ONTARIO POWER GENERATION	Report	Public Information	
		Document Number: W-REP-03443-00004	Usage Classification: Information
		Sheet Number: N/A	Revision: R000

Title:
2019 Results of Environmental Monitoring Program for Western Waste Management Facility

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W-REP-03443-00004
2020-08-07

Order Number: N/A
Other Reference Number:

Public Information

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2019 RESULTS OF THE ENVIRONMENTAL MONITORING PROGRAM FOR WESTERN WASTE MANAGEMENT FACILITY

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Ref. 20-2719
6 August 2020

2019 RESULTS OF THE ENVIRONMENTAL MONITORING PROGRAM FOR WESTERN WASTE MANAGEMENT FACILITY

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EXECUTIVE SUMMARY

Ontario Power Generation (OPG) maintains an environmental monitoring program (EMP) at the Western Waste Management Facility (WWMF). The detailed design of the WWMF EMP was developed in accordance with the Canadian Standards Association (CSA) N288.4-10 Environmental Monitoring Programs at Class 1 Nuclear Facilities and Uranium Mines and Mills in 2012. The 2019 program was implemented according to the recommended 2012 design. 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 WWMF and Radioactive Waste Operations Site (RWOS 1).

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

1. Assess 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 of the concentration and/or intensity of contaminants and physical stressors in the environment or assess 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 2019 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 WWMF and RWOS 1 sites. With the exception of C-14, relative contribution of dose to the public 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 WWMF property boundary was calculated using available data.

Operation of the WWMF resulted in extremely low public dose, well within regulatory limits. The potential exposure of non-Nuclear Energy workers near WWMF facilities was shown to be low and well within the derived dose rate limit. Waterborne tritium emissions from the WWMF were very low and acceptable with respect to the commitment for OPG to keep its impact on tritium levels at nearby water supply plants below 100 Bq/L on an annual average basis.

Bedrock aquifer groundwater sampling indicated that there were no significant increasing trends in radioactivity and no significant releases of radioactivity to groundwater travelling

offsite. Previously elevated tritium levels in one area of the middle sand aquifer near the Low Level Storage Buildings have steadily decreased since 2009.

Tritium sampling in precipitation and passive air sampling of C-14 have been implemented. Tritium levels in precipitation are not elevated compared to the background. C-14 activity is mainly contributed by the inground containers on the WWMF. No adverse effects to workers and non-human biota 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 2019 WWMF environmental monitoring program indicate confirmation of adequate protection of the public, workers and the environment.

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1.0 INTRODUCTION

Ontario Power Generation (OPG) owns and operates the Western Waste Management Facility (WWMF). To ensure activities at OPG facilities are conducted in a manner that minimizes any potential adverse impact on the public and the 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 [R-1]. Additionally, the OPG Environmental Management System is registered to the International Organization for Standardization (ISO) 14001 Environmental Management Systems standard [R-2].

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 to be monitored and conducts monitoring in the environment surrounding the facility.

In 2012, OPG developed a detailed design for an EMP for the 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” [R-3].

This report provides the results of the WMMF EMP for 2019.

1.1 Program Objectives

The objectives of the WWMF EMP are to:

1. Demonstrate that the radiological risk to the public due to the operation of the WWMF is low and well within the regulatory public dose limit.
2. Measure external gamma dose at the perimeter of the 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 inground storage structures at the WWMF and the RWOS 1.
4. Monitor HTO in precipitation to provide data for the purpose of establishing the source of HTO in on-site groundwater (from rainfall or from leaks/spills) and for trend analysis for tritium in precipitation.
5. Monitor the railway ditch water for tritium to show a reduction related to remedial measures taken to reduce tritium in WWMF Middle Sand Aquifer groundwater.
6. Monitor water and sediment for radionuclides and non-radioactive contaminants in the wetland east of the WWMF to confirm no ecological impact from the east site drainage discharge.
7. Demonstrate that WWMF waterborne emissions comply with OPG’s commitment to keep tritium concentrations at nearby Water Supply Plants (WSPs) below 100 Bq/L on an annual average basis.

