ONTARIO POWER GENERATION

Report

Public Information	
Document Number: W-REP-03443-00008	Usage Classification: Information
Sheet Number: N/A	Revision: R001

Title:

2023 RESULTS OF THE ENVIRONMENTAL MONITORING PROGRAM FOR NUCLEAR SUSTAINABILITY SERVICES - WESTERN WASTE MANAGEMENT FACILITY AND RADIOACTIVE WASTE OPERATIONS SITE 1

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W-REP-03443-00008
2025-01-21

Order Number: N/A
Other Reference Number:

Public Information

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2023 RESULTS OF THE ENVIRONMENTAL MONITORING PROGRAM FOR NUCLEAR SUSTAINABILITY SERVICES - WESTERN WASTE MANAGEMENT FACILITY AND RADIOACTIVE WASTE OPERATIONS SITE 1

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Ref. 23-3209:2
21 January 2025

Ecometrix | Environmental INTELLIGENCE

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LAND ACKNOWLEDGEMENT

OPG acknowledges that the Nuclear Sustainability Services – Western Waste Management Facility is located on the traditional territory of the Chippewas of Saugeen First Nation and the Chippewas of Nawash Unceded First Nation, collectively known as the Saugeen Ojibway Nation (SON), and are the traditional keepers of the land. The area is also home to many diverse First Nations, Inuit and, Métis peoples and as a company, we remain committed to fostering positive and mutually beneficial relationships with Indigenous people and communities across Ontario.

REPORT REVISIONS

<table>
<tr><th>Revision Number</th><th>Date</th><th>Comments</th></tr>
<tr><td>R000</td><td>2024-08-02</td><td>Issue of final report to OPG</td></tr>
<tr><td>R001</td><td>2025-01-21</td><td>Updated to address CNSC comments; the following revisions are noted:
Sections 2.2.5, and 2.3.4,revised to clarify sampling conducted as part of the EMP versus other supplementary sampling studies.
Section 2.3.5 revised to clarify data around WOD2.
Figure 2.3 revised to update the name of sampling location ‘GS-1’ to the current name ‘SMP-1’ and remove the discontinued WOD3 sampling location.
Section 2.3.3 revised:
To include that water removed from the NSS-WWMF storage structures and building sumps is transferred to Bruce Power’s Active Liquid Waste System.
To include explanation for WSH230 and that wells WSH257 and WSH285 will continue to be monitored and analyzed for future trends.
The following error has been corrected in Section 5.0:
R000 states: “No statistically significant trends were observed in the monitored locations for 2019-2023.”
R001 states: “A statistically significant increasing trend in tritium concentrations was detected at WOD4 between 2019 and 2023. However, tritium concentrations in the SRD and East Stormwater Management Pond are known to fluctuate annually; this is hypothesized to occur as a result of changes in surface water dilution from differing weather conditions and water table levels. No other statistically significant trends were observed in the monitored locations for 2019-2023.”</td></tr>
</table>

EXECUTIVE SUMMARY

Ontario Power Generation (OPG) maintains an environmental monitoring program (EMP) at the Nuclear Sustainability Services – Western Waste Management Facility (NSS-WWMF). Additionally, OPG maintains the Radioactive Waste Operation Site 1 (RWOS1), a waste storage facility that contains historic low- and intermediate-level waste (LILW). The detailed design of the NSS-WWMF EMP was developed in 2012 in accordance with the Canadian Standards Association (CSA) N288.4-10 Environmental Monitoring Programs at Class 1 Nuclear Facilities and Uranium Mines and Mills. The 2023 program was implemented according to the recommended 2012 design with updates made according to recommendations from the 2019 design update review, the 2021 environmental risk assessment (ERA) update, and the results of the Conceptual Site Model and Groundwater Protection and Monitoring Programs. The program scope encompasses protection of both the public and the environment from nuclear substances, hazardous substances, and physical stressors resulting from the operation of the NSS-WWMF and RWOS 1.

The EMP is designed to satisfy the following four primary objectives of CSA N288.4-10:

1. Support assessment of the impact on human health and the environment of contaminants and physical stressors of concern resulting from operation of OPG nuclear facilities.

2. Demonstrate compliance with limits on the concentration and/or intensity of contaminants and physical stressors in the environment or their effect on the environment.

3. Demonstrate the effectiveness of containment and effluent control and provide public assurance of the effectiveness of containment and effluent control, independent of effluent monitoring.

4. Verify the predictions made by the Environmental Risk Assessments (ERAs), refine the models used, and reduce the uncertainty in the predictions made by these assessments and models.

The 2023 program results contained in this report include concentrations of radionuclides in air, water, and groundwater as well as ambient dose measurements from the vicinity of the NSS-WWMF and RWOS 1 sites. The relative contribution by NSS-WWMF and RWOS 1 to public dose was assessed through comparison with effluents from the Bruce A and B Generating Stations. For C-14 emissions, dose to a hypothetical receptor at the NSS-WWMF property boundary was calculated using available data.

Operation of NSS-WWMF resulted in extremely low public dose, well within regulatory limits. The potential exposure of non-Nuclear Energy Workers (NEW) to gamma radiation near NSS-WWMF facilities was shown to be low and well below the derived dose rate limit. OPG continued to meet its commitment to keep its impact on tritium levels at nearby Water Supply Plants (WSPs) below 100 Bq/L on an annual average basis.

Bedrock aquifer groundwater and South Railway Ditch surface water sampling indicate that there are no elevated radionuclide concentrations in groundwater leaving the NSS-WWMF. Previously elevated tritium levels in one area of the Middle Sand Aquifer (MSA) near the Low Level Storage Buildings (LLSB) have steadily decreased since 2017.

Passive air sampling of C-14 has been conducted. C-14 activity in air is mainly contributed by the in-ground containers on the NSS-WWMF. No adverse effects to workers, the public and the environment are expected due to these emissions.

There is currently no indication of unacceptable levels of radioactivity leaving the site either in air, surface water or groundwater.

Overall, the results of the 2023 NSS-WWMF environmental monitoring program confirm adequate protection of the public, workers, and environment.

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1.0 Introduction

Ontario Power Generation (OPG) owns and operates the Nuclear Sustainability Services — Western Waste Management Facility (NSS-WWMF). Additionally, OPG maintains the Radioactive Waste Operation Site 1 (RWOS1). To ensure activities at OPG facilities are conducted in a manner that minimizes any potential adverse impact on the public and natural environment, OPG has established an Environmental Management System (EMS) that is consistent with the Canadian Nuclear Safety Commission (CNSC) Regulatory Document – 2.9.1: Environmental Protection: Environmental Protection Policies, Program and Procedures [1]. Additionally, the OPG EMS is registered to the International Organization for Standardization (ISO) 14001 Environmental Management Systems standard.

As part of this program, each OPG Class 1 Nuclear Generating Station and Facility has an Environmental Monitoring Program (EMP), which identifies the contaminants and physical stressors which require monitoring. It also conducts monitoring in the environment surrounding the facility.

In 2012, OPG developed a detailed design for an EMP to monitor the NSS-WWMF. It was developed in accordance with the guidance of the Canadian Standards Association (CSA) N288.4-10 standard, “Environmental Monitoring Programs at Class I Nuclear Facilities and Uranium Mines and Mills” [2].

This report provides the results of the NSS-WWMF EMP for 2023. The report has been prepared in compliance with Clause 11.1 of CSA N288.4-10 [2], as shown in Table 1.1.

Table 1.1: Concordance Table with Reporting Requirements in CSA N288.4-10

CSA N288.4-10 Clause 11.1.2	Section in EMP Report
The report shall include:	
a) the results of the EMP, including	Section 2.3
i) measurements of the monitored hazardous and/or nuclear substances, physical stressors, and physical and biological parameters, including their statistical analyses (i.e., assessments of changes through time and space);	
ii) radiation doses calculated as doses to receptors where this is required;	Section 3.0
iii) an assessment of the EMP results compared with the performance indicator targets; and	Section 2.3 and 3.0

CSA N288.4-10 Clause 11.1.2	Section in EMP Report
iv) documentation and justification of any deviations from field sampling, and analytical, and data management procedures;	Section 4.3
b) a summary and assessment of the field and laboratory QA/QC results, including any nonconformances	Section 4.1
c) a summary of the audit and review results and subsequent corrective actions	Section 4.2
d) a summary of any proposed modifications to the EMP	Section 6.0
e) documentation, assessment, and review of any supplementary studies that have been initiated, completed, or both.	Section 2.2.5 and 2.3.4

1.1 Program Objectives

The EMP is designed to satisfy the following four primary objectives of CSA N288.4-10:

1. Support assessment of the impact on human health and the environment of contaminants and physical stressors of concern resulting from operation of OPG nuclear facilities.

2. Demonstrate compliance with limits on the concentration and/or intensity of contaminants and physical stressors in the environment or their effect on the environment.

3. Demonstrate the effectiveness of containment and effluent control and provide public assurance of the effectiveness of containment and effluent control, independent of effluent monitoring.

4. Verify the predictions made by the Environmental Risk Assessments (ERAs), refine the models used, and reduce the uncertainty in the predictions made by these assessments and models.

More specifically, the objectives of the NSS-WWMF EMP are to [3]:

1. Demonstrate that the radiological risk to the public due to the operation of the NSS-WWMF is low and well within the regulatory public dose limit.

2. Measure external gamma dose at the perimeter of the NSS-WWMF and RWOS 1 to confirm compliance with the operating limit of 0.5 µSv/h.

3. Monitor groundwater to confirm the effectiveness of containment of in-ground storage structures at the NSS-WWMF and the RWOS 1.

4. Monitor the railway ditch water for tritium levels to assess remedial measures taken to reduce tritium in the NSS-WWMF MSA groundwater.

5. Monitor water and sediment for radionuclides and non-radioactive contaminants in the wetland east of the NSS-WWMF to confirm no ecological impact from the east site drainage discharge.

6. Demonstrate that NSS-WWMF waterborne emissions comply with OPG's commitment to keep tritium concentrations at nearby WSPs below 100 Bq/L on an annual average basis.

7. Update the estimated fugitive tritium and C-14 emissions from the site and determine if additional monitoring and reporting is warranted.

1.2 EMP Context and Background Information

OPG has established the current EMP to monitor and identify potential impacts to the environment associated with operation of the NSS-WWMF. Bruce Power conducts a full EMP for the overall Bruce nuclear site, including radiological monitoring [4]. Estimation of public radiological dose resulting from NSS-WWMF operations is achieved by estimating the NSS-WWMF contribution to the Bruce Power public radiological dose calculation by comparing the relative levels of monitored radiological emissions. See Section 3.1 for the results of this assessment.

Environmental data obtained through the EMP (and often other supplementary studies) are periodically assessed every five years as part of a detailed environmental risk assessment (ERA), which investigates potential risks posed to humans and the local environment from contaminant releases (radiological and non-radiological) resulting from normal NSS-WWMF operations. The risk calculations and conclusions of the ERA are used to recommend and direct future monitoring programs, including the current EMP, to verify that risk calculations are accurate and to minimize or eliminate uncertainties in environmental data and other modelling parameters used in the ERA.

Many of the environmental parameters monitored as part of the EMP and assessed as part of the ERA are of considerable interest to local Indigenous and non-Indigenous communities, with engagement being an important consideration for both documents. Through both the EMP and associated ERAs, OPG demonstrates that operation of the NSS-WWMF poses negligible levels of human health or ecological risks to local and regional waterways, soils, country foods, wildlife, or regional air quality. Were operational risk levels to change, the EMP and the greater ERA are designed to detect and identify any increases in contaminant releases to the environment, allowing for the immediate investigation and subsequent mitigation of any significant releases.

1.3 Overview of the Nuclear Sustainability Services – Western Waste Management Facility

The NSS-WWMF is located on the Bruce nuclear site along the east shore of Lake Huron, approximately 18 km north of Kincardine and 17 km southwest of Port Elgin (Figure 1.1). Although not located within the NSS-WWMF facility boundaries, the former Spent Solvent Treatment Facility (SSTF) and RWOS 1 are also located on the Bruce nuclear site (Figure 1.2) and are owned and operated by OPG. The SSTF has not accepted spent solvent since 2003, was decommissioned in 2019 and the CNSC licence has been removed. The RWOS 1 has not received waste since 1976 and remaining storage structures are in caretaking mode [5].

The Bruce nuclear site also hosts Bruce Nuclear Generating Station A (Bruce NGS-A) and Bruce Nuclear Generating Station B (Bruce NGS-B), the Douglas Point Waste Management Facility, the Central Maintenance Facility (CMF), Central Storage Facility (CSF) and other nuclear facilities and related infrastructures (Figure 1.2). Kinectrics North Facility is located 3 km from the Bruce site. Its main function is the decontamination and refurbishment of large nuclear reactor tools and equipment. The Bruce nuclear site occupies an area of 932 hectares (2,300 acres) within the Municipality of Kincardine, County of Bruce, and Province of Ontario. Land use in the immediate vicinity is primarily agricultural, recreational, and rural residential. Surrounding the Bruce nuclear site is a mixture of rural agricultural land, former gravel pits, fragmented woodlands, streams, and wetlands. Recreational land use includes Inverhuron Park and cottages in the hamlet of Inverhuron (south of Bruce nuclear site) and Baie du Doré/Scott Point Area (north of Bruce nuclear site).

The NSS-WWMF is owned and operated by OPG and has been in operation since 1974. It is a Class 1B nuclear facility for the storage of low and intermediate level (L&ILW) radioactive waste and used fuel. The NSS-WWMF consists of the L&ILW Management Area and the Used Fuel Management Area. The L&ILW Management area includes the Low-Level Storage Buildings (LLSBs), a Steam Generator Storage Building (SGSB), a Retube Component Storage Building (RCSB), a Waste Volume Reduction Building (WVRB), and a Transportation Package Maintenance Building (TPMB). In-ground structures include In-ground Containers (ICs), trenches and tile holes, while above-ground structures in this area include the Quadricells. The Used Fuel Management Area includes a Used Fuel Dry Storage Container Processing Building and six (6) Used Fuel Dry Storage Buildings. The layout of the NSS-WWMF is illustrated in Figure 1.3.

