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In the Matter of the

BWXT Medical Ltd.

Application for a Class IB nuclear substance processing facility operating licence

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Renseignements supplémentaires

Mémoire de BWXT Medical Ltd. (anciennement BWXT ITG Canada, Inc.)

À l’égard de

BWXT Medical Ltd.

Demande pour un permis d’exploitation d’une installation de traitement de substances nucléaires de catégorie IB

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BWXT Medical Ltd. Environmental Risk Assessment

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ACRONYMS

ACB	Air Contaminants Benchmark
ANSI	Area of Natural and Scientific Interest
AQI	Air Quality Index
ATSDR	Agency for Toxic Substances and Disease Registry
BCI	Bat Conservation International
BTL	Best Theratronics Ltd.
BWXT	BWXT Medical Ltd
CCME	Canadian Council of Ministers of the Environment
CNSC	Canadian Nuclear Safety Commission
CSA	Canadian Standards Association
CSM	Conceptual Site Model
DQRA	Detailed Quantitative Risk Assessment
DRL	Derived Release Limit
EcoRA	Ecological Risk Assessment
EIS	Environmental Impact Study
ERA	Environmental Risk Assessment
ESA	Endangered Species Act
ESDM	Emissions Summary and Dispersion Modelling
FPS	Fixed Point Surveillance
HEPA	High Efficiency Particulate Air
HHRA	Human Health Risk Assessment
HP	Central Heating Plant
IMPACT	Integrated Model for the Probabilistic Assessment of Contaminant Transport
KERMA	Kinetic Energy Released in unit MAss of Material
KOB	Kanata Operations Building
KRMF	Kanata Radiopharmaceutical Manufacturing Facility
LLLW	Low Level Liquid Waste
masl	Metres above sea level
MECP	Ministry of Environment, Conservation and Parks
MNRF	Ministry of Natural Resources and Forestry
MOE	Ministry of Environment
MPOI	Maximum Point of Impingement
NEW	Nuclear energy worker
NHIC	Natural Heritage Information Centre
NMPF	Nuclear Medicine Production Facility
NOx	Nitrogen oxides
NPRI	National Pollutant Release Inventory
NVS	Nuclear Ventilation System
OBBA	Atlas of Breeding Birds of Ontario
OEHHA	Office of Environmental Health Hazard Assessment

PHC	Petroleum Hydrocarbon
PIDPIE	Public Information and Disclosure Program and Indigenous Engagement
PQRA	Preliminary Quantitative Risk Assessment
QA/QC	Quality Assurance/Quality Control
QC	Quality Control
RE	Roy Errington
ROM	Royal Ontario Museum
ROPEC	Robert O. Pickard Environmental Centre
SAR	Species at Risk
SARA	Species at Risk Act
SARO	Species at Risk in Ontario
SLRA	Screening Level Risk Assessment
TCEQ	Texas Commission on Environmental Quality
TLD	Thermoluminescent Dosimeter
VEC	Valued Ecosystem Component
WHO	World Health Organization

EXECUTIVE SUMMARY

An Environmental Risk Assessment (ERA) was prepared in accordance with the approach described in Canadian Standards Association (CSA) Standard N288.6-12 *Environmental Risk Assessment at Class I Nuclear Facilities and Uranium Mines and Mills* [1] for the Medical Isotopes operations by BWXT Medical Ltd. (BWXT) at 447 March Road, Ottawa, Ontario (the "Site"). The Site houses operations for both Medical Isotopes and Gamma Technologies, with the Gamma Technologies operations conducted by Nordion. BWXT has leased the Medical Isotopes portion of the facility from Nordion. The two operations are conducted under separate licences. This ERA deals only with the operations undertaken by BWXT.

The ERA was carried out as per CSA Standard N288.6-12 [1] requirements, wherein the human and non-human biota (within 4 kilometers of the Site) are identified and described, the types of stressors are identified and quantified where possible (i.e., radiological and chemical releases, and physical stressors), and the pathways by which biota may be exposed to stressors are identified. For the applicable receptor-pathway-stressor combinations, screening against regulatory limits/guidelines is performed to demonstrate whether there could be a potential health and/or environmental risk associated with BWXT operations. The results of the ERA are as follows:

- The human health risk assessments (HHRA) for both radiological and chemical contaminants evaluated the following potential Critical Groups of human receptors: urban residents, farm residents, and workers. The key difference between urban residents and farm residents is an increased dependence on locally grown food by farm residents. Workers are considered to be adults who work within the Local Study Area, for example at the Kanata North Business Park. Indigenous communities are located far beyond the Local Study Area defined for the assessment and were therefore not considered to be affected by airborne emissions.
- The ecological risk assessments (EcoRA) for both radiological and chemical contaminants consider potential effects to terrestrial and aquatic biota. While the radiological assessment by design evaluates these receptors more generally as groups, the non-radiological assessment identified specific receptors including mammals, birds, plants, reptiles and amphibians, and invertebrates including species listed as threatened and endangered.
- Airborne non-radiological contaminants were predicted as part of the Emission Summary and Dispersion Modelling (ESDM) for the facility, all of which were retained for evaluation in the HHRA. Additionally, aerial deposition of non-volatile airborne contaminants onto soil and subsequent leaching to groundwater were assessed in the HHRA. Deposition onto small ponds at local farms was considered, although deposition onto the Ottawa River was not assessed given its large volume and high flow rate. Waterborne releases from the facility are retained in holding and delay tanks, and treated at the Robert O. Pickard Environmental Centre (ROPEC); however, given the large degree of dilution between the facility's discharge point and end of pipe at the ROPEC,

changes to water quality were considered to be negligible and the resulting risks to humans and non-human biota were not quantitatively assessed.

- For airborne radiological contaminants, quantitative emissions data were not available and potential releases were calculated using conservative inputs and assumptions. For the HHRA, these were compared to respective Derived Release Limits (DRLs) for screening. For the EcoRA, calculated airborne releases were screened by comparison to airborne releases used for the 2017 ERA [2]. Radiological waterborne releases were not quantified as releases are controlled and there is no reasonable circumstance where releases would come close to exceeding the screening criteria.
- The radiological and non-radiological risk assessments for both human and non-human biota resulted in negligible risks, given that all contaminants screen lower than their respective regulatory limits/guidelines.

Although this ERA was prepared for BWXT operations, the potential for cumulative effects due to both BWXT and Nordion operations at the same time was considered in the ERA as both sets of operations are located within the same spatial footprint. Cumulative effects were considered in this ERA as follows:

- An ERA was previously completed on behalf of Nordion in 2017, prior to BWXT acquiring the Medical Isotopes operations, which assessed both the Medical Isotopes and Gamma Technologies operations. The operations at the time resulted in negligible risks to human health and the environment as a result of airborne and waterborne radiological and non-radiological (chemical) releases, and physical stressors. Medical Isotope operations at the Site have changed since the initial ERA which has led to a considerable decrease in emissions. Therefore, risks continue to be negligible both attributed to the Medical Isotope operations and the combined operations of both facilities.
- Airborne emissions of chemical releases were assessed using the 2021 ESDM [3] report for the Site, which includes contributions from both BWXT and Nordion operations. As such, the assessment of airborne emissions carried out in this ERA has relied upon cumulative concentrations of chemical emissions from both operations.
- Waterborne effluents of chemicals were assessed considering monitored groundwater quality data collected from various locations across the Site footprint, and surface water quality at a sewer discharge point located downstream of both BWXT and Nordion operations. As such, water quality data has also relied upon cumulative inputs from both operations.
- Radiological contaminants from BWXT and Nordion operations can easily be differentiated and monitored, since these operations employ different processes with different contaminants, which are released through different stacks. Radiological airborne emissions were assessed by quantifying emissions specific to BWXT operations. Potential radiological waterborne releases were not quantified as they are controlled releases that are analysed and compared to release limits prior to discharge. Risks from radiological releases from BWXT are far below screening criteria, therefore the contribution to cumulative radiation dose to humans and biota is negligible.

Furthermore, the cumulative effects of both operations continue to be monitored through annual compliance reports.

Planning and preparation of this ERA was conducted in accordance with an ISO 9001:2015 certified Quality Management System. All work was internally reviewed and verified. Reviews included verification of data and calculations, as well as review of report content. The environmental data used in this report was collected through BWXT's Environmental Protection Program, which meets applicable nuclear regulatory requirements. Specific Quality Assurance/Quality Control (QA/QC) procedures undertaken during the collection of environmental monitoring data are outlined in Water Effluent Monitoring and Stack Air Sampling procedures, [4] and [5].

There were no specific recommendations for monitoring or risk management that were required as a result of the outcome of the ERA given that risks are expected to be negligible.

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1. INTRODUCTION

1.1 Background

This Environmental Risk Assessment (ERA) was prepared in accordance with the approach described in Canadian Standards Association (CSA) Standard N288.6-12 *Environmental Risk Assessment at Class I Nuclear Facilities and Uranium Mines and Mills* [1]. The purpose of this ERA is to identify and prioritize potential risks to either human health or non-human biota as a result of BWXT Medical Ltd. (BWXT) Medical Isotopes operations at 447 March Road, Ottawa, Ontario (hereafter referred to as the Site).

Notable inputs for this report include the previous 2017 ERA [2], the Nordion Class 1B Facility Derived Release Limits [6] and an Emission Summary and Dispersion Modelling (ESDM) report prepared for Nordion and BWXT by Wood Canada Limited (2021) [3]. The information provided by these studies and existing Nordion environmental programs is used to inform the identification of sources, pathways, receptors and any screening criteria exceedances in the human and ecological screening and exposure assessments.

1.2 Changes Since the Last ERA

Since the 2017 ERA [2], the following changes have been implemented:

- The scope has changed to focus solely on BWXT Medical Isotope operations;
- Emissions have decreased; and
- Two additional receptors have been identified.

The following paragraphs provide additional details on these changes.

Where the 2017 ERA [2] assessed all operations at the Site, the focus of this ERA is solely on the Medical Isotopes operations conducted by BWXT. A history of the organization and ownership of the operations and site is discussed in Section 1.3.

Medical Isotope operations at the Site have changed since the initial ERA [2] which has led to a considerable decrease in emissions. Historically, the major radiochemical products were Mo-99, I-131, I-125, and Xe-133, all of which ceased in November 2016. Currently, BWXT manufactures two radiopharmaceutical products: Y-90 TheraSphere and Indium-111 Oxyquinoline. The manufacturing process for these products consist of handling, dispensing, sterilizing and Quality Control (QC) testing of medical isotopes in the form of microspheres (Y-90) or a solution (In-111).

BWXT intends to additionally manufacture Tc-99m generators in the future. Emissions for this future process have been estimated based on the source term [7] and conservative assumptions.

Further information on the Environmental Protection Program and expected emissions are found in Section 2.2.

Based on developments to the area surrounding the Site since the 2017 ERA [2], two additional candidate groups are considered in the present ERA:

1. *Kids & Company Day Care Center*; and
2. *Potential two four-storey low-rise apartment buildings at 100 Steacie Drive*, for which there is an application for development currently under review.

The details of these receptors are discussed further in Section 3.1.1.1.

All other receptors and their characteristics, release points, environmental pathways, and transfer parameters remain the same as the previous ERA [2].

The 2017 ERA [2] completed a Preliminary Quantitative Risk Assessment (PQRA) and risks from the combined Medical Isotopes and Gamma Technologies operations were deemed negligible.

1.3 History of the Organization

The production operations for Medical Isotopes are housed in the Nuclear Medicine Production Facility (NMPF). The NMPF consists of a portion of the Kanata Operations Building (KOB) and the Kanata Radiopharmaceutical Manufacturing Facility (KRMF). The locations of the KOB and KRMF within the Site are shown in Figure 2.

On July 30, 2018, Sotera Health sold the Medical Isotopes segment of Nordion's business to BWXT. With the sale, BWXT became the owner of Nordion's former medical isotope business, including the radiochemical manufacturing operations in Ottawa, Ontario and the isotope production facility in Vancouver, British Columbia. Nordion has retained ownership of the Gamma Technologies operations and is the landlord for the BWXT portion of the facility. Notwithstanding the sale of the Medical Isotopes segment in July 2018, Nordion remains operator of the Class 1B Facility in Kanata. BWXT has applied for its own Class 1B Licence for Medical Isotope operations.

As noted in Section 1.2, the focus of this ERA is solely on the Medical Isotopes operations.

1.4 Site Operations Cumulative Effects

Cumulative effects of both BWXT and Nordion operations have been assessed through the previous ERA [2] where risks were deemed negligible and emissions were found to be far below respective Derived Release Limits (DRLs) [6].

Radiological contaminants from BWXT and Nordion operations can easily be differentiated and monitored, since these operations employ different processes with different contaminants, which are released through different stacks. Furthermore, the cumulative effects of both operations will continue to be reported through annual compliance reports to the Canadian Nuclear Safety Commission (CNSC).

Chemical contaminants are not as easily differentiated between the two sites given that both operations are potential sources of similar contaminants. For example, nitrogen oxides from natural gas combustion, which is sourced from various boilers and other combustion sources associated with both BWXT and Nordion operations. However, as the predictions for nitrogen oxides have been completed for both sites together (i.e., one concentration that represents the sum of both sites as reported in the annual compliance reports), cumulative effects are quantified within this ERA for chemical contaminants. A similar approach has been used for other media (i.e., surface water), as the predictions from the previous ERA [2] were relied upon for this assessment, and the previous ERA had considered contributions from both the Medical Isotopes and Gamma Technologies operations.

The contribution and cumulative effects of the emission sources of Best Theratronics Ltd. (BTL), which is located adjacent to Nordion and BWXT, is also acknowledged. BTL does not release airborne or waterborne radioactive material to the environment [8]. Therefore, operations at BTL have a negligible impact on the results of this ERA and will not be considered further.

1.5 Methodology

Following the tiered approach specified by CSA Standard N288.6-12 [1], a Screening Level Risk Assessment (SLRA) is required to identify issues requiring further quantitative evaluation. For potential issues identified in the SLRA, a PQRA or Detailed Quantitative Risk Assessment (DQRA) may be necessary to quantitatively characterize the risks. The methodology used to perform the ERA, which is described in CSA Standard N288.6-12 [1], is illustrated in Figure 1.

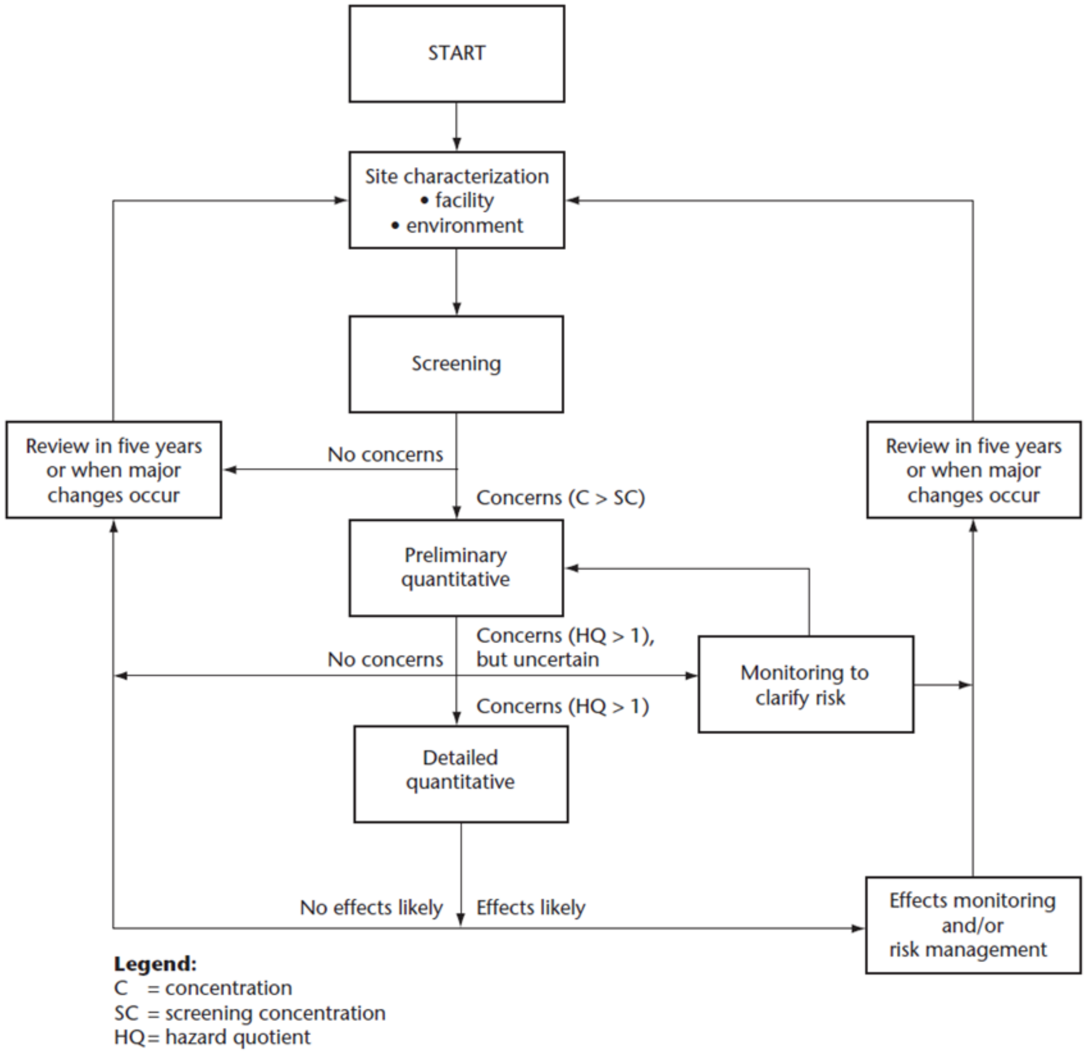


Figure 1: CSA Standard N288.6-12 ERA progression through tiers of assessment

First, a site characterization is performed, which consists of:

- Describing the Medical Isotopes facilities and operations;
- Identifying contaminants and physical stressors;
- Identifying human and ecological receptors; and
- Identification of exposure pathways.

Following the site characterization, a screening of the contaminants and stressors is carried out by:

- Identifying screening criteria;
- Identifying contaminants and stressors that exceed these criteria; and
- Determining if a PQRA is required for the contaminant or stressor.

A PQRA is performed if the screening criteria are exceeded. A PQRA may be performed regardless of the results of the SLRA, if the operator so desires (e.g., to address public concern). The PQRA aims to provide preliminary estimates of the exposure and risk for all receptors, contaminants, and physical stressors. Based on a comparison to benchmark values, the PQRA will determine if there is a need to perform the DQRA or if monitoring is required in order to more accurately quantify the risk.

The DQRA is either performed based on evidence (e.g., epidemiological studies) or by performing a more detailed exposure assessment and risk characterization (e.g., by using site measurements of environmental concentrations or more sophisticated modelling techniques). If the DQRA identifies that a concern is likely to generate an effect (e.g., radiation dose to public above the benchmark value), these concerns will be recommended for follow-up monitoring and risk mitigation.

1.6 Goals, Objectives and Scope

This report provides a description and the results of the ERA process used for the BWXT operations at the Site.

The objective of this ERA is to complete the following steps:

- Identify the presence or absence of risks to human health and non-human biota associated with potential exposure to contaminants and physical stressors as a result of operations;
- Identify contaminants and physical stressors that exceed the screening criteria specified and are therefore of potential concern; and
- Determine whether a PQRA is required, summarizing any contaminants, physical stressors, receptors, and exposure pathways to be considered.

