on the dose rate measurements carried out at the WWMF (see Section 5.11.2), it is predicted the dose rate during the operations phase will be less than 0.5 µSv/h at the perimeter of DGR Project, which corresponds to a dose rate of <1 mSv/a for a

2,000 h/a occupancy. This is also supported by calculations completed as part of the safety assessment as described in Chapter 7 of the Preliminary Safety Report [4].

This rate represents the bounding value compared with that for the site preparation and construction phase and decommissioning phase. It is not likely that the non-NEWs performing different duties will spend appreciable time in this area, and thus, the doses to non-NEWs are expected to be well below the 1 mSv/a criterion. Furthermore, the radiation doses to non-NEWs from the normal operation of the DGR Project are expected to be negligible as they are not expected to be within the vicinity of any radiation source of concern to the DGR Project.

8.2.5 Potential Dose to Members of the Public

8.2.5.1 Dose from Airborne and Waterborne Releases

The radiological effect on the public of any airborne and waterborne releases from the DGR Project during operations was estimated using the methods described in Section 8.1.4.1. The assessment determined the doses to the public due to airborne and waterborne releases is very small, and would be expected to be less than 1 μSv/a based on the REMP-based method [4].

8.2.5.2 External Radiation Dose from Direct Radiation and Skyshine

The external dose to members of the public as a result of the DGR Project was found to be negligible. The dose rate at the main entrance to the Bruce nuclear site (nearest Bruce nuclear site boundary) is less than the dose rate target of 10 μSv/a for the public at the Bruce nuclear site boundary [4].

Therefore, the total dose to the public is very much below the 1 mSv/a regulatory limit and below the OPG dose target of 0.01 mSv/a (10 μSv/a). These results are consistent with the dose to the public from the existing WWMF, taking into account the different inventories between the DGR and the WWMF. The effect (dose to public) will further decrease after the above-ground radioactive waste inventories are moved into the emplacement rooms, which are progressively closed off at repository level during operations, and when the DGR is ultimately sealed as part of decommissioning.

8.2.6 Summary of Doses to Humans

In summary, the assessment of potential exposure to workers and members of the public resulting from the normal operation of the DGR concluded:

- With regard to worker (NEW) dose, inhalation, immersion and external radiation doses as a result of the DGR Project are all expected to be much lower than OPG's occupational dose target of 10 mSv/a for workers. The predicted project-related dose is also expected to be less than that received by existing NEWs at the Bruce nuclear site. However, some potentially higher dose rate locations were identified where worker occupancy may be limited. This should be considered further within the context of ALARA.
- For non-NEWs, the project-related external dose rate is well below the compliance dose limit of 0.5 μSv/h. For the members of the public, the external dose rate is less than the OPG site boundary dose target of 10 μSv/a.

- Project-related doses to members of the public due to airborne and waterborne emissions from the DGR are predicted to be well below the regulatory limit for members of the public of 1 mSv/a.

Therefore, although measurable changes to humans because of incremental doses to workers and members of the public are likely, they are not considered to be adverse based on the criteria specified in Section 8.1.1.1, and no further consideration is warranted.

8.3 DOSE TO NON-HUMAN BIOTA

8.3.1 Linkage Analysis

The evaluation of the effects of the DGR Project on the non-human biota VECs used the dose to non-human biota to measure direct and indirect project effects.

No DGR Project works and activities were identified as resulting in a direct measurable change to any non-human biota VECs. Changes in a number of pathways (e.g., air quality, surface water quality, soil quality) were identified as indirect pathways of exposure to the non-human biota VECs, and are considered in the assessment, below.

8.3.2 In-design Mitigation

To minimize the radiological effects on non-human biota VECs, mitigation measures have been developed during the design of the DGR facilities. These in-design mitigation measures are consistent with those noted in Section 8.2.2, and include the following features:

- repository is located a nominal 680 m below ground surface;
- shielding (e.g., appropriate design of waste container, WPRB design);
- emission control;
- zoning and monitoring to prevent spread of contamination in or around the DGR;
- sump and stormwater collection and management; and
- fencing and security.

These in-design mitigation measures are taken into account in the following assessment.

8.3.3 Non-human Biota Exposure to Radiation

8.3.3.1 Existing Conditions

Aquatic and terrestrial biota receive radiation doses from exposure to radioactivity in the atmosphere, surface water and from other environmental media into which the radioactivity may transfer. Radiation doses to biota in the Regional, Site and Local Study Areas were calculated for the existing conditions and for the operations scenario. The results are summarized in the following sections.

Table 8.3.3-1 and Figure 8.3.3-1 present the existing dose rates. The figure also shows a comparison of the calculated existing dose rates with the criteria (ENEV value) outlined in Table 8.1.1-1.

Table 8.3.3-1: Non-Human Biota Calculated Dose Rates under Existing Conditions

Species Group	Species	Dose Rate (mGy/d)
Benthic Invertebrates	Burrowing crayfish	$4.4{\times}10^{-4}$
Aquatic Vegetation	Variable leaf pondweed	$3.6{\times}10^{-4}$
Benthic Fish	Lake whitefish	$4.6{\times}10^{-4}$
	Redbelly dace	
	Creek chub	
Pelagic Fish	Spottail shiner	$4.6{\times}10^{-4}$
	Smallmouth bass	
	Brook trout	
Aquatic Birds	Double-crested cormorant	$2.0{\times}10^{-4}$
	Mallard	$3.9{\times}10^{-4}$
Aquatic Mammals	Muskrat	$3.2{\times}10^{-4}$
Terrestrial Invertebrates	Earthworm	$5.7{\times}10^{-4}$
Terrestrial Vegetation	Eastern white cedar	$8.4{\times}10^{-5}$
	Common cattail	
	Heal-all	
Terrestrial Birds	Bald eagle	$1.3{\times}10^{-4}$
	Yellow warbler	$2.1{\times}10^{-5}$
	Wild turkey	$4.5{\times}10^{-4}$
	Red-eyed vireo	$2.7{\times}10^{-5}$
Terrestrial Mammals	White-tailed deer	$3.8{\times}10^{-3}$
	Northern short-tailed shrew	$5.9{\times}10^{-5}$
	Red fox	$4.8{\times}10^{-4}$
Amphibians and Reptiles	Midland painted turtle	$2.4{\times}10^{-4}$
	Northern leopard frog	

Note: The doses reported in this table account for relative biological effectiveness.

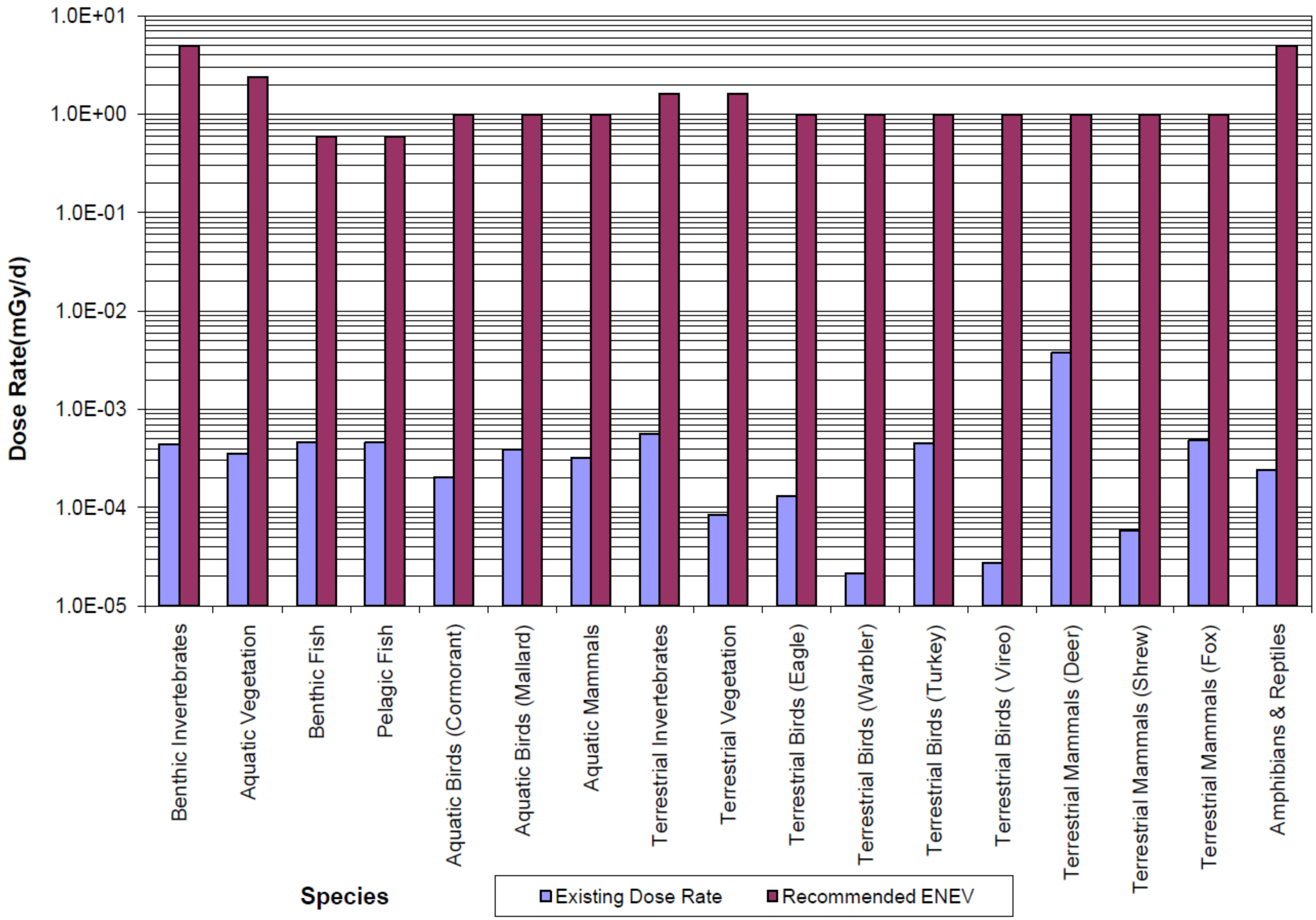

Figure 8.3.3-1: Dose Rates to Non-Human Biota under Existing Conditions

As shown by Figure 8.3.3-1, the doses are less than reference values (see Table 8.1.1-1) that are expected to ensure the survival of populations of biota. Table 8.3.3-2 demonstrates this by comparing the highest dose received by an indicator (white-tailed deer) to the relevant dose rate criterion.

Table 8.3.3-2: Comparison of Chronic Dose Rates with Benchmarks for White-tailed Deer under Existing Conditions

Predicted Operations Phase Dose (mGy/d)	Screening Criterion for Dose Rates (mGy/d)	% of the Criterion
0.004	1.0	0.4%

8.3.3.2 Operations Phase

The effects of DGR emissions would be an increment to the baseline concentrations around the site. It should also be noted that over 50% of the waste inventory intended for emplacement in the DGR is currently in storage at the WWMF, and will increase to about 70% by the time the operations phase begins. As wastes are transferred from the WWMF into the DGR, the corresponding emissions from the WWMF will decrease. Therefore, increases in environmental concentrations of radionuclides as a result of the DGR Project will be balanced in part by the decrease in emissions from the WWMF.

Since emissions from the DGR Project will clearly be less than the current Bruce nuclear site emissions, a screening level estimate of the potential DGR effects is provided by conservatively assuming the project causes an incremental increase in tritium and carbon-14 concentrations equal to the existing values. In other words, the dose rates to non-human biota during the operations phase of the DGR Project can be taken as a bounding case to be twice their existing value. Table 8.3.3-3 and Figure 8.3.3-2 present the projected dose rate attributable to the operations phase of the DGR Project.

Table 8.3.3-3: Non-Human Biota Calculated Dose Rates during Operations Phase

VEC	Indicators	Projected Dose Rate (mGy/d)
Benthic Invertebrates	Burrowing crayfish	8.9×10^{-4}
Aquatic Vegetation	Variable leaf pondweed	7.2×10^{-4}
Benthic Fish	Lake whitefish	9.3×10^{-4}
	Redbelly dace	
	Creek chub	
Pelagic Fish	Spottail shiner	9.3×10^{-4}
	Smallmouth bass	
	Brook trout	
Aquatic Birds	Double-crested cormorant	4.0×10^{-4}
	Mallard	7.8×10^{-4}

Table 8.3.3-3: Non-Human Biota Calculated Dose Rates during Operations Phase (continued)

VEC	Indicators	Projected Dose Rate (mGy/d)
Aquatic Mammals	Muskrat	6.3×10^{-4}
Terrestrial invertebrates	Earthworm	1.1×10^{-3}
Terrestrial Vegetation	Eastern white cedar	1.7×10^{-4}
	Common cattail	
	Heal-all	
Terrestrial Birds	Bald eagle	2.6×10^{-4}
	Yellow warbler	4.3×10^{-5}
	Wild turkey	9.1×10^{-4}
	Red-eyed vireo	5.4×10^{-5}
Terrestrial Mammals	White-tailed deer	7.5×10^{-3}
	Northern short-tailed shrew	1.2×10^{-4}
	Red fox	9.7×10^{-4}
Amphibians & Reptiles	Midland painted turtle	4.8×10^{-4}
	Northern leopard frog	

Note: The doses reported in this table account for relative biological effectiveness.

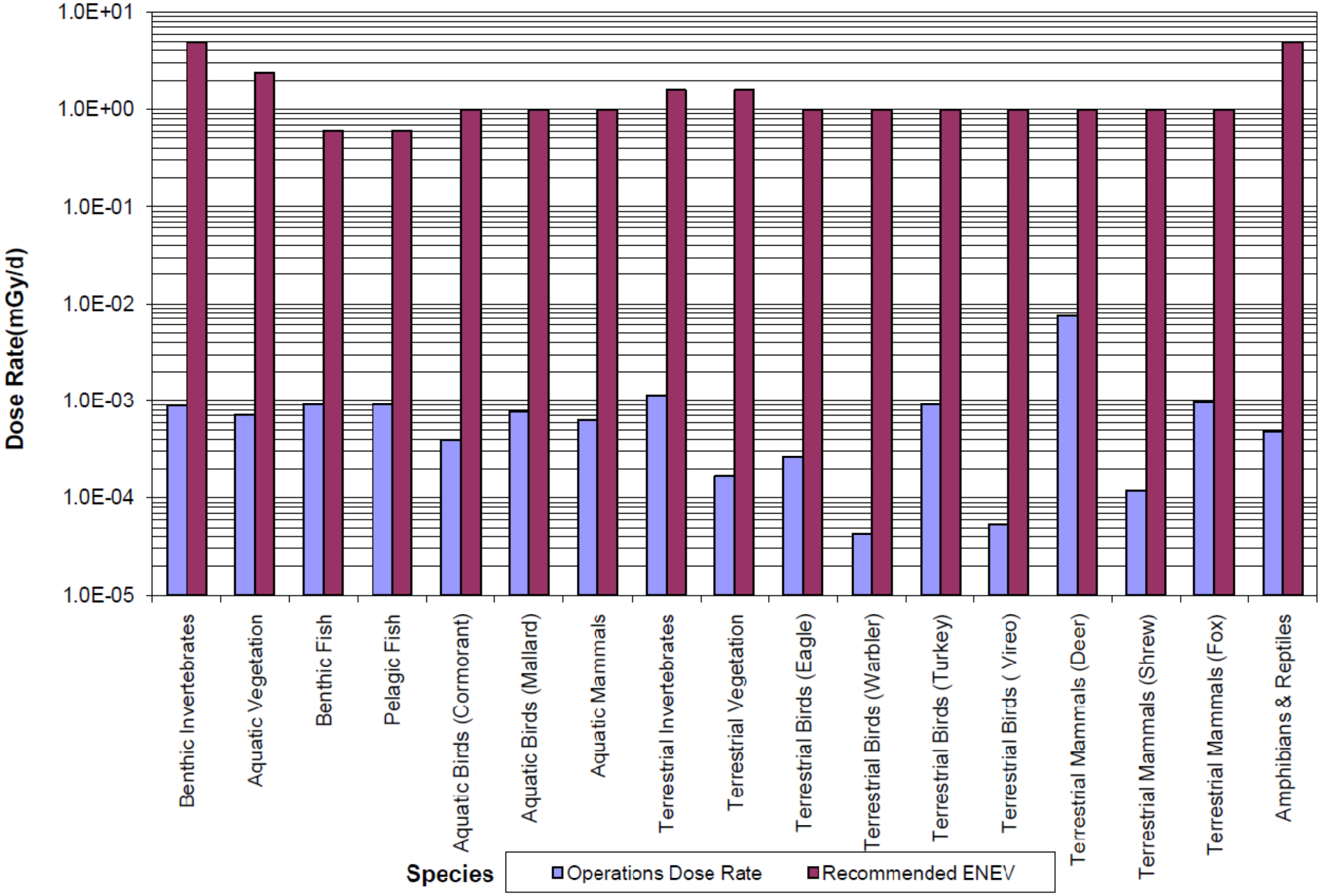

Figure 8.3.3-2: Dose Rates to Non-Human Biota during Operations Phase

As shown in Figure 8.3.3-2, the doses are less than reference values (see Table 8.1.1-1) that are expected to ensure the survival of populations of biota. Table 8.3.3-4 demonstrates this by comparing the highest dose received by an indicator to the selected dose rate criterion.