Figure 1.1: Location of Nuclear Sustainability Services – Western Waste Management Facility

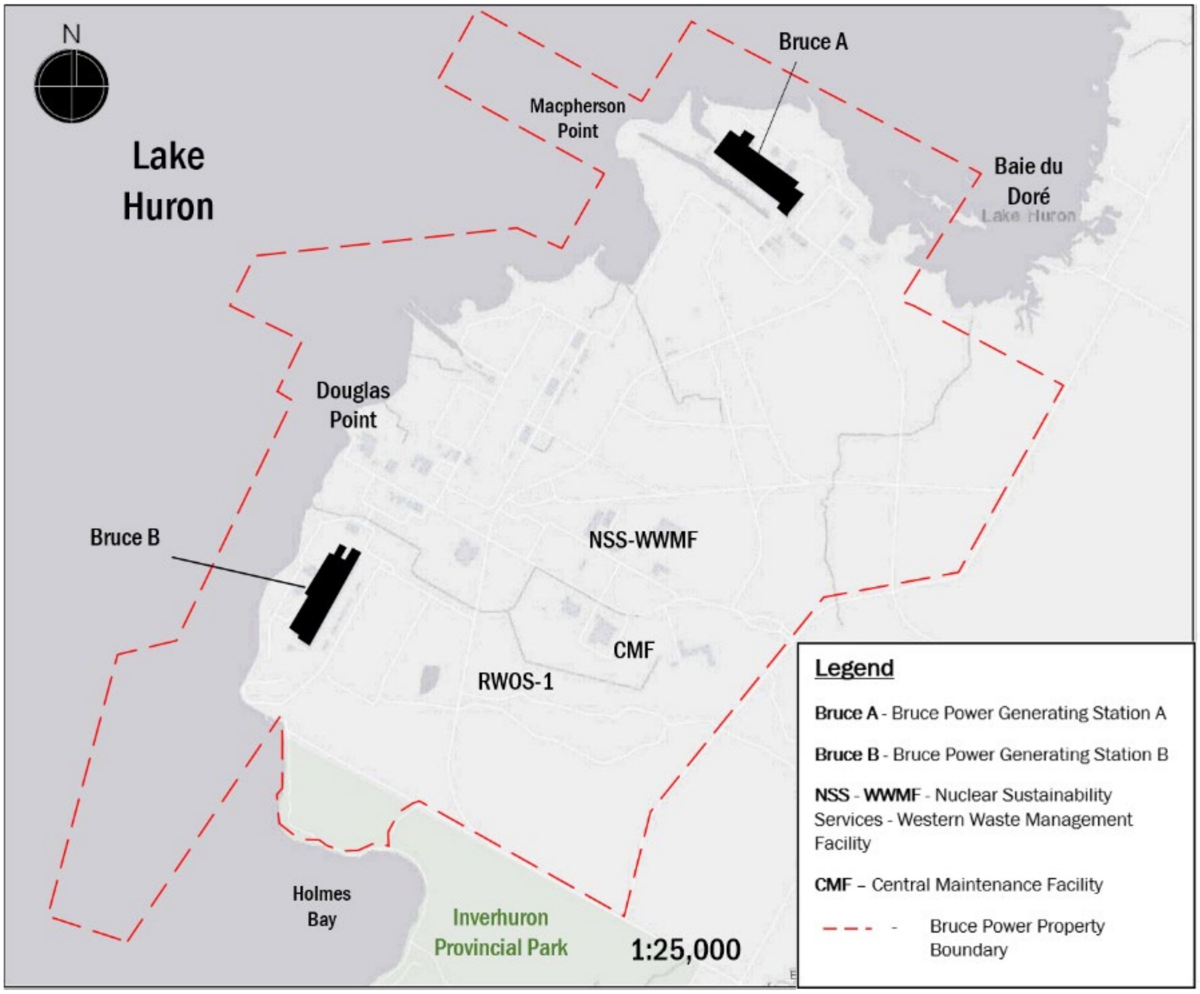

Figure 1.2: Location of Facilities on Bruce Nuclear Site

1. LLSBs
2. In-ground Storage (trenches, tile holes, ICs, In-ground container for heat exchangers (ICHXs))
3. SGSB (3-1) and RCSB (3-2)
4. Used Fuel Processing Building (4-1) and Used Fuel Dry Storage Buildings 1,2,3&4 (4-2)
5. Waste Volume Reduction Building and Amenities Buildings
6. Transportation Package Maintenance Building
7. Quadricells
8. Used Fuel Dry Storage Buildings 5&6

Figure 1.3: NSS-WWMF Aerial View

Source: AMEC, 2016 [6]

2.0 Environmental Monitoring Program

2.1 Design of EMP

Radiation protection, effluent monitoring, and environmental monitoring have taken place at the NSS-WWMF for many years. Results of the environmental monitoring are reported in the NSS-WWMF Quarterly Operation Reports (QORs) to the CNSC. Current EMP elements that were reported in the QORs include thermo luminescent dosimeter (TLD) measurements of external gamma dose rates, groundwater monitoring results and groundwater trend graphs. In 2012, an EMP for the NSS-WWMF was designed according to the guidance provided in the CSA N288.4-10 standard and monitoring has been ongoing based on this design [7].

2.1.1 Facilities included in EMP

NSS-WWMF operates under a Class IB Waste Facility Operating Licence. Although the EMP design report primarily addresses the NSS-WWMF, including all waste storage, waste processing, transportation equipment maintenance, and used fuel dry storage facilities, it also currently includes RWOS 1. Most of the low and intermediate level radiological waste was recovered from RWOS 1 and is stored at the NSS-WWMF. The RWOS 1 is in caretaking mode. Other OPG facilities on the Bruce nuclear site include the conventional landfill, the former Spent Solvent Treatment Facility (SSTF) which was decommissioned in 2019, and four (4) construction landfills. These were excluded from the EMP design as they did not meet the criteria for establishing the need for an EMP based on N288.4. These facilities are either regulated by the Ontario Ministry of the Environment, Conservation and Parks (MECP) or were not considered to present any significant risk [7]. The EMP design is also based on the results of NSS-WWMF ERA which did not identify significant risk associated with these other facilities.

2.1.2 Environmental Risk Assessment

The NSS-WWMF ERA assesses potential human health and ecological risks from exposure to radiological contaminants, conventional contaminants, and physical stressors present in the environment as a result of site operations. The ERA helps to identify which monitoring to include in the NSS-WWMF EMP. Subsequently EMP data are used to update the ERA on a regular time interval, with the data being used to refine models, test predictions of the last ERA and further enhance the understanding of potential risk from the site.

The most recent 2021 NSS-WWMF ERA update [8] was completed in accordance with the requirements of CSA N288.6-12, Environmental Risk Assessments at Class I Nuclear Facilities and Uranium Mines and Mills [9]. The ERA provided the following recommendations for monitoring:

- The current quarterly monitoring of tritium within the South Railway Ditch (SRD) as part of the EMP program is appropriate and should be continued.
- Hazard quotients above 1 were observed in the surface water at the SRD for several metals, which is consistent with observations from past monitoring and may be

attributed to the existence of a former rail line within the ditch for some metals, and to naturally elevated water concentrations for iron and manganese. Additional monitoring is recommended prior to the next ERA to confirm that conditions in the SRD remain unchanged.

- It was previously recommended that the supplementary precipitation study be repeated in 2020-21 to support the 2021 ERA update. However, based on analysis presented in the 2021 ERA, the precipitation monitoring program is not interpreted to provide additional insight into the NSS-WWMF inputs to precipitation since the results indicated that tritium is most likely attributed to the operation of Bruce A and Bruce B, and the location and elevation of the precipitation samples are not expected to capture the tritium off-gassing processes occurring at the LLSBs. Therefore, monitoring of precipitation was discontinued in Q1 of 2022 and is not included as part of the EMP.

- The source of inputs to the wetland is sufficiently understood; therefore, ongoing monitoring of the wetland is not currently necessary. However, additional wetland monitoring is recommended to support the next ERA update to determine if conditions are stable or have changed.

- The source of C-14 concentrations in vegetation near the IC-18s is understood. Therefore, it is recommended that routine air monitoring using the passive air samplers should continue as part of the EMP design to determine fugitive C-14 emissions, but additional investigations into C-14 in air and vegetation are not required. Future consideration of C-14 in vegetation can be modelled using the specific activity model, as modelled concentrations in vegetation are expected to correlate well with measured air concentrations.

- The 2021 ERA update determined that dioxins and furans are present in the SRD and West Ditch (WD) at concentrations above regulatory screening levels; however, adverse effects to benthic invertebrates at the community level are not expected within the SRD and the WD. Considering that dioxins and furans are not expected to cause adverse effects at the community level at either the SRD or WD, remediation is not warranted. Remediation efforts that involve disturbing the sediment within the SRD and WD are not recommended. Samples of benthic invertebrates can be collected and analyzed for dioxins and furans in a supplementary study to reduce uncertainty in risk characterization for the next ERA update.

2.1.3 Other Inputs

The EMP design was also informed by other inputs in addition to risk factors identified in the ERA, such as groundwater monitoring through the groundwater monitoring program, ongoing confirmation of containment of radioactivity in the NSS-WWMF storage structures through the aging management program [10], and confirmation of predictions in the ERAs.

2.2 EMP Sampling Plan

The EMP sampling plan outlines the parameters monitored, the monitoring locations, the sample types, and the frequency of collection. Samples collected, analyses performed, and interpretation of the data support the EMP objectives outlined in the following sections.

2.2.1 Public Radiological Dose Estimation

A direct determination of public radiological dose from NSS-WWMF operations based on environmental monitoring of nuclear substances is not feasible since environmental media around the Bruce nuclear site (e.g., air, soil, plant and animal food products, water, beach sand) contain radionuclides which are released from all nuclear facilities on the site operated by OPG, Bruce Power and Canadian Nuclear Laboratories (CNL); that is the NSS-WWMF, Bruce NGS-A, Bruce NGS-B, CMF, CSF, and Douglas Point Waste Facility (DPWF). Most of these radionuclides are common to all facilities and for the most part, one cannot determine the level of contributions in environmental media from each specific source by means of environmental measurements and laboratory analyses. Most of the radioactivity monitored in the environment is tritium, C-14, and beta/gamma emitters, all of which are released to some extent in airborne and waterborne effluents by all Bruce nuclear site facilities. Bruce Power conducts a full EMP for the overall Bruce nuclear site, including radiological monitoring [4]. Estimation of public radiological dose resulting from NSS-WWMF operations is achieved by estimating the NSS-WWMF contribution to the Bruce Power public radiological dose calculation by comparing the relative levels of monitored radiological emissions. See Section 3.1 for the results of this assessment.

2.2.2 Tritium Levels at Water Supply Plants

OPG has a commitment to the government of Ontario to control waterborne emissions of tritium from its facilities to levels that will keep tritium concentrations at nearby WSPs below 100 Bq/L on an annual average basis. Confirmation that OPG is keeping its commitment is achieved by estimating NSS-WWMF's relative contribution to Bruce Power's results of monitoring tritium in the Southampton and Kincardine WSPs, using measured waterborne tritium emissions. See Section 3.2 for the results of this assessment.

2.2.3 Direct Gamma and Skyshine Dose

Direct gamma and skyshine doses resulting from radioactivity in the waste storage facilities fall off rather quickly with distance. The NSS-WWMF storage facilities are located reasonably far from the Bruce nuclear site perimeter, and gamma dose from the NSS-WWMF is not a significant contributor to the radiological dose of the general public. However, external gamma doses near the storage facilities are monitored to ensure that potential non-Nuclear Energy Workers (non-NEWs) working in proximity of the NSS-WWMF are adequately protected. To protect non-NEWs near the NSS-WWMF site, the storage facilities have a gamma dose limit of 0.5 µSv/h at the fence line. This ensures that a non-NEW at a nearby location over the course of a normal work year would not be exposed to more than the non-NEW regulatory dose limit of 1 mSv/a.

Environmental TLDs are placed at several locations around the perimeters of the NSS-WWMF and RWOS 1 to measure direct gamma doses. There are 63 TLDs at the NSS-WWMF (16 around the Used Fuel Dry Storage Facility (UFDSF) buildings 1-4, 20 around the UFDSF buildings 5-6, and 20 around the rest of the NSS-WWMF). There are seven (7) TLDs around RWOS 1. The specific locations are shown in Figure 2.1 and Figure 2.2. The TLDs are replaced every quarter and shipped to the OPG Whitby Health Physics laboratory (HPL) for analysis. Preparation, shipping, deployment, and analysis of the TLDs are described in the Environmental Gamma Monitors (EGM) System Overview [11]. See sections 2.3.2 and 3.3 for results of TLD measurements. Data can also be found in the quarterly reports (see [12], [13], [14] and [15]).

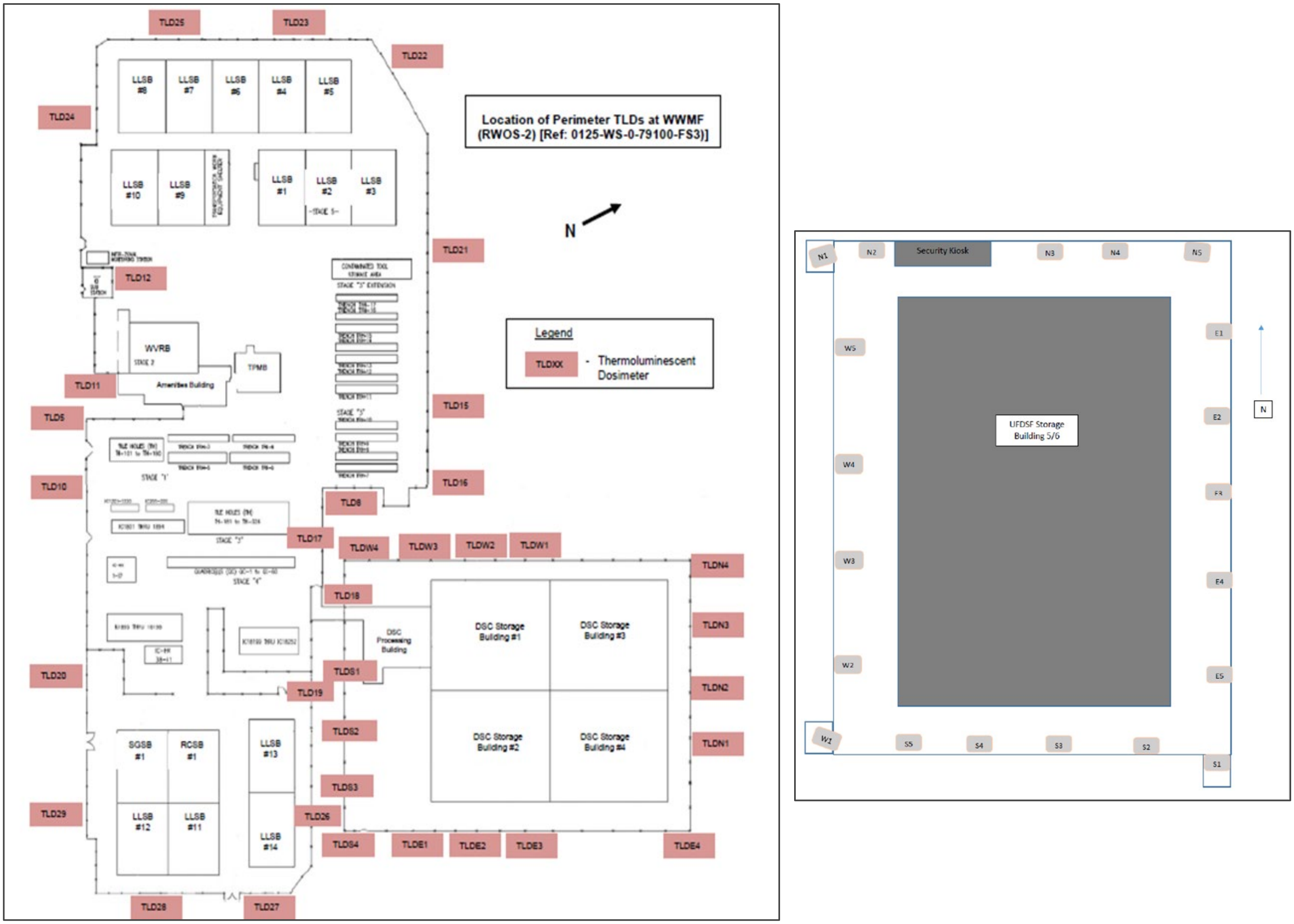

Figure 2.1: Location of TLDs at NSS-WWMF

Source: NSS-WWMF Quarterly Operations Report [12]

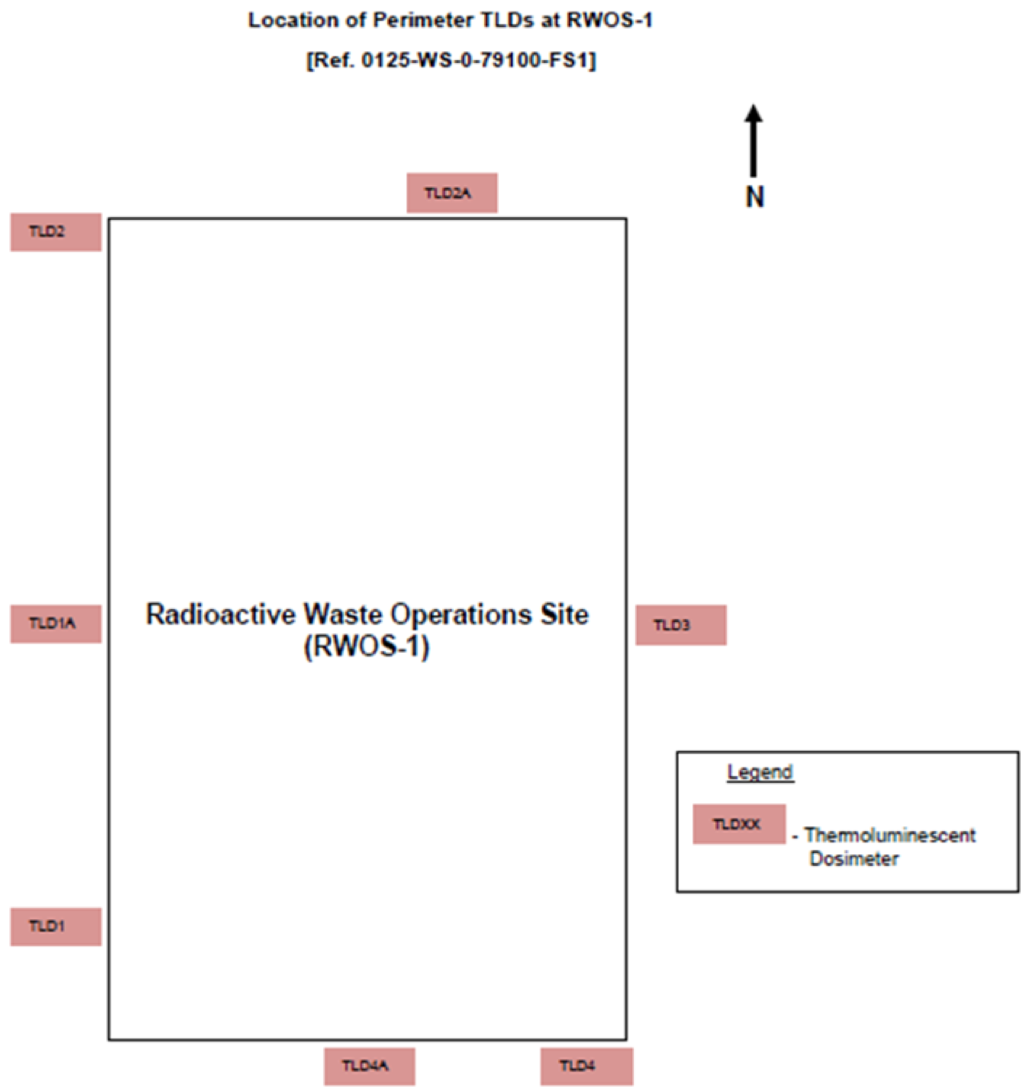

Figure 2.2: Locations of TLDs at RWOS 1

Source: NSS-WWMF Quarterly Operations Report [12]