Specifications regarding the scope of the ERA are as follows:

- The ERA considers contaminants and physical stressors associated with BWXT's operations in the NMPF;
- The ERA is applicable to all BWXT activities conducted within the NMPF during its operational state; it does not include subsequent lifecycle phases (e.g., decommissioning);
- For airborne releases, the ERA considers human and ecological receptors within 4 km of the Site;
- For liquid releases of radiological contaminants, the ERA considers human receptors up to 30 km downstream of Robert O. Pickard Environmental Centre (ROPEC) along the Ottawa River, as well as a farm resident using ROPEC biosolids as agricultural fertilizer, and a sludge truck driver transporting waste from ROPEC; and

- The ERA incorporates all applicable effluent monitoring data and relies on modelling tools to estimate concentrations in environmental media.

1.7 QA/QC Requirements

1.7.1 Environmental Risk Assessment

Throughout the planning and preparation of the ERA, all staff worked under an ISO 9001:2015 certified Quality Management System. All work was internally reviewed and verified. Reviews included verification of data and calculations, as well as review of report content.

1.7.2 Environmental Protection Program

The ERA makes extensive use of effluent monitoring data. The environmental protection program is designed to monitor and measure radioactive releases in accordance with nuclear regulatory requirements. The program includes:

1. Continuous monitoring of process ventilation, exhaust ductwork and stack emissions by use of in-situ detectors, samplers and computerized recording;
2. Weekly air sampling and analysis for NMPF exhaust stack emissions; and
3. Batch sampling and analysis for NMPF effluent discharges to the sanitary sewer system.

Specific Quality Assurance/Quality Control (QA/QC) procedures undertaken during the collection of environmental monitoring data are outlined in Water Effluent Monitoring and Stack Air Sampling procedures, [4] and [5].

1.8 Organization of this report

This report is structured in accordance with the suggested table of contents provided in Annex A of CSA Standard N288.6-12 [1], as they relate to the objectives and scope of this ERA:

- Section 2: Site Description - provides an overview of the physical site and the surrounding environment.
- Section 3: Human Health Risk Assessment - describes the methods and assumptions used to screen human health contaminants and stressors and provides the screening results.
- Section 4: Ecological Risk Assessment - describes the methods and assumptions used to screen non-human biota contaminants and stressors and provides the screening results.
- Section 5: Conclusions and Recommendations - concludes on the risk to the environment and provides applicable recommendations.
- Section 6: References.
- Annex A: Calculation of Radiological Releases – a breakdown of calculation of radiological releases by contaminant, including inputs and assumptions.

2. SITE DESCRIPTION

2.1 Engineered Site Facilities

The Site is located at 447 March Road in Kanata, Ontario. It occupies an area of 58.9 acres at the eastern end of March Township, Carleton County, 3.6 km south-west of the Ottawa River and 94 m above mean sea level [10] (Figure 2).

The area surrounding the Site includes an industrial park, subdivisions, and rural countryside used for mixed farming and cattle grazing. The nearest urban population is the Beaverbrook community, which is 0.5 km from the boundary of the Site. Extensive marshy areas exist to the west of the Site.

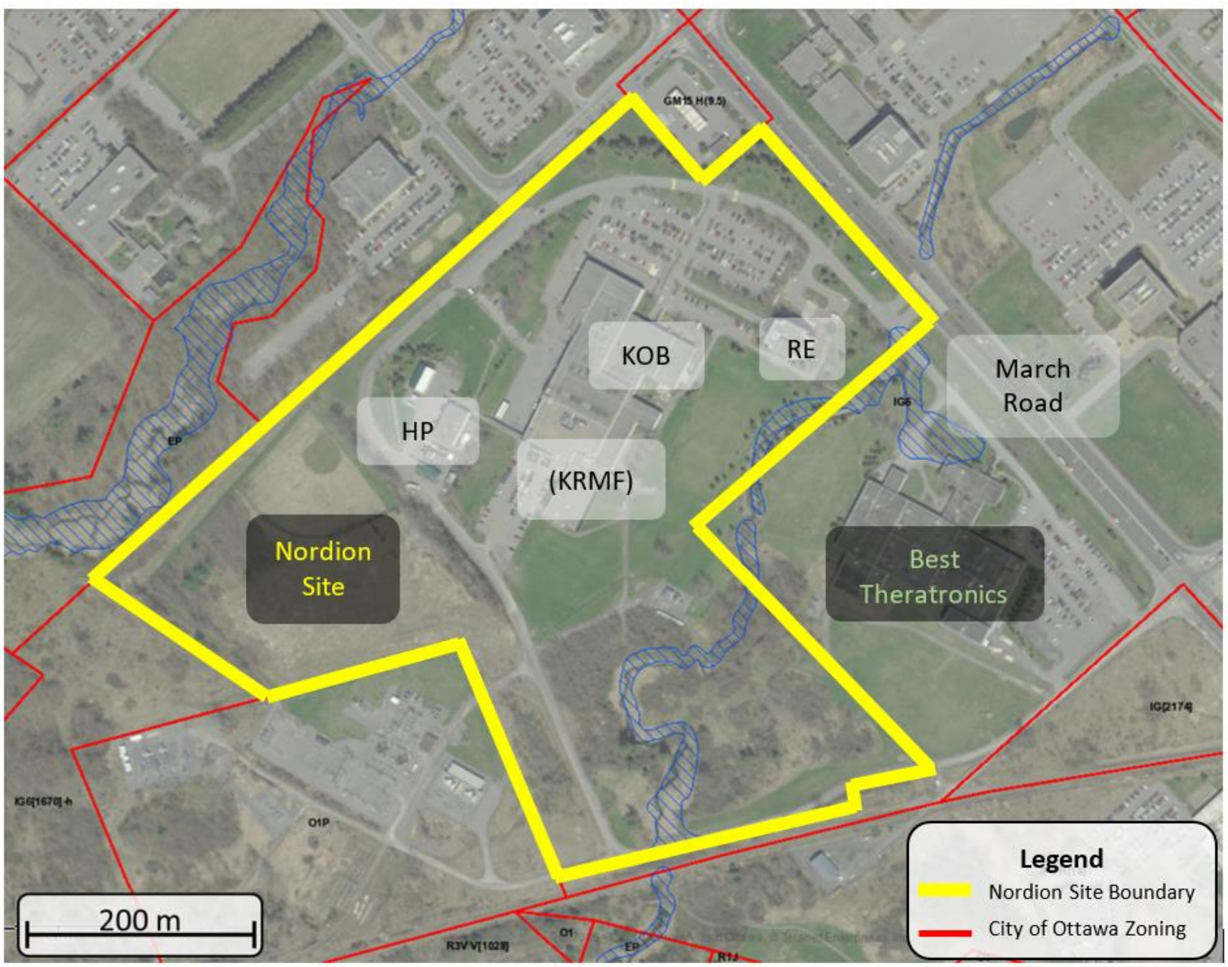


Figure 2: Site Plan

The following buildings are located on the Site as shown in Figure 2:

- Roy Errington (RE) Building (5-storey administrative building)

- Central Heating Plant (HP) (2-storey building)
- Kanata Operations Building (KOB) (2-storey production facility, including Nordion Cobalt Operations and BWXT Medical Isotopes Operations)
- Kanata Radiopharmaceutical Manufacturing Facility (KRMF) (2-storey production facility)

Approximately 250 BWXT employees work at the Ottawa site. This figure includes full-time, part-time, and temporary employees plus students.

The NMPF is comprised of the KRMF and the Medical Isotopes portion of the KOB. Operations within the KOB and KRMF involve the production of radioisotopes used in nuclear medicine as well as sealed sources used in cancer therapy and irradiation technologies.

The NMPF primarily processes unsealed radioisotopes. Cobalt Operations is dedicated to the manufacturing of sealed radioactive sources. The building is divided into Non-Active Areas and controlled access areas known as Active Areas.

Currently, the NMPF is used for the production of two radiopharmaceutical products: Y-90 TheraSphere and Indium-111 Oxyquinoline. BWXT intends to additionally manufacture Tc-99m generators in the future.

Supporting operations and equipment include natural gas boilers, four (4) back-up diesel generators, cooling equipment, and a metal fabrication shop.

2.2 Environmental Protection Program

Radioactive material may be released from the Site as airborne or waterborne effluent. An environmental protection program is in place to measure releases to the environment and to determine radiation levels in areas exterior to the NMPF. This program includes:

- Continuous monitoring of process ventilation, exhausts ductwork, and stack emissions;
- Weekly air sampling and analyses of exhaust stack emissions;
- Delay and holding tanks allowing sampling, analysis, and authorized release of Active Area liquid effluent;
- An environmental Thermoluminescent Dosimeter (TLD) program; and
- A soil monitoring program.

Airborne releases are monitored with an extensive array of monitoring and measurement systems, including routine exhaust monitoring, filter exhaust monitoring, and exhaust stack monitoring.

The Nuclear Ventilation System (NVS) captures and treats all exhaust from BWXT operations prior to release through one of three exhaust stacks.

It should be noted that the NVS creates a pressure gradient that moves internal building air from areas of low risk to areas of high risk. Accordingly, all internal process emissions are routed into the NMPF production areas and discharged from the NVS Stacks. Accordingly, all internal air emissions are passed through High Efficiency Particulate Air (HEPA) filters and if necessary, charcoal adsorbers prior to discharge.

Ventilation and stack sampling are conducted by using particulate and/or activated charcoal filters, depending on the physical and chemical nature of the emissions. Radioioidine sampling involves the use of activated charcoal filter cartridges and analyses by gamma measurement. Particulates are sampled by use of cellulose filter papers and analysed by gamma measurement.

All production operations are contained within cells, glove-boxes and/or fume hoods. Ventilated air from these containment systems is passed through a series of filters which may include a roughing filter, HEPA filters and, where appropriate, activated charcoal adsorbers. These systems are designed for continuous, uninterrupted operation with redundant fan/motor and filtration units that include pre-filters, primary and secondary filtration units. The NVS has been designed and is maintained to minimize the release of radioisotopes to the atmosphere.

Wastewater from the active area is collected in underground delay and holding tanks. For nuclear medicine, there are two delay tanks in each of the KOB and KRMF buildings. The tanks are sampled and analyzed for radioactivity using liquid scintillation or gamma spectroscopy. The analysis is reviewed and approved prior to discharge to the municipal sewer system. If the total activity exceeds internal administrative levels, the delay tank is not discharged to the sanitary sewer without the approval of the Senior Manager, Radiation Safety.

The Effluent Monitoring Program includes the monitoring of non-radiological contaminants in liquid effluent discharged to the municipal sewer system. Samples are taken from the main sanitary drain that leads off the property. The samples are analyzed by a third-party laboratory for contaminants and physical stressors identified in the City of Ottawa Sewer Use By-Law.

In November of 2016, production of Mo-99, I-125, I-131 and Xe-133 ceased. Therefore, radioxenon releases also ceased in November 2016. I-125 with its longer half-life is still present in some waste and components of the NVS. These radionuclides continue to be monitored as part of the Effluent Monitoring Program with releases decreasing to undetectable levels over recent years.

Currently, two radiopharmaceutical products are being produced as part of BWXT's operations: Y-90 TheraSphere and Indium-111 Oxyquinoline. The predominant source terms are Y-90 and In-111. Impurities for these processes are a low percentage of the total activity and pose a negligible contribution to environmental risk. It is noted that while stacks emissions are monitored for Y-90, releases are not reported because measured radioactivity does not exceed background and are consistently below detection limits. All airborne radiological contaminants associated with the In-111 and Y-90 processes are monitored and captured collectively as particulates as part of the Effluent Monitoring Program.

BWXT plans to begin producing Tc-99m generators. The predominant radionuclides associated with this operation are Mo-99 and its decay product Tc-99m, which account for over 95% of the source term [7].

Quantitative emissions data are not available for Y-90 and In-111 emissions because they have been consistently below detection limits, and Mo-99/Tc-99m emissions data are not available because it is a future process. Therefore, potential emissions rates of radionuclides associated with these processes will be estimated based on operational experience, commercial requirements, and conservative assumptions.

2.3 Description of the Natural and Physical Environment

The existing environment described herein includes all of the components that have the potential to be affected as a result of BWXT operations conducted on Site. The following subsections provide a general overview of the existing physical and biological environmental conditions in the vicinity of the Site. This environmental baseline describes the environment as it is now and is the basis for evaluating the risk to relevant human and ecological receptors resulting from exposure to contaminants and stressors related to the Site and its activities.

The results of environmental studies, the previous ERA [2] and the Nuclear Medicine Production Facility Final Safety Analysis Report [11] were used to provide a description of the natural and physical environment. Where the potential interactions between Site operations and environmental components were predicted to be nil, weak or remote in time and/or space, a less detailed description of the environmental component is provided.

2.3.1 Spatial and Temporal Boundaries

2.3.1.1 *Spatial Boundaries*

The Site includes the parcels of land, infrastructure and facilities in which current operational activities are located, and is delimited by the physical boundaries of the Site, including the Nordion buildings at 447 March Road and the immediately surrounding land. The features of the Site are identified in Figure 2.

The ERA also considers features on the lands immediately adjacent to the Site within which environmental effects could be anticipated. For the purpose of this project, this comprises all lands within and immediately surrounding (approximately 200 m) the Site, including the BTL buildings at 413 March Road. This area is generally bounded by March Road to the north-east and the perimeter Station Road which encircles the facilities on all other sides.

The Local Study Area surrounding the Site includes the area within which broader scale environmental effects, such as air quality and soil contamination, may be anticipated as a result of airborne emissions. For the purpose of this project, the Local Study Area includes the area within a 4 km radius (approximately) of the Site, as shown in Figure 3. This area is generally considered to be “Kanata North” and is bounded by the Ottawa River to the northeast and Highway 417 to the southeast.

Liquid effluent is released from delay and holding tanks to the municipal sewer system, and is subsequently treated and released from ROPEC, approximately 30 km northeast of the Site. Therefore, in addition to the Local Study Area shown in Figure 3, the ERA considers radiological exposure to human receptors up to 30 km downstream of ROPEC along the Ottawa River, as well as distant farm receptors that may use ROPEC biosolids as agricultural fertilizer.

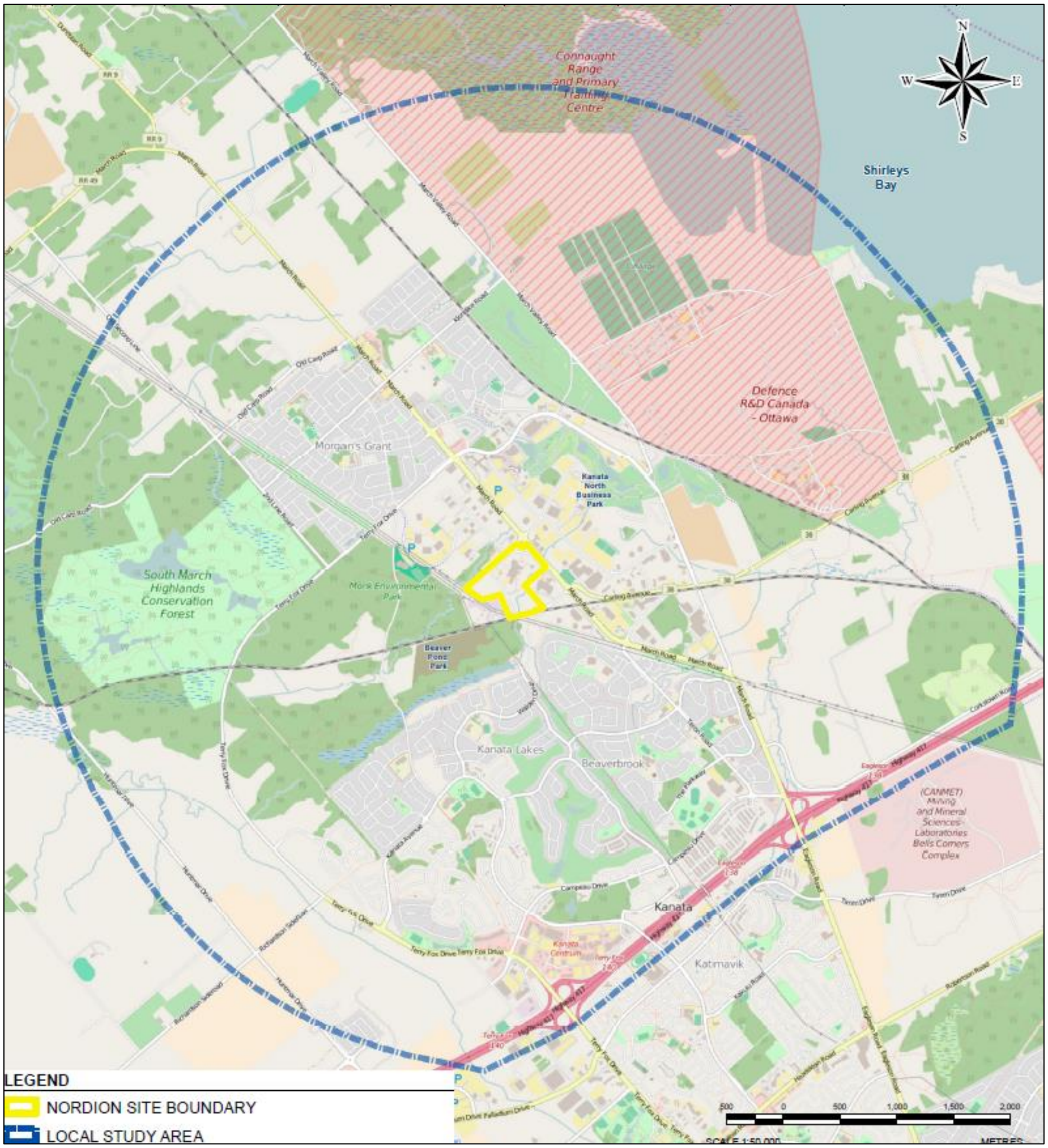


Figure 3: Local Study Area for airborne emissions

2.3.1.2 *Temporal Boundaries*

Where possible, the ERA is supported by environmental quality data for chemicals, radionuclides, and physical stressors that has been collected historically at and surrounding the Site. Where data from the past five years were not available for a given environmental medium or location, older data were used to fill data gaps. Therefore, facility operations that were active as of the time of data collection are considered in the ERA.

Within the next five years, BWXT intends on additionally manufacturing Tc-99m generators. Emissions for this future process have been estimated based on the source term [7], Safety Analysis standards and conservative assumptions.

2.3.2 Atmospheric Environment

2.3.2.1 *Air Quality*

The Ottawa central ambient air monitoring station is located in Downtown Ottawa, approximately 20 km from the Site. The Air Quality Index (AQI) is typically classified as “good” to “very good”.

Within the Site, engineering controls are used to reduce or eliminate air pollution. For example, an extensive and efficient NVS has been installed (see details in Section 2.2).

The National Pollutant Release Inventory (NPRI) identified results for the adjacent BTL property between 1994 and 2017 for the release of lead and its components for off-site recycling. The areas of concern were mitigated by historical investigations completed on-site, including air quality assessments for lead [12].

2.3.2.2 *Climate*

The City of Ottawa experiences a humid continental climate, marked by warm summers and cold winters. Temperature and precipitation data is shown in Figure 4 for the 30-year period of 1981 to 2010. During that period, the daily average temperature over a year was 6.6 °C and the annual average precipitation was 919.5 mm/year. Based on recorded information, the lowest temperature was -38.9 °C (December 1933) and the highest temperature was 37.8 °C (August 1917). The maximum daily precipitation was 108.6 mm (September 2004) and the maximum snow depth was 97 cm (February 1971).