Table 8.3.3-4: Comparison of Chronic Dose Rates with Benchmarks for White-tailed Deer during Operations Phase

Predicted Operations Phase Dose (mGy/d)	Screening Criterion for Dose Rates (mGy/d)	% of the Criterion
0.008	1.0	0.8%

Thus, the assessment determined the radioactivity releases from the DGR Project to the terrestrial and aquatic environment are not likely to have an adverse effect on the non-human biota VECs. Since there are no adverse effects, no mitigation measures are identified. Therefore, no likely adverse effects as a result of the DGR Project on non-human biota VECs are identified from a radiation and radioactivity perspective, and further consideration is not merited.

8.4 SUMMARY OF ASSESSMENT

Matrix 3 (Table 8.4-1) provides a summary of the third screening for the DGR Project, and is identical to Matrix 2 (Table 7.1.3-1) since no residual adverse effects on the radiation and radioactivity VECs are identified. Thus, consideration of significance of residual adverse effects is not required.

8.4.1 Cumulative Effects

Effects of the DGR Project have the potential to act cumulatively with those of other projects. The EIS Guidelines require that the EA considers the cumulative effects of past, present and reasonably foreseeable future projects. The description of the existing environmental conditions presented in Section 5 includes the cumulative effects of past and existing projects.

No residual adverse effects were identified during the assessment. However, the doses predicted in Section 8 consider the incremental effects of the DGR Project only for comparison with regulatory standards. Therefore, the potential for cumulative effects due to this measurable change in radioactivity with past, present and reasonably foreseeable future projects is considered in Section 10 of the EIS.

Table 8.4-1: Matrix 3 – Summary of the Assessment for Residual Adverse Effects on VECs

Project Work and Activity	Humans			Benthic Invertebrates			Aquatic Vegetation			Benthic Fish		
	C	O	D	C	O	D	C	O	D	C	O	D
Potential Effects from Direct Exposures												
Site Preparation		—	—		—	—		—	—		—	—
Construction of Surface Facilities		—	—		—	—		—	—		—	—
Excavation and Construction of Underground Facilities		—	—		—	—		—	—		—	—
Above-ground Transfer of Waste	—	■	—	—		—	—		—	—		—
Underground Transfer of Waste	—	■	—	—		—	—		—	—		—
Decommissioning of the DGR Project	—	—	■	—	—		—	—		—	—	
Abandonment of the DGR Facility	—	—		—	—		—	—		—	—	
Presence of the DGR Project												
Waste Management		■	■									
Support and Monitoring of DGR Life Cycle		■	■									
Workers, Payroll and Purchasing												
Potential Effects from Indirect Exposures												
Radiological Changes in Air Quality	•	■	■									
Radiological Changes in Surface Water Quality		■	■		■	■		■	■		■	■
Radiological Changes in Soil/Sediment Quality		■	■		■	■		■	■		■	■
Radiological Changes in Groundwater Quality		■	■		■	■						
Changed Radionuclide Concentrations in Food		■	■								■	■

Notes:
C = Site Preparation and Construction Phase
O = Operations Phase
D = Decommissioning Phase
The matrices are meant to indicate when the effect occurs and do not imply how long the effect will last. The duration of the effect is assessed in Section 11.

The abandonment and long-term performance phase is not included in the matrix as there are no activities during this phase. The abandonment of the DGR facility work and activity occurs immediately following decommissioning within the decommissioning phase and does not encompass the entirety of the abandonment and long-term performance phase.

• Potential project-environment interaction
■ Measurable change
— Activity does not occur during this phase
Blank No potential interaction

Table 8.4-1: Matrix 3 – Summary of the Assessment for Residual Adverse Effects on VECs (continued)

Project Work and Activity	Pelagic Fish			Aquatic Birds			Aquatic Mammals			Terrestrial Invertebrates		
	C	O	D	C	O	D	C	O	D	C	O	D
Potential Effects from Direct Exposures												
Site Preparation		—	—		—	—		—	—		—	—
Construction of Surface Facilities		—	—		—	—		—	—		—	—
Excavation and Construction of Underground Facilities		—	—		—	—		—	—		—	—
Above-ground Transfer of Waste	—		—	—	•	—	—	•	—	—	•	—
Underground Transfer of Waste	—		—	—		—	—		—	—		—
Decommissioning of the DGR Project	—	—		—	—		—	—		—	—	
Abandonment of the DGR Facility	—	—		—	—		—	—		—	—	
Presence of the DGR Project												
Waste Management												
Support and Monitoring of DGR Life Cycle												
Workers, Payroll and Purchasing												
Potential Effects from Indirect Exposures												
Radiological Changes in Air Quality					■	■		■	■			
Radiological Changes in Surface Water Quality		■	■		■	■		■	■			
Radiological Changes in Soil/Sediment Quality					■	■		■	■		■	■
Radiological Changes in Groundwater Quality											■	■
Changed Radionuclide Concentrations in Food		■	■		■	■		■	■			

Notes:
C = Site Preparation and Construction Phase
O = Operations Phase
D = Decommissioning Phase
The matrices are meant to indicate when the effect occurs and do not imply how long the effect will last. The duration of the effect is assessed in Section 11.

The abandonment and long-term performance phase is not included in the matrix as there are no activities during this phase. The abandonment of the DGR facility work and activity occurs immediately following decommissioning within the decommissioning phase and does not encompass the entirety of the abandonment and long-term performance phase.

• Potential project-environment interaction
■ Measurable change
— Activity does not occur during this phase
Blank No potential interaction

Table 8.4-1: Matrix 3 – Summary of the Assessment for Residual Adverse Effects on VECs (continued)

Project Work and Activity	Terrestrial Vegetation			Terrestrial Birds			Terrestrial Mammals			Amphibians and Reptiles		
	C	O	D	C	O	D	C	O	D	C	O	D
Potential Effects from Direct Exposures												
Site Preparation		—	—		—	—		—	—		—	—
Construction of Surface Facilities		—	—		—	—		—	—		—	—
Excavation and Construction of Underground Facilities		—	—		—	—		—	—		—	—
Above-ground Transfer of Waste	—	•	—	—	•	—	—	•	—	—	•	—
Underground Transfer of Waste	—		—	—		—	—		—	—		—
Decommissioning of the DGR Project	—	—		—	—		—	—		—	—	
Abandonment of the DGR Facility	—	—		—	—		—	—		—	—	
Presence of the DGR Project												
Waste Management												
Support and Monitoring of DGR Life Cycle												
Workers, Payroll and Purchasing												
Potential Effects from Indirect Exposures												
Radiological Changes in Air Quality		■	■		■	■		■	■		■	■
Radiological Changes in Surface Water Quality		■	■		■	■		■	■		■	■
Radiological Changes in Soil/Sediment Quality		■	■		■	■		■	■		■	■
Radiological Changes in Groundwater Quality												
Changed Radionuclide Concentrations in Food					■	■		■	■		■	■

Notes:
C = Site Preparation and Construction Phase
O = Operations Phase
D = Decommissioning Phase
The matrices are meant to indicate when the effect occurs and do not imply how long the effect will last. The duration of the effect is assessed in Section 11.

The abandonment and long-term performance phase is not included in the matrix as there are no activities during this phase. The abandonment of the DGR facility work and activity occurs immediately following decommissioning within the decommissioning phase and does not encompass the entirety of the abandonment and long-term performance phase.

• Potential project-environment interaction
■ Measurable change
— Activity does not occur during this phase
Blank No potential interaction

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9. EFFECTS OF THE ENVIRONMENT ON THE PROJECT

9.1 ASSESSMENT METHODS

The EA must include a consideration of how the environment could adversely affect the DGR Project. For example, the EA evaluates how hazards such as severe weather or seismic events are likely to affect the DGR Project with regard to radiation and radioactivity. This assessment was accomplished using the method illustrated on Figure 9.1-1. First, potential conditions in the environment that may affect the DGR Project are identified. Then, the level of effect these environmental conditions could have on the DGR Project are evaluated based on past experience at the site and professional judgement of the study team. The assessment of effects of the environment on the DGR Project focuses on those conditions associated with radiation and radioactivity. Identified residual adverse effects, if any, are then advanced to Section 11 for an assessment of significance.

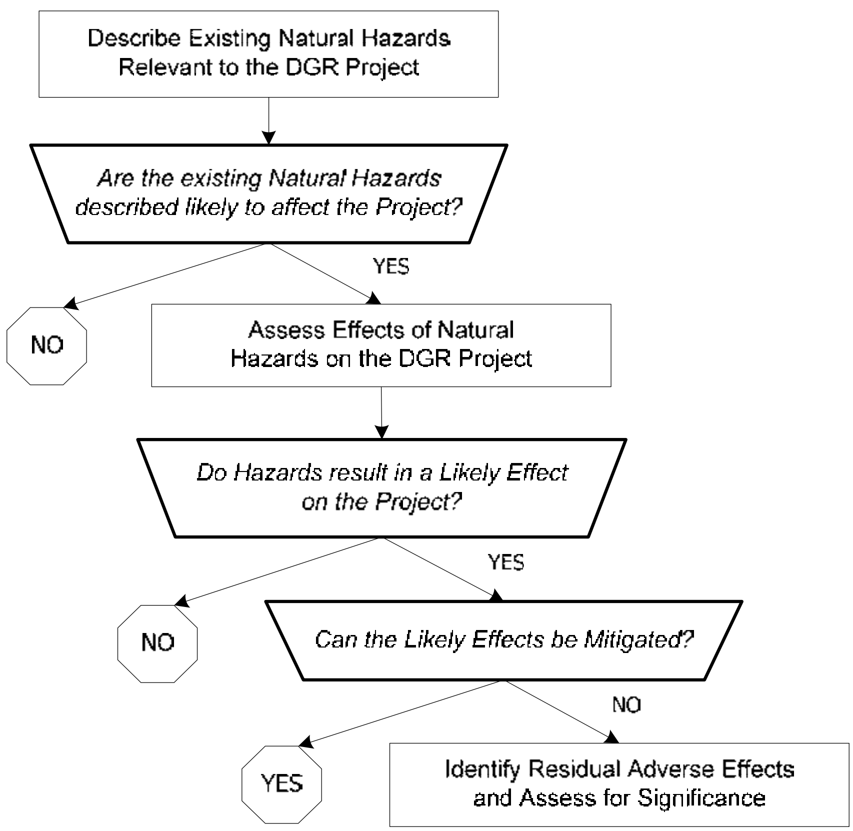

Figure 9.1-1: Method to Assess Effects of the Environment on the DGR Project

9.2 ASSESSMENT OF EFFECTS OF RADIATION AND RADIOACTIVITY ON THE DGR PROJECT

The description of the existing environment is provided in Section 5. No natural radiological hazards have been identified. Therefore, the environment, from the radiation and radioactivity perspective, has no potential to affect the DGR Project and no further consideration is warranted.

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10. CLIMATE CHANGE CONSIDERATIONS

The DGR Project EIS Guidelines require a consideration of whether the DGR Project and EA conclusions are sensitive to changes in climatic conditions. For the purpose of this TSD, climate change is considered over the life of the DGR Project spanning the site preparation and construction, operations, and decommissioning phases only. Shifts in climate that occur from one epoch to the next have been considered as part of the Postclosure Safety Assessment [2], and their effects on the DGR Project are described in the EIS (Section 9).

The requirement of the DGR Project EIS Guidelines (included as Appendix A to the EIS) to consider climate change is addressed through the following considerations:

- How will the future environment affect the DGR Project?
- How will the DGR Project affect the future environment? and
- How will the DGR Project affect climate change (e.g., contribution to climate change by the emission of greenhouse gasses)?

The methods used to consider the effects of climate change are described in the following sections. Establishing how the climate may change over the life of the DGR Project is an initial requirement for addressing the first two considerations. A determination of how climate has been changing and how it might change over the DGR Project life considered in this TSD is based on 30-year climate normals, literature review and the professional experience of the study team. The climate models used to predict high, medium and low climate change scenarios for the Regional Study Area are described in Section 10.1. These predicted climate change scenarios are used by all environmental disciplines for the assessment of the consequences of climatic conditions on the first two considerations.

10.1 DESCRIPTION OF PREDICTED CHANGES IN CLIMATE

Climate represents the long-term expected values for parameters such as temperature, precipitation and winds. The climate of an area is described using normals, which are averages calculated over a 30 year period (the latest accepted normals period is from 1971 to 2000) [73]. It is now widely accepted that climate is changing; therefore, consideration of these changes needs to be incorporated in the EA carried out for the DGR Project. Traditionally, scientists looked to past weather records to provide guidance for predicting future conditions. Historic climate trends for the DGR Project are determined using the temperature archives observed at Wiarton Airport over the period from 1971 through 2000. While past trends have traditionally been used to provide guidance to the future, reliance is shifting to global climate models, which incorporate accepted understandings of climate mechanisms and standardized scenarios reflecting potential human development in the future.

Tables 10.1-1 and 10.1-2 provide a summary of the past and future trends for temperature and precipitation, respectively. The tables describe how climate in the region has been changing, as well as how it is projected to change over the life of the DGR Project through the end of the decommissioning phase. These data are used to evaluate how climate change may affect the conclusions reached regarding the assessment of the effects of the DGR Project on the selected VECs. The Atmospheric Environment TSD provides further details on the predicted changes in climate.

Table 10.1-1: Historic and Future Temperature Trends

Criteria	1971-2000 Normals (°C)	1971-2000 Trend (°C/decade)	2011-2040 Forecast (°C/decade)			2041-2070 Forecast (°C/decade)			2071-2100 Forecast (°C/decade)		
			Low	Average	High	Low	Average	High	Low	Average	High
Annual	6.1	+0.31	+0.00	+0.41	+1.05	+0.15	+0.34	+0.66	+0.20	+0.33	+0.51
Spring	4.5	+0.50	+0.00	+0.45	+1.09	+0.14	+0.35	+0.69	+0.19	+0.34	+0.54
Summer	17.4	+0.26	+0.00	+0.43	+1.10	+0.15	+0.34	+0.69	+0.21	+0.34	+0.52
Fall	8.3	+0.05	+0.00	+0.36	+1.02	+0.12	+0.30	+0.63	+0.19	+0.32	+0.49
Winter	-5.7	+0.68	+0.00	+0.40	+0.99	+0.16	+0.33	+0.63	+0.21	+0.33	+0.50

Note:
The low and high data correspond to the forecasts for the scenario with the smallest and largest respective changes in temperature for each forecast horizon. The average represents the arithmetic average of the available forecasts. Refer to Appendix D of the Atmospheric Environment TSD for the derivation of climate data.

Table 10.1-2: Historic and Future Precipitation Trends

Season	1971-2000 Normals (mm)	1971-2000 Trend (mm/decade)	2011-2040 Forecast (%/decade)			2041 -2070 Forecast (%/decade)			2071 -2100 Forecast (%/decade)		
			Low	Average	High	Low	Average	High	Low	Average	High
Annual	1,041.3	+0.13%	+0.00%	+1.44%	+3.57%	+0.36%	+1.11%	+2.09%	+1.39%	+1.30%	+2.25%
Spring	216.8	+3.23%	+0.00%	+2.59%	+5.39%	+0.62%	+1.51%	+2.72%	+1.88%	+2.24%	+4.05%
Summer	230.8	-0.51%	+0.00%	-1.65%	-3.40%	-0.95%	-1.13%	-0.42%	-0.68%	-0.85%	-0.61%
Fall	310.9	+4.41%	+0.00%	+2.09%	+4.35%	+2.28%	+1.67%	+2.75%	+2.11%	+1.65%	+1.85%
Winter	282.8	-4.65%	+0.00%	+2.39%	+7.30%	-0.27%	+1.82%	+3.08%	+2.05%	+1.92%	+3.32%

Note:
The low and high data correspond to the forecasts for the scenario with the smallest and largest respective changes in temperature for each forecast horizon. The average represents the arithmetic average of the available forecasts. Refer to Appendix D of the Atmospheric Environment TSD for the derivation of climate data.