2.2.4 Confirmation of Containment Integrity of In-ground Storage Structures

In-ground storage structures are monitored in different ways. The trenches and tile holes have an engineered subsurface drainage system, which is routinely monitored for tritium. IC-12s and IC-18s have an accessible space outside the IC walls that is routinely checked for any water accumulation and radioactivity, thus providing a primary check of containment. As an additional barrier to ensure effective storage structure containment, groundwater around the NSS-WWMF and RWOS 1 is routinely sampled. The sampling wells are technically sound, sealed groundwater sampling wells, but are referred to as water sampling holes (WSHs). The WSHs are placed to detect a potential loss of containment in storage structures and any movement of radioactivity in groundwater from the NSS-WWMF. The specific locations of the WSHs at the NSS-WWMF are shown in Figure 2.3, and the locations of those at RWOS 1 are shown in Figure 2.4.

Both the shallower Middle Sand Aquifer (MSA) and the deeper bedrock aquifer are monitored. Detailed procedures are followed for technically sound monitoring of the groundwater wells [16].

The MSA is generally localized to the NSS-WWMF but is hydraulically connected to the bedrock aquifer. Groundwater from the MSA generally leaves the NSS-WWMF site via the bedrock aquifer. However, it appears that due to excavations and backfill material associated with the installation of a Stormceptor in the mid-2000s, some groundwater from the MSA discharges to the SRD (near the north-western area of the NSS-WWMF). For a more detailed description of groundwater flow within and outside of the NSS-WWMF, see the EMP design report [7]. A source term assessment and groundwater monitoring network design enhancement were completed in 2016 at the NSS-WWMF.

Based on the results of previous monitoring programs, the development of the Conceptual Site Model and Groundwater Monitoring Program identified tritium as the only contaminant of potential concern (COPC) at the site and discontinued the sampling of Gross β and Carbon-14 in groundwater in 2022. Groundwater sampling for Gross β was conducted as a supporting analysis for the purposes of general radiological trending and was removed because it does not include tritium, which is a low-energy beta. Groundwater sampling for Carbon-14 was conducted to confirm storage structure containment, but was removed because the majority of samples were non-detect, or well below the Ontario Drinking Water Quality Standard of 200 Bq/L [17] [18] [19] [20]. These efforts also resulted in the re-establishment of seven previously monitored wells, including WSH 252, WSH 256, WSH 267, WSH 275, WSH 276 and WSH 277 and the establishment of six new wells including WSH 301, WSH 302, WSH 307, DGRB12, DGRB12A and DGRB14 for the purposes of monitoring downgradient perimeter groundwater, upgradient groundwater, subsurface drainage, and general background tritium concentrations at the NSS-WWMF. Eight wells monitored in 2021 were also discontinued primarily due to redundancy, including WSH233, WSH 241, WSH246, WSH 248, WSH 271, WSH 127 and WSH 20S. Section 2.3.3 provides the WSHs monitored in 2023 for tritium at both RWOS 1 and the NSS-WWMF. Most wells at RWOS 1 and the NSS-WWMF are now monitored either annually or bi-annually.

Results of this program are reported in section 2.3.3 of this document and are documented separately in a CSA N288.7 compliant report.

There are no specific targets nor limits for radioactivity in groundwater at the NSS-WWMF nor RWOS 1. However, OPG has committed to notify the CNSC if tritium levels at WSH 231 exceed 60,000 Bq/L [21]. For the purposes of this report, groundwater tritium levels at each well are compared to a value of 500 Bq/L. Historically, the vast majority of tritium readings in wells throughout the NSS-WWMF and RWOS-1 sites are below the value of 500 Bq/L, thus the use of this value for comparative purposes highlights groundwater wells with tritium levels that are outside the range of what is typically expected across these sites. This allows for the effective identification of concentration spikes, and any changes in trends over time when compiling and examining the results of the groundwater monitoring portion of this EMP across years. In general, the radioactivity in each WSH is examined to see if there is an increasing trend over time that may indicate a loss of integrity of a storage structure. In the case of WSH 231, where elevated tritium in the MSA has been identified for some time, remedial measures such as sealing of select building sumps and pumpouts of water from LLSB electrical manhole sumps were initiated in 2010. WSH 231 data were examined for a decreasing trend from February 2010 onward to determine how effective the remedial measures have been in reducing tritium concentrations. See Section 2.3.3 and Appendix C for results of groundwater monitoring.

Figure 2.3: Monitoring Well Network at the NSS-WWMF

Figure 2.4: Monitoring Well Network at the RWOS 1

2.2.5 Water and Sediment in South Railway Ditch, Wetland and East Stormwater Management Pond

In addition to the regular environmental sampling that occurs as part of OPG's annual EMP, additional sampling of water and sediment may occur, as required, in support of future iterations of the NSS-WWMF environmental risk assessment (ERA). In 2023, no additional water or sediment sampling was conducted within the South Railway Ditch, the Wetland or the East Stormwater Management Pond. For further information regarding past sampling programs conducted at these locations in support of the 2021 NSS-WWMF ERA, the reader is referred to the 2022 NSS-WWMF EMP report [22].

2.2.6 Water in South Railway Ditch and East Stormwater Management Pond

The SRD and the East Stormwater Management Pond has been monitored routinely for tritium since 2010 and was also monitored in 2013 as part of the NSS-WWMF EMP supplementary studies [5], and in 2020 and 2021 as part of the NSS-WWMF ERA update [8]. The results provided no firm conclusions about changes in tritium in the SRD as compared with tritium levels measured in WSH 231 over the same period. Quarterly routine monitoring of the ditch continues at four locations (WOD1, WOD2, WOD4 and WOD5). The continued quarterly monitoring in the SRD and the groundwater wells should provide a better understanding of any trends in tritium moving forward.

2.2.7 HTO in Precipitation

HTO monitoring in precipitation at NSS-WWMF was discontinued in 2022, in accordance with the recommendations of the 2021 NSS-WWMF ERA [8].

2.2.8 Fugitive Emissions of C-14

Elevated C-14 in air on the NSS-WWMF site was identified in the 2013 EMP Report [5] and an integration into routine sampling was recommended. Bruce Power nuclear site passive C-14 samplers are shown in Figure 2.5. In 2020, 2021, 2022, and 2023 passive sampler results from Bruce Power indicated higher levels than provincial background locations. The highest concentrations were localized at NSS-WWMF. Measured C-14 levels were near provincial background levels at the site boundary [4].

The C-14 passive samplers consist of mixed soda lime pellets to absorb CO_2 from air at a controlled rate. Twenty samplers are positioned around the area of the NSS-WWMF for passive monitoring (Figure 2.6). The samples are collected and analyzed quarterly.

Elevated concentrations of C-14 at the NSS-WWMF are associated with the spent resin storage area, specifically the in-ground containers (IC-12s and IC-18s). The fugitive emissions reassessment was designed to update the estimated fugitive tritium and C-14 emissions from the site and determine if additional monitoring and reporting is warranted. Sampling for this assessment was completed in 2019 at the spent resin storage area. During this assessment air samples were also collected from 67 ICs. Emissions estimates from this sampling campaign confirmed that C-14 emissions from ICs were elevated. Following the fugitive emissions reassessment, gaskets were replaced on IC-12s and IC-18s to provide better sealing, and scrubbers were installed in select IC-18s to sequester C-14.

A model has been developed to estimate fugitive emissions and is being assessed against existing monitoring practices for emissions reporting purposes. Both environmental and health physics monitoring confirm that there is no significant impact on workers, the public, nor the environment.

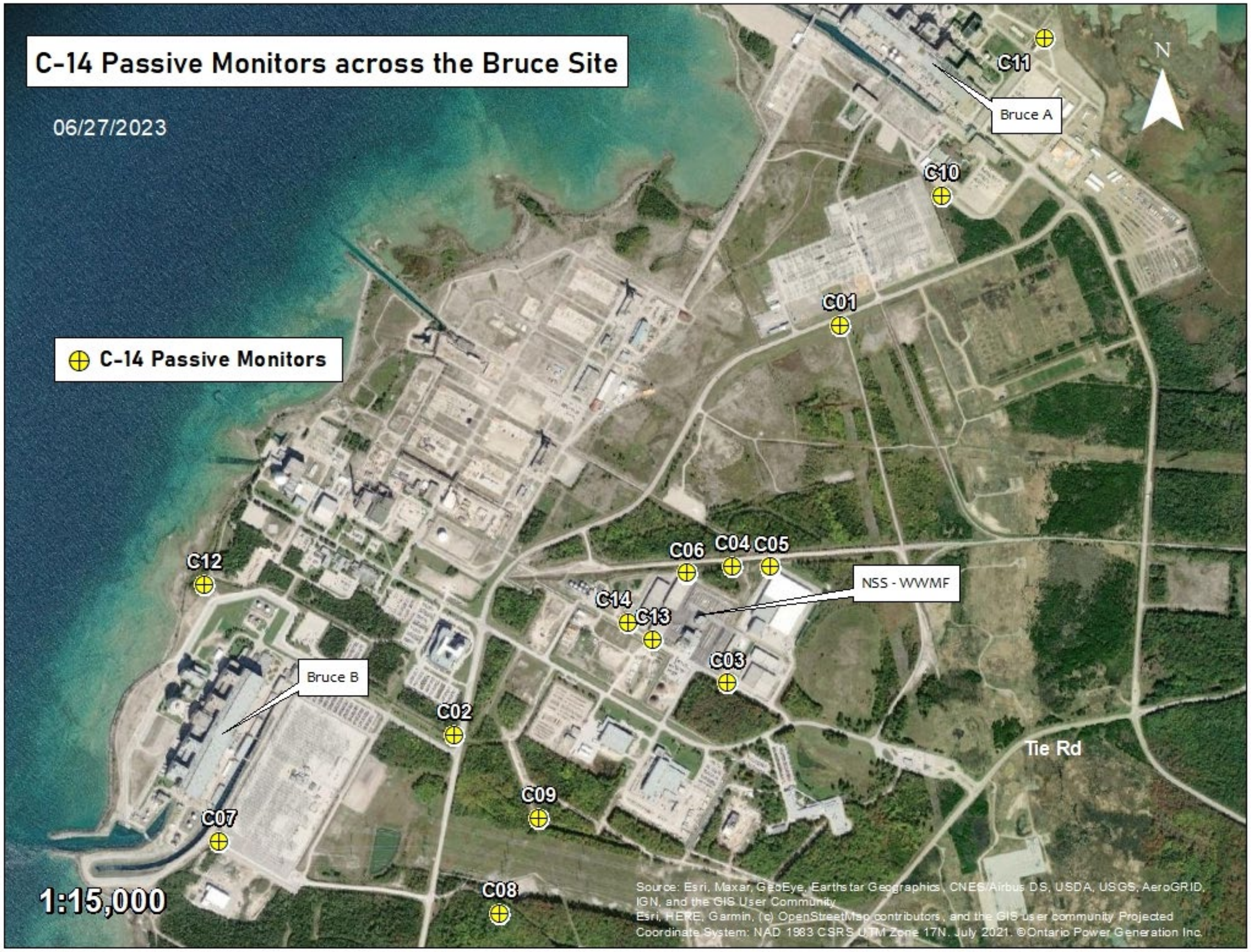

Figure 2.5: C-14 Passive Monitor Locations Across the NSS-WWMF/Bruce Power Site

Figure 2.6: C-14 Passive Monitor Locations in the Spent Resin Storage Area at the NSS-WWMF

2.3 EMP Results

This section contains the 2023 results of the EMP for the NSS-WWMF and RWOS 1. Sampling methods, analyses, and QA/QC measures are identified.

2.3.1 Reporting Data and Uncertainties

Descriptive statistics such as means, and standard deviations were calculated in Excel unless the dataset contained non-detects with values specified. Statistical analysis for trends were performed using the Microsoft Excel Real Statistics package [23].

Radionuclide concentrations and radiation levels in the environment are low and at times below levels which can be detected by routine analytical techniques. In these situations, the analytical result is reported as being below the detection limit (Ld).

Lc: The critical level is the level (relative to background) below which a quantity cannot reliably be measured. More specifically, the critical level is the largest value of the quantity for which the probability of a wrong conclusion that a quantity is present exceeds a specified probability [24]. The EMP uses a probability of 5%. For the EMP, Lc is approximately equal to half of the Ld.

Ld: The detection limit is the level (relative to background) above which a quantity can confidently be measured. More specifically, the detection limit is the smallest value of the quantity for which the probability of a wrong conclusion that the quantity is not present does not exceed a specified probability [24]. The EMP uses a probability of 5%.

When reporting the analytical data, the following conventions are used:

- Where a measured value is below the analytical Ld but above the Lc, the measured value is reported in bold type.
- Where a measured value is below the Lc, then "< Lc" is reported without an uncertainty measure.
- Where a measured value is censored at the Ld, it is reported as "< Ld". This is the case for gamma spectrometer results, noble gas data, and conventional contaminants.
- For a dataset comprised of a single measured value, the associated uncertainty is the laboratory analytical uncertainty for that specific sample.
- For a dataset without any data censored at the Ld, the arithmetic mean is reported and associated uncertainty is two times the standard deviation of the dataset.
- For a dataset containing some data censored at the Ld, the Kaplan-Meier (KM) estimation method is used. The KM mean is reported and associated uncertainty is two times the KM standard deviation of the dataset. An asterisk "*" is used to identify these datasets.

- For a dataset that consists entirely of data censored at the Ld, the average is reported as "<Ld" without an uncertainty measure.
- For a dataset that consists entirely of data below the Lc (with no censored data), the average is reported as "< Lc" without an uncertainty measure.

2.3.2 Gamma Radiation Dose Monitoring Results

The Harshaw Environmental TLD System was used to measure the direct gamma and skyshine doses around the perimeters of the NSS-WWMF and RWOS 1.

The dosimeters are changed quarterly and shipped to the OPG HPL for readout. For quality control (QC), transport dosimeters always accompany the field dosimeters on the trip to and from the field locations so that extraneous radiation dose received in transit is monitored and accounted for. Additional information on the TLDs and the readout procedure can be found in the EGM System Overview [11].

The 2023 TLD gamma dose results are shown in Table 2.1. Results are given as air kerma rates (µGy/h). All quarterly results and annual average results at RWOS 1 and the NSS-WWMF, including the UFDSF area, are well below the derived dose rate limit of 0.5 µGy/h. A graphical representation of the 2023 results is shown in Figure 2.7.