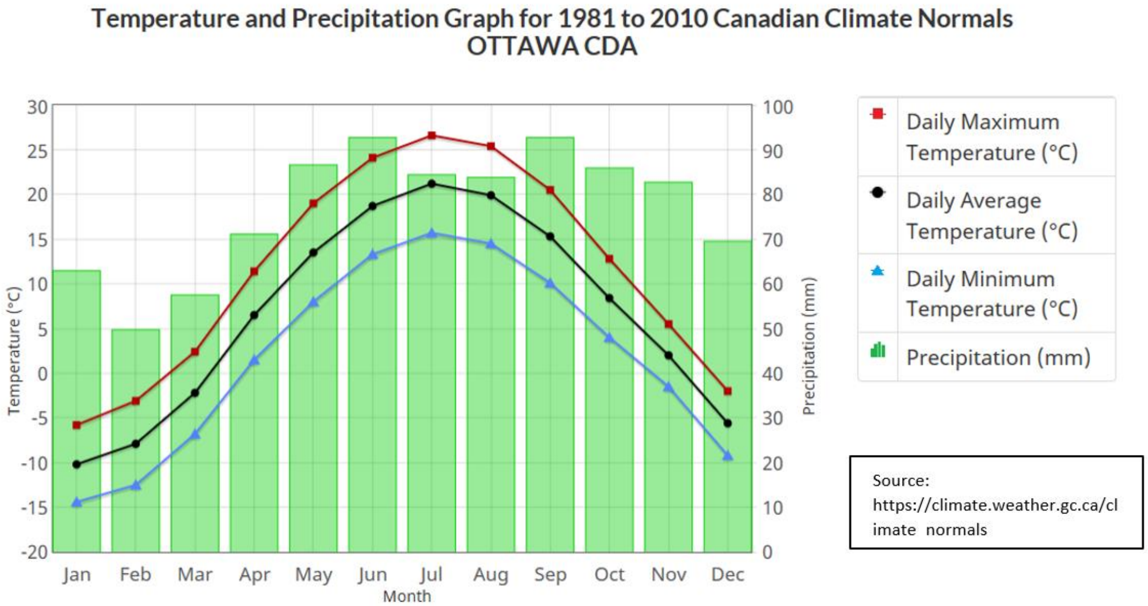


Figure 4: Meteorological data for Ottawa (1981 to 2010)

Climate conditions are predominant factors in determining contaminant transport (i.e., atmospheric dispersion). The direction and speed of the wind dictates the location and distance from the Site the contaminant may travel. The wind rose based on data from the Ottawa International Airport from 2015 to 2019 inclusive is shown below in Figure 5.

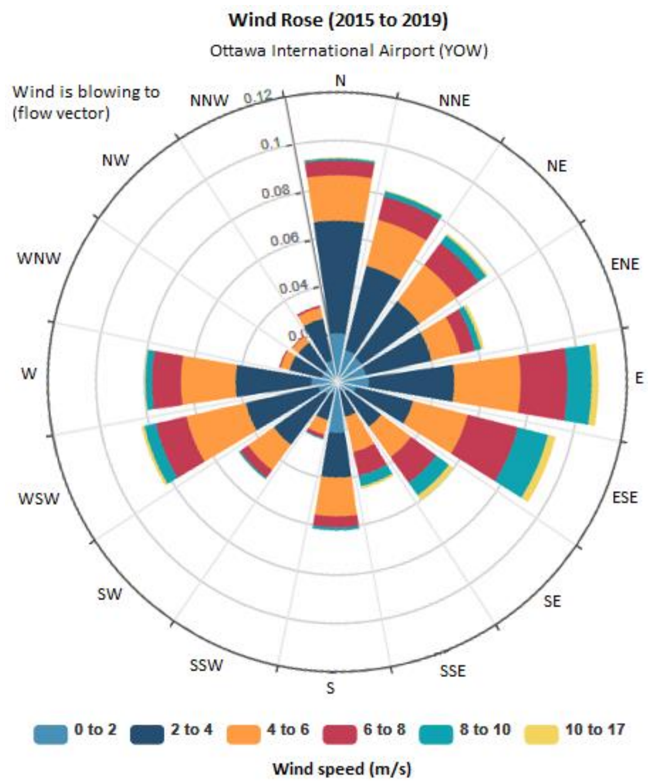


Figure 5: Ottawa International Airport Wind Rose (2015 to 2019)

2.3.2.3 *Noise*

Noise and vibration levels in the area are typical of an urban industrial setting. Existing sources of noise in the vicinity of the Site primarily comprise vehicular traffic on March Road and surrounding streets. The surrounding industrial area and nearby railway contribute the majority of ambient noise.

The Local Study Area is considered a Ministry of Environment, Conservation and Parks (MECP) Class 2 area [13], with an acoustical environment that has qualities representative of an urban area during the daytime, and low evening and nighttime background sound levels.

2.3.3 Radiation and Radioactivity

The following subsections provide a brief description of the origin of background radiation, and the ambient gamma dose rate and soil contamination observed in the Ottawa area.

2.3.3.1 *Dose from Natural Radiation*

The magnitude of radiation doses from natural sources vary greatly, both spatially and temporally, and are mainly attributable to: 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 [14].

Cosmic radiation originates from celestial events and the sun. This cosmic radiation and the secondary particles produced penetrate the Earth's atmosphere and give an external radiation dose at the Earth's surface. Naturally occurring radionuclides such as uranium, potassium, and thorium are present in soils, rocks and building materials. These naturally occurring radionuclides also contribute to the external gamma radiation dose.

Naturally occurring radionuclides also incorporate into plants, animals, and water from surrounding soils and rocks. Humans ingest these foodstuffs and receive an internal radiation dose. Radon gas, a product of the decay of uranium in soil, is inhaled and also contributes to the internal radiation dose.

As shown in Figure 6, the annual average effective dose from natural background radiation is approximately 1.8 mSv in Canada [14].

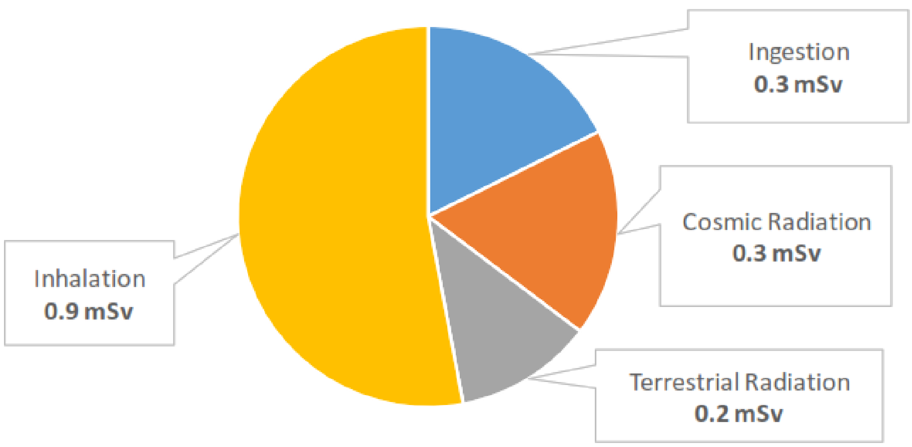


Figure 6: Background radiation doses to residents in Canada [14]

2.3.3.2 *External Gamma Dose Rate*

External gamma dose rate is a direct measure of external exposure to ionizing radiation for humans. The baseline external gamma dose rate in the vicinity of the Site is described using the Health Canada Radiation Protection Bureau Fixed Point Surveillance (FPS) network. The FPS Network is composed of 80 radiation detection stations located in population centres and other strategic locations across Canada. This network is remotely monitored, is an early warning system for radioactivity in Canadian airspace, and monitors radioactivity in the air and on the ground in real-time [15].

A map showing the general locations of the detection stations across Canada is provided in Figure 7. The FPS network monitors radiation dose to the public in real-time due to radioactive materials in the terrestrial environment, whether they are airborne or on the ground. It includes contributions from both natural and man-made sources. The FPS network measures the total external terrestrial gamma dose both as the Ambient Dose Equivalent H*(10) and as the physical dose Air KERMA (Kinetic Energy Released in unit MAss of Material). The contributions to external dose from 3 radioactive gases Argon-41, Xenon-133 and Xenon-135 are also reported as Air KERMA [16].

Health Canada publishes the monthly FPS network external dose rate data on a quarterly basis. Based on discussions with Health Canada [17], calibration activities were ongoing at the Ottawa FPS location between September 2019 and June 2020. As a result, dose rates during this period fluctuated and are not considered representative of background radiation. Since July 2020, Health Canada has recommended a correction factor for the data from the Ottawa FPS location.

After removing data for the period of September 2019 to June 2020, and applying the correction factor for data since July 2020, the average external gamma dose rate in Ottawa for 2020 was 12 μGy/month (or approximately 144 μGy/y) [16]. The annual average dose rates in Ottawa from 2016 to 2020 are plotted in Figure 8 and show relatively constant dose rates in Ottawa over the past five years. Slight variations in 2019 and 2020 are due to seasonal variations in the data that was included or excluded.

The external doses for Ar-41, Xe-133, and Xe-135 were below the detection limits of 6, 3, and 3 nGy/month, respectively. I-131 data is not provided as part of the routine monitoring data.

Figure 7: Canadian FPS Network [15]

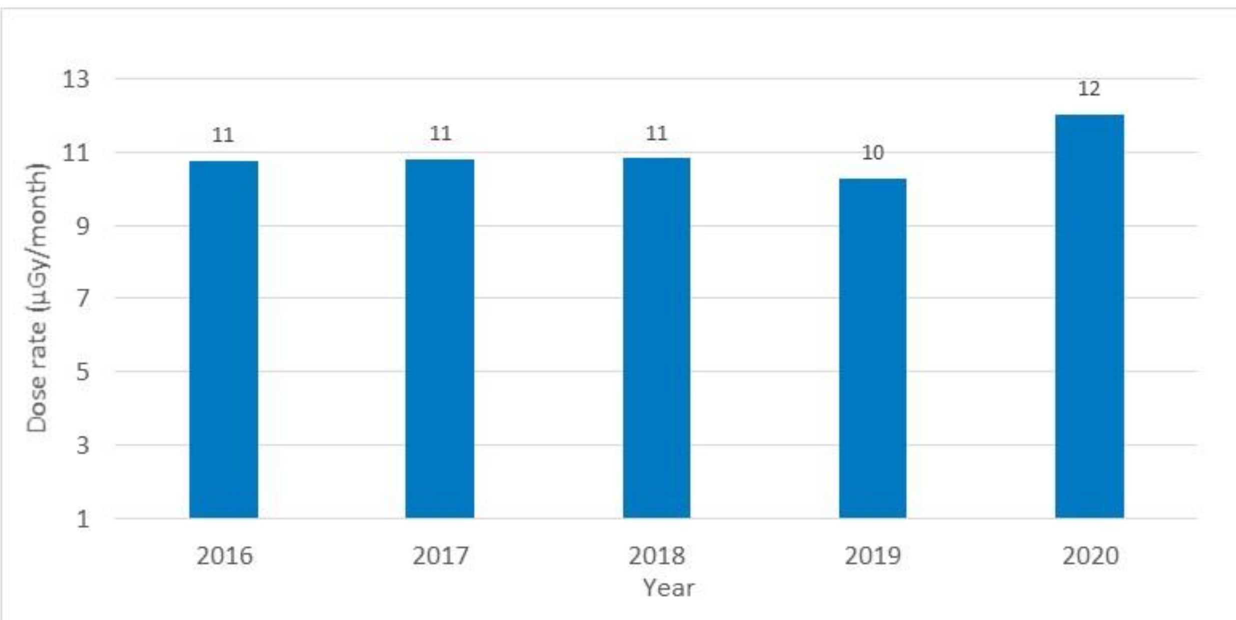


Figure 8: Average external gamma dose rates in Ottawa [16]

2.3.3.3 *Soil Contaminants*

Ontario Power Generation monitors soil samples from various locations in Ontario in five-year intervals. The most recent soil analysis was conducted in 2017 [18]. As part of this analysis, soil is collected from locations that are not affected by nuclear facility operations. These background soil samples are collected from Cobourg, Goderich, and Lakefield. Background soil sample analysis results for 2017 are presented in Table 1 [18].

Table 1: Soil contamination at various locations in Ontario

	Gamma Analysis (Bq/kg dw)			
Location	**Co-60 Result**	**Cs-134 Result**	**Cs-137 Result**	**K-40 Result**
Lakefield (A)	<0.2	<0.3	5.5	761.1
Lakefield (B)	<0.2	<0.2	5.6	745.6
Cobourg (A)	<0.2	<0.3	8.7	590.2
Cobourg (B)	<0.2	<0.3	9.0	585.4
Goderich (A)	<0.2	<0.3	1.8	393.5
Goderich (B)	<0.1	<0.2	1.7	394.4

The variation between soil contamination measurements is small. This analysis is assumed to be representative of the background soil contamination in the Ottawa region.

2.3.4 Geology and Hydrogeology

The Site is located at an elevation of approximately 81 metres above sea level (masl). The property is relatively flat with an overall gentle slope towards the north. On a regional scale, topographic relief slopes gently in the direction of the Ottawa River, approximately 3.5 km to the northeast [12].

The Local Study Area is wholly within the Kizell Drain subwatershed. The groundwater flow paths mimic the topography suggesting that groundwater flow in the area is topographically driven. Groundwater flow for the most part is to the northeast towards the local discharge areas, namely Shirley's Bay and the Ottawa River. Variations in the regional groundwater flow regime occur locally [19].

2.3.4.1 *Geology and Soil Quality*

The bedrock geology generally comprises undifferentiated metamorphic and igneous rocks from the Precambrian formation. The underlying bedrock comprises:

- Intrusive and metamorphic rocks of Precambrian age;
- Mainly bare, hummocky, rolling or hilly rock knob upland;
- Areas thinly veneered by unconsolidated sediments up to 2 m thick and medium-grained, stratified sand with some silt; and
- Fluvial terraces and channels cut in marine clay, and bars and spits within abandoned channels [12] [20].

Locally, the soils are comprised of fine grained surficial sediments (silts and clays) underlain by marine clays and till deposits, which in turn overlay sandstone and granite bedrock. The depth of bedrock on the Site is between 10 m and 30 m.

Based on subsurface drilling investigations at the adjacent BTL property, the overburden consists of brown sandy fill ranging from 0.5 m to 1 m overlying brownish grey silty clay with minor sand and gravel. The silty clay unit is dense and relatively dry, extending to depths between 2 m and 3 m, corresponding to the top of the water table or saturated zone.

2.3.4.2 *Hydrogeology*

Groundwater flow is to the east/southeast, likely representative of shallow groundwater flow. The small stream located between the Nordion and BTL buildings most likely influences the shallow groundwater movement on the Site. Groundwater levels were recorded at the Site from 2011 to 2014 and ranged from 1.32 m to 5.60 m below ground surface.

Groundwater samples have been collected once or twice yearly at four monitoring wells on Site since 2005. Samples from various depths have been analyzed for Petroleum Hydrocarbons (PHCs), metals (i.e., barium, boron and iron), and organic elements (i.e., ions, nitrogen compounds, pH and total suspended and dissolved solids). Analytical results are compared to Soil, Groundwater and Sediment Standards for Use under Part XV.1 of the Environmental Protection Act [21], and the Ontario Drinking Water Standards, Objectives and Guidelines [22]. Results indicate that there have been no significant changes in groundwater quality, and contaminant concentrations are below applicable limits. For example, the results for the groundwater samples collected on June 19, 2019 and the preceding five years are provided in Appendix F of the Nordion 2019 Annual Compliance Report [23]. The data indicate that groundwater quality has been consistent over the monitored timeframe and are within applicable limits.

Groundwater is not used as a potable water source in the vicinity of the Site.

2.3.5 Aquatic Environment

A subwatershed is an area that includes all of the land drained by a single watercourse. Shirley's Brook and Watts Creek/Kizell Drain subwatersheds are the two main drainage areas within the urban portions of the City of Kanata. The Local Study Area overlaps both subwatersheds; however, the Site lies wholly within the Watt's Creek/Kizell Drain subwatershed and will be the focus for this section.

2.3.5.1 *Surface Water Quality and Quantity*

All contaminated liquid is collected for disposal at a licensed treatment facility. In the event contaminated liquid is discharged to a domestic drain, it is collected at the low-level liquid waste handling system before being discharged to the municipal public sewer. Liquid effluent discharged into the public sewer is treated at the Gloucester Water Treatment plant (ROPEC), and eventually enters the Ottawa River.

The regional surface water drainage is also controlled by the Ottawa River, which is located approximately 3.5 km northeast of the property. According to the Shirley's Brook and Watt's Creek Subwatershed Study [19], Shirley's Brook and Watts Creek/Kizell Drain subwatersheds all share similar water quality characteristics and have all been impacted by human activities. For example, historical studies have shown that total phosphorus, E. coli bacteria and fecal coliforms exist at levels indicative of agricultural activities which may include fertilizers, manure runoff, livestock wastes, leaching of septic systems and soil erosion which can release these nutrients and bacteria into streams. They also showed elevated levels of sodium, iron, aluminum, cobalt, manganese, zinc and chloride, which is indicative of inputs from natural weathering of rocks and urban activities such as road salting. These constituents pose no threat to humans for recreational purposes, however excessively high levels may be detrimental to aquatic life [19].

There is a small stream located between the Nordion and BTL Buildings. It originates at a beaver-dammed pond (locally known as "the beaver pond") in Beaver Pond Park, approximately 900 m southwest of the Site. The stream flows northeast from the residential area located to the southwest of the subject property, through the Nordion and BTL properties to the Kanata North Business Park and outlets into the Ottawa River (see Figure 2 and Figure 3).

The on-site stormwater management system consists of a series of stormwater catch basins, drainage swales and a stormwater pit that drains to the small stream that flows between Nordion and BTL properties. Waste liquid is collected in underground delay and holding tanks for monitoring prior to being released to the sanitary sewer. A search of the NPRI [24] showed no reported release of contaminants to water during the reportable period (1994 to 2017). The Nordion Annual Compliance Reporting for 2016 to 2019 ([25], [26], [27], [28]) discusses the sewer monitoring results in comparison to the City of Ottawa Sewer Use by-law (2003-514) [29]. The City of Ottawa has not raised any concerns. It should be emphasized that average annual releases from delay and holding tanks from 2015 to 2019 were less than 10^6 L/year [23] with annual water volume from ROPEC being greater than 10^{11} L/year [30]; as the typical water demand from commercial facilities is on the order of approximately 2 L/m^2/day [31], substantial dilution is expected upon discharge (on the order of 10^3 to 10^4). In comparison to the 2017 ERA [2], there is potentially 10 times less dilution given a water demand of 0.2 L/m^2/day was assumed at that time. Nevertheless, given the large amount of dilution and the filtration of contaminants at ROPEC, the resulting non-radiological contaminant concentration of waterborne releases into the Ottawa River is considered to be negligible.

It has been previously reported that the water quality within the Nepean, March, and Oxford Formations is generally potable; however, iron and manganese generally exceed the Ministry of Environment (MOE) Drinking Water Aesthetic Objectives [19].

2.3.5.2 *Sediment Quality and Quantity*

No sediment samples have been collected on Site.

2.3.5.3 *Aquatic Biota*

The following provides an overview of the aquatic environment based on previous studies of the Local Study Area.

According to the Shirley’s Brook and Watt’s Creek Subwatershed Study [19], a tolerant warmwater fish community inhabits Watts Creek and Kizell Drain. The developed and agricultural sections of the watercourse exhibited low species diversity, identifying the following species: creek chub, brook stickleback, central mudminnow, fantail darter, common shiner and brook stickleback. The fish species captured were tolerant with the exception of the fantail darter which was captured at both the developed and undeveloped sites. The fantail darter is considered intermediate in tolerance of degraded stream conditions and is at the northern edge of its range resulting in a somewhat restricted distribution within Canada. It is primarily carnivorous and is found mainly in gravel bottom streams. All other species captured are omnivorous. No rare, threatened or endangered species were captured at the time of the study in 1999.