10.2 EFFECTS OF THE FUTURE ENVIRONMENT ON THE DGR PROJECT

10.2.1 Methods

Changes to the climate are predicted to occur over the lifetime of the DGR Project; therefore, it is also necessary to assess how the predicted future environment may affect the DGR Project. For example, climate change might result in new or more severe weather hazards. The method used to assess these changes is shown in Figure 10.2.1-1.

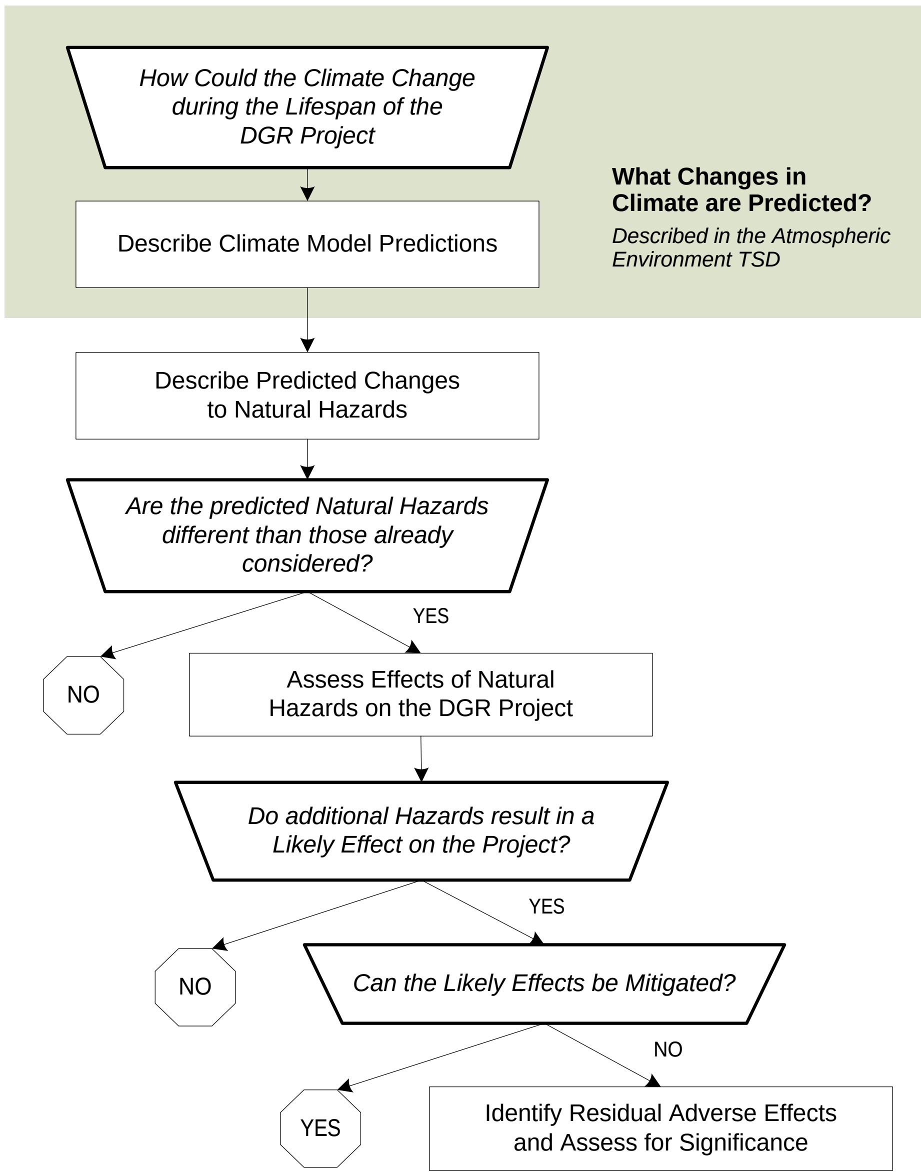

Figure10.2.1-1: Method to Assess Effects of the Future Environment on the DGR Project

Once the future environment is established (Section 10.1), the evaluation of changed and/or additional natural hazards on the DGR Project is carried out in a similar fashion to the assessment of effects of the current environment on the DGR Project (Section 9). The assessment addresses only predicted hazards that are different or in addition to those considered in the assessment of existing natural hazards. The EA predictions of future hazards as a result of a changing climate relies upon both qualitative and quantitative evaluations based on available data and technical experience, with consideration for the design and contingency measures incorporated into the DGR Project to mitigate likely effects. Identified residual adverse effects are advanced to Section 11 for an assessment of significance.

10.2.2 Assessment of Effects of the Future Radiation and Radioactivity Environment on the DGR Project

It is expected that the climate change discussed in Section 10.1 (small changes in temperature and precipitation) will not change the future radiation and radioactivity environment. Accordingly, the effect of future radiation and radioactivity environment on the DGR Project is negligible. For example, the potential effect of free radionuclides on the seal during the abandonment and long-term performance phase has been determined to be far too low to result in any adverse effects on seals [2].

10.3 EFFECTS OF THE DGR PROJECT ON THE FUTURE ENVIRONMENT

10.3.1 Methods

Climate change may result in an environment that is different from the current environment as less severe winters or increased precipitation might alter the habitat or behaviour of VECs. Climate-related changes to VECs may result in changed or additional effects of the DGR Project compared with those predicted on the current environment. The method used to assess these changes is shown in Figure 10.3.1-1.

The assessment of the effects of the DGR Project on VECs in a changed future environment begins with re-examining the EA predictions for the current environment by identifying whether or not the VECs might be altered as a result of climate change. The effects of the DGR Project on the altered VECs are then assessed to determine whether they are bounded by the predictions made for the effects assessment for the current environment (Section 8). All additional or different effects are fully assessed, using a similar method to that followed for assessing effects of the DGR Project on the current environment. Effects that cannot be fully mitigated will result in residual adverse effects, which are forwarded for an assessment of significance in Section 11.

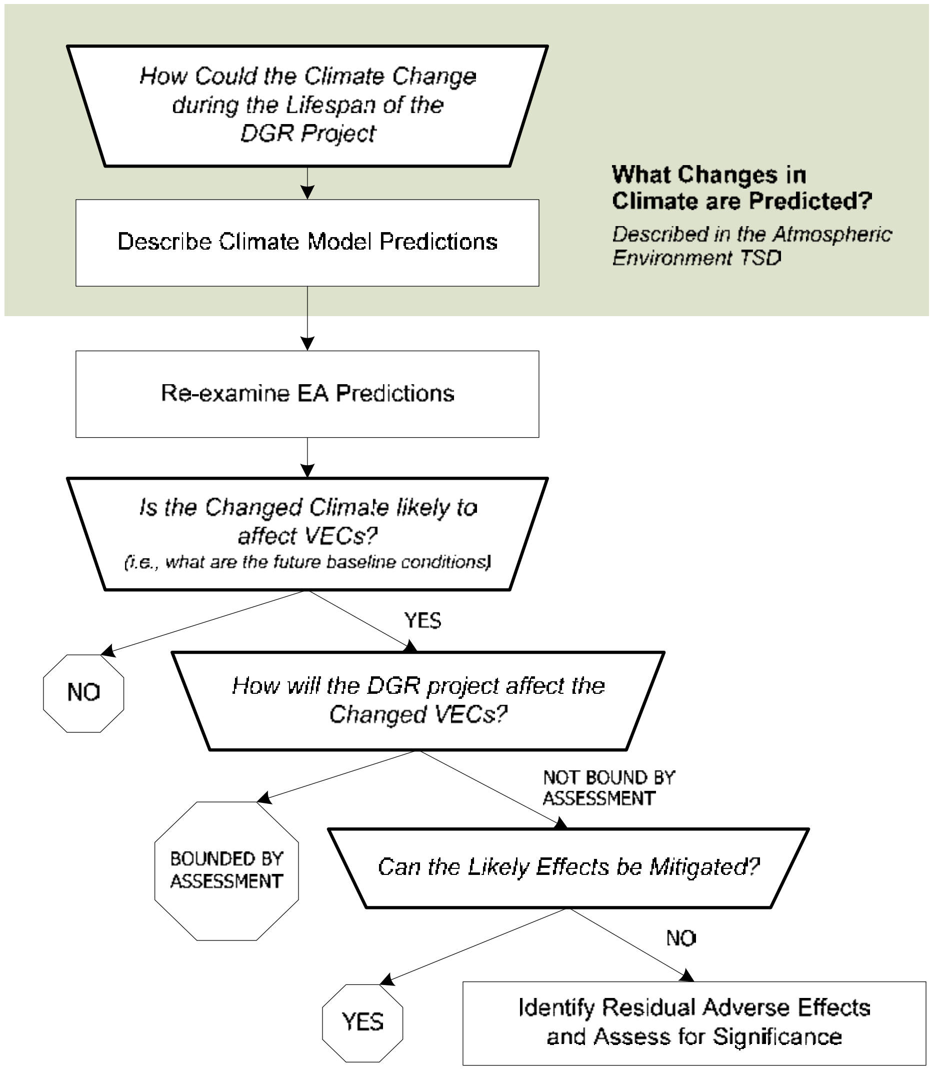

Figure 10.3.1-1: Method to Assess Effects of the DGR Project on the Future Environment

10.3.2 Assessment of the DGR Project on the Future Radiation and Radioactivity VECs

It is expected that the climate change discussed in Section 10.1 (small changes in temperature and precipitation) will not change atmospheric dispersion by any significant amount. Therefore, it is considered unlikely that climate change will alter any of the potential adverse effects of the DGR Project on the radiation and radioactivity VECs, as described in Section 8. Therefore, no additional effects have been passed on for consideration in Section 11 as a result of climate change.

10.4 EFFECTS OF THE DGR PROJECT ON CLIMATE CHANGE

10.4.1 Methods

The DGR Project may also contribute to how the climate is changing (e.g., through changes in the levels of greenhouse gas emissions). The assessment will quantify the direct and indirect changes as a result of the DGR Project with regard to radiation and radioactivity and climate change and put them into context on a sector, provincial and national basis.

10.4.2 Assessment of Effects of the DGR Project on Climate Change

The total energy associated with the radioactivity in the released radionuclides is negligible and will have no effect on climate. As a result, no effects of the DGR Project (from the radiation and radioactivity perspective) on climate change are advanced to Section 11 for further consideration.

10.5 SUMMARY

No effects of climate change are advanced to Section 11 for an evaluation of significance.

11. SIGNIFICANCE OF RESIDUAL ADVERSE EFFECTS

Residual adverse effects of the DGR Project are assessed for a consideration of significance. Methods for the evaluation of significance are provided in Section 7 of the EIS.

No residual adverse effects of the DGR Project were identified on radiation and radioactivity VECs in Sections 8, 9 and 10. Therefore, the assessment of the significance of the residual adverse effects is not required. Follow-up monitoring is proposed to confirm adverse effects do not occur and that in-design mitigation measures are effective. Cumulative effects are considered in Section 10 of the EIS.

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12. EFFECTS OF THE PROJECT ON RENEWABLE AND NON-RENEWABLE RESOURCES

The EIS Guidelines (included as Appendix A to the EIS) require the EA to consider the effects of the DGR Project on resource sustainability. For context, non-renewable resources are also discussed in this section.

12.1 METHODS

Potential project-environment interactions (as identified for the assessment of effects of the DGR Project) are reconsidered in the context of their likelihood to affect resource sustainability or availability through all time frames. Likely effects are predicted, described and their significance assessed by considering "renewable and non-renewable resources" as a VEC. In addition, the ability of the present generation and future generations to meet their own needs is evaluated, based on the professional judgement of the technical specialists.

One goal of the assessment is to determine whether renewable and non-renewable resources would be affected by the DGR Project to the point where they are not sustainable or appreciably depleted. Sustainability is defined in a manner consistent with the United Nation's definition of sustainable development as "*economic development that meets the needs of the present without compromising the ability of future generations to meet their own needs*".

Potential project-environment interactions identified in the screening matrices were reviewed to determine the likelihood of interactions between the DGR Project and resource sustainability and availability. For the purpose of this assessment, the likely residual adverse effects of the DGR Project's physical works and activities on the environment were considered as having the potential to adversely affect the sustainability of associated resources.

12.2 LIKELY EFFECTS

12.2.1 Non-renewable Resources

The DGR Project will be built for long-term management of L&ILW currently stored at the WWMF or subsequently generated at OPG's nuclear power generating stations. No radioactive materials (e.g., uranium) will be consumed for operating the DGR facility.

Based on the current preliminary design, the emplaced waste could be retrieved from the deep repository prior to the decommissioning of the DGR. Thus, these waste packages could be recycled if conditions (e.g., available technology, appropriate policy) for such an activity are suitable.

In summary, from radiation and radioactivity perspective, the DGR Project will not have any adverse effects on non-renewable resources.

12.2.2 Renewable Resources

Based on the assessment carried out previously, the airborne and waterborne emission from the DGR is very limited. Thus, it is unlikely the DGR Project has any adverse radiological effect on renewable resources including surface water, groundwater and air quality. Therefore, it is determined that the DGR Project will not have any adverse effects on the sustainability of renewable resources from the radiation and radioactivity perspective.

13. PRELIMINARY FOLLOW-UP PROGRAM

The EIS Guidelines stipulate that the need for, and the requirements of, any follow-up program for the DGR Project be identified. A follow-up program may be required to determine that the environmental and cumulative effects of the DGR Project are consistent with predictions reported in the EIS. It can also be used to verify that the mitigation measures are effective once implemented and determine whether there is a need for additional mitigation measures. A preliminary follow-up plan development plan is provided, below. The follow-up program is designed to be appropriate to the scale of the DGR Project and the effects identified through the EA process.

The follow-up monitoring program is generally required to achieve the following:

- verify the key predictions of the EA studies; or
- confirm the effectiveness of mitigation measures, and in so doing, determine if alternate mitigation strategies are required.

The CNSC will provide the regulatory oversight to ensure that OPG has implemented all appropriate mitigation measures and that the follow-up monitoring is designed and carried out. The CNSC compliance program can be used as the mechanism for ensuring the final design and implementation of the follow-up program and reporting of the follow-up program results.

13.1 INITIAL SCOPE OF THE FOLLOW-UP PROGRAM

In line with the requirements of the EIS Guidelines, the following programs, as part of the project EA follow-up monitoring plan, are recommended in relation to radiation and radioactivity:

- Radiological analysis of air: Air samples will be periodically collected to monitor radioactivity in vent exhaust air, including the measurement of radon concentrations in underground facilities during site preparation and construction, operations, and decommissioning phases, as appropriate, to ensure that worker exposure to radioactivity is limited.
- External radiation monitoring: An external radiation monitoring program will be carried out during the site preparation and construction phase, the operations phase, and the decommissioning phase, respectively. The monitoring program during the site preparation and construction phase is to ensure that the exposure of DGR construction workers (non-NEWs) attributable to operations at the WWMF, which is in the vicinity of the DGR Project site, is properly managed. This program can be coordinated with the existing WWMF monitoring network. During the operations and the decommissioning phases, gamma radiation can be monitored using TLD along the boundary of the DGR Project Area to ensure that dose rates at the DGR boundary meet the specific requirement.
- Radiological analysis of groundwater: Throughout the site preparation and construction, operations, and decommissioning phases, radiological analysis will be carried out for samples collected from monitoring wells around the DGR boundary to monitor any changes to groundwater radionuclide concentrations in the DGR Project Area, especially tritium levels. The changes could be a result of the migration of contaminants from

facilities in the immediate vicinity, such as the WWMF. This program will be similar to the groundwater monitoring program currently carried out for the WWMF.

- Radiological analysis of surface water: Water samples collected from the stormwater management system will be analyzed to determine radionuclide concentrations in surface water during the site preparation and construction phase, operations phase, and decommissioning phase. Water analysis during the site preparation and construction phase is to monitor the potential effect resulting from the operations at the WWMF and other nuclear facilities in the Site Study Area and establish a stormwater management system baseline for the operations and decommissioning phases.
- Dose to workers: A dose monitoring program will be carried out throughout the operations and decommissioning phases to determine worker exposure to radiation and radioactivity.

Table 13.1-1 summarizes the recommended follow-up monitoring programs associated with the radiation and radioactivity assessment. The recommendations identify the general timeframe for follow-up monitoring programs, and will be reviewed and incorporated, as appropriate, into the formal follow-up program that will be developed prior to the initiation of the DGR Project. The radon assessment document [69] suggests that there is no need for routine radon monitoring and radon concentration could be checked during construction, and then periodically during operations to confirm the estimates. The preliminary follow-up monitoring program [74] has been prepared and is submitted along with the EIS.