All TLD locations were analyzed for any statistically significant trends in the last five years (2019 – 2023) at the 95% significance level using the Mann-Kendall Test [23]. Most locations did not show any appreciable changes or trends that would warrant further investigation. Only two (2) TLD locations at the Western Low and Intermediate Level Waste Storage Facility (WLILWSF) showed statistically significant trends from 2019 to 2023 (TLDs 24 and 28). TLD 24 increased from 0.068 µGy/h in Q1 of 2019, to 0.090 µGy/h in Q4 of 2023 ($p=0.002$). TLD 28 decreased from 0.098 µGy/h in Q1 of 2019 to 0.088 µGy/h in Q4 of 2023 ($p<0.021$) (Figure 2.8). As noted, all TLD gamma dose results are below the dose rate limit of 0.5 µGy/h.

Table 2.1: 2023 TLD Average Air Kerma Rates

TLD - Average Air Kerma Rates (µGy/h)						
TLD Location	**Q1**	**Q2**	**Q3**	**Q4**	**Annual Average**	**2*SD[(3)]**
RWOS 1						
1	0.049	0.055	0.046	0.063	0.053	0.015
1A	0.054	0.061	0.05	0.065	0.058	0.014
2	0.055	0.06	0.047	0.068	0.058	0.018
2A	0.054	0.055	0.048	0.068	0.056	0.017
3	0.046	0.053	0.041	0.064	0.051	0.020
4	0.047	0.054	0.045	0.055	0.050	0.010
4A	0.049	0.057	0.046	0.064	0.054	0.016
WLILWSF[(1)]						
5	0.056	0.055	0.046	0.066	0.056	0.016
8	0.064	0.064	0.056	0.076	0.065	0.016
10	0.052	0.056	0.047	0.068	0.056	0.018
11	0.073	0.073	0.057	0.076	0.070	0.017
12	0.067	0.083	0.067	0.093	0.078	0.026
15	0.065	0.064	0.056	0.074	0.065	0.015
16	0.068	0.065	0.054	0.076	0.066	0.018
17	0.06	0.063	0.055	0.073	0.063	0.015
18	0.061	0.063	0.053	0.072	0.062	0.016
19	0.058	0.064	0.049	0.068	0.060	0.017
20	0.059	0.066	0.051	0.068	0.061	0.015
21	0.058	0.063	0.053	0.074	0.062	0.018
22	0.061	0.062	0.055	0.068	0.062	0.011
23	0.073	0.069	0.06	0.079	0.070	0.016
24	0.076	0.079	0.07	0.09	0.079	0.017
25	0.078	0.086	0.066	0.092	0.081	0.022
26	0.075	0.08	0.068	0.088	0.078	0.017
27	0.067	0.074	0.057	0.075	0.068	0.017
28	0.079	0.082	0.073	0.088	0.081	0.012
29	0.065	0.07	0.057	0.075	0.067	0.015
UFDSF Buildings 1-4[(2)]						
DFSN-1	0.08	0.086	0.072	0.092	0.083	0.017
DFSN-2	0.091	0.089	0.08	0.098	0.090	0.015
DFSN-3	0.077	0.084	0.074	0.087	0.081	0.012
DFSN-4	0.063	0.062	0.057	0.073	0.064	0.013
DFSS-1	0.07	0.07	0.059	0.078	0.069	0.016
DFSS-2	0.071	0.071	0.06	0.079	0.070	0.016

TLD - Average Air Kerma Rates (µGy/h)						
TLD Location	**Q1**	**Q2**	**Q3**	**Q4**	**Annual Average**	**2*SD[(3)]**
DFSS-3	0.07	0.072	0.064	0.076	0.071	0.010
DFSS-4	0.061	0.067	0.059	0.075	0.066	0.014
DFSE-1	0.066	0.069	0.06	0.085	0.070	0.021
DFSE-2	0.082	0.085	0.072	0.091	0.083	0.016
DFSE-3	0.085	0.085	0.076	0.093	0.085	0.014
DFSE-4	0.063	0.064	0.056	0.072	0.064	0.013
DFSW-1	0.09	0.09	0.075	0.094	0.087	0.017
DFSW-2	0.082	0.085	0.074	0.09	0.083	0.013
DFSW-3	0.074	0.079	0.067	0.089	0.077	0.019
DFSW-4	0.058	0.065	0.054	0.069	0.062	0.014
UFDSF Buildings 5-6						
DFSB56-N1	0.059	0.065	0.055	0.072	0.063	0.015
DFSB56-N2	0.061	0.068	0.055	0.074	0.065	0.017
DFSB56-N3	0.067	0.072	0.059	0.078	0.069	0.016
DFSB56-N4	0.063	0.068	0.058	0.074	0.066	0.014
DFSB56-N5	0.059	0.066	0.054	0.068	0.062	0.013
DFSB56-E1	0.054	0.058	0.048	0.069	0.057	0.018
DFSB56-E2	0.063	0.073	0.058	0.076	0.068	0.017
DFSB56-E3	0.078	0.085	0.077	0.098	0.085	0.019
DFSB56-E4	0.086	0.101	0.095	0.126	0.102	0.034
DFSB56-E5	0.071	0.079	0.077	0.093	0.080	0.019
DFSB56-W1	0.071	0.08	0.065	0.087	0.076	0.019
DFSB56-W2	0.149	0.162	0.152	0.173	0.159	0.022
DFSB56-W3	0.275	0.281	0.259	0.281	0.274	0.021
DFSB56-W4	0.156	0.183	0.178	0.2	0.179	0.036
DFSB56-W5	0.078	0.088	0.074	0.096	0.084	0.020
DFSB56-S1	0.063	0.072	0.06	0.072	0.067	0.012
DFSB56-S2	0.071	0.077	0.069	0.085	0.076	0.014
DFSB56-S3	0.108	0.122	0.122	0.138	0.123	0.025
DFSB56-S4	0.121	0.133	0.123	0.142	0.130	0.019
DFSB56-S5	0.119	0.135	0.124	0.148	0.132	0.026

1) WLILWSF: Western Low and Intermediate Level Waste Storage Facility
2) UFDSF: Used Fuel Dry Storage Facility
3) Uncertainty in annual average is given as ± 2 standard deviations.
   Ld = 0.7 µGy.

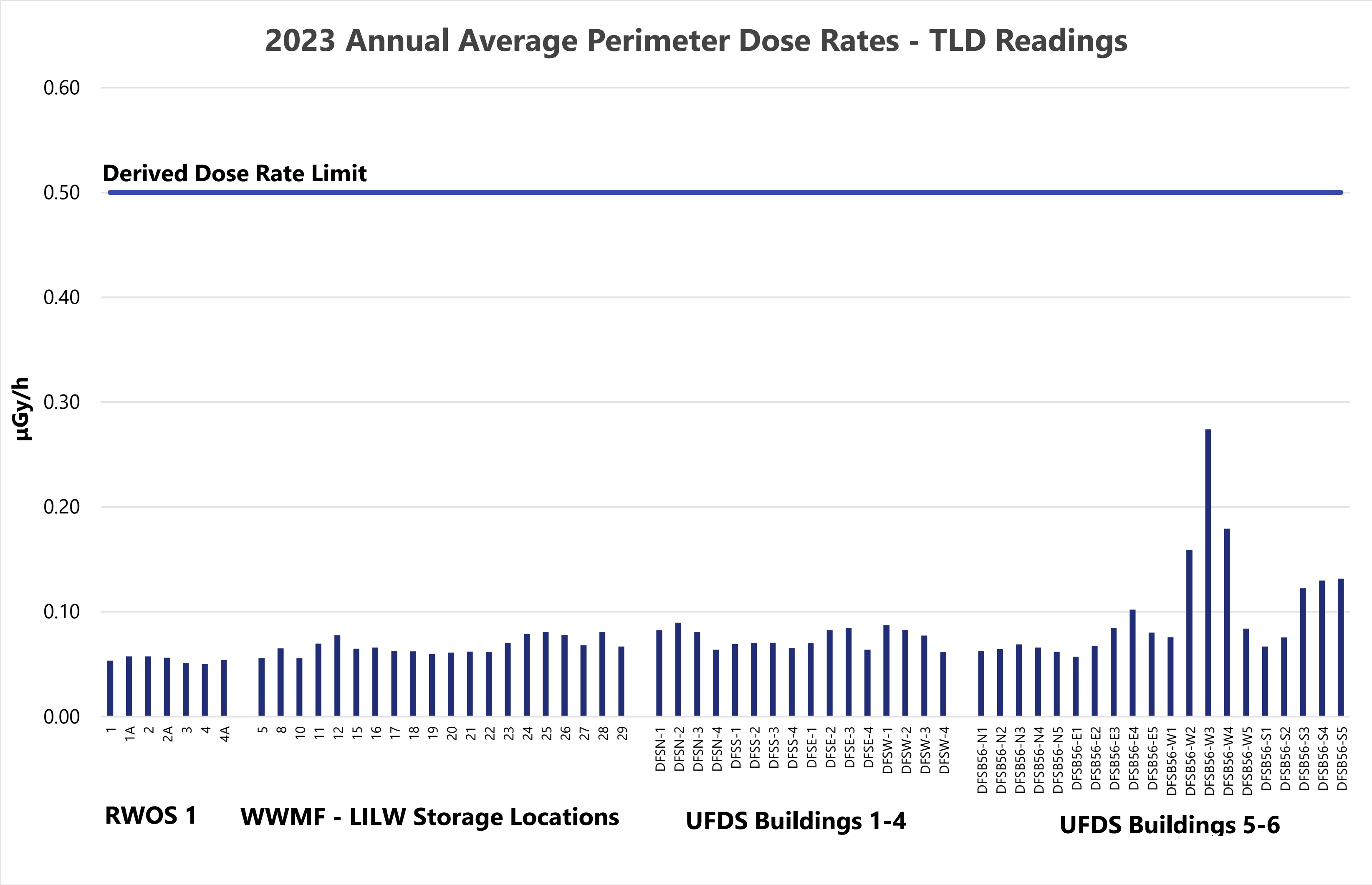

Figure 2.7: 2023 TLD Results

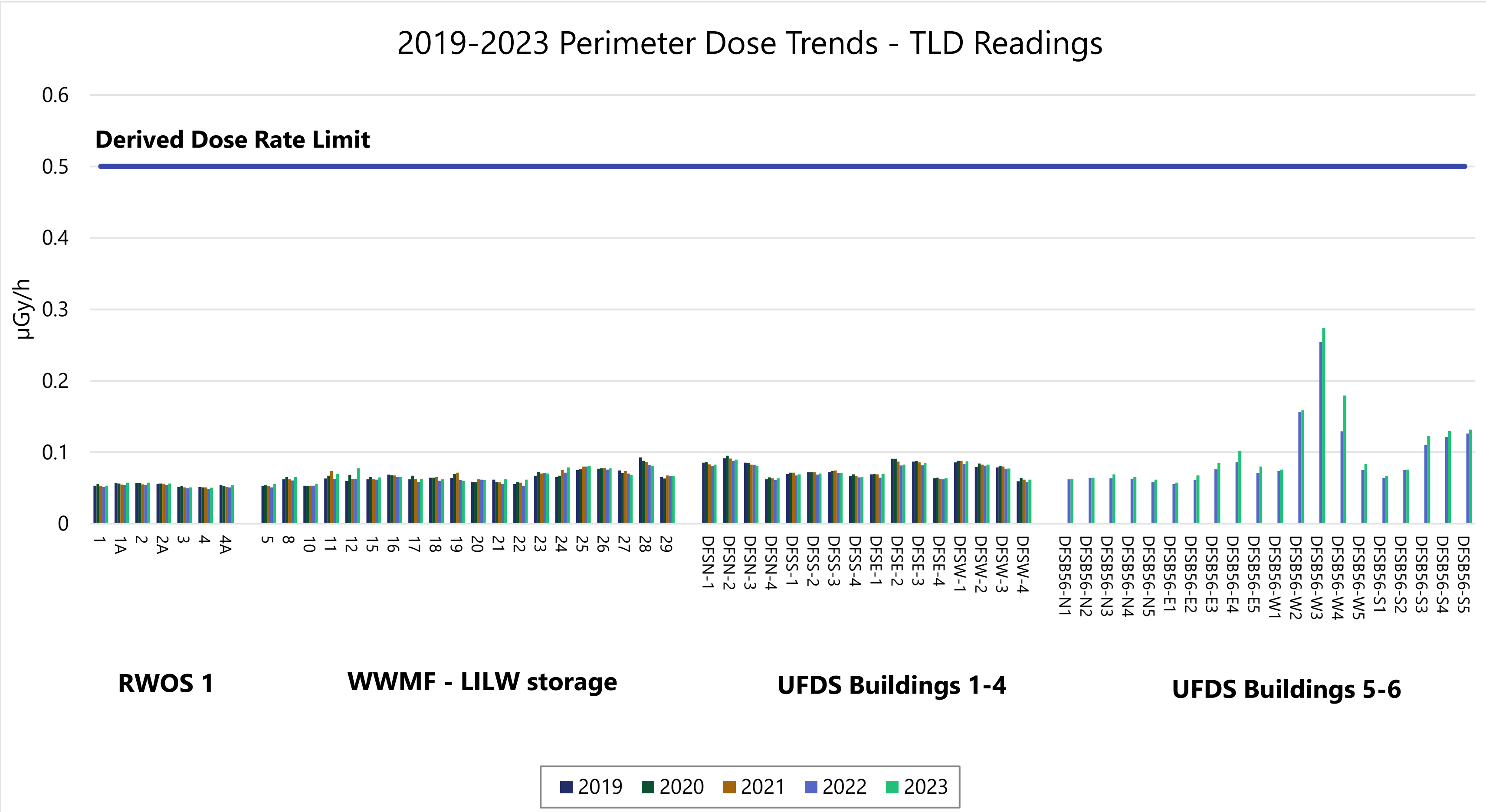

Figure 2.8: 2019-2023-TLD Results

2.3.3 Groundwater Monitoring Results

Of the 45 wells monitored in 2023 at the NSS-WWMF in the bedrock and the MSA, 19 wells are monitored for tritium activity bi-annually and 26 are monitored annually. Wells WSH 251, WSH 260, WSH 264, and WSH 268 are monitored once every two years, and were not monitored in 2023. Of the wells monitored in 2023, seven are historical wells that were re-established in 2022 including WSH 245, WSH 252, WSH 256, WSH 267, WSH 275, WSH 276, WSH 277, and six were newly established in 2022, including WSH 301, WSH 302, WSH 307, DGRB12, DGRB12A and DGRB14. Monitoring of WSH 233, WSH 241, WSH246, WSH 248 and WSH 271 was discontinued at the NSS-WWMF in the first quarter of 2022. Analysis results for all wells sampled on a bi-annual basis are shown in Table 2.2. Wells that are monitored annually are shown in Table 2.3. At RWOS 1 the bedrock aquifer is monitored for tritium activity semi-annually in five wells, and monthly for tritium and gross β at two surface water locations (Ditch N, Ditch S), shown in Table 2.2 and Table 2.4 respectively, Monitoring of WSH 127 and WSH 20S was discontinued at RWOS 1 in the first quarter of 2022.

In 2023, all of the RWOS 1 wells and 38 of the 45 NSS-WWMF wells measured had annual average tritium concentrations in groundwater below 500 Bq/L. Wells with average tritium concentrations higher than 500 Bq/L include WSH 229 (808 Bq/L), WSH 230 (732 Bq/L), WSH 231 (7,585 Bq/L), WSH 253 (21,050 Bq/L), WSH 255 (3,048 Bq/L), WSH 257 (3,570 Bq/L), WSH 265 (508 Bq/L) and WSH 282 (640 Bq/L). Tritium in WSH 231, which characterizes the MSA, averaged 7,585 Bq/L over the year, and never exceeded the level of 60,000 Bq/L at which OPG has committed to notify the CNSC [5]. A negative trend was identified for tritium concentrations at WSH 231 between 2019 and 2023 ($p<0.001$), indicating that tritium is steadily decreasing at this station over time. The highest tritium concentrations were measured at WSH 253, located close to WSH 231 with an annual average of 21,050 Bq/L. A negative trend was identified for tritium concentrations at WSH 253 between 2019 and 2023 ($p=0.003$), indicating that tritium is steadily decreasing at this station over time. This is the first detection of a significant decreasing trend at station WSH 253, indicating improvements since monitoring for this well began in 2017. The 2023 average tritium concentrations in groundwater for all WSHs are shown in Figure 2.9.