1.2 Implementation of EMP

Implementation of the EMP design started in 2013 for the WWMF and RWOS1. See the EMP design report for a detailed description of the design [R-4]. The routine monitoring components of the EMP design were introduced in 2013.

- TLD gamma dose monitoring is fully implemented.
- Groundwater monitoring is fully implemented. The 2016 monitoring well network assessment enhanced the monitoring well network and reported on a 2-year monitoring program (August 2014 to July 2016). The assessment resulted in an expanded network of wells [R-5].
- Routine precipitation monitoring is implemented at the WWMF and at two reference locations.
- The supplementary study to monitor tritium in surface water in the South Railway Ditch was implemented and completed. Routine monitoring of the South Railway Ditch continues.
- Monitoring of surface water and sediment in the wetland east of the WWMF was completed in 2013 and 2014. The data was incorporated into the WWMF ERA [R-6].

1.3 Overview of the Western Waste Management Facility

The WWMF is located on the Bruce nuclear site on the east shore of Lake Huron approximately 18 km north of Kincardine and 17 km southwest of Port Elgin (Figure 1.1Figure 1.1: Location of Western Waste Management Facility). Although not located within the WWMF facility boundaries, the former Spent Solvent Treatment Facility (SSTF) and Radioactive Waste Operations Site 1 (RWOS 1) are located elsewhere on the Bruce nuclear site (Figure 1.2) and are owned and operated by OPG. The SSTF has not accepted spent solvent since 2003 and 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 [R-7].

The site also hosts Bruce Nuclear Generating Station A (Bruce NGS-A) and Bruce Nuclear Generating Station B (Bruce NGS-B), the Central Maintenance and Laundry Facility (CMLF), and other nuclear facilities and related infrastructures (Figure 1.2). Kinetics North Facility is located 3 km from the Bruce site. Its main function is decontamination and refurbishment of large nuclear reactor tools and equipment. The Bruce nuclear site occupies an area of 932 hectares (2300 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 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 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 Waste Container Storage Building (RWCSB), a Waste Volume Reduction Building (WVRB), and a Transportation Package Maintenance Building (TPMB). Inground structures include: Inground Containers (ICs), trenches and tile holes. Aboveground structures include the Quadricells. The Used Fuel Management Area includes a Used Fuel Dry Storage Container Processing Building and four Used Fuel Dry Storage Buildings. The WWMF licensed area also includes land that has been reserved for future expansion. The layout of the WWMF is illustrated in Figure 1.3 and Figure 2.1.