2.3.5.4 *Aquatic Habitat*

Fish habitat in the Shirley's Brook/Watts Creek Subwatershed area was classified based on the Fish Habitat Conservation and Protection Guidelines for Developing Areas [32] and the Habitat Conservation and Protection Guidelines [33]. All of Watts Creek was classified as Type 2 habitat, which requires a moderate level of protection and includes areas utilized by fish for feeding, growth and migration [19].

2.3.6 Terrestrial Environment

The following provides an overview of the terrestrial environment based on previous studies of the Local Study Area.

The Site falls within the Kizell Drain subwatershed. This area covers an area of approximately 1,000 ha (10 km^2) of which natural areas are covered in forest, wetland or exposed rock. The remainder has been cleared for agricultural purposes or for residential, commercial or industrial purposes. The Local Study Area includes large expanses of upland (dry) forest, lowland (wet) forests, marsh wetland as well as exposed precambrian shield [19].

2.3.6.1 *Vegetation Communities and Species*

The Site comprises multiple buildings, surface parking areas, sections of manicured lawn and decorative gardens, as well as a small, deciduous woodlot of less than 10 ha (Figure 2).

Within the Site is the Kizell Drain Provincially Significant Wetland that is also connected to the South March Highlands candidate Life Science Area of Natural and Scientific Interest (ANSI), which includes the South March Highlands Provincially Significant Wetland.

In the upland forest of the Kizell subwatershed, typical species within the upper canopy include sugar maple, beech, white ash, white pine, hemlock and basswood. The shrub layer is composed of saplings of the upper canopy as well as choke cherry, hop hornbeam and hazelnut. The understorey varies according to the degree of sunlight reaching the forest floor, but typical species found here include white snakeroot, cloudberry, white trillium, enchanters nightshade, jack-in-the-pulpit and wild ginger [19].

In the lowland forest, which also included swamp communities, the upper canopy ranges from pure stands of white cedar or soft maple to a mixed stand of white cedar, alder, balsam fir, poplar, yellow birch, hemlock, willow/dogwood or black ash. It is reported that a stand of Tamarack is also contained here. The shrub layer is usually composed of saplings of the upper canopy as well as willows, alders and dogwood. The understorey is composed of ferns including maidenhair, sensitive, ostrich as well as typical riparian plants including spotted jewelweed, enchanters nightshade, mosses and lichens [19].

2.3.6.2 *Wildlife Habitat and Species (including Migratory Birds)*

The Kizell Drain subwatershed still has considerable forest resources that provide habitat to birds and wildlife. Based on the urban nature of the Local Study Area, the following species would be expected in or around the Site: American beaver (*Castor canadensis*), big brown bat (*Eptesicus fuscus*), eastern cottontail (*Sylvilagus floridanus*), coyote (*Canis latrans*), grey squirrel (*Sciurus carolinensis*), porcupine (Erethizon dorsatum), raccoon (*Procyon lotor*), red fox (*Vulpes*

vulpes), striped skunk (*Mephitis mephitis*), white-tailed deer (*Odocoileus virginianus*) and woodchuck (*Marmot monax*) [34].

The Site lies within the Ontario Breeding Bird Atlas square 18VR22. Between 2001 and 2005, 27 point count surveys for breeding birds were completed, which identified a total of 122 avian species. One heron was identified in 2012 in the vegetation along the banks of the stream between the Nordion and BTL buildings [35].

To the southwest of the property is the Kanata Beaver Pond Park (see Figure 3), which is a well-used recreational area. Species identified within the park area include beaver, pileated woodpecker, kingfisher, red winged blackbird, chipmunks and red squirrels, mallard and red-breasted mergansers.

2.3.6.3 *Species at Risk*

In support of the 2017 ERA [2], a number of resources were used to evaluate the potential for SAR to occur in the Local Study Area as well as existing conditions including:

- Natural Heritage Information Centre (NHIC) database maintained by the Ontario Ministry of Natural Resources and Forestry (MNRF) [36];
- Species at Risk (SAR) Public Registry [37];
- Species at Risk in Ontario (SARO) List [38];
- Royal Ontario Museum (ROM) range maps [39];
- Atlas of Breeding Birds of Ontario (OBBA) [40];
- Bat Conservation International (BCI) range maps [41];
- Atlas of the Mammals of Ontario [42];
- Ontario’s Reptile and Amphibian Atlas [43];
- Land Information Ontario [44]; and
- Existing aerial photography.

The potential for the species to occur was determined through a probability of occurrence. A ranking of low indicates no suitable habitat availability for that species in the Local Study Area and no specimens identified. Moderate probability indicates more potential for the species to occur, as suitable habitat appeared to be present in the Local Study Area, but no occurrence of the species has been recorded. High potential indicates a known species record in the Local Study Area (including during field surveys or background data review) and good quality habitat is present. The results of the desktop SAR screening completed in 2017 based on the potential for a species to occur within the Local Study Area are as follows:

- Moderate to high potential:
    - Little brown myotis (*Myotis lucifugus*);
    - Northern myotis (*Myotis septentrionalis*);
    - Tri-colored bat (*Perimyotis subflavus*); and

    - Butternut (*Juglans cinerea*).
- Moderate potential:
    - Monarch (*Danaus plexippus*);
    - Chimney swift (*Chaetura pelagica*);
    - Eastern wood-pewee (*Contopus virens*);
    - Red-headed woodpecker (*Melanerpes erythrocephalus*);
    - Milksnake (*Lampropeltis triangulum*); and
    - Snapping turtle (*Chelydra serpentina*).
- Low to moderate potential:
    - Barn swallow (*Hirundo rustica*); and
    - Common nighthawk (*Chordeiles minor*).

The following listings are current as of 2021. Chimney swift and barn swallow are designated as threatened and little brown myotis, northern myotis, tri-colored bat, and butternut are all listed as endangered under both the federal Species at Risk Act (SARA) [45] and provincial Endangered Species Act (ESA) [46]. Common nighthawk and red-headed woodpecker are both designated as threatened under the SARA, and as special concern under the ESA.

Monarch, eastern wood-pewee, milksnake, and snapping turtle are designated special concern under both SARA and ESA, but do not receive protection under either Act. These four species are not discussed further in this report.

Chimney swift breeds in a variety of habitats including urban, suburban, rural and wooded sites. They are most commonly associated with towns and cities with large concentrations of chimneys. Preferred nesting sites are dark, sheltered spots with a vertical surface to which the bird can grip. Unused chimneys are the primary nesting and roosting structure, but other anthropogenic structures and large diameter cavity trees may also be used. Trees used for nesting are typically greater than 50 cm diameter at breast height [47]. Based on available aerial imagery there does not appear to be any suitable unused chimney structures on the site or in the study area to provide appropriate nesting habitat for chimney swift. There is potential that trees of the deciduous woodland in the southwestern corner of the Local Study Area may provide suitable natural nesting habitat, depending on the size and availability of large cavities.

Little brown myotis and northern myotis both use forested areas for maternity roosting in the summer months. While little brown myotis will use both natural and man-made structures (e.g. attics), northern myotis prefers natural roosts. Natural roosts consist of large, dead trees with suitable cavities, hollows or peeling bark. Caves or abandoned mines may be used for hibernaculum over the winter [48]. The deciduous woodland in the southwestern corner of the Local Study Area may provide suitable natural maternity roosting habitat to support these two bat species.

Butternut is found along stream banks, on wooded valley slopes, and in deciduous and mixed forests. It is commonly associated with beech, maple, oak and hickory. Butternut prefers moist, fertile, well-drained soils, but can also be found in rocky limestone soils. This species is shade intolerant, and is often found in forest edges, in forest clearings and on roadsides [49]. There is potential for butternut to occur within the deciduous woodland in the southwest corner of the Local Study Area. There are historical records of occurrence of butternut in this area [36], and proximity to the watercourse and the open canopy of the woodland may increase habitat suitability.

Common nighthawk is an aerial forager that requires areas with large open habitat. This includes farmland, open woodlands, clearcuts, burns, rock outcrops, alvars, bog ferns, prairies, gravel pits and gravel rooftops in cities. Common nighthawk will also nest in mixed and coniferous forests [50]. The open deciduous woodland in the southwestern corner of the Local Study Area may provide suitable nesting habitat.

Red-headed woodpecker breeds in open, deciduous woodlands or woodland edges and are often found in parks, cemeteries, golf courses, orchards and savannahs. They may also breed in forest clearings or open agricultural areas provided that large trees are available for nesting. They prefer forests with little or no understory vegetation. They are often associated with beech or oak forests, beaver ponds and swamp forests where snags are numerous. Nests are excavated in the trunks of large dead trees [51]. The deciduous woodland in the southwestern corner of the Local Study Area may provide suitable nesting habitat, depending on the overall structure of the woodland and availability of snags.

Tri-colored bat may roost in foliage, in clumps of old leaves, hanging moss or squirrel nests. They are occasionally found in buildings although there are no records of this in Canada. They typically feed over aquatic areas with an affinity to large-bodied water and will likely roost in close proximity to these. Hibernation sites are found deep within caves or mines in areas of relatively warm temperatures [48]. The deciduous woodland in the southwestern corner of the Local Study Area may provide suitable natural maternity roosting habitat to support tri-colored bat.

Barn swallow nests in artificial structures such as barns, garages, and sheds that are near to open habitats including farmland and wetlands over which they forage [52]. There does not appear to be any suitable structures in the Local Study Area to provide nesting habitat for barn swallow. However, the watercourse in the Local Study Area may provide suitable foraging habitat for potential individuals nesting nearby.

2.3.7 Land Use and Transportation

2.3.7.1 *Land Use*

The Site has been used industrially since the 1960s and is zoned General Industrial (IG6), which permits a wide range of low to moderate impact, light industrial uses. Historically, Atomic Energy of Canada Ltd., Theratronics International Ltd., MDS Nordion and BTL have occupied the area to handle and process nuclear substances, primarily for medical purposes. The region is a mixed industrial, commercial and residential setting with commercial and industrial buildings located to the north, east and south. In general, the land on both sides of March Road between Solandt Road and Carling Avenue are zoned General Industrial (IG6).

2.3.7.2 *Transportation*

The facility is not located near any large bodies of water, ports, airports or pipelines. There is a Canadian National railway located within 300 m of the Facility to the southwest and a non-navigable stream runs between the Nordion and BTL properties.

Transportation within the Site is primarily vehicular movement of employees. Truck traffic includes shipment of supplies and product to and from the facility. Access to the Site is not controlled, though posted signs indicate that the Site is private property. Station Road, which surrounds the Nordion and BTL properties, is not a through road. The posted speed limit for Station Road is 40 km/h and the road is monitored by remote cameras including all site access points.

2.3.8 Socio-Economic Conditions

2.3.8.1 *Surrounding Area and Population*

The Site is located in Kanata North, which is the area of Kanata north of Highway 417 and includes the following communities: South March, Morgan's Grant, Kanata Lakes, and Beaverbrook. The area surrounding the site is a mixture of industrial park and subdivisions. The nearest urban population is the Beaverbrook community, which is located 0.5 km from the site boundary. From the 2016 Census, the Kanata North ward has an approximate population of 37,000. The population of all other wards in the City of Ottawa is shown in Table 2.

Table 2: Population figures from 2016 Census

Ward	Population
1. Orléans	48,789
2. Innes	41,211
3. Barrhaven	58,269
4. Kanata North	36,996
5. West Carleton-March	25,600
6. Stittsville	32,494
7. Bay	45,476
8. College	52,430
9. Knoxdale-Merivale	39,515
10. Gloucester-Southgate	47,233

Ward	Population
11. Beacon Hill-Cyrville	33,416
12. Rideau-Vanier	48,536
13. Rideau-Rockcliffe	38,154
14. Somerset	41,569
15. Kitchissippi	43,258
16. River	48,512
17. Capital	37,440
18. Alta-Vista	44,713
19. Cumberland	46,813
20. Osgoode	27,770
21. Rideau-Goulbourn	27,681
22. Gloucester-South Nepean	49,280
23. Kanata South	48,700
Ottawa total	**963,857**

2.3.8.2 *Nearby Industrial Facilities*

The area in the vicinity of the Site is designated as 'Employment Area' in the City of Ottawa Official Plan, along with the surrounding properties to the south and east. The surrounding lands immediately adjacent to the Site are occupied by several industrial operators, including Ottawa Hydro, BTL, and other high-tech companies within the Kanata North Business Park. Ottawa Hydro's facility is located 200 m southwest of the Site. The facility use is primarily for electrical distribution and houses transformers and other electricity transfer equipment. BTL is located approximately 150 m southeast of the Site at 413 March Road. (Prior to 2008, both buildings at 447 and 413 March Road operated as one facility). The BTL facility operations include the development of external beam therapy units, self-contained blood irradiators, linear accelerators for both medical and industrial usage, and cyclotrons. An Esso gas station is located approximately 100 m north of the Site, and an Ultramar gas station is located approximately 500 m east of the Site.

2.3.9 Indigenous Interests

2.3.9.1 *Indigenous Communities*

This region of Ontario is included in the Upper Canada Treaties Area with the Mississauga First Nation (1819). Under this historic treaty, the Mississauga have hunting and fishing rights. The nearest Mississauga band to the Site are the Mississauga's of Scugog Island First Nation, located approximately 160 km south of the Site.

The Algonquins of Pikwakanagàn First Nation are located over 100 km west of the Site. This band has one specific claim which includes the entire Ottawa River watershed in Ontario, including the lands within the Local Study Area; however, this claim has been concluded (Aboriginal Title – Resolved through Administrative Remedy).

There are no Indigenous communities known to be living within the Local Study Area. Through its program for Public Information and Disclosure Program and Indigenous Engagement (PIDPIE), BWXT communicates and engages with surrounding communities, stakeholders and other interested parties. BWXT has identified the following Indigenous communities as target audiences for the PIDPIE:

- Algonquins of Ontario which consists of ten Algonquin communities: Algonquins of Pikwàkanagàn First Nation, Antoine, Kijicho Manito Madaouskarini (Bancroft), Bonnechere, Greater Golden Lake, Mattawa/North Bay, Ottawa, Shabot Obaadjiwan, Snimikobi and Whitney and Area.
- Métis Nation of Ontario – Ottawa Region Métis Council
- Algonquin Anishinabeg Nation Tribal Council which is comprised of the Kebaowek First Nation, Nation Anishnabe du Lac Simon, Abitibiwinni, Kitigan Zibi, Long Point (Winneway), Kitcisakik, Wahgoshig, Algonquins of Barriere Lake (Mitchikanibikok), Timiskaming first Nation, and Wolf Lake First Nation.

Annually, the designated list of addresses for communications materials is reviewed for currency and new addresses that resulted from new, completed, and occupied construction within designated boundaries are added as needed.

2.3.9.2 *Traditional Land and Resource Use*

The Site and Local Study Area are currently zoned for industrial uses and are used as such. There are no known traditional land or resource uses by Indigenous persons (e.g., hunting or fishing) within the Site.

2.3.9.3 *Cultural and Heritage Resources*

There are no known Indigenous cultural or heritage features within the Site.

3. HUMAN HEALTH RISK ASSESSMENT

3.1 Problem Formulation

The purpose of problem formulation is to scope the assessment by identifying the environmental issues of concern, and identifying the receptors, exposure pathways and substances for which further quantitative analysis is warranted from those that can be eliminated from further consideration. Once this analysis is complete, the results from the problem formulation are summarized in a conceptual site model (CSM), which illustrates how receptors can potentially come into contact with substances in relevant environmental media that have been affected by historical and ongoing activities at the Site.

3.1.1 Receptor Selection and Characterization

3.1.1.1 *Receptor Selection*

Airborne emissions

A Potential Critical Group is a group of individuals that share dietary and behavioural habits, and because of their proximity to the Site, may receive the highest radiation dose for a given radionuclide and release pathway (i.e., airborne or liquid).

For the purpose of modeling radiation exposure, it is necessary to ascribe a single location to a single individual. These individuals are known as the Representative Person and is considered to be an average member of the Potential Critical Group.

For conservatism, the location of the Representative Person is assumed to be the point within the Potential Critical Group closest to the BWXT operations facilities.

Three types of Potential Critical Groups have been identified in the vicinity of the Site:

1. Urban resident (R);
2. Farm resident (F); and
3. Industrial worker (I).

Several candidate groups were selected for each type of Potential Critical Group for the purpose of identifying the group with the highest radiation exposure (i.e., the Critical Group). Candidate groups considered in the 2017 ERA [2] and DRL report [6] are listed in Table 3 and their locations are plotted on a map in Figure 9.

Table 3: Identification of Potential Critical Groups

Group name	General characteristics and location of potential Critical Groups
R1	Urban resident, Beaverbrook community, located approximately 500 m south of the Site.
R2	Urban resident, Kanata Lakes community, located approximately 1 km south of the Site.
R3	Urban resident, Morgan's Grant community, located approximately 1.5 km northeast of the Site.
F1	Farm, 3859 Carling Avenue, located approximately 1.25 km east of the Site. Features a dog training centre, cornfield, and several smaller farm plots.
F2	Farm, Pinewood Orchard, located approximately 2 km southeast of the Site. Produces apples as well as seasonal vegetables.
F3	Farm, Agriculture Environmental Renewal Canada Inc. (AERC) research farm, located approximately 2.5 km southeast of the Site. Produces Sorghum and Pearl Millet.
F4	Farm, Riverglen Biodynamic Farm, located 3 km east of the Site. Produces vegetables, eggs, and chicken.
F5	Farm, Dekok Berry Farm, located 3.5 km northeast of the Site. Produces strawberries, raspberries, corn, and apples. Many farm plots are located nearby, likely producing beans, corn, hay, and pasture for livestock.
F6	Farm, The Elk Ranch, located 3 km northwest of the Site. Consists of an elk pasture where elk graze on alfalfa and oats, and elk meat and velvet are produced for human consumption.
F7	Farm, located approximately 3 km southwest of the Site. Assumed to produce dairy, beef, and vegetables.
I1	Worker at Esso station. Located approximately 100 m northeast of KOB stacks.
I2	Worker in Kanata North Business Park, approximately 400 m East of KOB stacks across March road.

Figure 9: Potential Critical Groups in the vicinity of the Site

Based on developments to the area surrounding the Site since the 2017 ERA [2], two additional candidate groups are considered in the present ERA:

1. *Kids & Company Day Care Center*, which is located 360 m WNW from the closest stack, Stack 2, as seen in Figure 10. By comparison, the Esso station worker is closer (210 m) to Stack 2. Additionally, the Esso station is located in the NNE direction, which higher wind direction frequency based on the wind rose (Figure 5). Therefore, this receptor is bounded by the Worker at Esso station receptor (I1), defined in Table 3.

Figure 10: Location of Kids & Company Day Care Center

2. *Potential two four-storey low-rise apartment buildings at 100 Steacie Drive*, which has an application for development currently under review. The distance to the closest stack (Stack 2) is 510 m, as seen in Figure 11. The wind direction to the apartment buildings is S, SSE, which has relatively low frequencies based on the wind rose (Figure 5). Therefore, this receptor is bounded by the Worker at Esso station receptor (I1), defined in Table 3.