In 2023, gross β levels at RWOS 1 were only measured in surface water at the Ditch N and Ditch S locations. Ditch N averaged 0.120 Bq/L and ranged from 0.085 Bq/L to 0.164 Bq/L. Ditch S averaged 0.114 Bq/L and ranged from 0.0809 Bq/L to 0.194 Bq/L (Table 2.4). Examination of gross β in groundwater across the site was discontinued at the end of 2021 based on the results of the Conceptual Site Model and the Groundwater Protection and Monitoring Program development per CSA N288.7 [25] [26].

Historic data for tritium activity in the WSHs of both sites from 2019 to 2023 was analyzed for the presence of statistically significant trends over this 5-year period. The Mann-Kendall Test was used for trend analysis and tested for evidence of a statistical increasing or decreasing trend at the 95% confidence level. The results of the trend analyses for tritium in the NSS-WWMF wells indicated that WSH 230, WSH 257, and WSH 285 showed an increasing trend, however increases are minor, and concentrations of tritium remain well below the level of 60,000 Bq/L at which OPG has committed to notify the CNSC.

The increasing trend observed at WSH230 is discussed in the 2023 NSS-WWMF Groundwater Program report [27] and is known to result from migrating tritium and not from any new sources to groundwater. Low levels of tritium are migrating to the northwest in the groundwater in bedrock (HU7), however concentrations are still approximately one order of magnitude lower than concentrations in the overlying MSA at WSH231, where tritium levels are steadily decreasing. This increase in HU7 is expected as part of the vertical migration of tritium in groundwater originating from beneath the LLSBs #1 to #5, primarily, and is migrating downwards from the MSA into the deeper bedrock aquifer.

For wells WSH257 and WSH285, the concentrations observed in 2023 remain relatively low at these locations and are in a similar range to what was observed historically (2017 and 2018) for these locations. Notably, the statistically significant trend observed between 2019 to 2023 is no longer present when historical data from 2017 and 2018 are included in the Mann Kendall statistical analysis. Tritium in groundwater at WSH257 is influenced by the LLSB. In WSH285, tritium concentrations are increasing very gradually; however, tritium concentrations are still within the range of concentrations observed in the wells south of the ICs, tile holes and Quadricells and the slow increase is considered related to migration of groundwater across the area and not an inadvertent release. WSH257 and WSH285 continue to be monitored and analyzed for future trends consistent with the objectives of the Groundwater Protection and Monitoring Program [26].

Of the remaining NSS-WWMF wells, six (6) had a decreasing tritium trend (WSH 226, WSH 231, WSH 243, WSH 253, WSH 263, WSH 284) and the remainder had no statistically significant trend.

From 2019 to 2023, in RWOS 1 surface water samples, there we no significant trends in tritium or gross β levels detected.

These results indicate that there are no elevated radionuclide concentrations in groundwater leaving the NSS-WWMF in the bedrock aquifer. However, the localized elevated tritium in WSH 231 and WSH 253 indicate that there was a path from a source of elevated tritium concentration to groundwater in the MSA. There have been investigations to determine the source, which point to tritiated water vapour from waste stored in the LLSBs [27]. Remedial actions have been taken since 2007, which included resealing of select LLSB sumps and regular pump-outs of Electrical Manholes to prevent downgradient migration of tritiated groundwater. Water removed from the NSS-WWMF storage structures and building sumps is noted to be transferred to Bruce Power's Active Liquid Waste (ALW) system. Additionally, the tritium inventory in this area continues to decrease due to decay and off-gassing. As stated above, tritium levels in both WSH 231 and WSH 253 showed a statistically significant decreasing trend over the 2019 to 2023 period ($p<0.001$ and $p=0.003$, respectively). WSH 231 and the neighbouring WSH 253 annual averages over this period are plotted in Figure 2.10.

Table 2.2: 2023 Groundwater Monitoring Results (Bq/L)

WSH	Q2 HTO	Q4 HTO	Annual Average	
			HTO	Uncertainty [a]
RWOS 1				
122	1.71E+02	9.88E+01	1.35E+02	1.02E+02
123	6.29E+02	3.05E+02	4.67E+02	4.58E+02
124	2.05E+02	1.97E+02	2.01E+02	1.20E+01
125	1.79E+02	1.74E+02	1.77E+02	7.07E+00
126	1.89E+02	1.82E+02	1.86E+02	9.90E+00
NSS-WWMF				
226	**7.23E+00**	**7.51E+00**	7.37E+00	3.96E-01
228	1.79E+02	1.66E+02	1.73E+02	1.84E+01
229	7.87E+02	8.30E+02	8.08E+02	6.03E+01
230	6.96E+02	7.67E+02	7.32E+02	1.00E+02
231	8.65E+03	6.53E+03	7.59E+03	3.00E+03
240	**8.62E+00**	**8.20E+00**	8.41E+00	5.94E-01
242	4.53E+01	5.42E+01	4.98E+01	1.26E+01
243	2.59E+02	3.12E+02	2.85E+02	7.57E+01
253	1.99E+04	2.22E+04	2.11E+04	3.25E+03
255	3.13E+03	2.97E+03	3.05E+03	2.33E+02
265	4.96E+02	5.20E+02	5.08E+02	3.46E+01
269	4.81E+02	4.39E+02	4.60E+02	6.01E+01
276	3.34E+01	1.96E+01	2.65E+01	1.96E+01
282	6.17E+02	6.63E+02	6.40E+02	6.58E+01
283	1.48E+02	1.99E+02	1.73E+02	7.14E+01
284	3.77E+02	4.16E+02	3.96E+02	5.47E+01
285	3.85E+02	3.77E+02	3.81E+02	1.13E+01
286	3.85E+02	2.89E+02	3.37E+02	1.36E+02
287	2.86E+02	2.89E+02	2.87E+02	3.54E+00

Note:
Bolded values indicate measurements under the detection limit.
Values in grey are an average of two samples taken within a quarter.
[a] Uncertainty in annual average is given as ± 2 standard deviations

Table 2.3: 2023 Annual Tritium in Yearly Monitored Groundwater Wells (Bq/L)

WSH	Q2 HTO
NSS-WWMF	
224	5.79E+01
232	1.15E+01
237	**9.43E+00**
238	**6.67E+00**
239	**9.80E+00**
244	4.99E+01
245	8.20E+00
249	7.41E+00
251	NS
252	6.32E+03
256	2.85E+03
257	3.57E+03
259	1.18E+03
260	NS
263	5.26E+01
264	NS
267	**8.17E+00**
268	NS
270	**8.10E+00**
272	2.97E+02
275	**7.61E+00**
277	4.51E+02
278	1.36E+01
279	1.91E+02
301	**7.79E+00**
302	NS
307	**7.74E+00**
DGRB12	8.64E+01
DGRB12A	**7.80E+00**
DGRB14	4.42E+01

Note:
Bolded values indicate measurements under the detection limit.
Values in grey are an average of two samples taken within a quarter.
NS: Not Sampled as part of the 2023 EMP. These stations will be sampled again in 2024.

Table 2.4: 2023 Groundwater Monitoring Results RWOS 1 Surface Water (Bq/L)

Date	Discharge HTO Ditch (N)		Discharge HTO Ditch (S)	
	Tritium (Bq/L)	Gross β (Bq/L)	Tritium (Bq/L)	Gross β (Bq/L)
2023-01-10	2.04E+02	9.74E-02	1.31E+02	5.40E-02
2023-02-08	2.70E+02	1.33E-01	1.72E+02	1.09E-01
2023-03-10	2.45E+02	1.33E-01	1.56E+02	9.38E-02
2023-04-04	2.93E+02	1.38E-01	1.33E+02	8.09E-02
2023-05-09	2.58E+02	9.78E-02	3.02E+02	9.62E-02
2023-06-06	2.38E+02	8.53E-02	3.29E+02	1.10E-01
2023-07-05	2.31E+02	1.12E-01	NS	NS
2023-08-10	2.14E+02	1.02E-01	2.19E+02	1.71E-01
2023-09-06	2.18E+02	1.36E-01	2.03E+02	1.40E-01
2023-10-12	2.31E+02	1.64E-01	1.83E+02	1.94E-01
2023-11-07	3.05E+02	1.30E-01	2.12E+02	1.15E-01
2023-12-07	2.43E+02	1.09E-01	1.51E+02	8.82E-02
Annual Average	2.46E+02	1.20E-01	1.99E+02	1.14E-01
Annual Uncertainty[a]	6.18E+01	4.54E-02	1.30E+02	8.11E-02

Note:
Bolded values indicate measurements under the detection limit.
NS – Indicates no sample was taken.
[a] Uncertainty in annual average is given as ± 2 standard deviations

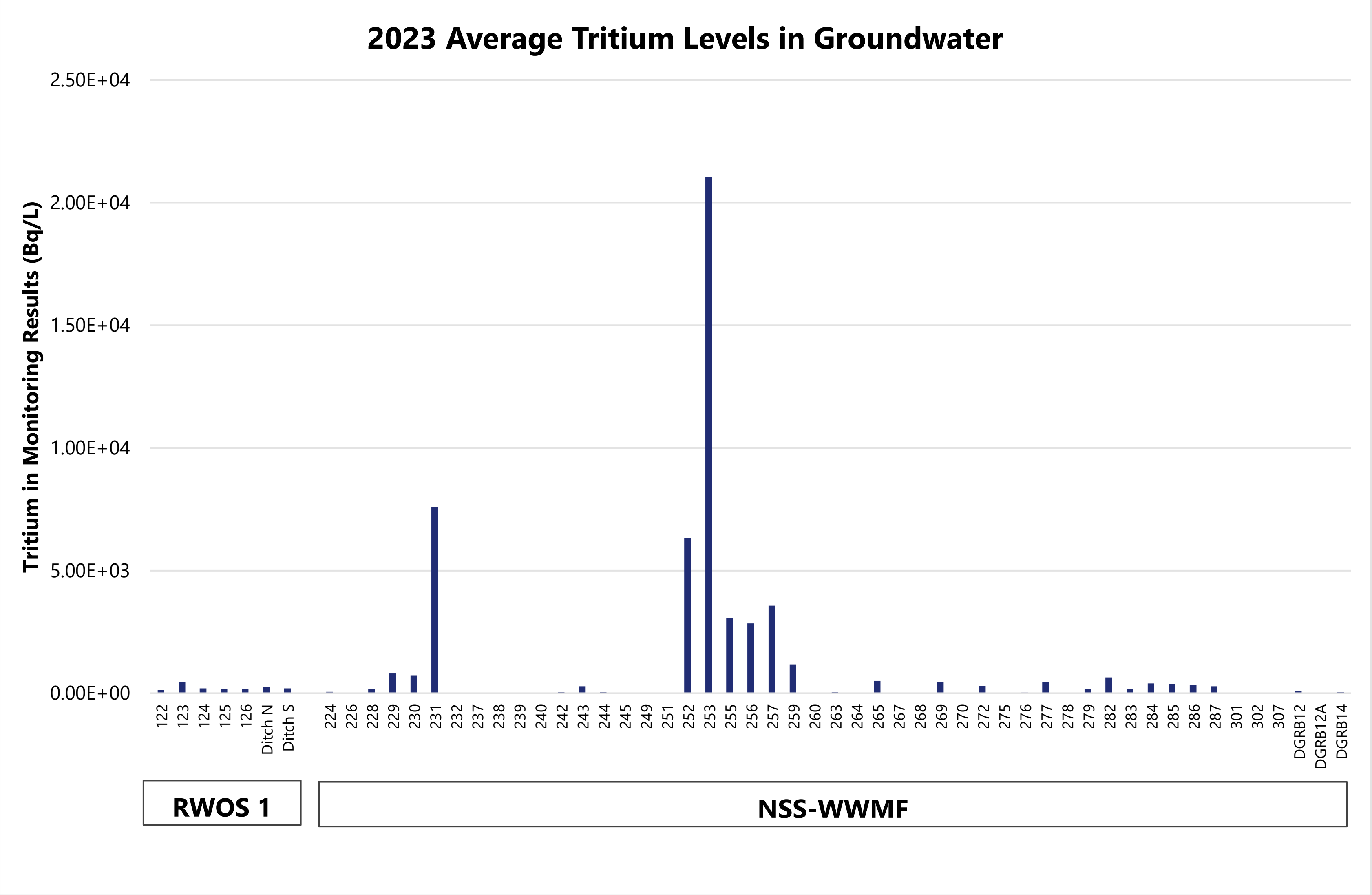

Figure 2.9: 2023 Average Annual Tritium Levels in Groundwater Monitoring Wells

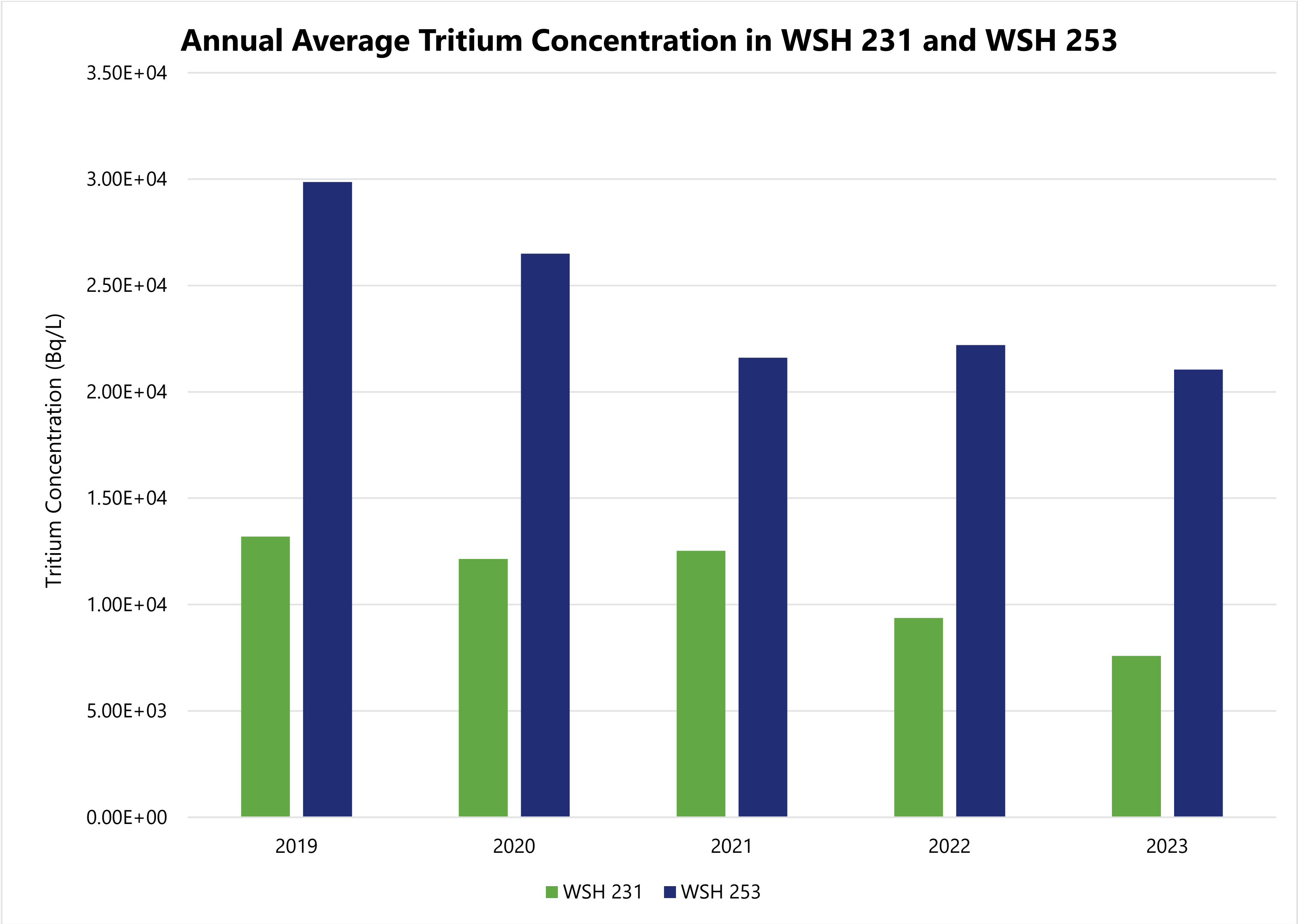

Figure 2.10: 2019 to 2023 Annual Average Concentration of Tritium in Groundwater at Well WSH 231 and WSH 253

2.3.4 Water and Sediment in South Railway Ditch, East Stormwater Management Pond, and Wetland

As previously noted in Section 2.2.5, additional sampling may occur, as required, in support of future iterations of the NSS-WWMF's environmental risk assessment (ERA). In 2023, no additional water or sediment sampling was conducted within the South Railway Ditch, the Wetland or the East Stormwater Management Pond. For further information regarding past sampling programs conducted at these locations in support of the 2021 NSS-WWMF ERA, the reader is referred to the 2022 NSS-WWMF EMP report [22].