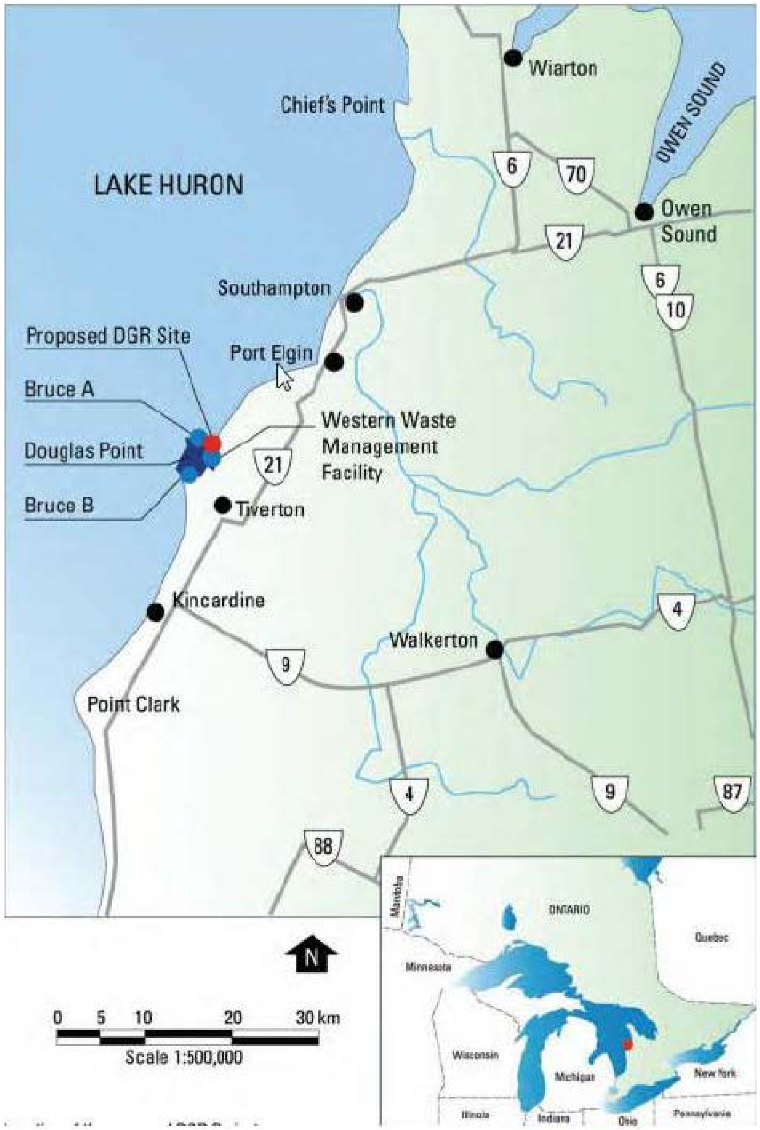

Figure 1.1: Location of Western Waste Management Facility

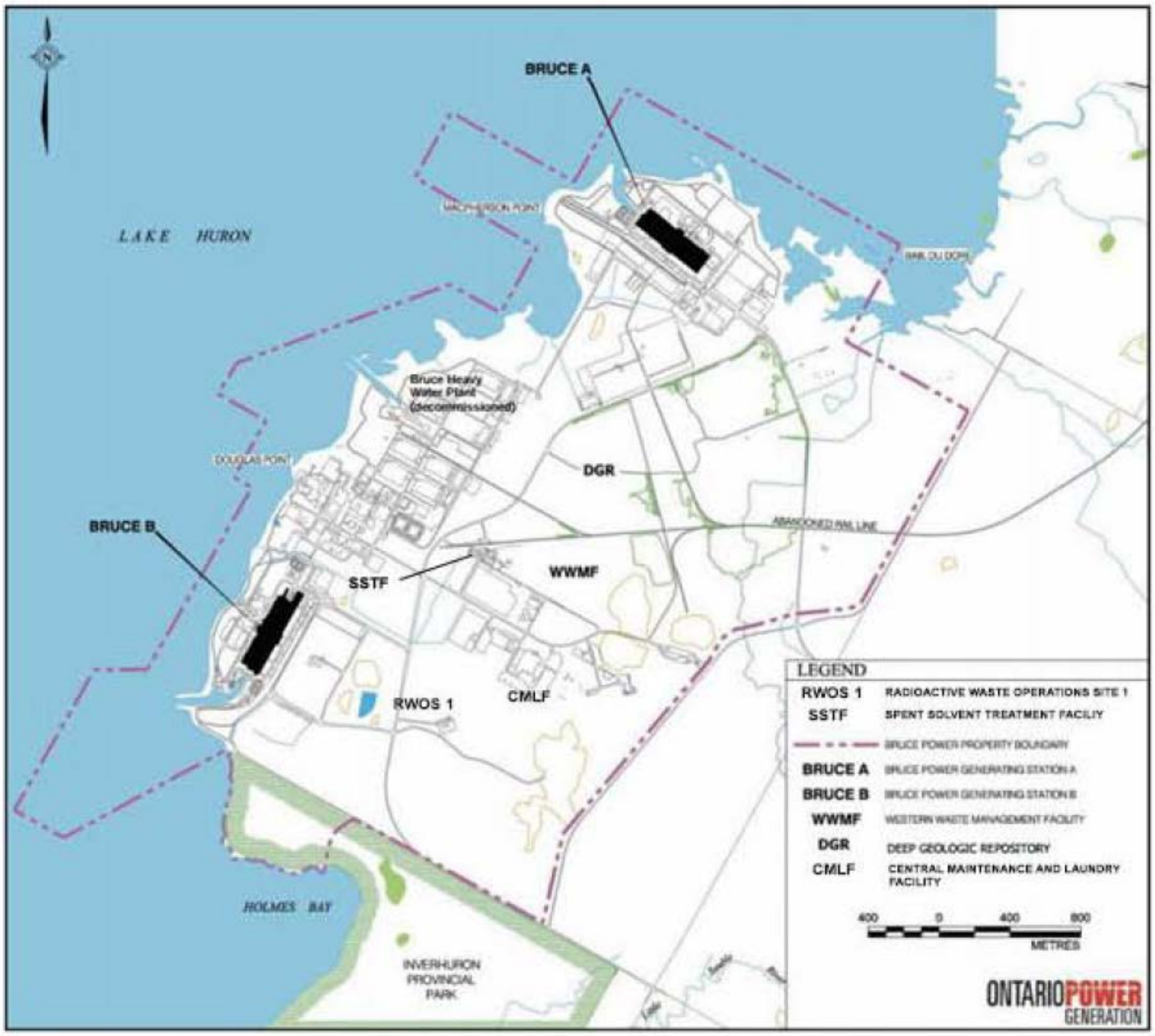

Figure 1.2: Location of Facilities on Bruce Nuclear Site.

Figure 1.3: WWMF Aerial View

2.0 ENVIRONMENTAL MONITORING PROGRAM

2.1 Design of EMP

Radiation protection, effluent monitoring, and environmental monitoring have taken place at the WWMF for many years and the results have been reported in the WWMF Quarterly Operation Reports (QORs) to the CNSC. Current EMP elements that were reported in the QORs are TLD gamma doses, groundwater monitoring results and groundwater trend graphs. A separate EMP for the WWMF was not needed prior to the issue of N288.4-10 because the previous version of the standard, N288.4-M90 only addressed the radioactivity in the environment outside the boundary of the facility, and such a program already existed as the Bruce site radioactive environmental monitoring program (REMP). CSA N288.4-10 [R-3], has an expanded scope for environmental monitoring which includes radioactivity, non-radioactive contaminants, human health, non-human biota and the areas of the environment within the facility boundaries. Thus, it was decided to develop an EMP for the WWMF that was designed according to the guidance provided in this standard. The detailed design of this EMP was completed in June 2012 [R-4] and monitoring has been ongoing based on the EMP design.

2.1.1 Facilities included in EMP

WWMF operates under a Class IB Nuclear Facility Licence. Although the EMP design report primarily addresses the 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 radiological waste was recovered from RWOS 1 and stored at the WWMF. The RWOS 1 is in caretaking mode. Other OPG facilities on the Bruce nuclear site that are owned by OPG include the conventional landfill and 4 construction landfills. These were excluded from the EMP design as they were either regulated by the Ontario Ministry of the Environment, Conservation and Parks or were not considered to present any significant risk [R-4].

2.1.2 Environmental Risk Assessment

The 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 WWMF EMP. Subsequently EMP data is then used to update the ERA on a regular time interval with the data used to refine models, test predictions of the last ERA and further enhance the understanding of potential risk from the site.

The most recent WWMF ERA was completed in October 2016 [R-6] in accordance with the requirements of CSA N288.6-12, Environmental Risk Assessments at Class I Nuclear Facilities and Uranium Mines and Mills [R-3] and concluded that the WWMF is operating in a manner that is protective of human and ecological receptors residing in the surrounding area.