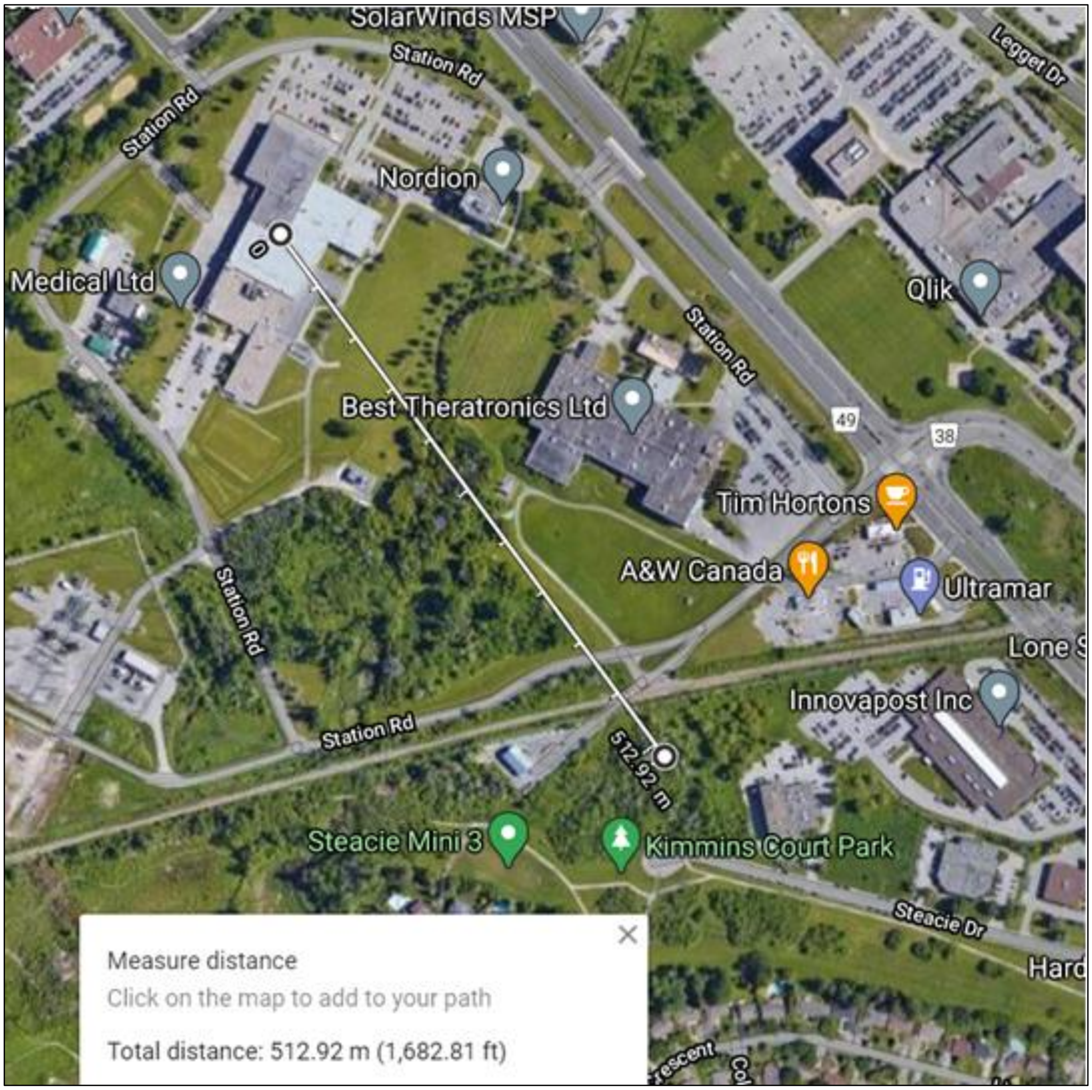


Figure 11: Location of potential apartment buildings at 100 Steacie Drive

Based on the justifications above, these receptors are considered, but their exposure is bounded by those considered in the 2017 ERA and DRL calculations.

The municipal water used by these receptors is sourced from the Ottawa River, but is upstream from ROPEC. This municipal water is used for drinking, bathing and swimming. This municipal water is assumed to be uncontaminated from operations performed at the Site. Other drinking water sources (e.g., bottled water) are also consumed, but are free of contaminants.

It is assumed that municipal water is used for crop irrigation and animal drinking.

Waterborne emissions

All of the waterborne effluents from the BWXT operations facilities are released into the municipal sewer system, and are discharged into the Ottawa River at ROPEC. Additional Potential Critical Groups have been identified in the vicinity of ROPEC (Table 4).

The nearest downstream water treatment plant that supplies drinking water from the Ottawa River is located approximately 30 km northeast from ROPEC in Thurso, Quebec (Figure 12).

The closest farm resident that may use river water for irrigation and livestock is located 6 km east of ROPEC. This location is also considered to be one of the closest swimming locations, along with Thurso, QC, which is located approximately 30 km northeast of ROPEC.

Table 4: Potential Critical Groups downstream of ROPEC discharge

Group name	General characteristics and location of potential Critical Groups
R4	Urban resident, Thurso, QC, located approximately 30 km northeast of ROPEC.
F8	Farm resident, approximately 6 km east of ROPEC, adjacent to Ottawa River. Farm production appears to include hay and livestock.
I3	Sewage treatment worker located on the ROPEC site.

Figure 12: Potential Critical Groups downstream of ROPEC

The municipal water used by the R4 receptor comes from the Thurso water treatment plant. This receptor is assumed to obtain 100% of their drinking water from this source. The farm resident is assumed to obtain 100% their irrigation water from the Ottawa River. Both of these water sources are assumed to be contaminated from waterborne releases at ROPEC. The farm resident would obtain their water from a municipal source upstream of ROPEC or from a well, and this water would be free of contamination. The R4 and F8 receptors are assumed to go swimming near their respective locations. Fish consumed by the receptors are assumed to be caught 100 m downstream from the ROPEC discharge point.

ROPEC annually produces over 51,000 metric tons of wet biosolids [6]. Part of the end-use of these biosolids processed at ROPEC from the wastewater treatment is used in farming applications in the form of agricultural fertilizer. The two potential Critical Groups that may be exposed to radioactive contaminants from the biosolids produced at ROPEC are shown in Table 5. The processed biosolids are assumed to be collected and transported in a sludge transport container. An adult receptor (I4) is expected to transport the container by truck from ROPEC to a distant farm (F9). While driving the truck, the driver is exposed to external radiation from the radioactive contaminants. The biosolids from ROPEC is assumed to be utilized on farmland owned by the F9 receptor. The F9 receptor uses the fertilizer from ROPEC on forage and crops. Forage is consumed by farm animals and both farm animals and crops are consumed by the farmer.

Table 5: Potential Critical Groups away from ROPEC

Group name	General characteristics and location of potential Critical Groups
F9	Farm resident using agricultural fertilizer from ROPEC who is located outside of Ottawa not affected by airborne or liquid releases. Assumed to produce beef, poultry, fruits and vegetables.
I4	Sludge truck driver transporting biosolids from ROPEC.

Employees and visitors

Potential health risks to BWXT or Nordion employees, contractors and visitors as a result of Site operations are not retained for quantitative assessment in the Human Health Risk Assessment (HHRA). All effects to these individuals due to radiological substances are monitored under the applicable Radiation Protection Program, and conventional safety is ensured under the Conventional Health & Safety Program.

Indigenous communities

Members of Indigenous communities, as described in Section 2.3.9, are not expected to be directly affected by emissions from the Site given that they reside in communities that are located beyond the Local Study Area and traditional uses by Indigenous persons within the identified study area have not been identified. As a result, potential health risks to Indigenous persons as a result of Site operations are expected to be negligible and therefore members of Indigenous communities were not retained for quantitative assessment in the HHRA.

3.1.1.2 *Receptor Characterization*

For the radiological risk assessment, urban residents and farm residents include people of all ages and are represented using the three age groups as defined in CSA N288.1-14 [53]: infant (birth to 5 years), child (6 to 15 years), and adult (16 years and older).

For the non-radiological risk assessment, urban residents and farm residents include people of all ages and are represented using the five age groups as defined by Health Canada [54]: infant (birth to <6 months), toddler (6 months to 4 years), child (5 to 11 years), adolescent (12 to 19 years), and adult (20 years and older).

The key difference between urban residents and farm residents is an increased dependence on locally grown food.

Workers are considered to be adults who work at ROPEC or within the vicinity of the Site, for example at the Kanata North Business Park.

3.1.2 Selection of Stressors

3.1.2.1 *Chemical Contaminants*

Airborne releases are addressed in the Emissions Summary and Dispersion Modelling (ESDM) Report completed for the combined BWXT and Nordion operations [13]. The following sources were considered:

BWXT:

- Three NVS exhaust stacks;
- One emergency generator system;
- Two natural gas-fired steam boilers;
- One natural gas-fired heating recirculator;
- One exhaust servicing the gas blowing laboratory; and
- One exhaust servicing the metal fabrication area (includes welding operations).

Nordion:

- NVS exhaust stack;
- Two evaporative cooling towers;
- Four emergency generator systems;
- Six natural gas-fired steam boilers;
- Three natural gas-fired hot water boilers; and
- Natural gas-fired comfort heating equipment.

Out of these possible sources, only the following had predicted emission rates that were significant for a single contaminant – nitrogen oxides (NOx):

BWXT:

- Two natural gas-fired steam boilers; and
- One natural gas-fired heating recirculator.

Nordion:

- Six natural gas-fired steam boilers;
- Three natural gas-fired hot water boilers; and
- Natural gas-fired comfort heating equipment.

The emissions from emergency generators did not exceed the allowable screening limits for NOx, and as such were not included in the Point of Impingement calculations. All other potential chemical contaminants that could be released from the BWXT and Nordion operations had predicted emission rates that were lower than their respective limits as presented in the 2021 ESDM [3] and as reproduced in Table 6.

Table 6: Contaminant Emission Rate Screening (reproduced in part from 2021 ESDM [3])

Contaminant	Total Facility Emission Rate (g/s)	Averaging Period (h)	Site-Specific Emission Threshold (g/s)	Considered Negligible or Significant?
Nitrogen Oxides	0.57	24	0.024	Significant
	0.57	1	0.020	Significant
Suspended particulate matter	4.60E-03	24	1.46E-02	Negligible
Iron	6.07E-06	24	4.87E-04	Negligible
Titanium dioxide	6.07E-07	24	4.14E-03	Negligible
Limestone	6.07E-07	8760	2.54E-03	Negligible
Potassium silicate	3.03E-07	24	6.09E-04	Negligible
Manganese	3.03E-07	24	4.87E-05	Negligible
Feldspar	3.03E-07	24	3.04E-04	Negligible
Aluminum oxide	3.03E-07	24	1.46E-02	Negligible
Silicon	6.07E-08	24	3.29E-03	Negligible
Quartz	6.07E-08	24	6.09E-04	Negligible
Carboxymethyl cellulose, sodium salt	6.07E-08	0.5	2.47E-01	Negligible
Hydroxyethyl cellulose	6.07E-08	24	1.83E-03	Negligible
Silicon dioxide	6.07E-08	24	6.09E-04	Negligible
Fluorides	6.07E-08	720	1.07E-04	Negligible
	6.07E-08	24	1.05E-04	Negligible
Ozone	7.13E-03	1	8.25E-03	Negligible

Contaminant	Total Facility Emission Rate (g/s)	Averaging Period (h)	Site-Specific Emission Threshold (g/s)	Considered Negligible or Significant?
Molybdenum	1.74E-10	24	1.46E-02	Negligible
Cobalt	1.85E-13	24	1.22E-05	Negligible
N-nitroso-N-methylurea[a]	1.74E-10	24	6.09E-10	Negligible

[a] As a conservative measure the emission rate of cobalt and molybdenum were combined to represent a theoretical emission of contaminants from the NVS. The emission rate was then compared to the emission threshold for N-nitroso-N-methylurea, a template value to represent the most stringent 24-hour Air Contaminants Benchmark (ACB) Limit published by the MECP with a 24-hour limit of 0.000005 µg/m^3. When compared to this limit, the theoretical emissions screen out as negligible per the Emission Threshold method; accordingly, all emissions from the NVS were determined to be negligible. This comparison to N-nitroso-N-methylurea represents an extremely conservative comparison and is included to illustrate the efficacy scale of the mitigation measures and the negligible scale of the process emissions.

Groundwater quality was described in Section 2.3.4.2, and surface water quality was described in Section 2.3.5.1. As the expected releases to water as a result of Site operations are expected to be negligible, no contaminants in water have been retained in the HHRA. Further discussion is provided in Section 3.1.3.

In summary, the only chemical contaminant retained in the HHRA for further screening assessment is NOx in air.

3.1.2.2 *Radiological Contaminants*

A full list of past, present and future Medical Isotope processes and associated radionuclides is provided in Table 7. From this list, contaminants which are no longer produced due to ceased processes, or exist in such low percentages of the total activity they pose a negligible risk to the environment, have been pre-screened out. It is noted that I-123 is still present in the NVS. These nuclides continue to be monitored as part of the Effluent Monitoring Program but releases have not been quantified as they have continued to decrease to undetectable levels over recent years and are considered to be negligible.

Table 7: Summary of past, present and future Medical Isotope processes and associated radionuclides

Radionuclide	Process	Type	Status
I-125	I-125	Main	Ceased in 2016
I-131	I-125	n/a	Ceased in 2016
In-111	Indium-111 Oxyquinoline	Main	Active
In-111 Impurities	Indium-111 Oxyquinoline	Impurity	Active
Mo-99/ Tc-99m	Tc-99m Generator	Main	Future process
Mo-99 Impurities	Tc-99m Generator	Impurity	Future process
Xe-133	Xe-133	Main	Ceased in 2016
Xe-135	Xe-133	Impurity	Ceased in 2016

Radionuclide	Process	Type	Status
Xe-135m	Xe-133	Impurity	Ceased in 2016
Y-90	Y-90 TheraSphere	Main	Active
Y-90 Impurities	Y-90 TheraSphere	Impurity	Active

The remaining radionuclides that may be released from BWXT operations are those associated with the Y-90 TheraSphere and Indium-111 Oxyquinoline processes, as well as the future Tc-99m Generator processes. Quantitative emissions data specific to each contaminant are not available. This is due to emissions being below detection limits (Y-90 and In-111) or because it is a future process (Mo-99/ Tc-99m). Potential emissions rates of radionuclides associated with the Y-90, In-111, and Mo-99/Tc-99m processes have been calculated. For established processes (Y-90 TheraSphere and Indium-111 Oxyquinoline), inputs were based on operational experience and commercial requirements. For the future production of Tc-99m generators, inputs were based on expected operational maximums and source term information [7].

The following conservative inputs and assumptions were applied when calculating the potential releases:

- For the production of Tc-99m generators, eight (8) targets per run at 21-day irradiation and 2 hours decay;
- The release is filtered by two (2) HEPA filters in series. This is conservative as at least two HEPA filters in series are expected for all processes, and roughing filters are also present but not credited;

The following standards were applied when calculating the potential releases, as per internal procedure CPM-6-20 *Safety Analysis Reports* [55]:

- Normal HEPA efficiency is taken as 0.9995;
- Non-volatile isotopes are assumed to have a volatility value of 0.002.

The airborne radiological contaminants and calculated maximum airborne releases per year are summarized in Table 8. Full details on the calculation of maximum airborne releases can be found in Annex A. The processes, source term, main impurities and calculated airborne release rates are discussed in detail below.

Y-90 TheraSphere

The manufacturing process of Y-90 TheraSphere consists of handling, dispensing, sterilizing and QC testing of medical isotopes in the form of microspheres. Y-90 is the main nuclide in this process; all other impurities are such a low percentage of total activity, they pose a negligible contribution to environmental risk and have not been included in emissions calculations. Historical airborne releases of Y-90 are consistently below detection limits. For this reason, an estimate of the maximum annual airborne release of Y-90 is provided based on operational experience, commercial requirements and conservative assumptions.

As shown in Table 8, the maximum airborne release for Y-90 is calculated to be 4.38E-04 GBq/year.

The 2019 Annual Compliance Report [23] shows the total activity in liquid releases of beta emitters (>1 MeV). If this is assumed to be entirely Y-90, the average Y-90 waterborne release is 0.05 GBq/year over the past five years. The corresponding DRL is 3.5E+04 GBq/year, and therefore releases are 1E-04% of the DRL, with a dose to public of 1 nSv/year. Since measurements during this period have consistently been below detection limits, the calculated release is based on multiplying the detection limit by the total volume of batch release. Therefore, the reported releases are considered significantly overestimated and the actual release of Y-90 in waterborne effluent is deemed negligible and not assessed further.

Indium-111 Oxyquinoline

The manufacturing process for Indium-111 Oxyquinoline consists of handling, dispensing, sterilizing and QC testing of medical isotopes in the form of a solution. In-111 is the main nuclide in this process. Predominant impurities (<0.25%) in the process are In-114m and In-114 with minor impurities (<0.02%) of Ag-110m and Zn-65. Since these impurities are a low percentage of total activity, they pose a negligible contribution to environmental risk and have not been included in emissions calculations. In-111 is monitored and captured collectively as particulate airborne emissions, and releases are consistently below detection limits. Therefore, quantitative emissions data specific to In-111 are not available. An estimate of the maximum annual release of In-111 is provided based on operational experience, commercial requirements, and conservative assumptions.

As shown in Table 8, the maximum airborne release of In-111 is calculated to be 1.06E-06 GBq/year.

The releases of In-111 in waterborne effluent are less than that of Y-90 (see above) due to lower production activity (lower by a factor of 100) and fewer production runs. Therefore, the actual release of In-111 in waterborne effluent is deemed negligible and not assessed further.

Tc-99m Generators

This future process involves capsule cutting, chemical processing of molybdenum metal, loading of the drug substance powder into columns, and assembly of the generators. The predominant radionuclides are Mo-99 and its decay product, Tc-99m, which account for 95% of the activity of the source term. The majority of the activity of impurities associated with the Tc-99m Generator Production Process come from W-187 and Tc-101 in the target material, and Zr-95, Zr-97, Nb-95, and Nb-97 activated in the zirconium cladding. Excluding Zr-95 and Nb-95, these radionuclides are very short-lived. For the purpose of the HHRA, all impurities are conservatively assumed to be Zr-95, since the DRL is bounding over Nb-95.

Since the Tc-99m generators process is an expected, future process, there is no historical effluent monitoring data. Maximum airborne releases have been calculated based on the source term [7] and conservative assumptions. As shown in Table 8, the maximum airborne release of Mo-99/ Tc-99m is calculated to be 1.56E-02 GBq/year and the maximum airborne release of impurities is calculated to be 2.16E-03 GBq/year.

Table 8: Airborne Radiological Contaminants and Release Rates

Radionuclide	Process	Type	Max. airborne release/year (GBq)
In-111	Indium-111 Oxyquinoline	Main	1.06E-06
Y-90	Y-90 TheraSphere	Main	4.38E-04
Mo-99/ Tc-99m	Tc-99m Generator	Main	1.56E-02
Mo-99 Impurities	Tc-99m Generator	Impurity	2.16E-03

All manufacturing wastewater will be collected, decayed and transported to a licensed waste management facility; it will not be released to the environment through the Low Level Liquid Waste (LLLW) system. Therefore, waterborne releases of radionuclides are screened out.

3.1.2.3 *Physical Stressors*

The CSA Standard N288.6-12 [1] indicates that physical stressors may be assessed if they may affect human or ecological receptors. As part of the 2013 ESDM report for the Site [13], a noise screening was completed which indicated that noise is not considered to be emitted from the facility at levels warranting further assessment. As such, noise as a physical stressor was not retained for consideration in the ERA. No other potential physical stressors for human health have been identified. Therefore, physical stressors were not considered further in the HHRA.