2.3.5 Water in South Railway Ditch and East Stormwater Management Pond

Tritium concentrations in the SRD and East Stormwater Management Pond were measured four times in 2023. The mean annual concentrations at each location are shown in Table 2.5. All locations were analyzed for statistically significant trends at the 95% significance level using the Mann-Kendall Test. Using measured tritium concentrations from 2019 to 2023 a statistically significant increasing trend was detected at WOD4 ($p=0.027$). Historically, tritium concentrations in the SRD and East Stormwater Management Pond are known to fluctuate annually, and are hypothesized to be influenced by shifting degrees of surface water dilution stemming from changing weather conditions and water table levels. No other statistically significant trends were detected (Figure 2.11).

In 2023, the average annual tritium concentration at WOD2 was found to have more than doubled compared with the previous annual averages calculated for 2019 to 2022. While the Q1 and Q2 tritium concentrations were found to be comparable to their respective historical quarterly averages, tritium concentrations in Q3 and Q4 were measured to be 3,760 and 6,850 Bq/L, respectively, significantly higher than their historical quarterly averages. When considering the last five years of data (2019-2023), the recent Q3 and Q4 tritium concentrations are flagged as potential outliers ($p<0.05$) using Grubb's Test. At this time, the cause of the increase in tritium at WOD2 is unknown; continued monitoring will further characterize whether the 2023 Q3 and Q4 tritium concentrations are true outliers or within the range of seasonal variability. Though the Q3 and Q4 tritium concentrations at WOD2 were higher than historically recorded, the conclusions made in the 2021 WWMF ERA [8] remain valid for tritium risk to both human health and the environment, as the measured tritium concentrations are well below the risk-based values developed for the ingestion of domestic well water and water sourced from Lake Huron that were used to assess risk in the ERA.

Table 2.5: Mean Annual Tritium Concentration in 2023 at the South Railway Ditch (WOD1-5) and East Stormwater Management Pond (SMP-1)

Location	HTO (Bq/L)	Uncertainty [a]
WOD1	8.07E+02	1.20E+03
WOD2	2.99E+03	5.91E+03
WOD4	1.28E+03	9.36E+02
WOD5	1.01E+03	8.96E+02
SMP-1	7.15E+02	7.72E+02

*Uncertainty is given as ± 2 standard deviations.

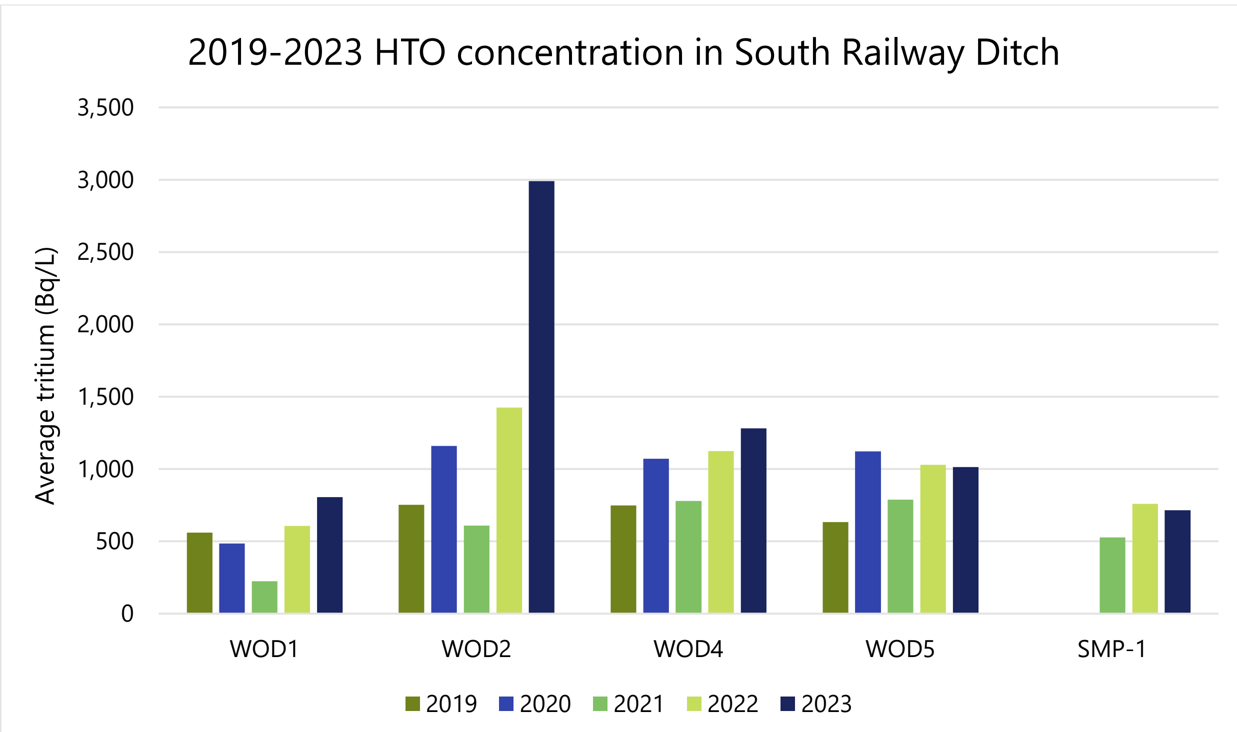

Figure 2.11: 2019-2023 Average Annual Tritium at Surface Water Sampling Locations in South Railway Ditch (WOD1-5) and East Stormwater Management Pond (SMP-1)

2.3.6 HTO in Precipitation

As of 2022, tritium is no longer monitored in precipitation at the NSS-WWMF, as per the recommendations in the 2021 NSS-WWMF ERA update [8].

2.3.7 Passive C-14 Sampling

Twenty passive monitors are used to measure C-14 in air at the NSS-WWMF on a quarterly basis. Quarterly and annual results from the passive monitors are shown in Table 2.6. Figure 2.12 shows all quarterly measurements from 2022 and 2023. Mann-Kendall testing identified that C-14 concentrations measured indicated significantly decreasing trends at passive monitor #1 from 77,700 Bq C-14 /kgC in Q1 of 2022 to 25,600 Bq C-14 /kgC in Q4 of 2023 (p=0.0187), at passive monitor #6 from 200,000 Bq C-14 /kgC in Q1 of 2022 to 77,900 Bq C-14 /kgC in Q4 of 2023 (p=0.0187), and at passive monitor #8 from 114,000 Bq C-14 /kgC in Q1 of 2022 to 48,100 Bq C-14 /kgC in Q4 of 2023 (p=0.0187). No other statistically significant trends were noted.

The elevated concentrations of C-14 at IC-18s are attributed to the storage of spent moderator ion exchange (IX) resin, and are subsequently investigated separately. C-14 concentration in air is highest in Area 1 (samplers 1-9), and in Area 2 (samplers 10-15). The highest concentration in Area 2 is noted for sampler #12 located at the center of the IC-18s (Figure 2.12). Sampler #12 is located beside an in-ground storage container (IC) known to contain the highest concentration of C-14, which was opened in May of 2022 to place a scrubber inside the IC-18s to mitigate future release of C-14, likely causing the large increase in C-14 concentrations in that sampler during Q2 2022. Between 2021 and 2023, 10 scrubbers have been installed in select IC-18s to mitigate C-14 emissions.

Figure 2.13 shows C-14 concentrations from the Bruce Power passive air sampler located closest to the IC-18s (i.e., B#3, Figure 2.13) and one representing background (i.e., B#13, Figure 2.13) for comparison. No statistically significant trends were noted with the Mann-Kendall Test based on the annual averages of C-14 at the NSS-WWMF for samplers B#3 (Near IC-18) and B#13 (background).

Table 2.6: 2023 C-14 Passive Air Sampling Results

Location	Q1 (Bq C-14 /kgC)	Q2 (Bq C-14 /kgC)	Q3 (Bq C-14 /kgC)	Q4 (Bq C-14 /kgC)	Annual Average (Bq C-14 /kgC)	Uncertainty [a] (Bq C-14 /kgC)	Annual Average (Bq/m^3)	Uncertainty [a] (Bq/m^3)
Area 1: Phase I-III								
#1	6.50E+04	3.34E+04	3.58E+04	2.56E+04	4.00E+04	3.45E+04	8.79E+00	7.59E+00
#2	7.95E+04	6.14E+04	4.06E+05	2.96E+04	1.44E+05	3.52E+05	3.17E+01	7.74E+01
#3	3.65E+04	1.85E+04	4.10E+04	2.24E+04	2.96E+04	2.17E+04	6.51E+00	4.77E+00
#4	4.41E+04	3.26E+04	5.19E+04	3.55E+04	4.10E+04	1.75E+04	9.03E+00	3.85E+00
#5	1.43E+05	6.77E+04	7.59E+04	3.23E+04	7.97E+04	9.25E+04	1.75E+01	2.03E+01
#6	1.95E+05	1.40E+05	1.05E+05	7.79E+04	1.29E+05	1.01E+05	2.85E+01	2.22E+01
#7	2.62E+05	1.18E+05	1.39E+05	6.55E+04	1.46E+05	1.66E+05	3.21E+01	3.66E+01
#8	9.45E+04	4.49E+04	5.02E+04	4.81E+04	5.94E+04	4.70E+04	1.31E+01	1.03E+01
#9	3.36E+05	1.82E+05	5.24E+05	8.34E+04	2.81E+05	3.85E+05	6.19E+01	8.46E+01
Area 2: Stage 6								
#10	2.67E+05	1.08E+05	1.20E+05	2.57E+05	1.88E+05	1.71E+05	4.14E+01	3.77E+01
#11	5.45E+04	2.39E+04	2.90E+04	3.41E+04	3.54E+04	2.68E+04	7.78E+00	5.90E+00
#12	2.21E+05	1.08E+05	1.02E+05	1.70E+05	1.50E+05	1.13E+05	3.31E+01	2.48E+01
#13	1.29E+05	3.72E+04	6.09E+04	1.52E+05	9.48E+04	1.09E+05	2.09E+01	2.40E+01
#14	3.00E+04	5.53E+03	1.50E+04	1.50E+04	1.64E+04	2.02E+04	3.60E+00	4.45E+00
#15	3.09E+05	3.81E+04	1.21E+05	1.80E+05	1.62E+05	2.28E+05	3.56E+01	5.01E+01
Area 3: Batch 5								
#16	3.42E+04	5.97E+03	1.54E+04	9.18E+03	1.62E+04	2.53E+04	3.56E+00	5.56E+00
#17	6.67E+03	2.45E+03	3.69E+03	4.97E+03	4.45E+03	3.61E+03	9.78E-01	7.94E-01
#18	7.72E+03	2.41E+03	3.53E+03	4.91E+03	4.64E+03	4.58E+03	1.02E+00	1.01E+00
#19	8.08E+03	3.23E+03	3.76E+03	5.71E+03	5.20E+03	4.40E+03	1.14E+00	9.68E-01
#20	6.96E+03	1.99E+03	3.67E+03	3.52E+03	4.04E+03	4.19E+03	8.88E-01	9.21E-01

Note: *Uncertainty is given as ±2 standard deviations.

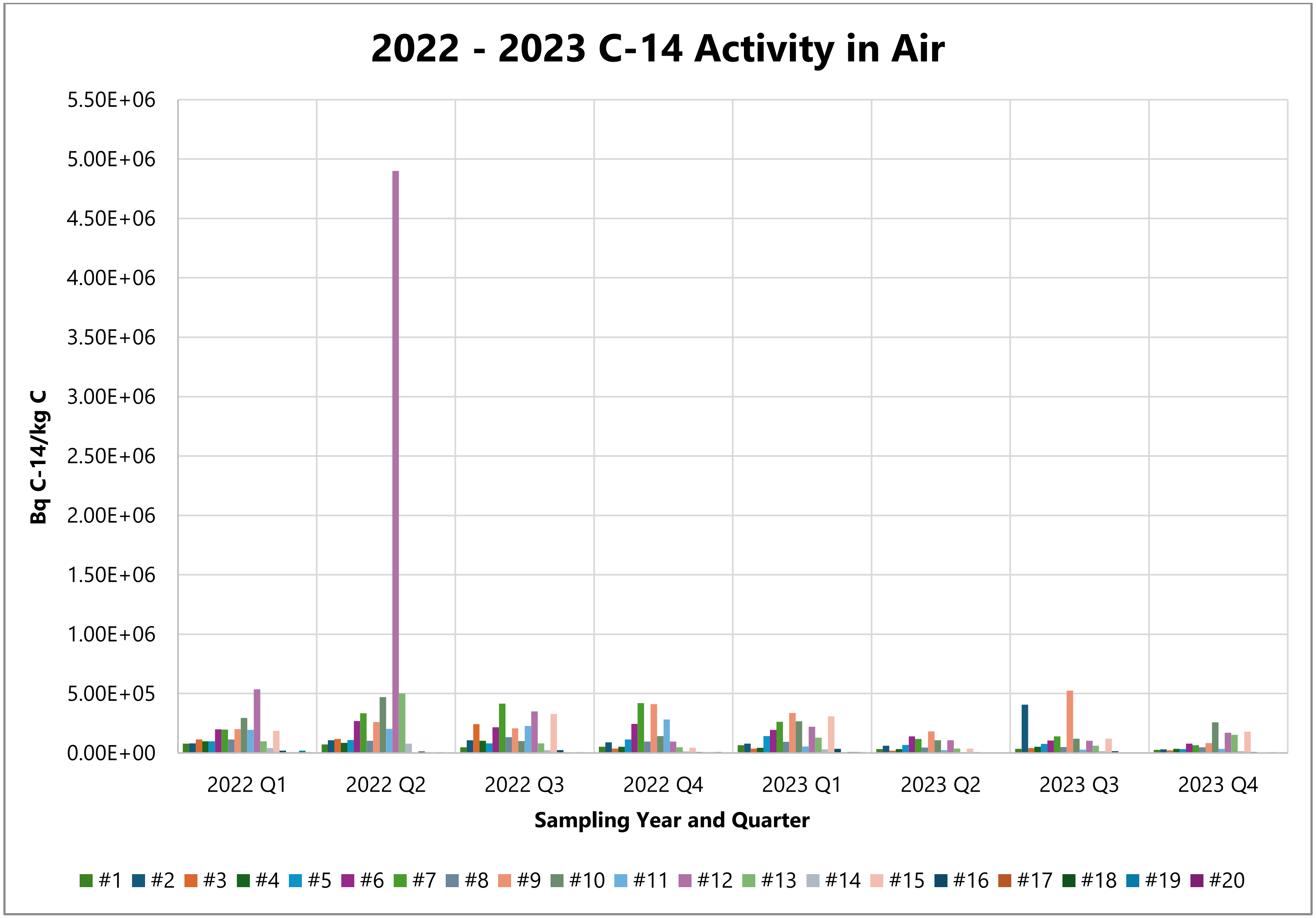

Figure 2.12: 2022 and 2023 C-14 concentration at the Passive Air Samplers by Quarter