Table 13.1-1: Potential Follow-up Monitoring Related to Radiation and Radioactivity

Programs	Program Objective	Description	Suggested Location and Schedule	
			Location	Implementation Schedule
Air monitoring	Confirm effectiveness of mitigation; confirm no residual adverse effects	Monitoring radioactivity in vent exhaust air, and radon concentration in underground facility.	Project Area	Throughout site preparation and construction and operations phases, and decommissioning phase, as appropriate.
External radiation monitoring	Confirm effectiveness of mitigation; confirm no residual adverse effects	Monitoring gamma dose around the boundary of the DGR facility.	Project Area	Throughout site preparation and construction, operations, and decommissioning phases.
Groundwater monitoring	Confirm no residual adverse effects	Monitoring radioactivity in wells to be installed around the DGR facility, especially tritium level, to determine changes in level of groundwater contamination and the potential source of contamination.	Project Area	Throughout site preparation and construction, operations, and decommissioning phases.
Stormwater monitoring	Confirm no residual adverse effects	Monitoring radioactivity in storm water management system to determine contamination of surface water.	Project Area	Throughout site preparation and construction, operations, and decommissioning phases.
Dose program	Confirm effectiveness of mitigation; confirm no residual adverse effects	Monitoring dose to workers: 1. Measure contact dose on packages. 2. Measure ambient dose rate in accessible areas. 3. Measure worker dose.	Project Area	Throughout operations and decommissioning phases.

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14. CONCLUSIONS

This TSD evaluates the potential effects of the works and activities associated with the DGR Project lifecycle from the radiation and radioactivity perspective. Successive screenings determined that there may be measurable doses to the selected VECs, which include project workers, members of the public, and non-human biota. The detailed assessment, however, determined that project-related doses to humans will be well below the established regulatory limits, and that doses to non-human biota will be small fractions of chronic dose rate benchmarks taken from the literature. A number of in-design mitigation measures to limit doses were accounted for, including shielding, emission controls, security barriers, and zoning. In conclusion, during the site preparation and construction, operations and decommissioning phases, the DGR Project is not expected to result in any residual adverse effects on workers, members of the public including Aboriginal peoples, and non-human biota from the radiation and radioactivity perspective. Section 9 of the EIS discusses the potential for radiation and radioactivity effects following abandonment of the DGR facility. An assessment of the cumulative effects associated with the DGR Project is included in Section 10 of the EIS.

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APPENDIX A: LIST OF ACRONYMS, UNITS AND TERMS

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LIST OF ACRONYMS

Acronym	Descriptive Term
ACNS	Advisory Committee on Nuclear Safety
ACRP	Canadian Advisory Committee on Radiological Protection
AECL	Atomic Energy of Canada Limited
ALARA	As Low As Reasonable Achievable
BEC	Bruce Energy Centre
CCW	Condenser Cooling Water
CEAA	*Canadian Environmental Assessment Act*
CMLF	Central Maintenance and Laundry Facility
CNSC	Canadian Nuclear Safety Commission
DGR	Deep Geologic Repository
DRL	Derived Release Limit
EA	Environmental Assessment
EIS	Environmental Impact Statement
ENEV	Estimated No Effect dose rate Values
HTO	Tritiated Water
ICRP	International Commission on Radiation Protection
ILW	Intermediate Level Waste
L&ILW	Low and Intermediate Level Radioactive Waste
LLSB	Low Level Storage Building
LLW	Low level waste
MAC	Maximum Acceptable Concentration
MDL	Method Detection Limit
NCRP	United States' National Council on Radiation Protection and Measurement
NEW	Nuclear Energy Workers
NORM	Naturally occurring radioactive material
NWMO	Nuclear Waste Management Organization
OBT	Organically Bound Tritium
ODWAC	Ontario Drinking Water Advisory Council
ODWQS	Ontario Drinking Water Quality Standards
OPG	Ontario Power Generation Inc.
RA	Responsible Authority
REMP	Radiological Environmental Monitoring Program

LIST OF ACRONYMS (continued)

Acronym	Descriptive Term
RWOS	Radioactive Waste Operations Site
TFWT	Tissue Free Water Tritium
TLD	Thermoluminescent Dosimeter
TSD	Technical Support Document
VEC	Valued Ecosystem Component
WPRB	Waste Package Receiving Building
WUFDSF	Western Used Fuel Dry Storage Facility
WWMF	Western Waste Management Facility

LIST OF UNITS

Symbol	Units
Bq	Becquerels
Bq/a	Becquerels per year
Bq/kg	Becquerels per Kilogram
Bq/kg-C	Becquerels per Kilogram Carbon
Bq/L	Becquerels per Litre
Bq-MeV/m^3	Becquerel MegaElectron volt per Cubic Metre
Bq/m^2	Bequerels per Square Metre
Bq/m^3	Becquerels per Cubic Metre
°C	Degrees Celsius
cm	Centimetre
h/a	Hours per Year
kg	Kilogram
kg/a	Kilograms per Year
km	Kilometre
km^2	Square Kilometre
L/a	Litres per Year
m^3/a	Cubic Metres per Year
mg/L	Milligrams per Litre
mGy/d	MilliGray per Day
mm	Millimetre
µGy/d	MicroGray per Day
µGy/h	MicroGray per Hour
µSv	MicroSievert
µSv/a	MicroSievert per Year
µSv/h	MicroSievert per Hour
mSv	MilliSievert
mSv/a	MilliSievert per Year
mSv/h	MilliSievert per Hour
nGy/h	NanoGray per Hour
person-mSv	Person-MilliSievert
person-Sv	Person-Sievert
Sv/a	Sieverts per Year

GLOSSARY OF TERMS

Aboriginal traditional knowledge – Knowledge that is held by, and unique to, Aboriginal peoples. Aboriginal traditional knowledge is a body of knowledge built up by a group of people through generations of living in close contact with nature. It is cumulative and dynamic and builds upon the historic experiences of a people and adapts to social, economic, environmental, spiritual and political change.

Action level – A specific dose of radiation or other parameter that, if reached, may indicate a loss of control of part of a facility's radiation protection program, and triggers a requirement for specific action to be taken.

Aquifer – A geological formation or structure that is sufficiently porous and permeable to store, transmit, and yield significant or economic quantities of groundwater to wells and springs. A confined aquifer is bound by low permeability formations such that it is under pressure. An unconfined aquifer is one whose upper groundwater surface (water table) is at atmospheric pressure.

Bio-magnification – Result of the process of bioaccumulation and biotransfer by which tissue concentrations of chemicals in organisms at one trophic level exceed tissue concentrations in organisms at the next lower trophic level in a food chain.

Bruce nuclear site – The 932 hectare (9.32 km^2) parcel of land located within the administrative boundaries of the Municipality of Kincardine in Bruce County. Two operating nuclear stations are located on the site. The site is owned by OPG but has been leased to Bruce Power since May 2001. However, parts of the site, including land on which the WWMF is located, have been retained by OPG. See also *OPG-retained lands*.

Bruce Power – The licensed operator of the Bruce A and Bruce B nuclear generating stations.

Canadian Nuclear Safety Commission (CNSC) – The Canadian federal agency responsible for regulating nuclear facilities and materials, including management of all radioactive waste in Canada.

Canadian Environmental Assessment Agency (CEAA) – The federal body accountable to the Minister of the Environment. The Agency works to provide Canadians with high-quality environmental assessments that contribute to informed decision making, in support of sustainable development.

Closure – The administrative and technical actions directed at a repository at the end of its operating lifetime. For example, covering the waste (for a near surface repository), backfilling and/or sealing of rooms, tunnels and/or shafts (for a geological repository), and termination or completion of activities in any associated structures.

Critical Group – A group of members of the public which is reasonably homogeneous with regard to its exposure for a given contamination source and given exposure pathway, and is typical of individuals receiving the highest health impacts by the given exposure pathway from the source.

Decommissioning – Those actions taken, in the interest of health, safety, security and protection of the environment, to retire a licensed activity/facility permanently from service and render it to a predetermined end-state condition.

Deep Geologic Repository (or DGR, or Repository) – The underground portion of the deep geologic repository facility for low- and intermediate-level waste. Initially, the repository includes the access-ways (shafts, ramps and/or tunnels), underground service areas and installations, and emplacement rooms. In the postclosure phase it also includes the engineered barrier systems. The repository includes the waste emplaced within the rooms and excludes the excavation damage zone.

Deep Geologic Repository Facility (or DGR Facility, or Repository Facility) – The deep geologic repository for low- and intermediate-level waste, and the various surface and underground support facilities. The support facilities include equipment, materials and infrastructure for receiving, inspecting and handling waste packages, for transferring waste packages from the surface to the repository horizon, for handling the waste packages in the repository, for emplacing waste packages, for excavating the repository (during operations), for constructing room shield walls, and for material storage. The repository facility excludes the waste emplaced within the rooms and any zones of damaged rock around underground openings.

DGR Project Site – The portion of the Project Area that will be affected by the site preparation and construction of the surface facilities (i.e., the surface footprint).

Direct Exposure – External exposure to radiation resulting from being in its immediate vicinity (shine).

Dose – A measure of the energy deposited by radiation in a tissue. Also referred to as absorbed dose, committed equivalent dose, committed effective dose, effective dose, equivalent dose or organ dose, depending on the context.

Emplacement Room – A portion of the underground repository into which waste packages are permanently placed. Rooms are bounded by the host rock for floor, ceiling and walls on most sides, and by a wall or access tunnel on one side.

Engineered Barrier – A physical obstruction that has been constructed to prevent or delay water seepage and/or radionuclide migration and/or migration of other materials between components in the repository, or between the repository and the surface environment.

Estimated No Effect dose rate Values – Estimated No Effect dose-rate Values (ENEVs) are used in ecological risk assessments as a benchmark for population-level impacts on non-human biota, as dose rates below the ENEV have not been observed to produce any adverse impacts upon populations of biota.

Exposure Pathway – A route by which contaminants can reach humans or biota and cause exposure. An exposure pathway may be very simple, for example external exposure from airborne contaminants, or involve a more complex chain, for example internal exposure from drinking milk from cows that ate grass contaminated with deposited contaminants.

Geosynthesis – The assembly of all the geologically-based evidence relevant to the repository safety case; the integration of multi-disciplinary geoscientific data relevant to the development of a descriptive conceptual geosphere model; explanation of a site-specific descriptive conceptual geosphere model within a systematic and structured framework.

Indirect Exposure – Exposures via pathways such as air, water and soil where the dose is received through ingestion, inhalation or immersion in radioactive matter.

Institutional Control – Control of a deep geologic repository by an authority or institution designated under the laws of a country or state. This control may be active (monitoring, surveillance, remedial work) or passive (land use control).

Intermediate-Level Waste (ILW) – Radioactive non-fuel waste, containing significant quantities of long-lived radionuclides (generally refers to half-lives greater than 30 years).

L&ILW – Low- and Intermediate-Level radioactive Waste.

Low Level Storage Building (LLSB) - Refers to a series of buildings at OPG's Western Waste Management Facility for the interim storage of low-level waste.

Low-Level Waste (LLW) – Radioactive waste in which the concentration or quantity of radionuclides is above the clearance levels established by the regulatory body (CNSC), and which contains primarily short-lived radionuclides (half-lives shorter than or equal to 30-years).

Nuclear Energy Worker (NEW) – a person who is required, in the course of the person's business or occupation in connection with a nuclear substance or nuclear facility, to perform duties in such circumstances that there is a reasonable probability that the person may receive a dose of radiation that is greater than the prescribed limit for the general public.

OPG-retained Land – The parcels of land at the Bruce nuclear site for which control has been retained by OPG. This includes the WWMF, certain landfills, and the Heavy Water Plant Lands.

Organically Bound Tritium (OBT) – Tritium released into the environment may be incorporated into organic matter. Organically bound tritium will show retention times in organisms that are considerably longer than those of tritiated water which has significant consequences on dose estimates.

Postclosure Monitoring – Monitoring during the time period following closure of the repository.

Postclosure Phase – The period of time following closure of the deep geologic repository.

Precautionary Approach – The precautionary approach is ultimately guided by judgement, based on values and is intended to address uncertainties in the assessment. This approach is consistent with Principle 15 of the 1992 Rio Declaration on Environment and Development. Principle 15 of 1992 Rio Declaration on Environment and Development and the Canadian government's framework for applying precaution in decision-making processes.

Radioactive Waste – Any material (liquid, gaseous or solid) that contains a radioactive "nuclear substance" as defined in Section 2 of Nuclear Safety and Control Act, and which the owner has declared to be waste. In addition to containing nuclear substances, radioactive waste may also contain non-radioactive "hazardous substances", as defined in Section 1 of the CNSC's General Nuclear Safety and Control Regulations.

Radionuclide – A radionuclide is an atom with an unstable nucleus which can undergo radioactive decay by the emission of gamma ray(s) and/or subatomic particles. The resulting emission(s) is defined as radiation.

Receptor – Any person or environmental entity that is exposed to radiation, or a hazardous substance, or both. A receptor is usually an organism or a population, but it could also be an abiotic entity such as surface water or sediment.

Risk – A multi-attribute quantity expressing hazard, danger or chance of harmful or injurious consequences associated with actual or potential exposures. It relates to quantities such as the probability that specific deleterious consequences may arise and the magnitude and character of such consequences.

Safety Report – A key licensing document which provides an overview of the facility design and operations, summarizes the integrated results of individual safety assessments, and demonstrates that a facility can be constructed, operated, or continue to be operated, without undue risk to health and safety of the workers and the public, and the environment.

Preliminary Safety Report (PSR) is the Safety Report submitted to CNSC in support of an application for a Site Preparation/Construction Licence.

Final Safety Report (FSR) is the Safety Report submitted to CNSC in support of an application for a Licence to Operate.

Scenarios – A postulated or assumed set of conditions or events. They are most commonly used in analysis or assessment to represent possible future conditions or events to be modelled, such as the possible future evolution of a repository and its surroundings.

Shaft – A vertical or near-vertical excavated passageway that connects the surface with an underground workplace or connects two or more underground workplaces at different elevations.

Traditional ecological knowledge – Traditional ecological knowledge is a subset of Aboriginal traditional knowledge. Traditional ecological knowledge refers specifically to all types of knowledge about the environment derived from the experience and traditions of a particular group of people. There are four traditional ecological knowledge categories: knowledge about the environment; knowledge about the use of the environment; values about the environment; and the foundation of the knowledge system.

Underground Service Areas – Any excavations within the deep geologic repository that provide the space for the infrastructure to characterize, demonstrate, construct, operate, monitor and decommission a deep geologic repository. Service areas include all excavations in a deep geologic repository that are not classified as tunnels, shafts, ramps, emplacement rooms or boreholes.

Valued Ecosystem Component (VEC) – VECs are features of the environment selected to be a focus of the environmental assessment because of their ecological, social, or economic value, and their potential vulnerability to the effects of the DGR Project.

Waste Package – The waste material, the container, and any external barriers (e.g. shielding material), as prepared in accordance with requirements for handling, transfer and emplacement in the repository. It is a discrete unit that can be individually identified and handled at the repository facility.

Waste Package Receiving Building (WPRB) – The building at the DGR surface where waste packages arrive for transfer underground.

Western Waste Management Facility (WWMF) – The centralized processing and storage facility at the Bruce nuclear site for OPG's L&ILW and for the dry storage of used fuel from Bruce nuclear generating stations.

APPENDIX B: BASIS FOR THE EA

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Table B-1: Basis for the EA

Project Works and Activities	Description
Site Preparation	Site preparation would begin after receipt of a Site Preparation Licence and would include clearing approximately 30 ha of the DGR Project site and preparing the construction laydown areas. Activities would include: • Removal of brush and trees and transfer by truck to on-site storage; • Excavation for removal and stockpiling of topsoil and truck transfer of soil to stockpile on-site; • Grading of sites, including roads, construction laydown areas, stormwater management area, ditches; • Receipt of materials including gravel, concrete, and steel; • Installation of construction roads and fencing; • Receipt and installation of construction trailers and associated temporary services; and • Install and operate fuel depot for construction equipment.
Construction of Surface Facilities	Construction of surface facilities will include the construction of the waste transfer, material handling, shaft headframes and all other temporary and permanent facilities at the site. Activities would include: • establish a concrete batch plant; • receipt of construction materials, including supplies for concrete, gravel, and steel by road transportation; • excavation for and construction of footings for permanent buildings, and for site services such as domestic water, sewage, electrical; • construction of permanent buildings, including headframe buildings associated with main and ventilation shafts; • receipt and set up of equipment for shaft sinking; • construction of abandoned rail bed crossing between WWMF and the DGR site; • fuelling of vehicles; and • construction of electrical substation and receipt and installation of standby generators.
Excavation and Construction of Underground Facilities	Excavation and construction of underground facilities will include excavation of the shafts, installation of the shaft and underground infrastructure (e.g., ventilation system) and the underground excavation of the emplacement and non-storage rooms. Activities will include: • drilling and blasting (use of explosives) for construction of main and ventilation shafts, and access tunnels and emplacement rooms; • receipt and placement of grout and concrete, steel and equipment; • dewatering of the shaft construction area by pumping and transfer to the above-ground stormwater management facility; • temporary storage of explosives underground for construction of emplacement rooms and tunnels; • receipt and installation of rock bolts and services; and • installation of shotcrete.