3.1.3 Exposure Pathways

Atmospheric pathways

For the radiological and non-radiological assessments, airborne releases are considered for the exposure assessment.

Exposure Pathways relevant for Radiological Contaminants

In the radiological HHRA, the screening is based on comparing emissions to DRLs. Therefore, the pathways considered in the assessment are those defined in the DRL model [6]. These include the following terrestrial exposure pathways are considered for farm and urban residents:

- Air inhalation/skin absorption;
- Air immersion (external exposure to radionuclides only);
- Soil external exposure (soil ground shine);
- Soil ingestion (incidental);
- Terrestrial plant ingestion (foodstuff); and
- Terrestrial animal ingestion (foodstuff).

For the industrial worker receptors, exposure to air (i.e., inhalation and external exposure to radionuclides) is the only pathway considered in this assessment.

Exposure Pathways relevant for Chemical Contaminants

For the evaluation of human health risks from chemical contaminants, the following exposure pathways were considered to be possible for farm residents and urban residents:

- Air inhalation; and
- Water ingestion/dermal contact;
- Soil ingestion/dermal contact/inhalation of dust;
- Terrestrial plant ingestion (foodstuff); and
- Terrestrial animal ingestion (foodstuff).

For workers, only exposure via inhalation of air was considered to be relevant.

Leaching to groundwater

Changes to soil quality as a result of aerial deposition may have the potential to affect groundwater quality through leaching of contaminants from soil. The MOE [21] provides soil quality guidelines that are protective of the groundwater leaching pathway; however, these guidelines are only available for organic contaminants. Given that leaching of inorganic parameters from soil is expected to be minimal when soil pH is within the ranges considered when setting soil quality standards (i.e., typically pH range of 5 to 9 for surface soils [21] [56], leaching of inorganic parameters from soil into groundwater is not expected to be a significant pathway. Furthermore, given that the only contaminant retained in the HHRA is NOx which is not expected to result in deposition and accumulation onto soils, and subsequently leach from soils into groundwater, this pathway was not considered further in the HHRA.

Deposition onto surface water

Deposition rates were calculated and used to estimate potential changes to surface water quality in the 2017 ERA [2]. These deposition rates were based upon the then-applicable emissions from the Site, which were greater than for the current 5-year period as previously discussed in Section 3.1.2.1. A summary of the approach is provided below.

Since Watts Creek and Kizell Drain is not a gauged watershed, the average annual flows for the average, dry and wet years were determined at March Road by prorating the flows observed at a neighbouring gauging station and comparing contributing catchment areas. The Environment Canada (EC) hydrometric station located at Graham Creek at Nepean (station ID 02KF015) was used to prorate the flow at the areas of interest. Daily flows were collected for the period of record ranging from 1987 to 1995 and from 2006 to 2014. Given the lack of flow data for the winter season for the first period of record and missing data during the first half of 2006, the analysis focused on the period ranging from 2007 to 2014.

The catchment area for the stream was estimated to be 2.76 km^2. The prorated average annual flows at March Road were estimated to range from 0.012 m^3/s (dry year) to 0.035 m^3/s (wet year), with an overall average of 0.023 m^3/s [2].

The effects of the atmospheric deposition to the water quality in the watershed were conservatively estimated by assuming that all the material deposited in the watershed directly affects the water quality. In reality, a portion of the particles would be captured by vegetation and the actual increases in water concentration would be less than the values estimated. The calculation was completed on an annual average basis to eliminate any seasonal effects (e.g., spring runoff). The results were also estimated for representative wet and dry years to provide an expected range of the effects. The results presented in Table 9 represent the increase in water quality parameters that would be above the existing background concentrations.

It is expected that the deposition rates and corresponding changes to water concentrations would be lower than those shown below for the current 5-year period, given that the predicted NOx concentrations in the updated ESDM are lower than those in the previous ESDM (i.e., 24-hour Maximum Point of Impingement (MPOI) concentration of 52.5 $\mu g/m^3$ in 2021 [3] versus 71.06 $\mu g/m^3$ in 2013 [13]).

Table 9: Estimated increases in concentrations of non-radiological COPCs due to wet and dry deposition [2]

Contaminant	Dry deposition rate		Concentration increase (mg/L)		
	$g/m^2/yr$	g/yr	Avg	Min	Max
NO_X	5.80E-01	1.60E+06	2.17E+00	1.44E+00	4.20E+00
Contaminant	**Wet deposition rate**		**Concentration increase (mg/L)**		
	$g/m^2/yr$	g/yr	Avg	Min	Max
NO_X	3.61E-02	9.98E+04	1.35E-01	8.97E-02	2.62E-01

The maximum increase in water concentration combining both wet and dry deposition were then compared to water quality criteria including the Canadian Drinking Water Quality Guidelines [57] as shown in Table 10.

Table 10: Comparison of maximum increase in surface water concentration due to wet and dry deposition to screening guidelines [2]

Contaminant	Maximum Concentration Increase (mg/L)	Screening Guideline	Source
NO_X	4.46E+00	4.50E+01	Health Canada [57]

As the maximum concentration increase was one order of magnitude less than its guideline, no significant changes to water quality are anticipated. As a result, no significant changes to water quality are expected as a result of deposition of airborne emissions.

Given that changes to water quality at Watts Creek resulting from deposition of airborne contaminants were within water quality guidelines, negligible changes to water quality (including radioactivity) at other locations within the Local Study Area are expected, particularly given the conservative approach taken in estimating potential changes to water quality.

Surface water pathways

The waterborne releases are held in delay and holding tanks prior to being released to the sanitary sewer. The radiological and chemical properties of the sample are analyzed before the delay or holding tank is emptied to ensure that release limits are not exceeded. Once released, the effluents travel over 30 km underground through the City of Ottawa sewer system to ROPEC. The effluents from BWXT are diluted as they travel to ROPEC due to other wastewater releases.

As described in Section 2.3.5.1, water releases from 2015 to 2019 into the sanitary sewer system were less than 10^6 L/year [23] with annual water volume from ROPEC being greater than 10^{11} L/year [30]; as the typical water demand from commercial facilities is on the order of approximately 2 L/m^2/day [31], substantial dilution is expected upon discharge (on the order of 10^3 to 10^4). In comparison to the 2017 ERA [2], there is potentially 10x less dilution given a water demand of 0.2 L/m^2/day was assumed at that time. The City of Ottawa has not expressed any concerns with the occasional exceedances observed as the sources of the exceedances were readily identified and remedied, if applicable.

Therefore, given this large amount of dilution and the filtration of contaminants at ROPEC, the resulting non-radiological contaminant concentration of waterborne releases into the Ottawa River is considered to be negligible.

As discussed in Section 3.1.2.2, waterborne releases of radionuclides are screened out. Pathways associated with waterborne releases of radionuclides are implicitly considered based on the DRL model [6]. The farm receptor using ROPEC waste as fertilizer has the most restrictive DRLs for each radionuclide. The following exposure pathways are considered:

- Soil external exposure (soil ground shine);

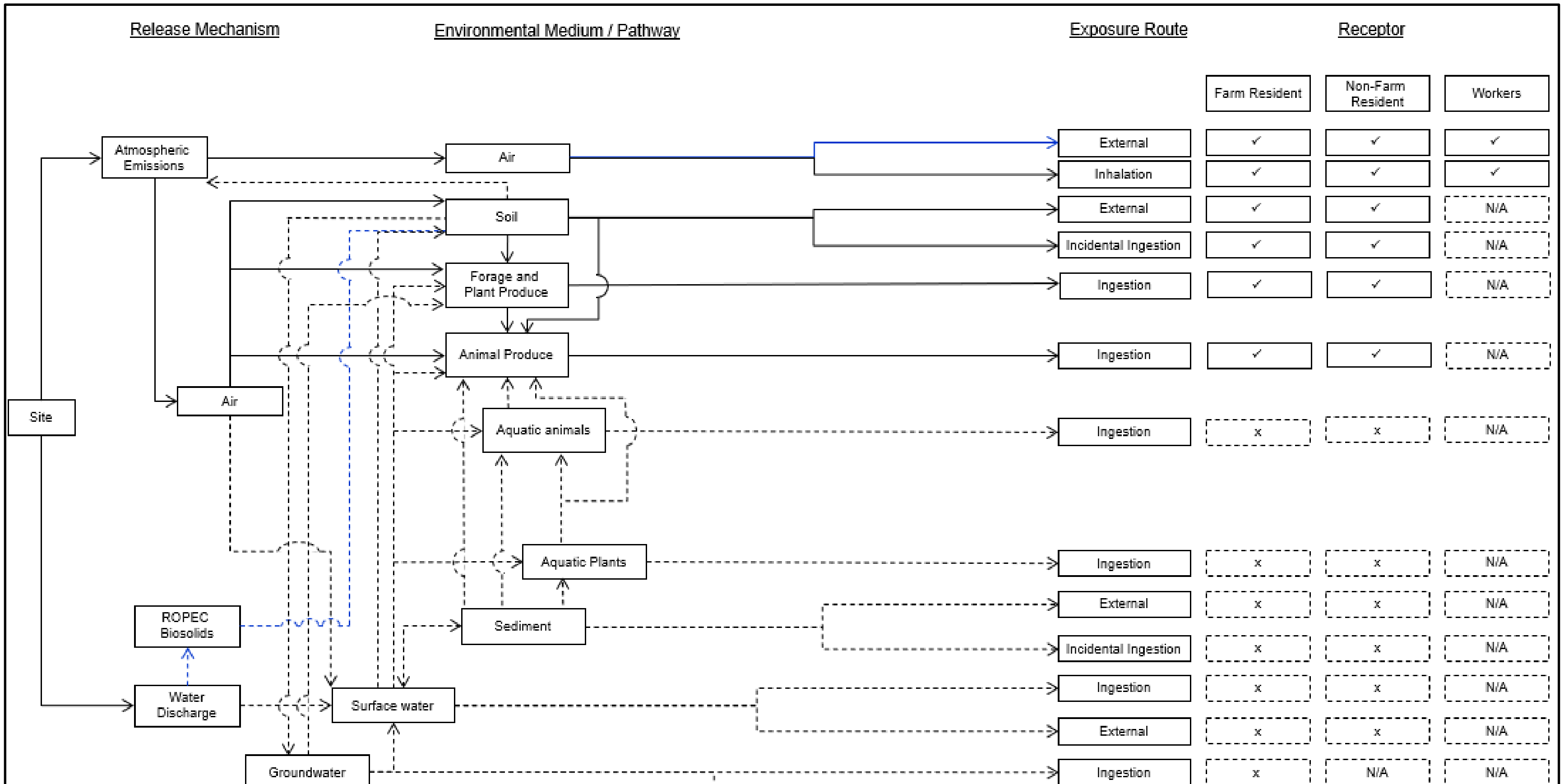
- Soil ingestion (incidental);
- Terrestrial plant ingestion (foodstuff); and
- Terrestrial animal ingestion (foodstuff).

3.2 Human Health Conceptual Model

Humans may be exposed to substances through direct and indirect pathways as described in Section 3.1.3 above. Direct pathways are those in which the receptor comes into direct contact with the source of the substances (e.g., inhalation of contaminated air). Indirect exposure pathways are those in which the exposure results from secondary residency media (e.g., ingestion of locally-grown foodstuffs that are raised in impacted soils).

As discussed in Section 3.1.3, pathways associated with airborne and waterborne releases of radionuclides are implicitly considered based on the DRL model [6]. Airborne releases of radionuclides are screened by comparison to DRLs. Waterborne releases of radionuclides are screened out (see Section 3.1.2.2).

The human health CSM is displayed in Figure 11. This graphically illustrates the source of the substances, the release mechanisms, environmental transport and residency media, and exposure routes for human receptors. Pathways relevant only for radiological contaminants are highlighted in blue, while pathways that are relevant for both radiological and non-radiological assessments are coloured black. Pathways that are considered incomplete are marked with dashed lines, and are not assessed.



LEGEND

NA Pathway is not applicable for that receptor or media type

x Pathway incomplete and/or not evaluated

✓ Pathway is complete and evaluated

Solid lines indicate source-pathway-receptor linkages that are complete; dashed lines indicate linkages that are incomplete.

Blue lines indicate pathways that only apply to the radiological assessment

Figure 13: Conceptual Site Model for human receptors

3.3 Screening Criteria

3.3.1 Chemical Screening Criteria

As discussed in Section 3.1.2.1, the only chemical contaminant retained for further consideration in the HHRA is NOx in air. The MPOI is the location along the Site's fence line that is associated with the highest predicted ambient air concentrations of the contaminant of interest. The MPOI therefore represents a bounding scenario for the individual receptor locations identified in Section 3.1.1.

The MPOI concentrations of NOx versus the MECP Air Contaminants Benchmarks (ACBs) for the 1-hour and 24-hour averaging periods are shown in the table below and are reproduced from the 2021 ESDM [3]:

Table 11: MPOI concentrations of NOx versus the MECP ACBs for the 1-hour and 24-hour averaging periods

Chemical Contaminant	MPOI (µg/m^3)	Averaging Period (hour)	MECP ACB (µg/m^3)	Percentage of Limit
Nitrogen oxides	52.5	24	200	26.2%
Nitrogen oxides	150.9	1	400	37.7%

Given that the 2021 ESDM [3] considered both BWXT and Nordion sources, the expected MPOI concentrations due to BWXT's emissions alone would be expected to be lower than those shown in the table above. However, given that the proximity of the two facilities does not allow for the emissions to be considered separately, the MPOI concentrations as presented in the table above were considered to be the exposure concentrations to which receptors may be exposed due to BWXT's operations.

While the MECP ACB is the applicable limit for the purposes of the ESDM (which is used to support permitting in the province of Ontario), in support of this ERA alternate health-based benchmarks available from a variety of jurisdictions were also considered. These benchmarks are protective of receptors of all ages, including sensitive receptors (e.g. with pre-existing health conditions such as asthma). The sources of air benchmarks are listed below:

- Ontario MOE/MECP [58] [59]
- Canadian Council of Ministers of the Environment [60]
- Agency for Toxic Substances and Disease Registry [61]
- California Office of Environmental Health Hazard Assessment [62]
- World Health Organization [63]
- Texas Commission on Environmental Quality [64]

The available benchmarks for 1-hour and 24-hour averaging periods are listed in the table below.

Table 12: Health-based Air Benchmarks for Nitrogen Oxides

Source	Averaging Period	Air Benchmark (µg/m^3)	Toxicological Endpoints and Derivations
Ontario MOE [58]	1-hour	400	Based on unspecified health effects for NO_2
	24-hour	200	Based on unspecified health effects for NO_2
Ontario MECP [59]	1-hour	400	Based on unspecified health effects for NO_2
	24-hour	200	Based on unspecified health effects for NO_2
Canadian Council of Ministers of the Environment (CCME) [60]	1-hour	400 (acceptable) 1000 (tolerable)	Based on unspecified health effects for NO_2
	24-hour	200 (acceptable) 300 (tolerable)	Based on unspecified health effects for NO_2
Agency for Toxic Substances and Disease Registry (ATSDR) [61]	--	No values	--
Office of Environmental Health Hazard Assessment (OEHHA) [62]	1-hour[a]	470	Based on a NOAEL of 0.25 ppm for increase in airway reactivity in asthmatic humans. Uncertainty factor of 1 was applied.
World Health Organization (WHO) [63]	1-hour[a]	200	Changes in lung function and airway responsiveness following acute exposure in asthmatics and patients with chronic obstructive pulmonary disease at nitrogen dioxide concentrations of 375-565 µg/m^3. A 50% margin of safety was used to set the air quality guideline of 200 µg/m^3.
Texas Commission on Environmental Quality (TCEQ) [64]	1-hour[a]	190	For nitrogen dioxide, must meet NAAQS. The NAAQS of 0.1 ppm (190 µg/m^3) is based on 98th percentile of 1 hour daily maximum concentrations, averaged over 3 years.

[a] 24-hour benchmarks are not available from OEHHA, WHO nor TCEQ.

Although the lowest of the available benchmarks was 190 µg/m^3 from TCEQ, it is ultimately based upon meeting a limit that is based upon monitoring data rather than modelled (predicted) concentrations. Therefore, it was not considered to be applicable for the purposes of the ERA. Excluding that value, the next lowest 1-hour benchmark is 200 µg/m^3 from WHO [63]. This value was selected for the 1-hour screening shown in Section 3.4.1.

3.3.2 Radiological Screening Criteria

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 health effects is acceptably low. These are specified in the *Radiation Protection Regulations* [65] and are as follows:

- Nuclear energy worker (NEW): 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.
- A person who is not a nuclear energy worker (members of the public and non-NEWs): 1 mSv for one calendar year.

The DRL is the release rate of a radionuclide which would cause the most exposed individual(s) to receive an annual radiation dose equal to the effective dose limit of 1 mSv to the public, as set out in the *Radiation Protection Regulations* [65]. DRLs have been calculated for the in the Nordion Class 1B Facility Derived Release Limits [6] report.

The DRLs for airborne releases of the radiological contaminants discussed in 3.1.2.2 are shown in Table 13. The receptor associated with each radionuclide is the critical receptor, i.e., the individual receiving the highest radiation dose as a result of the radionuclide being emitted from the BWXT Facility.

Table 13: Derived Release Limits for airborne releases [6]

Radionuclide	Receptor	Location	DRL (GBq•a^{-1})
In-111	I1 - Industrial worker	Esso	**8.38E+05**
Mo-99	F7 – Infant	Farm	**5.17E+05**
Y-90	I1 - Industrial worker	Esso	**7.31E+05**
Zr-95[a]	I1 - Industrial worker	Esso	**6.81E+03**

[a] All Mo-99 Impurities are assumed as Zr-95 since it is conservative among the nuclides present as impurities.

As discussed in Section 3.1.2.2, waterborne releases of radionuclides are screened out.

For the purpose of this ERA, estimated airborne releases of radionuclides will be compared to DRLs to confirm that the total potential dose to members of the public is negligible.

3.4 Screening

3.4.1 Chemical Screening Results

The MPOI concentrations for NOx for the 1-hour and 24-hour averaging periods were compared to their respective health-based benchmarks. If the MPOI is greater than its benchmark, there is the potential for a risk due to inhalation for receptors further afield and further quantitative assessment in a PQRA may be required. However, if the MPOI is less than its benchmark, then risks are expected to be negligible for receptors at the fence line and those further afield at the specific receptor locations described in Section 3.1.1.

Table 14 below shows the comparison of the MPOI concentrations to the health-based benchmarks.

Table 14: Chemical Screening Results

Chemical Contaminant	MPOI Concentration (µg/m^3)	Averaging Period (h)	Air Benchmark (µg/m^3)	% of Benchmark	Potential Risk?
NOx	52.5	24	200	26%	Negligible
NOx	150.9	1	200	75%	Negligible

Given that there were no exceedances of the screening benchmarks, risks are expected to be negligible for human health. Therefore, no further assessment is required.

3.4.2 Radiological Screening Results

The maximum airborne releases for each radiological contaminant have been calculated in Annex A. The releases have been compared to the associated DRL which corresponds to a dose to the most exposed member of the public (i.e., the Critical Receptor). The sum of emissions as a fraction of the DRL is calculated to confirm that the maximum dose to members of the public is a small fraction of the CNSC dose limit of 1 mSv for one calendar year [65].

As discussed in Section 3.1.2.2, two radiopharmaceutical products are currently produced as part of BWXT's operations, Y-90 TheraSphere and Indium-111 Oxyquinoline, and the production of Tc-99m generators is an expected, future process. The releases for the associated contaminants are screened against their respective DRLs and summed to estimate the maximum dose to members of the public (Table 15). Details on the calculation of maximum airborne releases are provided in Annex A.