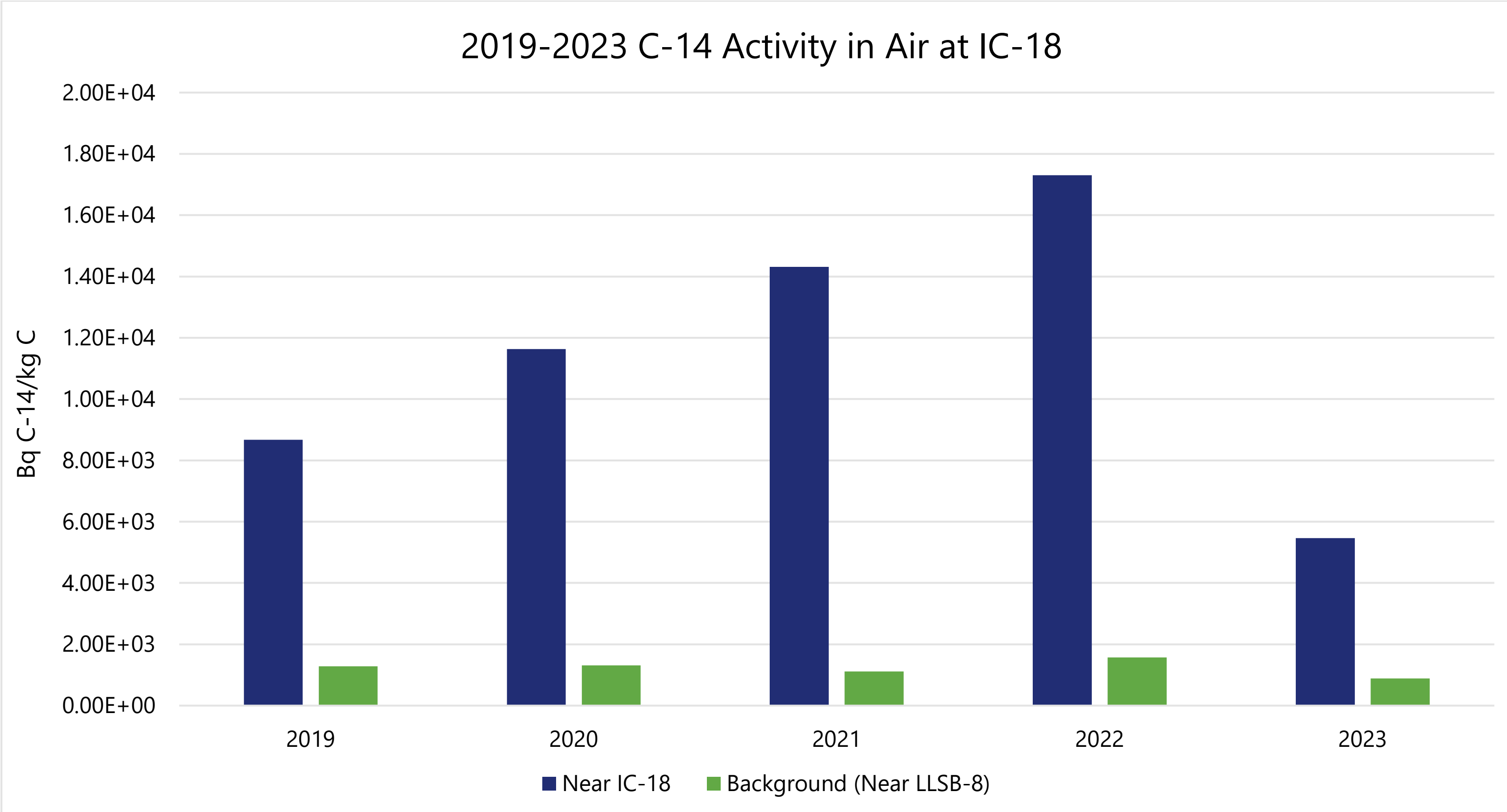

Figure 2.13: 2018-2022 C-14 Average Annual Concentration at NSS-WWMF for Samplers B#3 (Near IC-18) and B#13 (Background)

3.0 Radiological Dose to the Public

One NSS-WWMF EMP objective is to demonstrate that the radiological risk to the public from the operation of NSS-WWMF is low and any potential dose to the public is below the regulatory dose limit of 1 mSv/a. Non-NEWs on site may be exposed to direct/in-direct radiation from NSS-WWMF facilities or RWOS 1. The regulatory dose limit for these workers is the same as for members of the public. OPG has also committed to keeping levels of tritium in drinking water, due to operation of OPG facilities, below 100 Bq/L on an annual average basis at nearby WSPs.

3.1 Public Radiological Dose Estimation Results

As discussed in Section 2.2.1, the calculated public radiological dose based on measurements of radioactivity in environmental media outside the Bruce nuclear site is the result of public exposure to the combined emissions of all facilities on the Bruce nuclear site.

3.1.1 Basis for Calculation of Dose to Members of the Public

Bruce Power calculates the public radiological dose to the various surrounding population groups most likely to receive the highest doses. These groups are referred to as the potential critical groups. The methodology used follows the guidance provided in CSA N288.1-14 [28]. Public dose is calculated using mostly measured concentrations of radionuclides in the environment, exposure pathways for the identified potential critical groups, and critical group characteristics. Important pathways and group characteristics were determined by a pathways analysis and a site-specific survey. Further information on how Bruce Power determines public dose can be found in Bruce Power's annual environmental report [4].

3.1.2 Public Dose from NSS-WWMF Operations

Bruce Power reported the annual public dose to be 1.4 µSv to the Bruce Subsistence Farmer (child) in 2023 based on results from their 2023 EMP [4]. This is approximately three orders of magnitude below the public dose limit of 1 mSv/a. The public dose arising from NSS-WWMF operations is a portion of the 1.4 µSv value. Thus, the dose to members of the public from NSS-WWMF operations is well below the regulatory limit.

3.2 Tritium Levels at Nearby Water Supply Plants

The WSPs influenced by NSS-WWMF emissions are the same as those monitored by Bruce Power in their EMP, that is, the Kincardine WSP and the Southampton WSP. For 2023, Bruce Power reported that the annual average tritium in drinking water at these WSPs was 2.81 Bq/L at the Kincardine WSP and 10.2 Bq/L at the Southampton WSP [4]. These are well below the Ontario Drinking Water Standard for tritium of 7,000 Bq/L, and meet OPG's commitment to keep these levels below 100 Bq/L on an annual average basis.

3.3 Direct Gamma Radiation Exposure

The NSS-WWMF facilities, including the UFDSF and RWOS 1 are relatively far from the Bruce nuclear site boundaries. Gamma radiation and skyshine from the NSS-WWMF facilities is attenuated to a very large degree at and beyond the site boundaries and does not contribute significantly to public dose. The gamma dose and skyshine were measured at the RWOS 1 and NSS-WWMF facility boundaries (see Section 2.3.2) to ensure that non-NEWs did not receive doses that exceed the regulatory limit. The TLD measurements for 2023 showed that doses at all locations around the facility boundaries were around 0.1 µGy/h, compared to the derived dose rate limit of 0.5 µGy/h.

3.4 Radiation Dose from C-14 in Air

Dose related to C-14 emissions is expected to be negligible for human and non-human receptors. Using average C-14 concentration in air at the IC-18s (Figure 2.13) from 2023 of 5.47E+03 Bq/kgC, the dose in a worst-case scenario to a non-NEW worker at the fence line of the NSS-WWMF can be estimated. In the case of 8-hour occupancy year-round, the expected dose due to C-14 inhalation is estimated to be 0.02 µSv/a. This is well below the dose limit for a non-NEW of 1,000 µSv/a.

Sampling close to the IC-18s found that the concentration of C-14 in grass is comparable to the concentration in air on a Bq/kgC basis. From this, the dose to non-human biota (grasses) in the immediate vicinity of the C-14 emission was estimated. Calculated dose rates to grasses were determined to be 3.72E-04 mGy/day, well below the terrestrial dose benchmark of 2.4 mGy/day [9], [29].

3.5 Discussion of Results

All direct and indirect estimations of radiological dose to members of the public, including non-NEWs on-site, produced results well below regulatory limits. Additionally, the tritium levels at WSPs were well below the OPG commitment level of 100 Bq/L. These results indicate that the NSS-WWMF is meeting its EMP objectives in these areas.

Table 3.1: Radiological Emissions from Bruce Nuclear Site Facilities (Bq/year)

Parameter	Bruce A	Bruce B	CMF	CSF	NSS-WWMF[b]	CNL	Kinectrics KI[c]	Total	% NSS-WWMF
Airborne Emissions (Bq/year)									
Tritium Oxide	8.8E+14	4.4E+14	3.7E+09	1.8E+11	1.5E+13	2.7E+11	1.3E+11	1.3E+15	1.12%
Noble gas (Bq-MeV/year)	7.4E+13	2.2E+13	NA	NA	NA	NA	NA	9.6E+13	NA
Iodine-131	1.4E+07	4.9E+05	0.0E+00	NA	1.2E+05	NA	NA	1.5E+07	0.82%
Particulate Beta/Gamma[a]	2.5E+06	6.8E+06	0.0E+00	0.0E+00	5.1E+05	1.3E+05	NA	9.9E+06	5.13%
Particulate-Gross Alpha	4.3E+04	1.2E+05	2.2E+03	NA	NA	NA	NA	1.7E+05	NA
Carbon-14	1.8E+12	8.7E+11	NA	NA	2.1E+10	NA	NA	2.7E+12	0.78%
Waterborne Emissions (Bq/year)									
Tritium Oxide	2.6E+14	7.2E+14	-	-	NA	2.4E+10	NA	9.8E+14	NA
Carbon-14	8.4E+09	4.7E+09	-	-	NA	NA	NA	1.3E+10	NA
Gross Beta/Gamma	1.5E+09	3.2E+09	-	-	NA	NA	NA	4.7E+09	NA
Gross Beta	NA	NA	-	-	NA	8.2E+06	NA	8.2E+06	NA
Gross Alpha	1.6E+05	3.7E+05	-	-	NA	8.0E+06	NA	8.6E+06	NA

Notes:

a) Naturally occurring radionuclide material detected in gamma spectrum analysis is not reported.

b) This is the net airborne emission from KI North Facility for the period of December 31, 2022 to December 30, 2023.

c) Beginning in January 2021, waterborne emissions from the NSS-WWMF are no longer reported under the effluent monitoring program since surface discharge is stormwater and subsurface discharge is groundwater. Effluent from the NSS-WWMF is not released into the stormwater system – any tritium in stormwater is from atmospheric deposition.

< Ld = less than limit of detection

4.0 Quality Assurance and Performance

The NSS-WWMF EMP design report recommends that a QA/QC program for the NSS-WWMF EMP be implemented and that it should be based on OPG's existing EMP QA manual (for Darlington and Pickering EMPs) [24], with adjustments for the specific characteristics of the NSS-WWMF site and operations. The program would encompass all activities including field sample collection, laboratory analysis, laboratory quality control, and external laboratory intercomparison. The objectives would include ensuring that EMP samples are representative, and their analytical results are accurate, as well as complying with procedures and program quality requirements. This section provides an overview of quality assurance activities.

4.1 Laboratory Quality Assurance and Quality Control

The OPG HPL has a QA/QC program that includes measurement of environmental TLDs. The system uses TLD-100H LiF dosimeters capable of measuring gamma dose down to ambient environmental levels. These are suitable for the intended purpose. Part of the QA program is to read out eight dosimeters every quarter that were irradiated to known environmental exposures by the National Research Council Canada and achieve a mean relative bias less than ±30% and a coefficient of variation less than 0.35. In addition, the sum of the mean relative bias (as a fraction) and the coefficient of variation is required to be less than 0.50. For 2023, the OPG EGM system met these accuracy and precision requirements. Results of its HPL QA testing for 2023 were satisfactory and are documented in its annual QA report [30].

The OPG HPL has a commitment to perform a minimum of one annual independent audit of the quality system used for dosimetry and environmental measurement services. These may not always be related to the EMPs. In 2023, an HPL QA audit was conducted on the Health Physics Laboratory Gamma Analysis Test Method.

The Health Physics Laboratory identified no significant adverse conditions. However, the audit identified one strength and eleven recommendations which will be addressed by updating procedures, performing further assessments, and implementing process improvements. The recommendations are tracked via AR 28263224.

The MECP performed Drinking Water Licence Inspections of the HPL on May 11th (announced) and November 29th (unannounced) in 2023. During the May inspection there was one finding and one request for evidence of sampling instructions provided to clients. The one finding and one request for evidence were completed (see N-CORR-03443-1335453) for details of the action taken. The responses were accepted by the MECP Inspector, and a Satisfaction Letter was provided for the inspection (see N-CORR-03443-1335447). During the November inspection there were no non-compliant findings and a final Inspection Rating of 100% was given (see N-CORR-03443-1348107) [30].

Canadian Association of Laboratory Accreditation (CALA) conducted an audit of Health Physics Environment lab from 14 – 16 November 2023 (see N-CORR-03443-1348108). This audit is on a 2-year cycle to assess accreditation of analyses performed for the Environment Monitoring Program. There were 11 findings identified during this audit. SCR N-2023-19161 (see Appendix A) was filed to document these findings and actions to address the findings. The responses for these findings were submitted to CALA, which were accepted by the CALA review panel. The HPL CALA Accreditation was renewed, and the latest certificate can be found under N-CERT-00580-13488.

Environmental tritium and gross β analysis in water samples are performed for the NSS-WWMF by the Bruce Power Health Physics laboratory. The Bruce Power Health Physics Lab operates a comprehensive QA program in accordance with ISO 14001, which includes quality control samples, blank/background samples, process control samples and externally generated proficiency testing samples. QA/QC results for testing relevant to the groundwater and surface water sample analyses, that is, HTO and gross β activity in water, met all requirements, including accuracy and precision requirements as per external laboratory testing.

4.2 Program Quality Assurance

EMP program QA includes self-assessments and audits as per the requirements of CSA N288.4-10 [2] and OPG procedures. There were no audits of the EMP program in 2023. The most recent internal audit was conducted in 2019.

4.2.1 Self-assessments

Performance Assessment

The most recent self-assessment was completed for the 2022 NSS-WWMF EMP Annual Performance Assessment (NO24-000301-SA). The assessment confirmed that all EMP design objectives were met and the results of the 2022 NSS-WWMF EMP indicated adequate protection of the public, workers, and the environment. No necessary revisions to the NSS-WWMF EMP were identified.

4.3 Program Performance

4.3.1 Sample Unavailability

Table D.1 (Appendix D) provides a summary of samples collected, the monitoring period and deviations from the Plan during the 2023 EMP, for all media.

TLD deployment and analysis and groundwater sampling and analysis are done on a planned schedule. All data were examined to determine the unavailability for 2023. Unavailability is the fraction of the total planned samples that were missed or produced invalid results. The NSS-WWMF does not currently have unavailability targets for EMP samples.

A total of 232 TLD samples were planned for 2023, consisting of quarterly samples at seven locations at RWOS 1, quarterly samples at 20 locations at the NSS-WWMF/LILW storage area, quarterly samples at 16 locations at the NSS-WWMF/UFDSF Buildings 1-4 and 20 quarterly samples (starting in Q2 2022) at the UFDSF Buildings 5-6. All 232 results were obtained and valid, producing an overall unavailability of 0%.

As per the recommendation of the 2021 ERA tritium monitoring in precipitation was discontinued in 2022.

Table E.1 (Appendix E) shows the numbers of planned and actual samples and analyses for the groundwater and ditch surface water monitoring components of the EMP, and the unavailability for these. The 2023 groundwater monitoring plan collected 106 of the planned 106 samples and had an overall unavailability of 0%.

Sampling of C-14 in groundwater was discontinued in 2022 based on the results of the Conceptual Site Model and the Groundwater Protection and Monitoring Program development per CSA N288.7.

5.0 Overall Summary of EMP

An EMP detailed design was developed for the NSS-WWMF in 2012 [7] with updates made in 2019 [3]. All objectives of the EMP concerning public and worker safety and demonstrating containment of radioactivity were met in 2023. Operation of the NSS-WWMF resulted in extremely low public dose, well below regulatory limits. The potential exposure of non-NEWs near NSS-WWMF facilities to gamma radiation and skyshine was low and well within the derived dose rate limit. Concentrations of tritium at nearby WSPs were below 100 Bq/L on an annual average basis (Objectives 1 and 7).

Measurements of TLDs around the NSS-WWMF and RWOS 1 (Objective 2) are below the derived dose rate limit of 0.5 µGy/h. Despite an increasing trend in two locations, the highest dose rate measured was 0.281 µGy/h and no effects are expected due to this exposure.

Bedrock aquifer groundwater sampling (Objective 3) indicated that there were no significant releases of radioactivity to groundwater travelling offsite. Three wells at the NSS-WWMF showed statistically significant increasing trends in tritium, however they remain well below the level of 60,000 Bq/L at which OPG has committed to notify the CNSC. Of these wells, WSH 230 (annual average 732 Bq/L) and WSH 257 (annual average 3,570 Bq/L) had concentrations above 500 Bq/L.