Table B-1: Basis for the EA (continued)

Project Works and Activities	Description
Above-ground Transfer and Receipt of Waste	Above-ground handling of wastes will occur during the operations phase of the DGR Project and will include receipt of L&ILW from the WWMF at the staging area in the DGR Waste Package Receiving Building (WPRB) and on-site transfer to shaft. Above-ground handling of wastes includes: • receipt of disposal-ready waste packages from the WWMF by forklift or truck • offloading of waste packages at the WPRB; • transfer of waste packages within the WPRB by forklift or rail cart; • temporary storage of waste packages inside the WPRB.
Underground Transfer of Waste	Underground handling of wastes will take place during the operations phase of the DGR Project and will include: • receipt of waste packages at the the main shaft station; • offloading from cage and transfer of waste packages by forklift to emplacement rooms; • rail cart transfer of some large packages (Heat Exchangers/Shield Plug Containers) to emplacement rooms; • installation of end walls on full emplacement rooms; • remedial rock bolting and rock wall scaling; • fuelling and maintenance of underground vehicles and equipment; • receipt and storage of fuel for underground vehicles. Emplacement activities will be followed by a period of monitoring to ensure that the DGR facility is performing as expected prior to decommissioning.
Decommissioning of the DGR Project	Decommissioning of the DGR Project will require a separate environmental assessment before any activities can begin. Decommissioning of the DGR Project will include all activities required to seal shafts and remove surface facilities including: • removal of fuels from underground equipment; • removal of surface buildings, including foundations and equipment; • receipt and placement of materials, including concrete, asphalt, sand, bentonite for sealing the shaft; • construction of concrete monolith at base of two shafts, removal of shaft infrastructure and concrete liners, and reaming of some rock from the shafts and shaft stations; • sealing the shaft; and • grading of the site. The waste rock pile (limestones) will be covered and remain on-site.
Abandonment of the DGR Facility	Timing of abandonment of the DGR facility will be based on discussion with the regulator. Activities may include removal of access controls.
Presence of the DGR Project	Presence of the DGR Project represents the meaning people may attach to the existence of the DGR Project in their community and the influence its operations may have on their sense of health, safety and personal security over the life cycle of the DGR Project. This includes the aesthetics and vista of the DGR facility.

Table B-1: Basis for the EA (continued)

Project Works and Activities	Description
Waste Management	Waste management represents all activities required to manage waste during the DGR Project. During construction waste management will include managing the waste rock along with conventional waste management. During operations, waste management would include managing conventional and radiological wastes from the underground and above-ground operations. Decommissioning waste management may include management of conventional and construction wastes. Activities include: • transfer of waste rock, by truck to the WRMA; • placement of waste rock on the storage pile; • collection and transfer of construction waste to on-site or licensed off-site facility; • collection and transfer of domestic waste to licensed facility; • collection, processing and management of any radioactive waste produced at the DGR facility; • collection, temporary storage and transfer of toxic/hazardous waste to licensed facility.
Support and Monitoring of DGR Life Cycle	Support and monitoring of DGR life cycle will include all activities to support the safe construction, operation, and decommissioning of the DGR Project. This includes: • operation and maintenance of the ventilation fans, heating system, electrical systems, fire protection system, communications services, sewage and potable water system and the standby generator; • collection, storage, and disposal of water from underground sumps, and of wastewater from above-and below ground facilities; • management of surface drainage in a stormwater management facility; • monitoring of air quality in the facility, exhaust from the facility, water quality of run-off from the developed area around the shafts and Waste Rock Management Area, water quality from underground shaft sumps and geotechnical monitoring of various underground openings; • maintenance and operation of fuel depots above-ground (construction only) and below-ground; and • administrative activities above- and below-ground involving office space, lunch room and amenities space.
Workers, Payroll and Purchasing	Workers, payroll and purchasing will include all workers required during each phase to implement the DGR Project. Activities include: • spending in commercial and industrial sectors; • transport of materials purchased to the site; and • workers travelling to and from site.

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APPENDIX C: DETAILED RADIATION DOSE CALCULATIONS (NON-HUMAN BIOTA)

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C. DETAILED RADIATION DOSE CALCULATIONS (NON-HUMAN BIOTA)

Standard ecological risk assessment frameworks that categorize the levels of detail and quality of the data required for the assessment were employed to calculate the dose to non-human biota, based on a similar methodology employed in [C1]. This constituted a Tier 2 assessment as defined in the EIS guidelines (a semi-quantitative evaluation using site-specific data, existing site information, and very conservative assumptions). As there were no adverse effects identified, a Tier 3 assessment was not required (field surveys, less conservative assumptions and more detailed modelling).

The simplified exposure pathway for non-human biota is illustrated in Figure C-1. A summary of the dose rates to non-human biota has been provided in Section 8. The general method to calculate dose to non-human biota as follows:

1. Characterization of representative species from an ecological perspective. The parameters for example, water intake rate, food intake rate, fraction of diet components, habitat occupancy rates, have been extensively discussed in [C1].

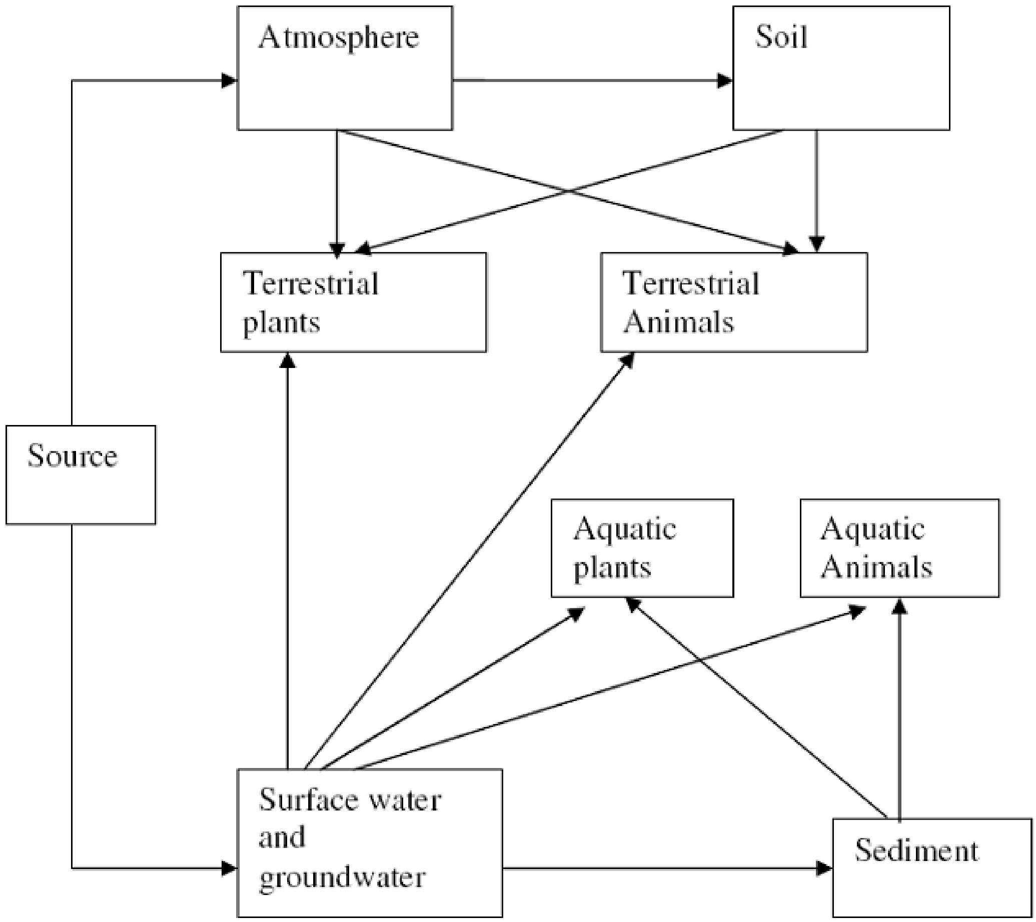
2. Characterization of representative species and the environment from the radiation perspective. The parameters, for example, internal and external dose coefficients, transfer factor, have been extensively discussed in [C1]. The concentrations of radionuclides in different environmental media such as air, surface water, soil and sediment are discussed in Section C.1. These concentrations are used to determine the intake of each radionuclide via important pathways such as ingestion and inhalation (as applicable), and consequently, their concentrations within the representative species. This is relevant in the calculation of the internal dose received. The effects of gamma radiation due to direct exposure have been discussed previously (refer to Sections 6 and 7).

3. Calculation of internal dose and external dose to representative species. The general equations are as follow:

   Internal dose = dose coefficient × concentration of radionuclide in species

   External dose = dose coefficient × concentration of radionuclide in environmental media

Detailed calculations are provided in Section C.2. Note that the equations to calculate specific parameters and the total dose are provided for Benthic Invertebrates only (please refer to the last column in the calculation sheet for Benthic Invertebrates) as the examples illustrating how they are derived.



Note: Food pathways for animals are not shown on this figure.

Figure C-1: Simplified Non-human Biota Exposure Pathway

C.1 ENVIRONMENTAL CONCENTRATIONS

The maximum concentrations for tritium (H-3) and carbon-14 (C-14) recorded in environmental media in naturalized /undisturbed areas at the Bruce nuclear site are provided below. The locations where the maximum concentrations were detected can be found in [C4].

Medium	H-3 Concentration	C-14 Concentration
Air	3.9 Bq/m^3	0.21 Bq/m^3
Surface Water	1850 Bq/L	0.3 Bq/L
Soil	122 Bq/kg	430 Bq/kg
Sediment	0.00024 Bq/kg	250 Bq/kg

Other environmental concentrations were derived as follows:

- H-3 concentration in vegetation: Measured site maximum from [C2] for leafy vegetation is under 90 Bq/kg; 100 Bq/kg was taken as a conservative value.
- H-3 concentration in berries: Measured site maximum from [C2] for fruits is 289.5 Bq/kg.
- C-14 concentration in berries: Measured site maximum from [C2] for fruits is 326 Bq/kg.

Certain environmental concentrations were not available from sampling, and had to be scaled from corresponding values in [C1] using either air, water, soil or sediment concentrations. These are described in the following pages at the point of calculation.

C.2 DETAILED CALCULATIONS

Benthic Invertebrates

Parameter	Unit	Acronym	DGR EA	
C-14				
sediment conc-DW	Bq/kg(DW)	sedconc(DW)	2.50E+02	Measured site max
sediment-water Kd	L/kg	Kd	5.00E+01	Ref DN EA [C1]
pore water conc	Bq/L	pwconc	5.00E+00	=sedconc(DW)/Kd
sediment conc-WW	Bq/kg(WW)	sedconc(WW)	2.95E+01	=pwconc*0.9+sedconc(DW)*0.1
Transfer factor	L/kg(FW)	Tfbi	2.25E+05	Ref DN EA [C1]
benthic invert. Conc	Bq/kg(FW)	biconc(FW)	6.38E+02	=(biconc(FW)_DN/sedconc(DW)_DN)*sedconc(DW)_DGR
internal DC	Gy/y per Bq/kg	Dci	2.54E-07	Ref DN EA [C1]
internal dose	Gy/y	Di	1.62E-04	=Dci*biconc(FW)
external DC	Gy/y per Bq/kg	Dce	2.72E-10	Ref DN EA [C1]
external dose from sediment	Gy/y	De	8.02E-09	=Dce*sedconc(WW)
total dose	Gy/y	Dt	1.62E-04	=Di+De
	mGy/d		4.44E-04	=Dt*1000/365
H-3				
sediment conc-DW	Bq/kg(DW)	sedconc(DW)	2.40E-04	Measured site max
sediment-water Kd	L/kg	Kd	1.00E+00	Ref DN EA [C1]
pore water conc	Bq/L	pwconc	2.40E-04	=sedconc(DW)/Kd
sediment conc-WW	Bq/kg(WW)	sedconc(WW)	2.40E-04	=pwconc*0.9+sedconc(DW)*0.1
Transfer factor	L/kg(FW)	Tfbi	1.00E+00	Ref DN EA [C1]
benthic invert. Conc	Bq/kg(FW)	biconc(FW)	8.05E-06	=(biconc(FW)_DN/sedconc(DW)_DN)*sedconc(DW)_DGR
internal DC	Gy/y per Bq/kg	Dci	2.89E-08	Ref DN EA [C1]
internal dose	Gy/y	Di_uw	2.33E-13	=Dci*biconc(FW)
weighted internal dose	Gy/y	Di	6.98E-13	=Di_uw*3
external DC	Gy/y per Bq/kg	Dce	1.05E-12	Ref DN EA [C1]
external dose from sediment	Gy/y	De	2.52E-16	=Dce*sedconc(WW)
total dose	Gy/y	Dt	6.99E-13	=Di+De
	mGy/d		1.91E-12	=Dt*1000/365
TOTAL DOSE	mGy/d		4.44E-04	

Aquatic Vegetation

Parameter	Unit	Acronym	DGR EA
C-14			
water conc	Bq/L	wconc	3.00E-01
AquaVeg transfer factor	L/kg(DW)	Tfaq	1.01E+05
AquaVeg conc-DW	Bq/kg(DW)	aqconc(DW)	3.03E+04
AquaVeg conc-FW	Bq/kg(FW)	aqconc(FW)	5.24E+01
internal DC	Gy/y per Bq/kg	Dci	2.10E-07
internal dose	Gy/y	Di	1.10E-05
external DC	Gy/y per Bq/kg	Dce	4.03E-08
external dose from water	Gy/y	De	1.21E-08
total dose	Gy/y	Dt	1.10E-05
	mGy/d		3.02E-05
H-3			
water conc	Bq/L	wconc	1.85E+03
AquaVeg transfer factor	L/kg(DW)	Tfaq	1.00E+00
AquaVeg conc-DW	Bq/kg(DW)	aqconc(DW)	1.85E+03
AquaVeg conc-FW	Bq/kg(FW)	aqconc(FW)	1.38E+03
internal DC	Gy/y per Bq/kg	Dci	2.89E-08
internal dose	Gy/y	Di_uw	3.98E-05
weighted internal dose	Gy/y	Di	1.19E-04
external DC	Gy/y per Bq/kg	Dce	1.66E-10
external dose from water	Gy/y	De	3.07E-07
total dose	Gy/y	Dt	1.20E-04
	mGy/d		3.28E-04
TOTAL DOSE	mGy/d		3.58E-04

Benthic Fish

Parameter	Unit	Acronym	DGR EA
Fraction of time in water		ffw	0.5
Fraction of time in sediment		ffs	0.5
C-14			
water conc	Bq/L	wconc	3.00E-01
Transfer factor fish	L/kg(FW)	TFf	5.72E+03
Fish conc-FW	Bq/kg(FW)	fconc(FW)	4.20E+01
internal DC	Gy/y per Bq/kg	Dci	2.54E-07
internal dose	Gy/y	Di-w	1.07E-05
external DC	Gy/y per Bq/kg	Dce	1.40E-10
external dose from water	Gy/y	De-w	2.10E-11
total dose-water	Gy/y	Dt-w	1.07E-05
sediment conc-DW	Bq/kg(DW)	sedconc(DW)	2.50E+02
sediment-water Kd	L/kg	Kd	5.00E+01
pore water conc	Bq/L	pwconc	5.00E+00
sediment conc-WW	Bq/kg(WW)	sedconc(WW)	2.95E+01
external DC-sediment	Gy/y per Bq/kg	Dce	1.40E-10
external dose from sediment	Gy/y	De-s	2.07E-09
total dose-water+sediment	Gy/y	Dt	1.07E-05
	mGy/d		2.92E-05
H-3			
water conc	Bq/L	wconc	1.85E+03
Transfer factor fish	L/kg(FW)	TFf	1.00E+00
Fish conc-FW	Bq/kg(FW)	fconc(FW)	1.83E+03
internal DC	Gy/y per Bq/kg	Dci	2.89E-08
internal dose	Gy/y	Di_uw	5.28E-05
weighted internal dose	Gy/y	Di	1.58E-04
external DC	Gy/y per Bq/kg	Dce	5.52E-13
external dose from water	Gy/y	De-w	5.11E-10
total dose-water	Gy/y	Dt-w	1.58E-04
sediment conc-DW	Bq/kg(DW)	sedconc(DW)	2.40E-04
sediment-water Kd	L/kg	Kd	1.00E+00
pore water conc	Bq/L	pwconc	2.40E-04
sediment conc-WW	Bq/kg(WW)	sedconc(WW)	2.40E-04
external DC-sediment	Gy/y per Bq/kg	Dce	5.52E-13
external dose from sediment	Gy/y	De-s	6.62E-17
total dose-water+sediment	Gy/y	Dt	1.58E-04
	mGy/d		4.34E-04
TOTAL DOSE	mGy/d		4.63E-04