The 2016 WWMF ERA identified potential risks to benthic invertebrates in the South Railway Ditch from exposure to copper and zinc in sediment. However, no further monitoring was recommended as the elevated levels of copper and zinc in the ditch are likely attributed to historical releases from the SSTF (located upstream of the WWMF), which is no longer operational and not related to WWMF operations. Additionally, the wetland downstream of the ditch did not show any sediment concentrations above toxicity reference values (TRVs) and adverse impacts to the benthic invertebrate community are not anticipated.

Additionally, silver in the West Ditch exceeded the sediment TRV; however, a low potential for effects was identified based on the benthic invertebrate field data. The WWMF is not known to be a source of silver contamination to the West Ditch.

2.1.3 Other Factors

The EMP design was also based on other factors unrelated to risk factors in the ERAs, such as ongoing confirmation of containment of radioactivity in the WWMF storage structures, contamination of groundwater, 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 as follows:

2.2.1 Public Radiological Dose Estimation

A direct determination of public radiological dose based on environmental monitoring of emissions sources released from WWMF operations is not feasible. 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), i.e. the WWMF, Bruce NGS-A , Bruce NGS-B, CMLF, 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, including radiological monitoring [R-8]. Estimation of public radiological dose resulting from WWMF operations is achieved by referencing the Bruce Power public radiological dose calculation based on environmental monitoring, and estimating the WWMF contribution by comparing the relative levels of monitored radiological emissions. See section 3.1 for 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 in a manner similar to the public radiological dose estimation, i.e. Bruce Power's results of monitoring tritium in the Southampton and Kincardine WSPs are referenced and the WWMF's relative contribution is estimated using measured waterborne tritium emissions. See section 3.2 for results of this assessment.

2.2.3 Direct Gamma and Skyshine Dose

Direct gamma and skyshine doses result from radioactivity in the waste storage facilities and fall off rather quickly with distance. The WWMF storage facilities are located reasonably far from the Bruce nuclear site perimeter, and gamma dose from the WWMF is not a significant contributor to radiological dose of the general public. However, external gamma doses near the storage facilities are monitored to ensure that potential non-Nuclear Energy Workers (NEWs) working in proximity of the WWMF are adequately protected. In order to protect non-NEWs near the 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 level TLDs were placed at a number of locations around the perimeters of the WWMF and RWOS 1 to measure direct gamma doses. There are 36 TLDs in the WWMF (16 around the Used Fuel Dry Storage Facility (UFDSF) and 20 around the rest of the WWMF). There are 7 TLDs at RWOS 1. The specific locations are shown in Figure 2.1 and Figure 2.2. The TLDs were replaced every quarter and shipped to the OPG Whitby Health Physics laboratory for analysis. Preparation, shipping, deployment and analysis of the TLDs are described in the EGM System Overview [R-9]. See sections 2.3.2 and 3.3 for results of TLD measurements.