Previously elevated tritium levels in one area of the MSA have steadily decreased since 2009. Remedial measures taken to reduce tritium in groundwater have been effective. A statistically significant decrease in tritium concentrations in groundwater at WSH 231 was identified for the period 2019 to 2023. Comparing to the Ontario Drinking Water Quality Standards for tritium (7,000 Bq/L), there is currently no evidence of unacceptable levels of radioactivity leaving the site either in surface water or groundwater. The groundwater monitoring program has been updated to meet CSA N288.7 and implementation was initiated in 2022. Results of this program have been reported in this document and are additionally reported in a separate NSS-WWMF Annual Groundwater Report [27] which is compliant with CSA N288.7.

Monitoring of HTO in precipitation (previously objective 4) was discontinued in 2022.

Monitoring in the SRD (Objective 4) is completed as part of routine sampling. Surface water in the SRD and East Stormwater Management Pond is monitored quarterly. The supplementary study conducted in 2013, concluded that the NSS-WWMF runoff/groundwater has a negligible influence on tritium concentrations and found no statistically significant trends. A statistically significant increasing trend in tritium concentrations was detected at WOD4 between 2019 and 2023. However, tritium concentrations in the SRD and East Stormwater Management Pond are known to fluctuate annually; this is hypothesized to occur as a result of changes in surface water dilution from differing weather conditions and water table levels. No other statistically significant trends were observed in the monitored locations for 2019-2023.

No water or sediment sampling was conducted in the SRD, wetland and East Stormwater Management Pond areas of the NSS-WWMF (Objective 5) for 2023. Details of previously completed sampling programs can be found in the 2022 NSS-WWMF EMP report [22].

Increasing C-14 concentration in air at the NSS-WWMF has been attributed to moderator exchange resin stored in Area 1. A fugitive emissions reassessment has been completed to address this finding. OPG has reviewed the estimating methodology and is working with a contractor to further refine the prediction instrument. Scrubbers were installed in select ICs in 2021, 2022 and 2023 to reduce the amount of fugitive emissions to help mitigate this trend. Despite these emissions, both environmental and health physics monitoring confirm that there is no significant impact on workers, the public, or the environment.

Overall, the results of the 2023 NSS-WWMF EMP indicate confirmation of adequate protection of the public, on-site workers, and the surrounding environment.

6.0 Outlook for EMP

Ongoing implementation of the EMP design will be continued. Some additional work to address existing areas of uncertainty will also be planned. Areas that will be addressed are:

- **Surface Water:** The SRD routine and supplementary studies indicated little impact from the NSS-WWMF, with levels remaining within the range of findings in previous years. The routine tritium sampling in the SRD and East Stormwater Management Pond will continue. A supplementary study to collect water and sediment data for non-radionuclides was completed in 2020-2021 in support of the 2021 NSS-WWMF ERA update and should be repeated prior to the next ERA update.
- **Wetland sampling:** The East Wetland was sampled in 2020-2021 as part of supplementary studies to support the 2021 NSS-WWMF ERA and should be repeated prior to the next ERA update.
- **C-14 monitoring in air:** Currently implemented with a focus on the upward trend close to IC-18. Scrubbers were installed in select ICs in 2021, 2022 and 2023. Subsequent results should indicate if this mitigation is sufficient to address the recently observed upward trend.

7.0 References

[1] Canadian Nuclear Safety Commission (CNSC), "Environmental Protection: Environmental Principles, Assessments and Protection Measures, REGDOC-2.9.1, Version 1.1," 2016.

[2] Canadian Standards Association (CSA), "Environmental Monitoring Programs at Class I Nuclear Facilities and Uranium Mines and Mills, CSA N288.4-10," May 2010.

[3] Ontario Power Generation (OPG), "Western Waste Management Facility Environmental Monitoring, W-MAN-03443-00001-R001," 2019.

[4] Bruce Power, "2023 Environmental Protection Report", BP Assigned Document No. B-REP-07000-00016, May 2023.

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Appendix A Radiological Units and Conversions

Absorbed Dose

1 gray (Gy)	=	1 joule/kg

Effective Dose

1 sievert (Sv)	=	100 rem
1 millisievert (mSv)	=	100 millirem (mrem)
1 microsievert (µSv)	=	0.1 millirem (mrem)

Quantity of Radionuclide

1 becquerel (Bq)	=	1 disintegration per second
1 curie (Ci)	=	3.7×10^{10} Bq
1 mCi/(km^2·month)	=	37 Bq/(m^2·month)

Appendix B Glossary of Acronyms and Symbols

Radionuclides and Units of Measure

C-14	Carbon-14
HTO	Tritium Oxide
Gross α	Gross Alpha
Gross β	Gross Beta
μGy	microgray
μSv	microsievert
Bq	becquerel
Gy	Gray
kg	kilogram
L	Litre
mGy	milligray
mSv	millisievert
Sv	Sievert

Acronyms and Abbreviations

AECL	Atomic Energy of Canada Limited
CMF	Central Maintenance Facility
CNL	Canadian Nuclear Laboratories
CNSC	Canadian Nuclear Safety Commission
COPC	Contaminant of Potential Concern
CSA	Canadian Standards Association
CSF	Central Storage Facility
DRL	Derived Release Limit
EGM	Environmental Gamma Monitors
EMP	Environmental Monitoring Program
EMS	Environmental Management System
EPA	Environmental Protection Agency
ERA	Environmental Risk Assessment
HPL	OPG Health Physics Laboratory
IAEA	International Atomic Energy Agency
ICs	In-ground storage containers
IC-12	12 m^3 capacity ICs
IC-18	18 m^3 capacity ICs
ISO	International Organization for Standardization
KM	Kaplan-Meier Estimation Method
Lc	Critical Level

Ld	Limit of Detection
LILW	Low and Intermediate Level Waste
LLSB	Low Level Storage Building
MECP	Ontario Ministry of the Environment, Conservation and Parks
MSA	Middle Sand Aquifer
NEW	Nuclear Energy Worker
NRC	National Research Council of Canada
NSS-WWMF	Nuclear Sustainability Services – Western Waste Management Facility
OPG	Ontario Power Generation
QA	Quality Assurance
QC	Quality Control
QOR	Quarterly Operations Report
RCSB	Retube Component Storage Building
RWOS 1	Radioactive Waste Operations Site 1
SD	Standard Deviation
SGSB	Steam Generator Storage Building
SMP-1	East Stormwater Management Pond
SRD	South Railway Ditch
SSTF	Spent Solvent Treatment Facility
TLD	Thermoluminescent Dosimeter
TOC	Total Organic Carbon
TPMB	Transportation Package Maintenance Building
UFDSF	Used Fuel Dry Storage Facility
WD	West Ditch
WLILWSF	Western Low and Intermediate Level Waste Storage Facility
WSH	Water Sampling Hole
WSP	Water Supply Plant
WVRB	Waste Volume Reduction Building

Appendix C Tritium in Groundwater 2019-2023

This appendix contains the plots of tritium with statistically significant increases over the 5-year period 2019-2023. All datasets were analyzed for the presence of statistically significant trends using the Mann-Kendall test in the Microsoft Excel Real Statistics package. The results of the trend analyses are reported in Section 2.3.3.

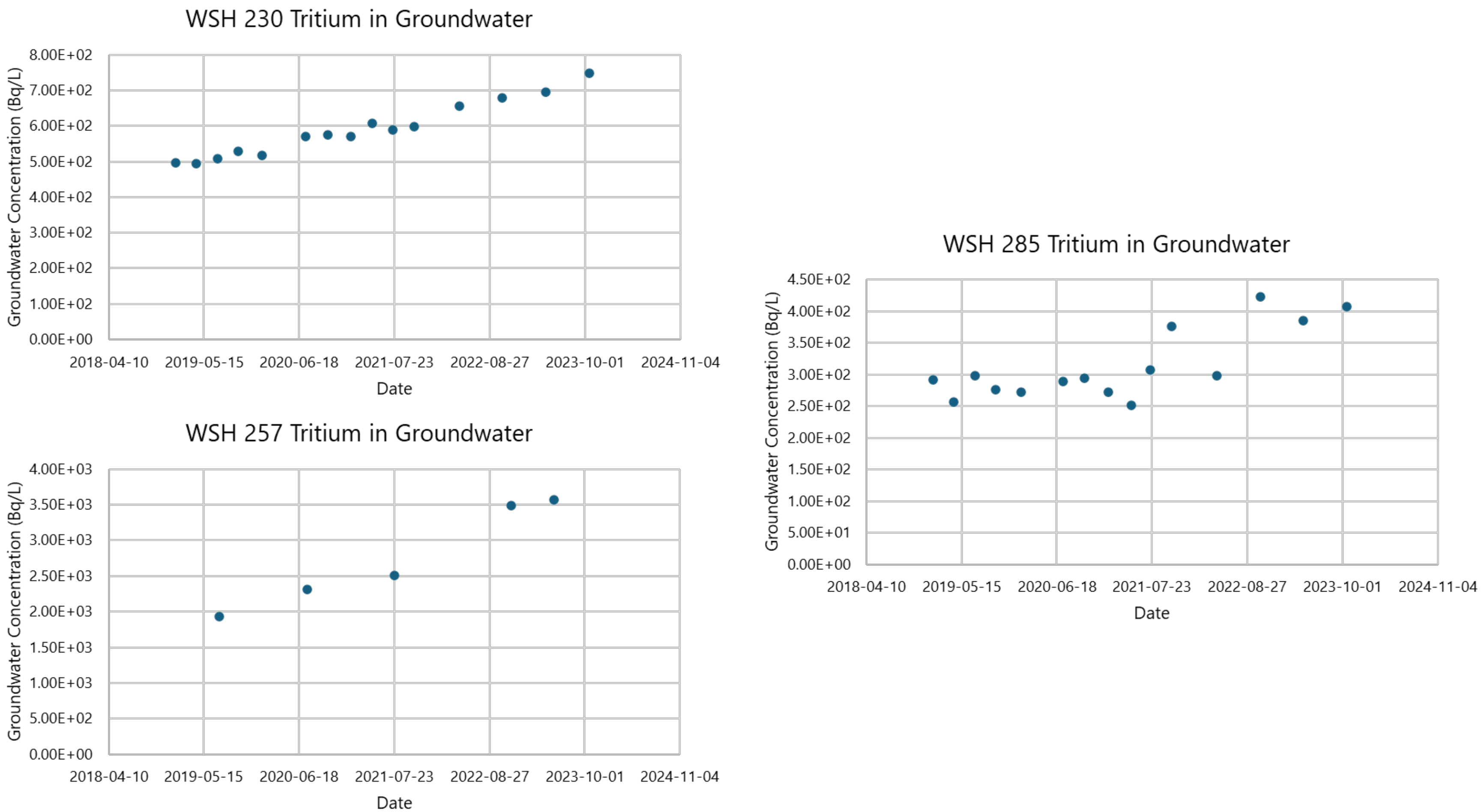

Figure C.1: Measured Tritium in Groundwater Wells with Significant Trends

Appendix D Summary of Samples Collected

Table D.1: Summary of Samples Collected, Monitoring Period and Deviation from the Plan during the 2023 EMP

Sampling Program	Monitoring Results Presented in EMP (all raw data)	Monitoring Period	Deviations from Monitoring Period	Assessment Period
Gamma Radiation Monitoring	Yes	4 quarters of 2023	No	2023, trend analysis: 2019 - 2023
Groundwater Monitoring	Yes	2023 (wells monitored either annually or bi-annually)	No	2023, trend analysis: 2019 - 2023
SRD	Yes – (presented average and 2 sigma for each measurement station consistent with the 2021 and 2022 EMP). Raw data is not provided in the EMP Report.	2023	No	2023, trend analysis 2019 - 2023
C-14 in air	Yes	2023	No (80 of the 80 planned samples were obtained)	2023, trend analysis 2022 - 2023

Appendix E Groundwater and Ditch Surface Sample Unavailability

Table E.2: 2023 Planned and Actual Samples and Analyses for Groundwater and Ditch Surface Water at NSS-WWMF

	Planned Samples								Total Planned	Total Actual	% Unavailability
	HTO				Gross β						
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4			
RWOS 1											
122	-	1	-	1	-	-	-	-	2	2	0.0
123	-	1	-	1	-	-	-	-	2	2	0.0
124	-	1	-	1	-	-	-	-	2	2	0.0
125	-	1	-	1	-	-	-	-	2	2	0.0
126	-	1	-	1	-	-	-	-	2	2	0.0
NSS-WWMF Bi-Annual											
226	-	1	-	1	-	-	-	-	2	2	0.0
228	-	1	-	1	-	-	-	-	2	2	0.0
229	-	1	-	1	-	-	-	-	2	2	0.0
230	-	1	-	1	-	-	-	-	2	2	0.0
231	-	1	-	1	-	-	-	-	2	2	0.0
240	-	1	-	1	-	-	-	-	2	2	0.0
242	-	1	-	1	-	-	-	-	2	2	0.0
243	-	1	-	1	-	-	-	-	2	2	0.0
253	-	1	-	1	-	-	-	-	2	2	0.0
255	-	1	-	1	-	-	-	-	2	2	0.0
265	-	1	-	1	-	-	-	-	2	2	0.0
269	-	1	-	1	-	-	-	-	2	2	0.0
276	-	1	-	1	-	-	-	-	2	2	0.0
282	-	1	-	1	-	-	-	-	2	2	0.0

	Planned Samples								Total Planned	Total Actual	% Unavailability
	HTO				Gross β						
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4			
283	-	1	-	1	-	-	-	-	2	2	0.0
284	-	1	-	1	-	-	-	-	2	2	0.0
285	-	1	-	1	-	-	-	-	2	2	0.0
286	-	1	-	1	-	-	-	-	2	2	0.0
287	-	1	-	1	-	-	-	-	2	2	0.0
NSS-WWMF Annual											
224	-	-	-	1	-	-	-	-	1	1	0.0
232	-	-	-	1	-	-	-	-	1	1	0.0
237	-	-	-	1	-	-	-	-	1	1	0.0
238	-	-	-	1	-	-	-	-	1	1	0.0
239	-	-	-	1	-	-	-	-	1	1	0.0
244	-	-	-	1	-	-	-	-	1	1	0.0
245	-	-	-	1	-	-	-	-	1	1	0.0
249	-	-	-	1	-	-	-	-	1	1	0.0
251	-	-	-	0	-	-	-	-	0	0	0.0
252	-	-	-	1	-	-	-	-	1	1	0.0
256	-	-	-	1	-	-	-	-	1	1	0.0
257	-	-	-	1	-	-	-	-	1	1	0.0
259	-	-	-	1	-	-	-	-	1	1	0.0
260	-	-	-	0	-	-	-	-	0	0	0.0
263	-	-	-	1	-	-	-	-	1	1	0.0
264	-	-	-	0	-	-	-	-	0	0	0.0
267	-	-	-	1	-	-	-	-	1	1	0.0
268	-	-	-	0	-	-	-	-	0	0	0.0
270	-	-	-	1	-	-	-	-	1	1	0.0

	Planned Samples								Total Planned	Total Actual	% Unavailability
	HTO				Gross β						
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4			
272	-	-	-	1	-	-	-	-	1	1	0.0
275	-	-	-	1	-	-	-	-	1	1	0.0
277	-	-	-	1	-	-	-	-	1	1	0.0
278	-	-	-	1	-	-	-	-	1	1	0.0
279	-	-	-	1	-	-	-	-	1	1	0.0
301	-	-	-	1	-	-	-	-	1	1	0.0
302	-	-	-	0	-	-	-	-	0	0	0.0
307	-	-	-	1	-	-	-	-	1	1	0.0
DGRB12	-	-	-	1	-	-	-	-	1	1	0.0
DGRB12A	-	-	-	1	-	-	-	-	1	1	0.0
DGRB14	-	-	-	1	-	-	-	-	1	1	0.0
South Railway Ditch and East Stormwater Management Pond											
WOD1	1	1	1	1	1	1	1	1	8	8	0.0
WOD2	1	1	1	1	1	1	1	1	8	8	0.0
WOD4	1	1	1	1	1	1	1	1	8	8	0.0
WOD5	1	1	1	1	1	1	1	1	8	8	0.0
SMP-1	1	1	1	1	1	1	1	1	8	8	0.0