Table 15: Airborne Contaminants Screening against DRLs

Radionuclide	Max. airborne release/year (GBq)	Airborne DRL/ year (GBq) [6]	Maximum % DRL	Maximum Dose (nSv/year)	Critical Receptor [6]
In-111	1.06E-06	8.38E+05	1.26E-10%	1.26E-06	I1 - Industrial worker
Mo-99/ Tc-99m	1.56E-02	5.17E+05	3.01E-06%	3.01E-02	F7 – Infant
Mo-99 Impurities[a]	2.16E-03	6.81E+03	3.17E-05%	3.17E-01	I1 - Industrial worker
Y-90	4.38E-04	7.31E+05	5.99E-08%	5.99E-04	I1 - Industrial worker
Total max. release/ year	**1.82E-02**		**Total Dose**	**3.48E-01**	

[a] All Mo-99 Impurities are assumed as Zr-95 since it is conservative among the nuclides present as impurities.

As shown in Table 15, based on the sum of % DRL values for all radionuclides, the total dose to critical receptors is 3.48E-01 nSv/year (or 3.48E-07 mSv/year), which is more than six orders of magnitude lower than the CNSC dose limit of 1 mSv/year for members of the public [65]. The main contributor to the total dose is the Mo-99 Impurities, which are assumed as Zr-95 since it is conservative among the predominant radionuclides present as impurities.

In summary, all airborne radiological contaminants produced as a result of BWXT operations pose a negligible risk to humans and are screened out. Therefore, a PQRA is not required.

3.4.3 Uncertainties in the Screening

Chemical Contaminant Assessment

The following elements of conservatism are incorporated into the chemical screening approach which each have a tendency to overestimate potential exposure and risk, as follows:

- The MPOI concentrations were modelled as described in the 2021 ESDM Report [4]. As described in Section 4.1 of that report, all operating equipment was assumed to be operating simultaneously at maximum thermal input for 24 hours per day. It is unlikely that this situation would occur, and as such the estimated MPOI concentrations are likely overestimated and result in a potential overestimate of potential exposure and risk.
- The MPOI concentrations were considered to be representative of the exposure point concentrations for all receptors described in Section 3.1.1 (i.e., urban residents, farm residents and industrial workers). This is likely to be conservative, given the relative differences in the MPOI concentrations and receptor location concentrations presented in the 2017 ERA [2]. The 24-hour MPOI concentration of NOx from the 2013 ESDM [13] was 71.06 µg/m^3, and the highest 24-hour predicted concentration of NOx at a nearby receptor location (I1) was 58.6 µg/m^3 (i.e., the nearest receptor ambient air concentration

was approximately 82% of the MPOI concentration). Therefore, the actual concentrations at the specific receptor locations are likely lower than those predicted for the MPOI and as such risks have been overestimated.

- The benchmarks used in the HHRA are generally based on the most sensitive endpoints, with the application of safety factors to protect sensitive subpopulations. The uncertainty associated with TRVs is highly dependent on the number of studies available, and whether the key study was based on humans (low uncertainty) or small mammals (high uncertainty). When few studies are available, and the studies available are conducted using animals as test organisms, several types of safety factors must be applied to account for this uncertainty (e.g., factors for inter- and intraspecies sensitivity). Uncertainty factors are also applied for human variability to account for increased sensitivities in certain subpopulations, such as children, the elderly, or those with pre-existing conditions (e.g. asthma). The selected benchmark for the 1-hour averaging period was sourced from the WHO [63] and is generally consistent with the air quality guidelines from other jurisdictions, except that it has incorporated an additional safety factor of 2 which the other jurisdictions have not done. Therefore, the WHO guideline may be overly conservative and may result in an overestimation of potential risks.

Radiological assessment

Since the radiological screening relies on calculated emissions and comparison of emissions to DRLs, the uncertainties lie in the calculations of the DRLs and emissions. Conservative methods have been used to manage these uncertainties.

The following are the predominant sources of uncertainty in the calculation of DRLs in [6] for radioactive emissions from the Site:

- The use of the Integrated Model for the Probabilistic Assessment of Contaminant Transport (IMPACT) model to evaluate environmental concentrations of radiological contaminants corresponding to facility emissions.
- The assumption that generic exposure factors apply to all receptors considered in this assessment.

The calculated DRLs used IMPACT to model the environmental transport of radionuclides from release points at the Site to each receptor location. Utilizing dispersion modelling rather than environmental measurements is a significant source of uncertainty. However, based on environmental measurements at other facilities, the modelling parameters in the IMPACT software result in an overestimation of the radiological impact.

Since there was no site-specific survey data available, conservative exposure factors are applied based on CSA Standard N288.1-14 [53]. The default local fraction values provided by the Standard were modified based on conservative assumptions of food usage within the Local Study Area. The use of these exposure factors introduces some uncertainty in the analysis, as the lifestyles and diets of individual receptors are not being modeled exactly as they are in reality. Therefore, the resultant exposure and radiation doses are considered to be overestimated.

Overall, the approach of comparing DRLs to emissions is more conservative than calculating doses using emissions and environmental monitoring data. In Table 15, the releases are screened against their DRLs and summed to estimate the total maximum dose to critical receptors. This total dose estimate is used for comparison against the screening criteria outlined in 3.3.2, but it is noted that this conservatively sums the dose of each critical group corresponding to each radionuclide release.

More detailed information on the conservative inputs and values applied in the calculation of DRLs can be found in [6].

Airborne release calculations for radiological contaminants are shown in Annex A. The assumptions used in the calculations are the predominant sources of uncertainty. These are:

- For the production of Tc-99m generators, eight (8) targets per run at 21-day irradiation and 2 hours decay;
- Two (2) HEPA filters in series for the year;
- All impurities associated with the Mo-99 process are conservatively assumed to be Zr-95;
- Normal HEPA efficiency is taken as 0.9995 as per CPM-6-20 *Safety Analysis Reports* [55];
- Non-volatile isotopes are assumed to have a volatility value of 0.002 as per CPM-6-20 *Safety Analysis Reports* [55].

For the production of Tc-99m generators, the activity of 8 targets per run is assumed, but this is the maximum expected. Some process runs may include fewer targets. Additionally, the activity at 2 hours of decay after irradiation is used which is very conservative as it ignores decay during transportation to the Site, and during the production process.

For ventilation, the isotope production processes include multiple stages of filtration, including local filtration, primary (trench) filtration, and secondary filtration in the NVS. All releases will be filtered through at least two stages of HEPA filters, therefore these are credited in the release calculation. Any additional roughing or HEPA filters that may be present are conservatively excluded.

All impurities in the Tc-99m Generator process are assumed to be Zr-95 since it is conservative among the nuclides present as impurities. Due to its longer half-life, the DRL for Zr-95 is the most restrictive of all the predominant impurities, many of which have very short half-lives. The application of the Zr-95 DRL for all Mo-99/Tc-99m Generator process impurities results in airborne emissions being a higher % of the airborne DRL than is actually expected.

The standards assumptions applied as per internal procedure CPM-6-20 *Safety Analysis Reports* [55] (i.e. normal HEPA efficiency 0.9995 efficiency and a isotope volatility value of 0.002) are both conservative estimates consistent with safety analysis procedures and requirements.

In conclusion, the most conservative parameters were selected as inputs to calculate DRLs and airborne emissions which has likely led to an overestimation of potential doses and emissions. Even so, the corresponding total dose to critical receptors is 3.48E-01 nSv/year (or 3.48E-07 mSv/year), which is more than six orders of magnitude lower than the lowest CNSC dose limit of 1 mSv/year [65].

4. ECOLOGICAL RISK ASSESSMENT

4.1 Problem Formulation

4.1.1 Receptor Valued Ecosystem Component (VEC) Selection and Characterization

4.1.1.1 *Receptor (VEC) Characterization*

A functioning ecosystem involves interaction of multiple species and each species responds differently to chemical, radiological and/or physical stressors. Because it is not possible to directly assess the risk for each individual species, the ecosystem was divided into components (e.g., plants, invertebrates, birds, mammals and fish). For birds, mammals and fish, a limited number of species were selected from each of the components to be representative of the entire component. For plants and invertebrates, individual species were not selected but rather these receptors were defined at the component level (e.g., terrestrial plants, soil invertebrates, aquatic plants, phytoplankton, zooplankton and benthic invertebrates). Ecological receptors were selected for the Ecological Risk Assessment (EcoRA) in consideration of the following criteria:

- Species and habitats observed on the Site as documented in previous environmental studies;
- Representation of all major plant and animal groups present on the Site (e.g., bird species with terrestrial and aquatic habitat, soil and benthic invertebrates, etc.);
- Receptors that reflect the interests of the facility, regulatory agencies, local Indigenous groups and community stakeholders;
- Potential for exposure (i.e., diet, habitat preferences and behaviours that make the species likely to contact the substances);
- Receptors that play important roles in community structure and function (e.g., top predators and major herbivores);
- Inclusion of the various trophic levels (e.g., primary producer, herbivore, carnivore) for species that could potentially use the Site;
- Receptors that have cultural or socio-economic significance;
- The availability of information on the receptor, including exposure-related and ecotoxicological data; and
- Species with conservation status (e.g., vulnerable, threatened or endangered species).

Valued ecosystem components (VECs) or receptors were identified in support of an Environmental Impact Study (EIS) completed for the adjacent BTL facility [35]. Given the proximity of the BTL facility to the Site, the VECs identified for the EIS were considered to be relevant for this EcoRA. The identified VECs were selected by technical specialists with input from regulatory agencies, local Indigenous groups and community stakeholders. The identified VECs were considered in the selection of receptors for the current EcoRA. In some cases, the identified VECs would be difficult to assess or were not reflective of receptors associated with the highest exposures (and thus potential risks) reported on the Site. In these cases, the identified VECs were represented by ecologically similar species with better known exposure factors and higher exposures in the EcoRA.

Special consideration was given to SAR in order to protect and conserve rare flora and fauna. In Ontario, two different legislations apply to SAR, the federal SARA [45] and provincial ESA [46].

4.1.1.2 *Receptor (VEC) Selection*

The terrestrial and aquatic species considered for the EcoRA are listed below. Although no detailed surveys have been completed, these species were considered to be potentially present within the Local Study Area based upon the urban nature of the area.

Terrestrial Species:

- North American beaver (*Castor canadensis*);
- Big brown bat (*Eptesicus fuscus*);
- Eastern cottontail (*Sylvilagus floridanus*);
- Coyote (*Canis latrans*);
- Grey squirrel (*Sciurus carolinensis*);
- Porcupine (*Erethizon dorsatum*);
- Raccoon (*Procyon lotor*);
- Red fox (*Vulpes vulpes*);
- Striped skunk (*Mephitis mephitis*);
- White-tailed deer (*Odocoileus virginianus*); and
- Woodchuck (*Marmot monax*).

In addition to the terrestrial species listed above, terrestrial plants and soil invertebrates will be considered as VECs for the EcoRA.

Aquatic Species:

- Creek chub;
- Brook stickleback;
- Central mudminnow;
- Fantail darter; and
- Common shiner.

The fish species listed above were captured within Watt’s Creek and Kizell Drain as described in the BTL EIS [35]. In addition to the aquatic species listed above, aquatic plants, algae and aquatic invertebrates will be considered as VECs for the EcoRA.

In addition to the species listed above identified as relevant for the Site, the following additional terrestrial species were identified within the Kanata Beaver Pond Park located to the east of the Site:

- North American beaver (*Castor canadensis*);
- Pileated woodpecker (*Dryocopus pileatus*);
- Kingfisher (*Megaceryle alcyon*);
- Red-winged blackbird (*Agelaius phoeniceus*);
- Chipmunk (*Tamias striatus*);
- Red squirrel (*Sciurus vulgaris*);
- Mallard (*Anas platyrhynchos*); and
- Red-breasted merganser (*Mergus serrator*).

The South March Highlands candidate Life Science ANSI is located several hundred metres east of the Site and includes the following federally and/or provincially listed species:

- Blanding's turtle (*Emys blandingii* or *Emydoidea blandingii*);
- Butternut tree (*Juglans cinerea*);
- Golden-winged warbler (*Vermivora chrysoptera*);
- Milksnake (*Lampropeltis triangulum triangulum*); and
- Chorus frog (*Pseudacris triseriata*).

As discussed in Section 2.3.6.3, species at risk with a moderate to high potential of being present within the Local Study Area are the little brown myotis (*Myotis lucifugus*), the northern myotis (*Myotis septentrionalis*), the tri-colored bat (*Perimyotis subflavus*), and the butternut (*Juglans cinerea*). The three species of bats are consumers of aerial insects; since aerial insects have a low potential of accumulating soil contaminants given their limited contact with soil, there was not considered to be a complete exposure pathway by which bats could come into contact with impacted soil within the Local Study Area. The butternut, a species of tree, has been identified in the South March Highlands and has been considered when assessing risks to terrestrial plants.

As described in Section 4.1.1.1 above, surrogate species representing each receptor type (e.g., bird, mammal, fish, reptile, amphibian) and feeding guild (e.g., herbivore, carnivore) that have been identified on the Site or within the Local Study Area will be selected. These representative receptors will be selected largely based upon protective ingestion rate to body weight ratios and the availability of receptor characteristics with which a quantitative assessment could be carried out.

Table 16 and Table 17 below list the selected terrestrial and aquatic receptors that were selected for assessment and provide justification for their selection.

Table 16: Terrestrial receptors and justification for their selection

Terrestrial receptor	Justification for selection
Terrestrial plants	• High potential for exposure to chemicals because of root contact with soils • Primary producers so play a critical role in the terrestrial environment • Food source for wildlife • Representative of species at risk such as butternut
Soil invertebrates	• Closely associated with soil as they both live and feed within soil • Play a vital role in soil fertility • Food source for wildlife
Mammals	
Meadow vole *(Microtus pennsylvanicus)*	• Herbivorous small mammal • Inhabits grassy fields, marshes and bogs, which are available habitats within the Site and Local Study Area • High potential for exposure to chemicals due to feeding habits (consumes plants in large amounts relative to body weight) • Plays a key role in the food web (component of the diet of larger mammals and birds of prey) • Life history information is readily available • Representative of other herbivorous mammals documented on the Site, including the eastern cottontail and white-tailed deer (larger herbivores such as deer would have lower exposure doses than the vole because of a lower food ingestion rate relative to a higher body weight and larger home range)
Northern short-tailed shrew (*Blarina brevicauda*)	• Small insectivorous or vermivorous mammal • Inhabits forest, wetlands and grasslands • High rate of food consumption relative to body weight which increases potential exposure to chemicals • Plays a key role in the food web (component of the diet of larger mammals and birds of prey) • Life history information is readily available
Muskrat (*Ondatra ziebethicus*)	• Eats aquatic plants with cattails being one of the most important plant foods • Inhabit freshwater creeks, streams, lakes, marshes and ponds • Use ditches and wetland features on the Site that support dense stands of cattail species • Consumes about 1/3 of its weight every day which increases potential exposure to chemicals • Life history information is readily available
Birds	
Mourning dove (*Zenaida macroura*)	• Herbivorous bird that consumes 99% seeds in its diet • Most common in open woodlands and forest edges near grasslands and fields • Documented on the Site • Life history information readily available

Terrestrial receptor	Justification for selection
	• Representative of other herbivorous birds documented on the Site, including the wild turkey
American woodcock (*Scolopax minor*)	• Vermivorous bird • 50 to 90% of diet is earthworms so potential for high exposure to soil contaminants • Lives in moist early successional woodlots near open fields or forest clearings, abandoned fields, edges of streams and ponds • Representative of other vermivores/insectivores documented on the Site such as the pileated woodpecker
Mallard (*Anas platyrhynchos*)	• Small duck that feeds mainly on aquatic plants in adulthood • Early life stages consume a higher proportion of aquatic insects • Documented on the Site • Life history information readily available
Semipalmated sandpiper (*Calidris pusilla*)	• Feeds mainly on benthic invertebrates so potential for high exposure to chemicals in sediment
Belted kingfisher (*Megaceryle alcyon*)	• Piscivorous bird • Documented at the Kanata Beaver Pond Park within the Local Study Area • Life history information readily available
Reptiles and Amphibians	
Spotted turtle (*Clemmys guttata*)	• Reptile that consumes aquatic insects • Prefer shallow waters with a soft bottom substrate and some submergent and emergent vegetation • Documented on and/or around the Site • Considered representative of other insectivorous reptiles documented in the Local Study Area including the Blanding's turtle, which is a species at risk
Eastern fox snake (*Elaphe gloydi*)	• Carnivorous reptile that consumes mostly small mammals, birds eggs or small birds • Found in flat, marshy or partially drained areas • Considered representative of other carnivorous reptiles documented in the Local Study Area including the milk snake, which is a species at risk
Western chorus frog (*Pseudacris triseriata*)	• Amphibian that consumes terrestrial insects • Found in a variety of habitats, including marshes, meadows, swales and other open areas • Documented at the South March Highlands within the Local Study Area • Species at risk

Table 17: Aquatic receptors and justification for their selection

Aquatic receptor	Justification for selection
Aquatic plants	• Provide habitat (i.e., food, shelter and spawning areas) to many animals, both aquatic and terrestrial • Important food source for other aquatic life, including fish • Expected to be present along watercourses such as Watts Creek and Kizell Drain on-Site
Zooplankton	• Important food source for other aquatic life, including fish • *Ceriodaphnia dubia* and *Daphnia magna* are common test organisms in laboratory toxicity testing for a number of reasons, including their broad distribution in freshwater systems, their importance in the aquatic food chain, their sensitivity to a wide range of chemicals and their relatively short life cycles that allows for chronic toxicity testing • Large toxicological database for species such as *C. dubia* and *D. magna*
Benthic invertebrates	• Play a vital role in nutrient cycling and breakdown of detritus in the aquatic environment • Important food source for fish, birds and amphibians • Live and feed in sediments so potential for exposure is maximized • Sessile animals so potential for exposure is maximized • Can be sensitive to contamination
Creek chub	• Small freshwater fish species • Opportunistic consumers, which may include fish, amphipods, insects, and aquatic plants • Important prey species for other fish, also piscivorous birds and mammals
Common shiner (*Luxilus cornutus*)	• Represents small minnow species observed in Watts Creek and Kizell Drain • Important prey species for other fish, also piscivorous birds and mammals

4.1.2 Selection of Stressors

4.1.2.1 *Chemical Contaminants*

For the non-radiological assessment, air quality guidelines generally do not consider potential exposure by terrestrial wildlife; air quality guidelines from some jurisdictions like Ontario consider effects to terrestrial plants (such as sulphur dioxide). As described in Section 3.1.2.1, the only chemical contaminant retained for consideration is NOx. As this parameter was less than its selected air quality guidelines as demonstrated in Section 3.4.1, no further assessment of airborne contaminants was completed in the non-radiological assessment of the EcoRA.

Groundwater quality has been measured in four on-site shallow groundwater monitoring wells. These wells were installed as part of WESA's 2005 Phase I and Phase II Environmental Site Assessment [66]. Groundwater quality has been measured from 2005 to 2013 and includes water quality parameters, select metals, and PHCs. All chemicals met their respective *Full-depth Background Site Condition Standards* ("Table 1 SCS" under Ontario Regulation 153/04) and their respective 97.5th percentile background groundwater concentrations collected under the Provincial Groundwater Monitoring Information System (PGMIS) from 2002 to 2007 [21]. Therefore, no substances in groundwater were retained for further assessment in the EcoRA.