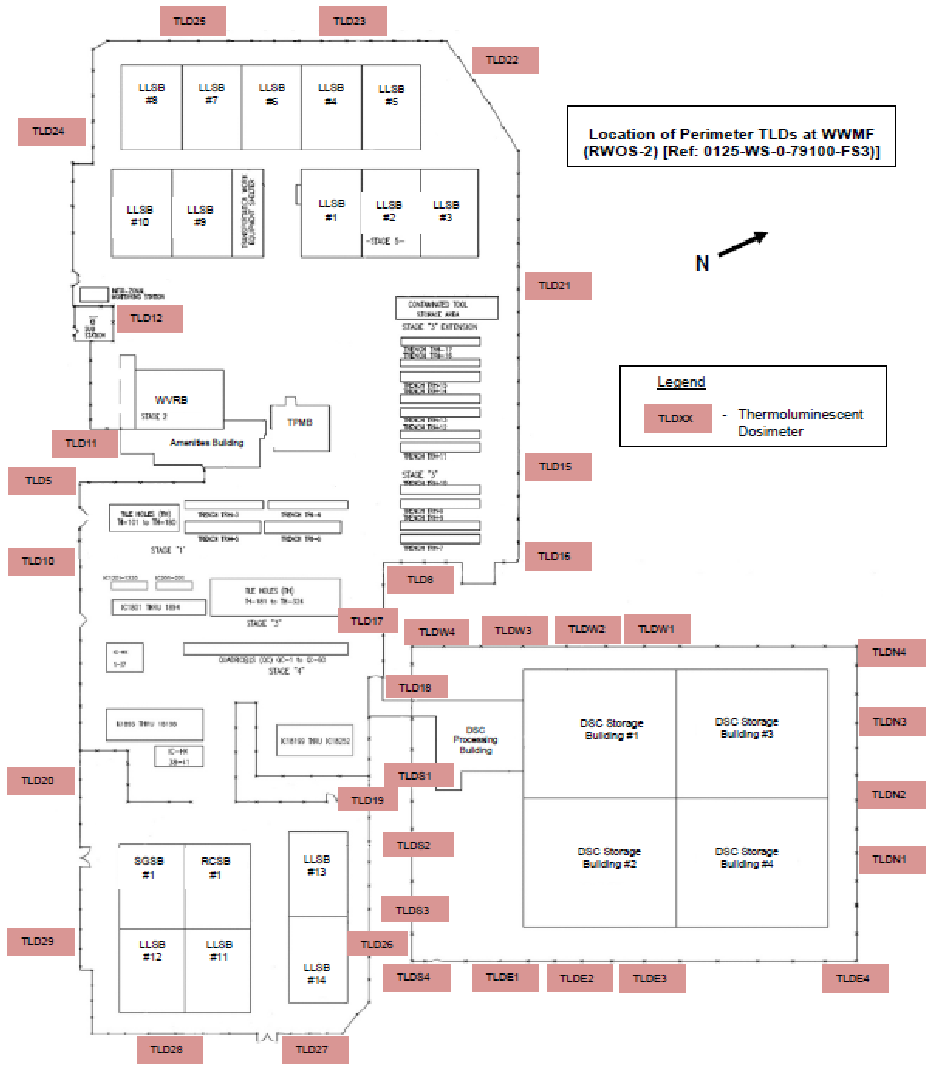

Figure 2.1: Location of TLDs at WWMF

Source: WWMF Quarterly Operations Report [R-10]