Pelagic Fish

Parameter	Unit	Acronym	DGR EA
C-14			
water conc	Bq/L	wconc	3.00E-01
Transfer factor fish	L/kg(FW)	TFf	5.72E+03
Fish conc-FW	Bq/kg(FW)	fconc(FW)	4.20E+01
internal DC	Gy/y per Bq/kg	Dci	2.54E-07
internal dose	Gy/y	Di	1.07E-05
external DC	Gy/y per Bq/kg	Dce	2.37E-10
external dose from water	Gy/y	De	7.11E-11
total dose	Gy/y	Dt	1.07E-05
	mGy/d		2.92E-05
H-3			
water conc	Bq/L	wconc	1.85E+03
Transfer factor fish	L/kg(FW)	TFf	1.00E+00
Fish conc-FW	Bq/kg(FW)	fconc(FW)	1.83E+03
internal DC	Gy/y per Bq/kg	Dci	2.89E-08
internal dose	Gy/y	Di_uw	5.28E-05
weighted internal dose	Gy/y	Di	1.58E-04
external DC	Gy/y per Bq/kg	Dce	1.05E-12
external dose from water	Gy/y	De	1.94E-09
total dose	Gy/y	Dt	1.58E-04
	mGy/d		4.34E-04
TOTAL DOSE	mGy/d		4.63E-04

Double-crested Cormorant

Parameter	Unit	Acronym	DGR EA
water intake	L/d	Qwats	0.03
total food intake	g (FW)/d	Qffws	173
benthos fraction		fbis	0.5
fish fraction		favs	0.5
sediment intake	g (DW)/d	Qsdws	0.7
fraction of time in area		flocs	0.5
C-14			
water conc	Bq/L	wconc	3.00E-01
fish conc	Bq/kg (FW)	fconc(FW)	4.20E+01
benthos conc	Bq/kg (FW)	biconc(FW)	6.38E+02
sediment conc	Bq/kg (DW)	sedconc(DW)	2.50E+02
intake of water	Bq/d	Iwat	4.50E-03
intake of benthos	Bq/d	Ibi	2.76E+01
intake of fish	Bq/d	Ifish	1.82E+00
intake of sediment	Bq/d	Ised	8.75E-02
total intake	Bq/d	Itot	2.95E+01
Transfer factor	d/kg (FW)	Tfbird	8.50E+00
cormorant concentration	Bq/kg (FW)	corconc(FW)	2.51E+02
internal DC	Gy/y per Bq/kg	Dci	2.54E-07
internal dose	Gy/y	Di	6.37E-05
external DC from water	Gy/y per Bq/kg	Dce-w	6.13E-11
external dose from water	Gy/y	De	9.20E-12
total dose	Gy/y	Dt	6.37E-05
	mGy/d		1.74E-04
H-3			
water conc	Bq/L	wconc	1.85E+03
fish conc	Bq/kg (FW)	fconc(FW)	1.83E+03
benthos conc	Bq/kg (FW)	biconc(FW)	8.05E-06
sediment conc	Bq/kg (DW)	sedconc(DW)	2.40E-04
intake of water	Bq/d	Iwat	2.78E+01
intake of benthos	Bq/d	Ibi	3.48E-07
intake of fish	Bq/d	Ifish	7.90E+01
intake of sediment	Bq/d	Ised	8.40E-08
total intake	Bq/d	Itot	1.07E+02
Transfer factor	d/kg (FW)	Tfbird	1.00E+00
Cormorant concentration	Bq/kg (FW)	corconc(FW)	1.07E+02
internal DC	Gy/y per Bq/kg	Dci	2.89E-08
internal dose	Gy/y	Di_uw	3.08E-06
weighted internal dose	Gy/y	Di	9.25E-06
external DC from water	Gy/y per Bq/kg	Dce-w	2.72E-13
external dose from water	Gy/y	De	2.52E-10
total dose	Gy/y	Dt	9.25E-06
	mGy/d		2.54E-05
TOTAL DOSE	mGy/d		2.00E-04

Mallard

Parameter	Unit	Acronym	DGR EA
water intake	L/d	Qwats	0.06
total food intake	g (FW)/d	Qffws	250
benthos fraction		fbis	0.75
aquatic veg fraction		favs	0.25
sediment intake	g (DW)/d	Qsdws	1.7
fraction of time in area		flocs	0.5
C-14			
water conc	Bq/L	wconc	3.00E-01
aquatic plant conc	Bq/kg (FW)	aqconc(FW)	5.24E+01
benthos conc	Bq/kg (FW)	biconc(FW)	6.38E+02
sediment conc	Bq/kg (DW)	sedconc(DW)	2.50E+02
intake of water	Bq/d	Iwat	9.00E-03
intake of benthos	Bq/d	Ibi	5.98E+01
intake of aquatic veg	Bq/d	Iaq	1.64E+00
intake of sediment	Bq/d	Ised	2.13E-01
total intake	Bq/d	Itot	6.16E+01
Transfer factor	d/kg (FW)	Tfbird	8.50E+00
mallard concentration	Bq/kg (FW)	malconc(FW)	5.24E+02
internal DC	Gy/y per Bq/kg	Dci	2.54E-07
internal dose	Gy/y	Di	1.33E-04
external DC from water	Gy/y per Bq/kg	Dce-w	6.13E-11
external dose from water	Gy/y	De	9.20E-12
total dose	Gy/y	Dt	1.33E-04
	mGy/d		3.65E-04
H-3			
water conc	Bq/L	wconc	1.85E+03
aquatic plant conc	Bq/kg (FW)	aqconc(FW)	1.38E+03
benthos conc	Bq/kg (FW)	biconc(FW)	8.05E-06
sediment conc	Bq/kg (DW)	sedconc(DW)	2.40E-04
intake of water	Bq/d	Iwat	5.55E+01
intake of benthos	Bq/d	Ibi	7.55E-07
intake of aquatic veg	Bq/d	Iaq	4.30E+01
intake of sediment	Bq/d	Ised	2.04E-07
total intake	Bq/d	Itot	9.85E+01
Transfer factor	d/kg (FW)	Tfbird	1.00E+00
mallard concentration	Bq/kg (FW)	malconc(FW)	9.85E+01
internal DC	Gy/y per Bq/kg	Dci	2.89E-08
internal dose	Gy/y	Di_uw	2.85E-06
weighted internal dose	Gy/y	Di	8.54E-06
external DC from water	Gy/y per Bq/kg	Dce-w	2.72E-13
external dose from water	Gy/y	De	2.52E-10
total dose	Gy/y	Dt	8.54E-06
	mGy/d		2.34E-05
TOTAL DOSE	mGy/d		3.88E-04

Muskrat

Parameter	Unit	Acronym	DGR EA
water intake	L/d	Qwatm	0.12
total food intake	g (FW)/d	Qffwm	360
benthos fraction		fbim	0.02
aquatic veg fraction		favm	0.98
sediment intake	g (DW)/d	Qsedm	2.4
body weight	kg	BWm	1.2
fraction of time in area		flocm	1
fraction of time in house		fhm	0.7
C-14			
water conc	Bq/L	wconc	3.00E-01
sediment conc-DW	Bq/kg (DW)	sedconc(DW)	2.50E+02
sediment-water Kd	L/kg	Kd	5.00E+01
porewater conc	Bq/L	pwconc	5.00E+00
sediment conc-WW	Bq/kg (WW)	sedconc(WW)	2.95E+01
aquatic plan conc	Bq/kg (FW)	aqconc(FW)	5.24E+01
benthic invert conc	Bq/kg (FW)	biconc(FW)	6.38E+02
intake of water	Bq/d	Iwat	3.60E-02
intake of aquatic plants	Bq/d	Iaq	1.85E+01
intake of benthic invert	Bq/d	Ibi	4.59E+00
intake of sediment	Bq/d	Ised	6.00E-01
total intake	Bq/d	Itot	2.37E+01
transfer factor	d/kg	TFm	8.90E+00
muskrat conc	Bq/kg	mconc	2.11E+02
internal DC	Gy/y per Bq/kg	Dci	2.54E-07
internal dose	Gy/y	Di	5.36E-05
external DC (water)	Gy/y per Bq/kg	Dce	7.36E-11
external dose from water	Gy/y	Dew	6.62E-12
external DC (sediment)	Gy/y per Bq/kg	DCe	7.36E-11
external dose from house	Gy/y	Des-h	1.52E-09
External dose from sediment-base	Gy/y	Des-b	1.52E-09
total dose	Gy/y	Dt	5.36E-05
	mGy/d		1.47E-04
H-3			
water conc	Bq/L	wconc	1.85E+03
sediment conc-DW	Bq/kg (DW)	sedconc(DW)	2.40E-04
sediment-water Kd	L/kg	Kd	1.00E+00
porewater conc	Bq/L	pwconc	2.40E-04
sediment conc-WW	Bq/kg (WW)	sedconc(WW)	2.40E-04
aquatic plan conc	Bq/kg (FW)	aqconc(FW)	1.38E+03
benthic invert conc	Bq/kg (FW)	biconc(FW)	8.05E-06
intake of water	Bq/d	Iwat	2.22E+02
intake of aquatic plants	Bq/d	Iaq	4.85E+02
intake of benthic invert	Bq/d	Ibi	5.80E-08
intake of sediment	Bq/d	Ised	5.76E-07

total intake	Bq/d	Itot	7.07E+02
transfer factor	d/kg	TFm	1.00E+00
muskrat conc-ingestion	Bq/kg(FW)	mconc(FW)	7.07E+02
air conc	Bq/m^3	aconc	3.90E+00
transfer air to animal	$m^3/kg(FW)$	TFrc-inh	2.33E+00
muskrat conc-inhalation	Bq/kg	mconc-inh(FW)	9.09E+00
internal DC	Gy/y per Bq/kg	Dci	2.89E-08
internal dose	Gy/y	Di_uw	2.07E-05
weighted internal dose	Gy/y	Di	6.21E-05
external DC (water)	Gy/y per Bq/kg	Dce	3.15E-13
external dose from water	Gy/y	Dew	1.75E-10
external DC (sediment)	Gy/y per Bq/kg	DCe	3.15E-13
external dose from house	Gy/y	Des-h	5.29E-17
External dose from sediment-base	Gy/y	Des-b	5.29E-17
total dose	Gy/y	Dt	6.21E-05
	mGy/d		1.70E-04
TOTAL DOSE	mGy/d		3.17E-04

Earthworm

Parameter	Unit	Acronym	DGR EA
C-14			
soil concentration	Bq/kg(DW)	sconc	2.50E+02
Transfer factor	kg/kg DW	Tfe	1.00E+00
earthworm conc	Bq/kg(DW)	econc(DW)	2.50E+02
earthworm conc	Bq/kg(FW)	econc(FW)	6.36E+02
internal DC	Gy/y per Bq/kg	Dci	2.45E-07
internal dose	Gy/y	Di	1.56E-04
external DC	Gy/y per Bq/kg	Dce	0.00E+00
external dose from soil	Gy/y	De	0.00E+00
total dose	Gy/y	Dt	1.56E-04
	mGy/d		4.27E-04
H-3			
soil concentration	Bq/kg(DW)	sconc	2.40E-04
Transfer factor	kg/kg DW	Tfe	1.00E+00
earthworm conc	Bq/kg(DW)	econc(DW)	2.40E-04
earthworm conc	Bq/kg(FW)	econc(FW)	6.01E+02
internal DC	Gy/y per Bq/kg	Dci	2.89E-08
internal dose	Gy/y	Di_uw	1.74E-05
weighted internal dose	Gy/y	Di	5.21E-05
external DC	Gy/y per Bq/kg	Dce	0.00E+00
external dose from soil	Gy/y	De	0.00E+00
total dose	Gy/y	Dt	5.21E-05
	mGy/d		1.43E-04
TOTAL DOSE	mGy/d		5.69E-04

Terrestrial Plants

Parameter	Unit	Acronym	DGR EA
C-14			
soil conc	Bq/kg(DW)	sconc	4.30E+02
air conc	Bq/m^3	aconc	2.10E-01
veg-air TF	$m^3/kg(FW)$	TFvs	4.75E+02
vegetation conc	Bq/kg(FW)	vconc(FW)	1.05E+02
internal DC	Gy/y per Bq/kg	Dci	2.10E-07
internal dose	Gy/y	Di	2.20E-05
external DC	Gy/y per Bq/kg	Dce	0.00E+00
external dose from soil	Gy/y	De	0.00E+00
total dose	Gy/y	Dt	2.20E-05
	mGy/d		6.02E-05
H-3			
soil conc	Bq/kg(DW)	sconc	1.22E+02
veg-soil TF	kg/kg(DW)	TFvs	1.00E+00
vegetation conc (soil)	Bq/kg(DW)	vconc(DW)	1.22E+02
vegetation conc	Bq/kg(FW)	vconc(FW)	1.00E+02
internal DC	Gy/y per Bq/kg	Dci	2.89E-08
internal dose	Gy/y	Di_uw	2.89E-06
weighted internal dose	Gy/y	Di	8.67E-06
external DC	Gy/y per Bq/kg	Dce	0.00E+00
external dose from soil	Gy/y	De	0.00E+00
total dose	Gy/y	Dt	8.67E-06
	mGy/d		2.38E-05
TOTAL DOSE	mGy/d		8.39E-05

White-tailed Deer

Parameter	Unit	Acronym	DGR EA
water intake	L/d	Qwatdr	6.8
total food intake (DW)	g(FW)/d	Qffwdr	10900
soil intake	g/d	Qsdr	66
veg fraction		fvdr	1
fraction of time in area		flocdr	1
C-14			
water conc	Bq/L	wconc	3.00E-01
soil conc	Bq/kg(DW)	sconc	4.30E+02
veg conc	Bq/kg(FW)	vconc(FW)	1.05E+02
intake of water	Bq/d	Iwat	2.04E+00
intake of soil	Bq/d	Is	2.84E+01
intake of veg	Bq/d	Iveg	1.14E+03
total intake	Bq/d	Itot	1.17E+03
transfer factor	d/kg(FW)	TFdr	6.20E-01
deer conc	Bq/kg	drconc(FW)	7.26E+02
internal DC	Gy/y per Bq/kg	Dci	2.54E-07
internal dose	Gy/y	Di	1.84E-04
external DC	Gy/y per Bq/kg	Dce	0.00E+00
external dose	Gy/y	De	0.00E+00
total dose	Gy/y	Dt	1.84E-04
	mGy/d		5.05E-04
H-3			
water conc	Bq/L	wconc	1.85E+03
soil conc	Bq/kg(DW)	sconc	1.22E+02
veg conc	Bq/kg(FW)	vconc(FW)	1.00E+02
intake of water	Bq/d	Iwat	1.26E+04
intake of soil	Bq/d	Is	8.05E+00
intake of veg	Bq/d	Iveg	1.09E+03
total intake	Bq/d	Itot	1.37E+04
transfer factor	d/kg(FW)	TFdr	1.00E+00
deer conc - ingestion	Bq/kg	drconc-ing(FW)	1.37E+04
air conc	Bq/m^3	aconc	3.90E+00
transfer factor air to mammal	m^3/kg(FW)	TFrc-inh	2.33E+00
deer conc - inhalation	Bq/kg	drconc-inh(FW)	9.09E+00
internal DC	Gy/y per Bq/kg	Dci	2.89E-08
internal dose	Gy/y	Di_uw	3.96E-04
weighted internal dose	Gy/y	Di	1.19E-03
external DC	Gy/y per Bq/kg	Dce	0.00E+00
external dose	Gy/y	De	0.00E+00
total dose	Gy/y	Dt	1.19E-03
	mGy/d		3.25E-03
TOTAL DOSE	mGy/d		3.76E-03