It is considered unlikely that surface water or sediment quality within the Local Study Area would be affected by operations on the Site. As described in Section 2.3.5.1, no direct disposal of contaminated liquid from facility operations is discharged into the environment; it is either disposed at a licensed facility or sampled and analyzed for radioactivity and pH prior to discharge to the municipal sewer system. Deposition of the airborne particulate onto the Ottawa River is also plausible. As discussed in Section 3.1.3, the relative contribution of subsequent exposure to the total exposure is considered to be insignificant, and therefore these pathways are excluded from the ecological exposure assessment.

4.1.2.2 *Radiological Contaminants*

For the radiological assessment, all the radionuclides retained for the HHRA are retained for the EcoRA. Radiological contaminants and their calculated releases are shown in 3.1.2.2.

4.1.2.3 *Physical Stressors*

The CSA Standard N288.6-12 [1] indicates that physical stressors may be assessed if they may affect human or ecological receptors. As part of the 2013 ESDM report for the Site [13], a noise screening was completed which indicated that noise is not considered to be emitted from the facility at levels warranting further assessment. As such, noise as a physical stressor was not retained for consideration in the ERA. No other potential physical stressors for ecological health have been identified. Therefore, physical stressors were not considered further in the EcoRA.

4.1.3 Exposure Pathways

For the radiological EcoRA, all exposure pathways are categorized into external exposure and internal consumption of contaminated foods. Only airborne releases were considered to contribute to non-human biota exposure, and only terrestrial biota were considered as receptors.

As discussed in Section 3.1.2.2, waterborne releases are screened out. Additionally, this is consistent with the 2017 ERA [2] in which pathways associated with waterborne releases of radionuclides are considered negligible in the ecological risk assessment due to dilution in the municipal sewer system and Ottawa River, removal of contaminants during treatment, and the assumption that farm animals do not reside on land that may be fertilized with ROPEC biosolids.

The external exposure pathways for terrestrial biota include:

- Air immersion (exposure from gaseous radionuclides in the air, primarily noble gases); and
- Ground shine (exposure from radioactive particulate on the ground).

All internal exposure pathways are examined inherently with the use of concentration ratios (CRs), which correlate the radionuclide concentrations in environmental media (e.g., soil) to the concentrations in the tissue. The predominant internal exposure pathway for terrestrial biota is the terrestrial food chain.

Non-radiological exposure pathways relevant for ecological receptors are listed below.

Terrestrial mammals and birds:

- Incidental ingestion of soil while foraging, preening and grooming;
- Ingestion of terrestrial plants; and
- Ingestion of soil invertebrates.

Terrestrial plants and soil invertebrates:

- Direct contact with soil.

4.2 Ecological Conceptual Model

The results of the receptor (VEC) identification, contaminant screening and exposure pathway screening are summarized in a CSM, which graphically illustrates the source of the contaminants, the release mechanisms, environmental transport and residency media, and exposure route for each ecological receptor.

Ecological receptors may be exposed to substances through direct and indirect pathways as described in Section 4.1.3 above. Direct pathways are those in which the receptor comes into direct contact with the source of the contaminant (e.g., soil). Indirect exposure pathways are those in which the exposure results from secondary residency media (e.g., ingestion of vegetation and/or prey, which is represented by invertebrates and small mammals).

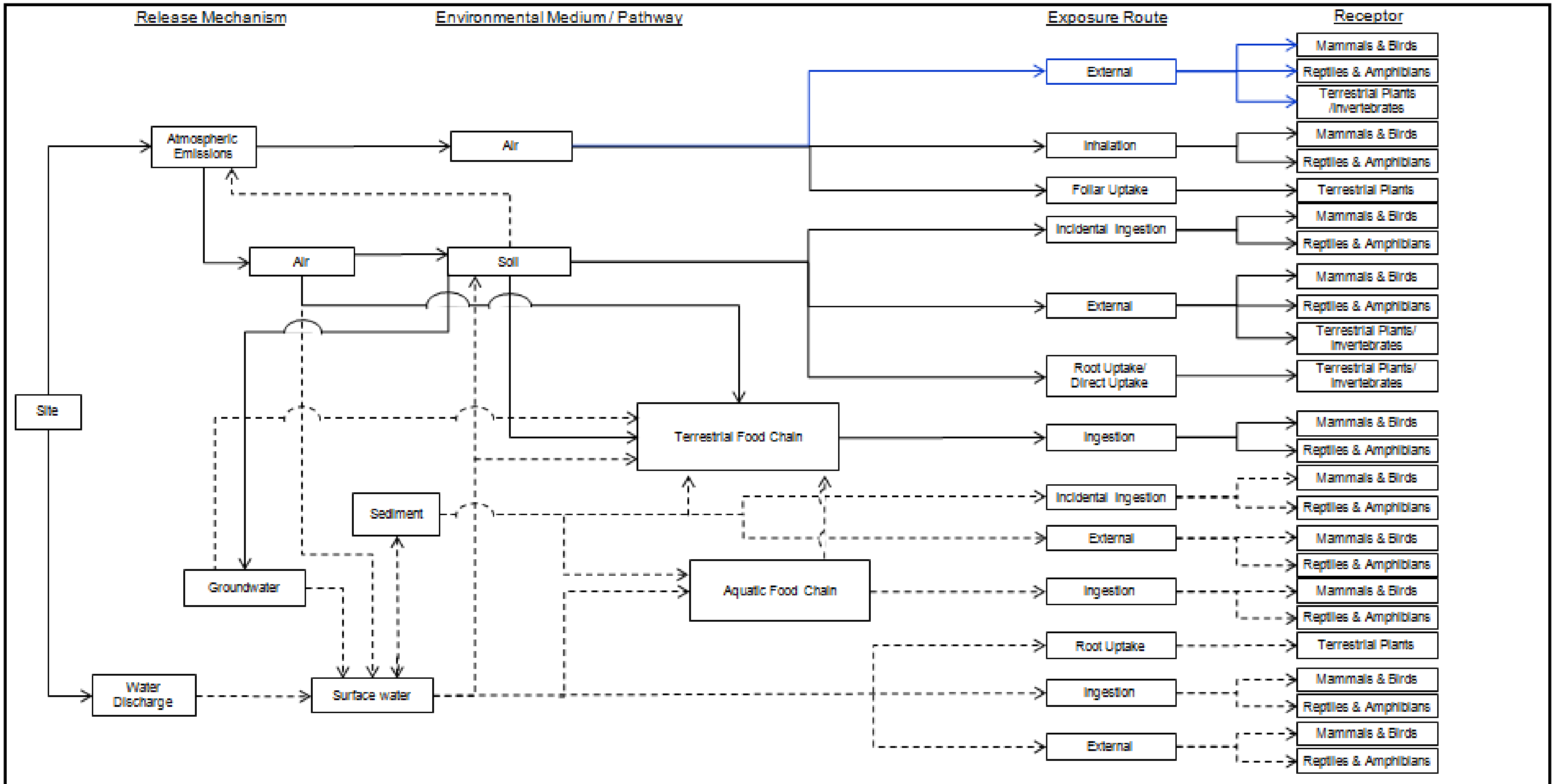
A consolidated CSM for radiological and non-radiological exposure to terrestrial receptors is presented in Figure 14. Pathways that are only relevant for radiological contaminants (e.g., the air immersion external exposure route) are displayed in blue. In summary, a quantitative assessment was only performed for terrestrial biota. For aquatic biota, no contaminant-pathway-receptor linkages were complete and as such, a quantitative assessment was not required.

Because surface water pathways are not complete, the muskrat, mallard, semipalmated sandpiper, and belted kingfisher and aquatic reptiles and amphibians were not assessed. The terrestrial reptile, Eastern fox snake, was not assessed as it is a carnivore. The non-radiological COPCs considered in the EcoRA do not bioaccumulate in animal tissue, therefore exposure through ingestion of prey by the Eastern fox snake is considered to be negligible. In addition to terrestrial plants and soil invertebrates, the non-radiological EcoRA will consider the following mammal and bird receptors:

- Short-tailed shrew;
- Meadow vole;
- Mourning dove; and
- American woodcock.

Given the limited availability and accuracy of environmental transfer parameters for radionuclides, the following broad categories of ecological receptors were considered in the radiological EcoRA:

- Tree;
- Annelid;
- Mammal – small-burrowing;
- Mammal – large;
- Bird;
- Amphibian; and
- Grasses & herbs.



LEGEND

NA Pathway is not applicable for that receptor or media type

x Pathway incomplete and/or not evaluated

✓ Pathway is complete and evaluated

Solid lines indicate source-pathway-receptor linkages that are complete; dashed lines indicate linkages that are incomplete.

Blue lines indicate pathways that only apply to the radiological assessment

Figure 14: Conceptual Site Model for terrestrial ecological receptors

4.3 Screening Criteria

4.3.1 Chemical Screening Criteria

Given that no chemical contaminants were retained for further consideration in the EcoRA (see Section 4.1.2.1), no chemical screening criteria are required.

4.3.2 Radiological Screening Criteria

The reference benchmarks for the radiological effects assessment are based on United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) guidance [67]:

*Chronic dose rates of less than **100 µGy/h** to the most highly exposed individuals would be unlikely to have significant effects on most terrestrial communities*.

A chronic dose rate of 100 µGy/h corresponds to 2.4 mGy/day for terrestrial biota.

For the EcoRA, radiological contaminants identified in Section 3.1.2.2 will be screened by comparing the current airborne releases (Table 8) to airborne releases used for the 2017 ERA [2], which concluded no risk to non-human biota as a result of radiological emissions from the facility. Airborne releases used for the 2017 ERA consisted of upper range emissions over a five-year period (2010-2014) and are displayed in Table 18.

Table 18: Airborne releases used for the 2017 ERA [2]

Isotope	2010-2014 five-year release maximum (GBq/year)
C-14	6.79E+01
Co-60	6.00E-03
I-125	4.60E-01
I-131	9.90E-01
Xe-133	3.62E+04
Xe-135	2.82E+04
Xe-135m	4.34E+04
Total maximum release/ year	**1.08E+05**

4.4 Screening

4.4.1 Chemical Screening Results

Given that no chemical contaminants were retained for further consideration in the EcoRA (see Section 4.1.2.1), no chemical screening is required.

4.4.2 Radiological Screening Results

As discussed in Section 4.3.2, radiological contaminants identified in Section 3.1.2.2 will be screened by comparing current emissions (Table 8) to emissions calculated in the 2017 ERA [2], which concluded no risk to non-human biota as a result of radiological emissions from the facility.

In 2017, maximum dose rate to ecological receptors was 1.75E-04 (mGy/d), which is more than four orders of magnitude lower than the reference benchmark of 2.4 mGy/d for terrestrial biota [67]. The 2017 ERA [2] states that the doses to the ecological receptors are dominated by external exposures (in air) to Xe-135m and Xe-135, which together contributed to 98% of the total dose. Tertiary contributions of less than 2% of the total dose for all receptors are from external exposure to Xe-133 and contributions from all other radionuclides were negligible. In particular, the airborne release from Co-60 used in the 2017 ERA [2] (6.00E-03 GBq/year) contributed less than 0.2% to the maximum dose rate to ecological receptors, and the maximum dose rate to ecological receptors from Co-60 was 3.00E-07 mGy/d.

The radionuclides Xe-135, Xe-135m and Xe-133 are no longer produced or released from the facility. Additionally, radioiodines considered in the 2017 EcoRA are no longer released. The radiological emissions associated with BWXT operations are all particulate beta/gamma emitters (Y-90; In-111; Mo-99/Tc-99m and associated impurities), and the estimated annual release of these particulate emissions from BWXT is 1.82E-02 GBq/y (Table 8). These are compared to the Co-60 emissions from the 2017 ERA in order to estimate dose to biota. This is conservative, given that Co-60 has a much longer half life than the radionuclides that may be released from BWXT operations, and is expected to be bounding in terms of dose consequences to biota.

Assuming all current radiological contaminants are Co-60, the total emission rate is 1.82E-02 GBq/y which is approximately 3x higher than the Co-60 emissions in 2017. Based on scaling the Co-60 results from 2017 ERA modeling, the dose to biota is estimated to be 9.09E-07 mGy/d. This is far below the reference benchmark of 2.4 mGy/d for terrestrial biota [67], and the maximum dose to biota calculated in the 2017 ERA.

In summary, with total emissions decreased since 2017 and the main contributors to dose to biota in 2017 no longer present, it is concluded that there continues to be no risk to non-human biota as a result of radiological emissions from the NMPF. The dose to biota from BWXT operations is estimated to be far below that calculated in the 2017 ERA.

4.4.3 Uncertainties in Screening

Section 3.4.3 describes the uncertainties associated with the source term and emissions estimates for the HHRA. These uncertainties in screening for the EcoRA are the same as those for the HHRA.

The dose to biota from BWXT operations is estimated based on comparing emissions to those considered in the 2017 ERA, and scaling the dose to biota based on the ratio of current versus previous emissions.

The total maximum airborne release for all radiological contaminants (1.82E-02 GBq/year) is seven orders of magnitude less than the total annual maximum release of 1.08E+05 GBq/year used in the 2017 ERA, which concluded that there was no risk to non-human biota as a result of the radiological emissions. Furthermore, over 98% of the dose in 2017 is attributed to the radionuclides Xe-135, Xe-135m and Xe-133 which are no longer part of the current contaminants.

The total BWXT emissions of Y-90, In-111, Mo-99 and associated impurities are compared to the Co-60 emission rate from the 2017 ERA in order to estimate the dose to biota based on the results of the 2017 ERA model. There is significant conservatism in this approach, given that radionuclides associated with BWXT operations have much shorter half lives than Co-60, and are expected to have lesser contributions to dose to biota. The resulting bounding estimate of dose to biota is orders of magnitude lower than the doses calculated in the 2017 ERA, and applicable benchmark values.

For chemical contaminants, air quality guidelines are generally not derived for wildlife (some air quality guidelines consider effects to plants). However, as there are no methods by which to assess inhalation risk to wildlife, the guidelines that are based on human health are considered to be sufficiently protective.

Water quality guidelines for chemical contaminants generally consider pathways such as effects to aquatic life, and can consider effects to semi-aquatic wildlife where applicable (for example, in terms of food-chain effects or effects to egg quality for selenium, which was not a contaminant of concern for this Site). Water quality guidelines are generally conservative as they often include safety factors that bias the guidelines lower and as such are more protective. Therefore, the use of water quality guidelines in the chemical screening is considered to be conservative and tend to overestimate risks to ecological species.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The ERA was carried out as per CSA Standard N288.6-12 [1] requirements and involved comparison of predicted environmental concentrations to risk-based benchmarks to determine whether further quantitative evaluation is required. The screening for chemical contaminants and radiological contaminants both concluded that predicted concentrations and doses are less than their respective benchmarks, and as such risks are expected to be negligible for both human and ecological health at all receptor locations. As such, no further assessment is required.

Details on the results of each assessment are summarized below.

Chemical Contaminants

The human health risk assessment for chemical contaminants evaluated the potential for adverse effects on human health for members of the public residing in the area surrounding the Site including farm residents and urban residents, industrial workers, and children at a daycare within the Local Study Area. The potential for health risks due to chemical contaminants were negligible (i.e., concentrations were less than screening criteria) considering typical operations at the Site.

The ecological risk assessment for chemical contaminants evaluated the potential for adverse effects to wildlife (i.e., mammals, birds, terrestrial plants and invertebrates, including species at risk) at Watts Creek adjacent to the Site. No chemical contaminants were retained for screening, indicating that risks to receptors at Watts Creek are negligible, and risks at locations in the Local Study Area that may represent ecological habitat (i.e., The Kanata Beaver Pond Park and the South March Highlands) are also expected to be negligible.

Radiological Contaminants

The human health risk assessment for radiological contaminants evaluated the potential maximum dose to the most exposed member of the public. The sum of emissions as a fraction of the DRL was calculated to confirm that the maximum dose to members of the public is a small fraction of the CNSC dose limit of 1 mSv for one calendar year [65]. Waterborne releases of radionuclides have shown to be undetectable and are screened out. Therefore, the health risks due to radiological contaminants were negligible (i.e., concentrations were less than screening criteria) considering typical operations at the Site.

The ecological risk assessment for radiological contaminants evaluated current airborne releases against airborne releases used for the 2017 ERA [2], which concluded no risk to non-human biota as a result of radiological emissions. With total emissions decreased since 2017 and the main contributors to dose to biota in 2017 no longer present, it is concluded that there continues to be no risk to non-human biota as a result of radiological emissions from the NMPF.

5.2 Recommendations for Monitoring and Risk Management

Potential risks to human and non-human biota have been assessed as negligible in the ERA; as such, there are no specific requirements for monitoring or risk management. It is noted that BWXT will monitor and measure radioactive releases in accordance with its CNSC licence requirements. Additionally, it is recommended that BWXT continue to operate in a manner that would minimize natural gas combustion releases at the Site, such as testing emergency generators one at a time rather than all at once, per the 2021 ESDM [3].

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ANNEX A. CALCULATION OF RADIOLOGICAL RELEASES

Airborne release calculations are shown in Table 19.

For established processes (Y-90 TheraSphere and Indium-111 Oxyquinoline), inputs were based on operational experience and commercial requirements. For the future production of Tc-99m generators, inputs were based on expected operational maximums and source term information [7].

The following conservative inputs and assumptions were applied when calculating potential releases:

- For the production of Tc-99m generators, eight (8) targets per run at 21-day irradiation and 2 hours decay;
- Two (2) HEPA filters in series for the year. This is conservative as at least two HEPA filters in series are expected for all processes, and roughing filters are also present but not credited;
- All impurities associated with the Tc-99m Generator process are assumed as Zr-95 since it is conservative among the nuclides present as predominant impurities with respect to DRLs.

The following standards were applied when calculating the potential releases, as per internal procedure CPM-6-20 *Safety Analysis Reports* [55]:

- Normal HEPA efficiency is taken as 0.9995;
- Non-volatile isotopes are assumed to have a volatility value of 0.002.

Table 19: Calculation of Airborne Radiological Releases

Radionuclide	In-111	Mo-99/ Tc-99m	Mo-99 Impurities	Y-90
Process	In-111	Future Tc-99m generators	Future Tc-99m generators	Y-90
Type	Main	Main	Impurity	Main
Incoming irradiated materials[a]	Vial	Molybdenum metal target	Molybdenum metal target and Zircaloy capsule	Ampoule
Number of incoming irradiated materials/ run[a]	1	8	8	1
Maximum activity/ incoming irradiated material (GBq)	4.07E+01 [a]	1.87E+04 [b]	2.60E+03 [b]	4.21E+03 [a]
Total activity/run (GBq)	4.07E+01	1.50E+05	2.08E+04	4.21E+03
Runs/week	1	4	4	4
Weeks/year	52	52	52	52
Activity/year (GBq)	2.12E+03	3.11E+07	4.32E+06	8.76E+05
Volatility [c]	0.20%	0.20%	0.20%	0.20%
Max. HEPA transmission [d]	2.50E-07	2.50E-07	2.50E-07	2.50E-07
Max. airborne release/year (GBq)	1.06E-06	1.56E-02	2.16E-03	4.38E-04
Airborne DRL/year (GBq) [6] [e]	8.38E+05	5.17E+05	6.81E+03	7.31E+05
Max. % DRL (airborne)	1.26E-10%	3.01E-06%	3.17E-05%	5.99E-08%

a. Based on projected production requirements.
b. Based on 21-day irradiation and 2 hours decay for the production of Tc-99m generators [7].
c. As per CPM-6-20 [55].
d. Assumes 2 HEPA filters in series for the year at 0.9995 efficiency, as per CPM-6-20 [55].
e. All impurities associated with the Mo-99 process are conservatively assumed to be Zr-95 and releases are compared to the Zr-95 DRL.