Northern Short-tailed Shrew

Parameter	Unit	Acronym	DGR EA
water intake	L/d	Qwatsh	0.007
total food intake (DW)	g(FW)/d	Qffwwsh	13
soil intake	g/d	Qssh	0.09
earthworm fraction		fvsh	1
fraction of time in area		flocsh	1
C-14			
water conc	Bq/L	wconc	3.00E-01
soil conc	Bq/kg(DW)	sconc	4.30E+02
earthworm conc	Bq/kg(FW)	econc(FW)	6.36E+02
intake of water	Bq/d	Iwat	2.10E-03
intake of soil	Bq/d	Is	3.87E-02
intake of earthworm	Bq/d	Ie	8.26E+00
total intake	Bq/d	Itot	8.31E+00
transfer factor	d/kg(FW)	TFsh	8.90E+00
shrew conc	Bq/kg	shconc(FW)	7.39E+01
internal DC	Gy/y per Bq/kg	Dci	2.54E-07
internal dose	Gy/y	Di	1.88E-05
external DC	Gy/y per Bq/kg	Dce	0.00E+00
external dose	Gy/y	De	0.00E+00
total dose	Gy/y	Dt	1.88E-05
	mGy/d		5.14E-05
H-3			
water conc	Bq/L	wconc	1.85E+03
soil conc	Bq/kg(DW)	sconc	1.22E+02
earthworm conc	Bq/kg(FW)	econc(FW)	6.01E+02
intake of water	Bq/d	Iwat	1.30E+01
intake of soil	Bq/d	Is	1.10E-02
intake of earthworm	Bq/d	Ie	7.81E+00
total intake	Bq/d	Itot	2.08E+01
transfer factor	d/kg(FW)	TFsh	1.00E+00
shrew conc - ingestion	Bq/kg	shconc-ing(FW)	2.08E+01
air conc	Bq/m^3	aconc	3.90E+00
transfer factor air to mammal	m^3/kg(FW)	TFrc-inh	2.33E+00
shrew conc - inhalation	Bq/kg	shconc-inh(FW)	9.09E+00
internal DC	Gy/y per Bq/kg	Dci	2.89E-08
internal dose	Gy/y	Di_uw	8.63E-07
weighted internal dose	Gy/y	Di	2.59E-06
external DC	Gy/y per Bq/kg	Dce	0.00E+00
external dose	Gy/y	De	0.00E+00
total dose	Gy/y	Dt	2.59E-06
	mGy/d		7.09E-06
TOTAL DOSE	mGy/d		5.85E-05

Red fox

Parameter	Unit	Acronym	DGR EA
water intake	L/d	Qwatfx	0.4
total food intake (DW)	g(FW)/d	Qffwfx	313
soil intake	g/d	Qsfx	2.6
veg fraction		fvfx	0.15
rabbit fraction		frfx	0.4
bird fraction		fbfx	0.2
small mammal fraction		fsmfx	0.25
fraction of time in area		flocfx	1
C-14			
water conc	Bq/L	wconc	3.00E-01
soil conc	Bq/kg(DW)	sconc	4.30E+02
rabbit conc	Bq/kg(FW)	rconc	2.70E+02
bird conc	Bq/kg(FW)	bconc	3.64E+01
veg conc	Bq/kg(FW)	vconc(FW)	1.05E+02
small mammal conc	Bq/kg(FW)	smc	7.39E+01
intake of water	Bq/d	Iwat	1.20E-01
intake of soil	Bq/d	Is	1.12E+00
intake of rabbit	Bq/d	Ir	3.38E+01
intake of veg	Bq/d	Iveg	4.91E+00
intake of birds	Bq/d	Ib	2.28E+00
intake of small mammal	Bq/d	Ism	5.78E+00
total intake	Bq/d	Itot	4.80E+01
transfer factor	d/kg(FW)	TFfx	8.90E+00
fox conc	Bq/kg	fxconc(FW)	4.27E+02
internal DC	Gy/y per Bq/kg	Dci	2.54E-07
internal dose	Gy/y	Di	1.09E-04
external DC	Gy/y per Bq/kg	Dce	0.00E+00
external dose	Gy/y	De	0.00E+00
total dose	Gy/y	Dt	1.09E-04
	mGy/d		2.97E-04
H-3			
water conc	Bq/L	wconc	1.85E+03
soil conc	Bq/kg(DW)	sconc	1.22E+02
rabbit conc	Bq/kg(FW)	rconc	2.59E+02
bird conc	Bq/kg(FW)	bconc	7.70E+00
veg conc	Bq/kg(FW)	vconc(FW)	1.00E+02
small mammal conc	Bq/kg(FW)	smc	2.99E+01
intake of water	Bq/d	Iwat	7.40E+02
intake of soil	Bq/d	Is	3.17E-01
intake of rabbit	Bq/d	Ir	3.24E+01
intake of veg	Bq/d	Iveg	4.70E+00
intake of birds	Bq/d	Ib	4.82E-01
intake of small mammal	Bq/d	Ism	2.34E+00
total intake	Bq/d	Itot	7.80E+02
transfer factor	d/kg(FW)	TFfx	1.00E+00

Fox conc - ingestion	Bq/kg	fxconc-ing(FW)	7.80E+02
air conc	Bq/m^3	aconc	3.90E+00
transfer factor air to mammal	$m^3/kg(FW)$	TFrc-inh	2.33E+00
fox conc - inhalation	Bq/kg	fxconc-inh(FW)	9.09E+00
internal DC	Gy/y per Bq/kg	Dci	2.89E-08
internal dose	Gy/y	Di_uw	2.28E-05
weighted internal dose	Gy/y	Di	6.84E-05
external DC	Gy/y per Bq/kg	Dce	0.00E+00
external dose	Gy/y	De	0.00E+00
total dose	Gy/y	Dt	6.84E-05
	mGy/d		1.87E-04
TOTAL DOSE	mGy/d		4.85E-04

Wild Turkey

Parameter	Unit	Acronym	DGR EA
water intake	L/d	Qwattu	0.2
total food intake (DW)	g(FW)/d	Qffwtu	200
soil intake	g/d	Qstu	18.6
earthworm fraction		fetu	0.2
berries fraction		fbtu	0.2
nut fraction		fnuttu	0.6
fraction of time in area		floctu	1
C-14			
water conc	Bq/L	wconc	3.00E-01
soil conc	Bq/kg(DW)	sconc	4.30E+02
earthworm conc	Bq/kg(FW)	econc(FW)	6.36E+02
nut conc	Bq/kg(FW)	nutconc(FW)	1.05E+02
berry-soil TF	kg/kg(DW)	TFbs	7.00E-01
berry conc	Bq/kg(FW)	berconc(FW)	3.26E+02
intake of water	Bq/d	Iwat	6.30E-02
intake of soil	Bq/d	Is	7.98E+00
intake of earthworms	Bq/d	Ie	2.54E+01
intake of berries	Bq/d	Iber	1.30E+01
intake of nuts	Bq/d	Inut	1.25E+01
total intake	Bq/d	Itot	5.90E+01
transfer factor	d/kg(FW)	Tftu	8.50E+00
turkey conc	Bq/kg	tuconc(FW)	5.01E+02
internal DC	Gy/y per Bq/kg	Dci	2.54E-07
internal dose	Gy/y	Di	1.27E-04
external DC	Gy/y per Bq/kg	Dce	0.00E+00
external dose	Gy/y	De	0.00E+00
total dose	Gy/y	Dt	1.27E-04
	mGy/d		3.49E-04
H-3			
water conc	Bq/L	wconc	1.85E+03
soil conc	Bq/kg(DW)	sconc	1.22E+02
earthworm conc	Bq/kg(FW)	econc(FW)	6.01E+02
nut conc	Bq/kg(FW)	nutconc(FW)	1.00E+02
berry-soil TF	kg/kg(DW)	TFbs	1.00E+00
berry conc	Bq/kg(FW)	berconc(FW)	2.90E+02
intake of water	Bq/d	Iwat	3.88E+02
intake of soil	Bq/d	Is	2.27E+00
intake of earthworms	Bq/d	Ie	2.40E+01
intake of berries	Bq/d	Iber	1.16E+01
intake of nuts	Bq/d	Inut	1.20E+01
total intake	Bq/d	Itot	4.38E+02
transfer factor	d/kg(FW)	Tftu	1.00E+00
turkey conc	Bq/kg	tuconc(FW)	4.38E+02
internal DC	Gy/y per Bq/kg	Dci	2.89E-08

internal dose	Gy/y	Di_uw	1.27E-05
weighted internal dose	Gy/y	Di	3.80E-05
external DC	Gy/y per Bq/kg	Dce	0.00E+00
external dose	Gy/y	De	0.00E+00
total dose	Gy/y	Dt	3.80E-05
	mGy/d		1.04E-04
TOTAL DOSE	mGy/d		4.53E-04

Bald Eagle

Parameter	Unit	Acronym	DGR EA
water intake	L/d	Qwatea	0.18
total food intake (DW)	g(FW)/d	Qffwea	176
soil intake	g/d	Qsea	0
fish fraction		feea	0.8
rabbit fraction		fbea	0.1
mallard fraction		fbdea	0.1
fraction of time in area		flocea	0.5
C-14			
water conc	Bq/L	wconc	3.00E-01
soil conc	Bq/kg(DW)	sconc	4.30E+02
fish conc	Bq/kg(FW)	fconc(FW)	4.20E+01
rabbit conc	Bq/kg(FW)	raconc(FW)	2.70E+02
berry-soil TF	kg/kg(DW)	TFbs	7.00E-01
mallard conc	Bq/kg(FW)	maconc(FW)	5.24E+02
intake of water	Bq/d	Iwat	2.77E-02
intake of soil	Bq/d	Is	0.00E+00
intake of fish	Bq/d	If	2.96E+00
intake of rabbit	Bq/d	Ira	2.38E+00
intake of mallard	Bq/d	Ima	4.62E+00
total intake	Bq/d	Itot	9.99E+00
transfer factor	d/kg(FW)	TFea	8.50E+00
eagle conc	Bq/kg	eaconc(FW)	8.49E+01
internal DC	Gy/y per Bq/kg	Dci	2.54E-07
internal dose	Gy/y	Di	2.16E-05
external DC	Gy/y per Bq/kg	Dce	6.13E-11
external dose	Gy/y	De	9.20E-12
total dose	Gy/y	Dt	2.16E-05
	mGy/d		5.91E-05
H-3			
water conc	Bq/L	wconc	1.85E+03
soil conc	Bq/kg(DW)	sconc	1.22E+02
fish conc	Bq/kg(FW)	fconc(FW)	1.83E+03
rabbit conc	Bq/kg(FW)	raconc(FW)	2.59E+02
berry-soil TF	kg/kg(DW)	TFbs	1.00E+00
mallard conc	Bq/kg(FW)	maconc(FW)	9.85E+01
intake of water	Bq/d	Iwat	1.71E+02
intake of soil	Bq/d	Is	0.00E+00
intake of fish	Bq/d	If	1.29E+02
intake of mallard	Bq/d	Ima	8.69E-01
intake of rabbit	Bq/d	Ira	2.28E+00
total intake	Bq/d	Itot	3.03E+02
transfer factor	d/kg(FW)	TFea	1.00E+00
eagle conc	Bq/kg	eaconc(FW)	3.03E+02
internal DC	Gy/y per Bq/kg	Dci	2.89E-08
internal dose	Gy/y	Di_uw	8.76E-06

weighted internal dose	Gy/y	Di	2.63E-05
external DC	Gy/y per Bq/kg	Dce	2.72E-13
external dose	Gy/y	De	2.52E-10
total dose	Gy/y	Dt	2.63E-05
	mGy/d		7.20E-05
TOTAL DOSE	mGy/d		1.31E-04

Red-eyed Vireo

Parameter	Unit	Acronym	DGR EA
water intake	L/d	Qwatvi	0.004
total food intake (DW)	g(FW)/d	Qffwvi	14
soil intake	g/d	Qsvi	0.2
insects fraction		fevi	0.9
berries fraction		fbvi	0.1
fraction of time in area		flocvi	0.5
C-14			
water conc	Bq/L	wconc	3.00E-01
soil conc	Bq/kg(DW)	sconc	4.30E+02
insect conc	Bq/kg(FW)	econc(FW)	6.36E+02
berry-soil TF	kg/kg(DW)	TFbs	7.00E-01
berry conc	Bq/kg(FW)	berconc(FW)	3.26E+02
intake of water	Bq/d	Iwat	6.00E-04
intake of soil	Bq/d	Is	4.30E-02
intake of insects	Bq/d	Ie	4.01E+00
intake of berries	Bq/d	Iber	2.28E-01
total intake	Bq/d	Itot	4.28E+00
transfer factor	d/kg(FW)	TFvi	8.50E+00
vireo conc	Bq/kg	viconc(FW)	3.64E+01
internal DC	Gy/y per Bq/kg	Dci	2.54E-07
internal dose	Gy/y	Di	9.23E-06
external DC	Gy/y per Bq/kg	Dce	0.00E+00
external dose	Gy/y	De	0.00E+00
total dose	Gy/y	Dt	9.23E-06
	mGy/d		2.53E-05
H-3			
water conc	Bq/L	wconc	1.85E+03
soil conc	Bq/kg(DW)	sconc	1.22E+02
insect conc	Bq/kg(FW)	econc(FW)	6.01E+02
berry-soil TF	kg/kg(DW)	TFbs	1.00E+00
berry conc	Bq/kg(FW)	berconc(FW)	2.90E+02
intake of water	Bq/d	Iwat	3.70E+00
intake of soil	Bq/d	Is	1.22E-02
intake of insects	Bq/d	Ie	3.78E+00
intake of berries	Bq/d	Iber	2.03E-01
total intake	Bq/d	Itot	7.70E+00
transfer factor	d/kg(FW)	TFvi	1.00E+00
vireo conc	Bq/kg	viconc(FW)	7.70E+00
internal DC	Gy/y per Bq/kg	Dci	2.89E-08
internal dose	Gy/y	Di_uw	2.22E-07
weighted internal dose	Gy/y	Di	6.67E-07
external DC	Gy/y per Bq/kg	Dce	0.00E+00

external dose	Gy/y	De	0.00E+00
total dose	Gy/y	Dt	6.67E-07
	mGy/d		1.83E-06
TOTAL DOSE	mGy/d		2.71E-05

Yellow Warbler

Parameter	Unit	Acronym	DGR EA
water intake	L/d	Qwatcr	0.003
total food intake (DW)	g(FW)/d	Qffwcr	11
soil intake	g/d	Qscr	0.15
insects fraction		fecr	0.9
berries fraction		fbcr	0.1
fraction of time in area		floccr	0.5
C-14			
water conc	Bq/L	wconc	3.00E-01
soil conc	Bq/kg(DW)	sconc	4.30E+02
insect conc	Bq/kg(FW)	econc(FW)	6.36E+02
berry-soil TF	kg/kg(DW)	TFbs	7.00E-01
berry conc	Bq/kg(FW)	berconc(FW)	3.26E+02
intake of water	Bq/d	Iwat	4.50E-04
intake of soil	Bq/d	Is	3.23E-02
intake of insects	Bq/d	Ie	3.15E+00
intake of berries	Bq/d	Iber	1.79E-01
total intake	Bq/d	Itot	3.36E+00
transfer factor	d/kg(FW)	TFcr	8.50E+00
yellow warbler conc	Bq/kg	crconc(FW)	2.86E+01
internal DC	Gy/y per Bq/kg	Dci	2.54E-07
internal dose	Gy/y	Di	7.25E-06
external DC	Gy/y per Bq/kg	Dce	0.00E+00
external dose	Gy/y	De	0.00E+00
total dose	Gy/y	Dt	7.25E-06
	mGy/d		1.99E-05
H-3			
water conc	Bq/L	wconc	1.85E+03
soil conc	Bq/kg(DW)	sconc	1.22E+02
insect conc	Bq/kg(FW)	econc(FW)	6.01E+02
berry-soil TF	kg/kg(DW)	TFbs	1.00E+00
berry conc	Bq/kg(FW)	berconc(FW)	2.90E+02
intake of water	Bq/d	Iwat	2.78E+00
intake of soil	Bq/d	Is	9.15E-03
intake of insects	Bq/d	Ie	2.97E+00
intake of berries	Bq/d	Iber	1.59E-01
total intake	Bq/d	Itot	5.92E+00
transfer factor	d/kg(FW)	TFcr	1.00E+00
yellow warbler conc	Bq/kg	crconc(FW)	5.92E+00
internal DC	Gy/y per Bq/kg	Dci	2.89E-08
internal dose	Gy/y	Di_uw	1.71E-07
weighted internal dose	Gy/y	Di	5.13E-07
external DC	Gy/y per Bq/kg	Dce	0.00E+00
external dose	Gy/y	De	0.00E+00
total dose	Gy/y	Dt	5.13E-07

	mGy/d	1.41E-06
TOTAL DOSE	mGy/d	2.13E-05

Amphibians and Reptiles

Parameter	Unit	Acronym	DGR EA
fraction of time in water		ffrogw	0.5
fraction of time in sediment		ffrogs	0.5
C-14			
water conc	Bq/L	wconc	3.00E-01
TF frog	L/kg(FW)	TFfr	5.72E+03
Frog conc(FW)	Bq/kg(FW)	frconc(FW)	4.07E+01
internal DC	Gy/y per Bq/kg	Dci	2.45E-07
internal dose	Gy/y	Di	9.97E-06
external DC	Gy/y per Bq/kg	Dce	4.20E-10
external dose from water	Gy/y	De-w	6.30E-11
total dose-water	Gy/y	Dt-w	9.97E-06
sediment conc-dw	Bq/kg(DW)	sedconc(DW)	2.50E+02
sediment water Kd	L/kg(FW)	Kd	5.00E+01
pore water conc	Bq/L	pwconc	5.00E+00
sediment conc-ww	Bq/kg(WW)	sedconc(WW)	2.95E+01
external DC-from sediment	Gy/y per Bq/kg	Dce	4.20E-10
external dose from sediment	Gy/y	De-s	6.20E-09
total dose-water&sediment	Gy/y	Dt	9.97E-06
	mGy/d		2.73E-05
H-3			
water conc	Bq/L	wconc	1.85E+03
TF frog	L/kg(FW)	TFfr	1.00E+00
Frog conc(FW)	Bq/kg(FW)	frconc(FW)	9.01E+02
internal DC	Gy/y per Bq/kg	Dci	2.89E-08
internal dose	Gy/y	Di_uw	2.60E-05
weighted internal dose	Gy/y	Di	7.81E-05
external DC	Gy/y per Bq/kg	Dce	1.66E-10
external dose from water	Gy/y	De-w	1.54E-07
total dose-water	Gy/y	Dt-w	7.83E-05
sediment conc-dw	Bq/kg(DW)	sedconc(DW)	2.40E-04
sediment water Kd	L/kg(FW)	Kd	1.00E+00
pore water conc	Bq/L	pwconc	2.40E-04
sediment conc-ww	Bq/kg(WW)	sedconc(WW)	2.40E-04
external DC-from sediment	Gy/y per Bq/kg	Dce	1.66E-10
external dose from sediment	Gy/y	De-s	1.99E-14
total dose-water&sediment	Gy/y	Dt	7.83E-05
	mGy/d		2.15E-04
TOTAL DOSE	mGy/d		2.42E-04

C.3 REFERENCES

[C1] Ontario Power Generation (OPG). 2009. *Ecological Risk Assessment and Assessment of Effects on Nonhuman Biota Technical Support Document New Nuclear– Darlington.* NK054-REP-07730-00022 Rev 000. September 2009.

[C2] Bruce Power. 2009. *Annual Summary and Assessment of Environmental Radiological Data for 2008.* B-REP-03419-00009-R00. April 2009.

[C3] UK Environment Agency. 2001. *Impact Assessment of Ionising Radiation on Wildlife*. R&D Publication 128. June

[C4] NWMO 2009. *Bounding environmental concentrations*. July 31. Filing No. DGR-01900-P.

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APPENDIX D: DETAILED RADIATION DOSE CALCULATIONS (HUMANS)

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D1. ESTIMATED WORKER INHALATION DOSE

The dose coefficients, or estimates of dose per unit exposure to individual radionuclides are taken from Canadian Standards Association (CSA) N288.1 [D1]. The inhalation dose coefficient for tritium (H-3) as HTO is 3.0×10^{-11} Sv/Bq for an adult; this value includes the contribution from skin absorption. For carbon-14 (C-14) as CO_2, the inhalation dose coefficient is 1.2×10^{-11} Sv/Bq for an adult, and the immersion dose coefficient is 8.2×10^{-11} Sv/year per Bq/m^3. The worker inhalation rate is 1.6 m^3/h (adult, moderate activity, [D2]).

Underground

Table D1-1 gives the maximum estimated inhalation doses for DGR workers underground at two locations — the main shaft station and the ventilation shaft. The main shaft station is a normally occupied area, which will routinely have one or two packages present. For example, assuming 2000 hours per year occupancy, 18 m^3/s nominal air flow rate, and 2 non-processible (NP) drums (H-3 concentration and package volume given in Preliminary Safety Report [D3]), the airborne H-3 concentration can be estimated from the ratio of annual tritium release rate over the air flow rate:

$$\frac{2\times(1.2\ \text{m}^3/\text{pkg})\times(6.1\times10^{11}\ \text{Bq/m}^3\ \text{NP drum})\times(0.0042/\text{year})\times(3.17\times10^{-8}\ \text{a/s})}{(18\ \text{m}^3/\text{s})} = 10.8\ \text{Bq/m}^3$$

The factor of 0.0042/year is the estimated fractional release rate of tritium from LLW package, as described in Chapter 7 of the Preliminary Safety Report [D3]. The tritium dose rate can then be calculated by multiplying the tritium concentration by the inhalation rate, exposure time, and tritium inhalation dose coefficient:

$$(10.8\ \text{Bq/m}^3)\times(1.6\ \text{m}^3/\text{hr inhalation})\times(2000\ \text{hr})\times(3\times10^{-8}\ \text{mSv/Bq}) = 0.001\ \text{mSv/year}$$

Similar calculation can also be done to estimate the dose rate for C-14.

Table D1-1: Estimated Maximum Annual Inhalation Dose to a Worker

Location	H-3 Dose Rate (mSv/year)	C-14 Dose Rate (mSv/year)	Total Dose Rate (mSv/year)
WPRB	0.08	0.007	0.09
Main Shaft Station	0.001	<0.0001	0.001
Ventilation Shaft	0.05	0.003	0.05
Ventilation Drift	0.08	0.006	0.08

At the other end of the repository, the ventilation shaft will collect all the off-gassed H-3 and C-14 and is a higher air concentration location — up to 3700 Bq/m^3 day — although still much less than DAC. This area will normally not be occupied by workers. It was estimated that workers will spend about 260 hours per year in the shaft conducting weekly/monthly inspections of the liner and shaft hoisting equipment, which corresponds to a dose of about 0.05 mSv/year.

As Figures D1-1 and D1-2 show, the air concentration will vary significantly over the operation of the DGR, and the dose rate will normally be less. The ventilation shaft conditions are monitored, and if necessary, worker exposure can be reduced through use of appropriate protective equipment and/or by adjusting air flow for the duration of each inspection to provide cleaner air.

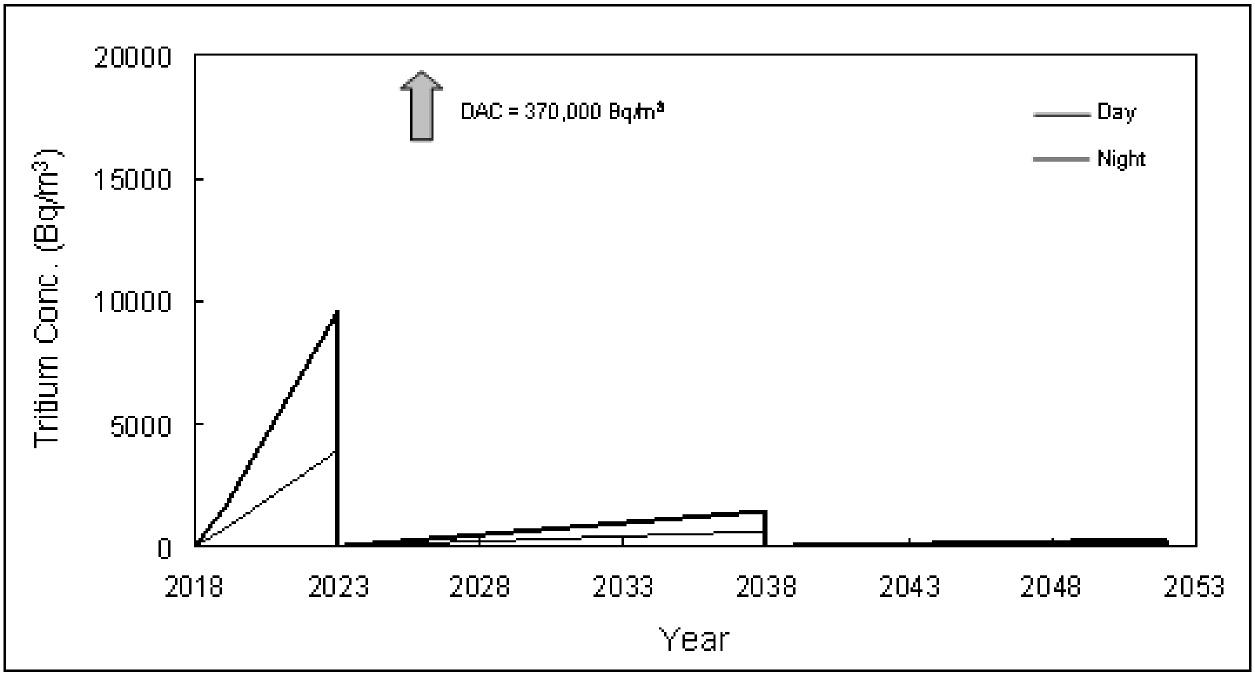

Figure D1-1: Estimated Airborne Tritium Concentrations in the Ventilation Shaft

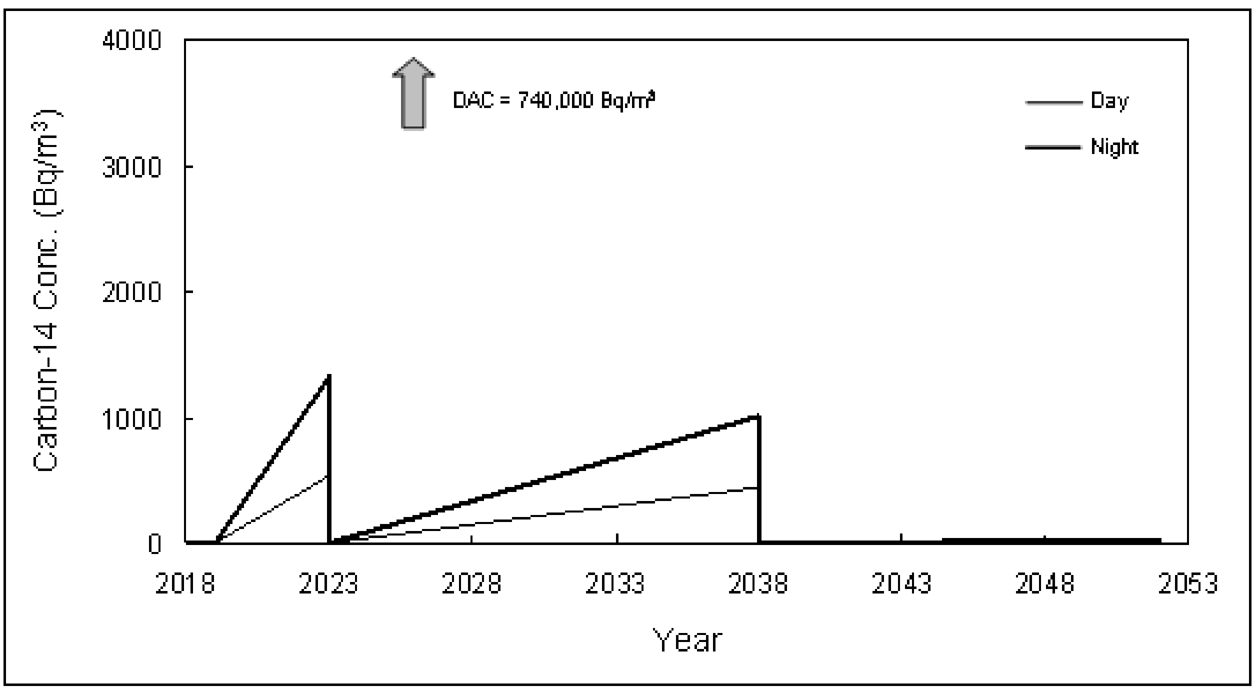

Figure D1-2: Estimated Airborne C-14 Concentrations in the Ventilation Shaft

Above Ground

The ventilation shaft exhaust is not a normally occupied area, and would have appropriate access controls to limit exposure. Air concentrations would be less than in ventilation shaft, and much less than DAC.

The WPRB is a normally occupied area. Based on the estimated maximum airborne concentrations of H-3 (900 Bq/m^3) and C-14 (200 Bq/m^3) in WPRB, the total inhalation dose to a worker was calculated to be about 0.09 mSv/year, based on working 2000 hours per year in WPRB and assuming the WPRB contains the maximum inventory of staged packages for 100% of the time.

In summary, the estimated worker doses are all much less than the OPG's occupational dose target of 10 mSv/year, and the regulatory limit. Further mitigation can be addressed in the context of ALARA.

D2 ESTIMATED DOSE TO THE PUBLIC – SAMPLE CALCULATION FOR DOSE FROM C-14 THROUGH THE AIR PATHWAY

The C-14 inventory in ventilated emplacement rooms in the repository is highest at the end of the initial placement period before the first closure wall is installed. In the emplacement schedule assumed in the preclosure safety assessment, this is at around 2023. Most of the C-14 inventory is on ILW.

Based on Table 7-7 of the Preliminary Safety Report [D3], the maximum C-14 inventory in ventilated ILW packages is:

- C-14 ILW Inventory (2023): 3.6×10^{15} Bq.

The Fractional Airborne Release Rate Estimate for C-14 from ILW packages was estimated using the method described in and is also listed in Table 7-9 of the Preliminary Safety Report [D3].

Fractional Airborne Release Rate Estimate for C-14 from ILW packages: 5.0×10^{-4} Bq/a/Bq (shown in Table 7-9 of the Preliminary Safety Report [D3]).

Therefore, the maximum airborne release rate of C-14 from all ILW packages is:

$$\left(3.65 \times 1015 \quad Bq\right) \times \left(5.0 \times 10 - 4 \quad Bq/a\,/Bq\right) = 1.8 \times 10^{12} Bq$$

(shown in Table 7-10 of the Preliminary Safety Report [D3]).

If LLW emissions of C-14 are also included, the total C-14 release rate goes up slightly to 1.9×10^{12} Bq (Table 7-10 of the Preliminary Safety Report [D3]).

The impact of the airborne and waterborne releases on the public can be assessed using two methods:

- Dose based on the DGR estimated release rate in comparison to the WWMF dose pathways model used for the DRL.
- Dose based on the DGR estimated releases in comparison to the Bruce emissions and the Radiological Environmental Monitoring Program (REMP) dose.

Using the REMP method, and scaling based on 2009 data:

The calculated air emission rate (C-14) for the whole Bruce nuclear site in 2009: 2.5×10^{12} Bq/a (from Table 7-13 of the Preliminary Safety Report [D3], based on Bruce nuclear site REMP reports).

Estimated Air Dose Rate for the Bruce nuclear site in 2009: 2.2×10^{-1} µSv/a (from Table 7-13 of the Preliminary Safety Report [D3], based on Bruce site quarterly REMP reports).

Therefore the maximum estimated dose from Air releases of C-14 from the DGR is:

$$(1.9 \times 10^{12}\ Bq/a)/(2.5 \times 10^{12}\ Bq/a) \times (2.2 \times 10^{-1}\ \mu Sv/a) = 0.17\ \mu Sv/a$$

The estimated maximum dose from air releases for C-14 to the public during DGR normal operations using the REMP based dose model is 0.17 µSV/a. The sum of the results of similar calculations for all other radionuclides and all pathways would provide the total estimated maximum dose to the public.

D3 REFERENCES

[D1] Canadian Standards Association (CSA). 2008. *Guidelines for calculating derived release limits for radioactive material in airborne and liquid effluents for normal operation of nuclear facilities,* CSA-N288.1-08.

[D2] U.S. Environmental Protection Agency. 1997. *Exposure Factors Handbook Volume 1 – General Factors*. EPA/600/P-95.002Fa.

[D3] Ontario Power Generation (OPG). 2011. *Deep Geologic Repository for Low and Intermediate Level Waste - Preliminary Safety Report*. 00216-REP-01320-355682 R000.