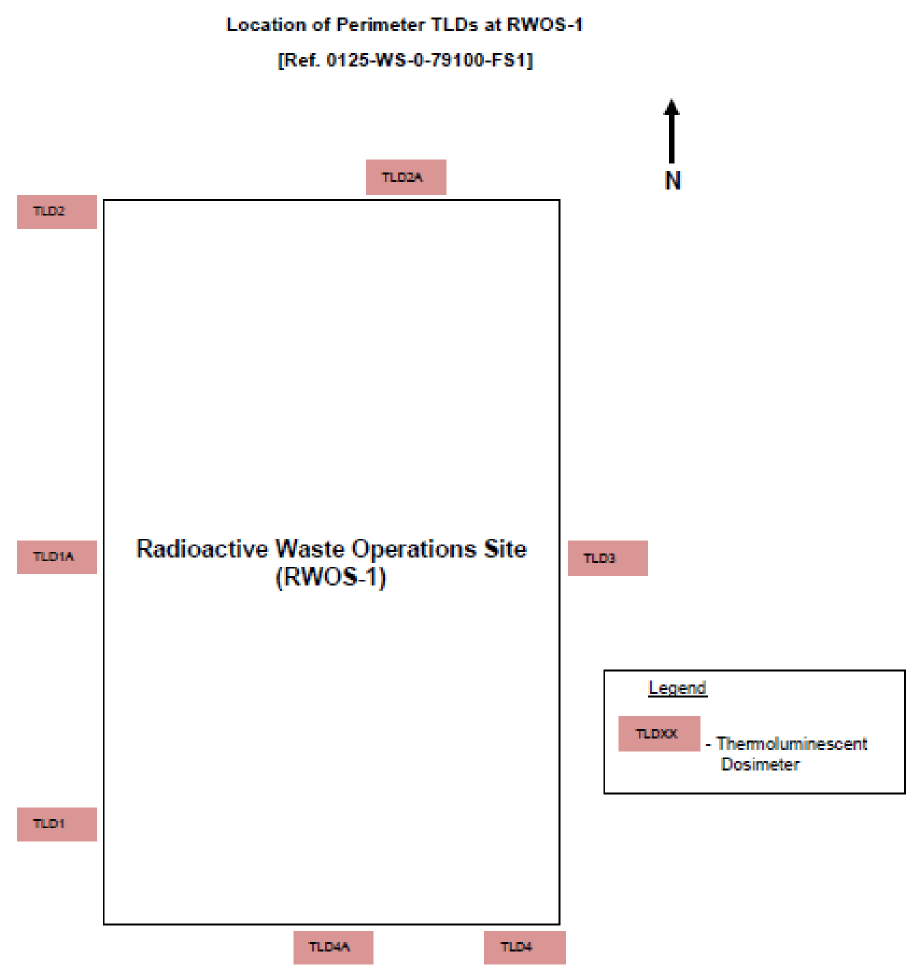

Figure 2.2: Locations of TLDs at RWOS 1
Source: WWMF Quarterly Operations Report [R-10]

2.2.4 Confirmation of Containment Integrity of Inground Storage Structures

Inground storage structures are monitored in different ways. The trenches and tile holes have an engineered subsurface drainage system, and any radioactivity released from these structures to water in the subsurface drainage system is routinely reported in the monitored waterborne effluents. 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 WWMF and RWOS 1 is routinely sampled. The sampling wells are proper, sealed groundwater sampling wells, but are called water sampling holes (WSHs). The WSHs are placed so as to detect a potential loss of containment in storage structures and any movement of radioactivity in groundwater from the WWMF. Locations of the monitoring wells are shown in Figure 2.3 and Figure 2.4. Both the shallower Middle Sand Aquifer (MSA) and the deeper bedrock aquifer are monitored. Detailed procedures are followed for proper monitoring of the groundwater wells [R-11].

The MSA is generally localized to the WWMF but is hydraulically connected to the bedrock aquifer. Groundwater from the MSA generally leaves the WWMF site via the bedrock aquifer. However, it appears that due to the stormceptor, some groundwater from the MSA discharges to the South Railway Ditch (near the north-western area of the WWMF). For a more detailed description of groundwater flow within and outside of the WWMF, see the EMP design report [R-4]. A source term assessment and groundwater monitoring network design enhancement was completed in 2016 at the WWMF. The specific locations of the WSHs at the WWMF are shown in Figure 2.3, and the locations of those at RWOS 1 are shown in Figure 2.4

Table 2.2 shows all of the WSHs that were monitored in 2019, whether they are in RWOS 1 or WWMF for sampling of tritium, gross beta, or for C-14. Most wells in RWOS 1 and WWMF are monitored quarterly. Yearly monitored wells are presented in Table 2.3. The frequency of sampling and analysis for tritium and gross beta activity in WSH 231 is currently monthly. The higher frequency addresses the elevated tritium activity in WSH 231.

There is no specific target or limit for radioactivity in groundwater at WWMF and RWOS 1. However, OPG has committed to notify the CNSC if tritium levels at WSH 231 exceed 60,000 Bq/L [R-7]. 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 (pumpouts of water from LLSB electrical manhole sumps) were initiated starting in February 2010. This WSH is examined for a decreasing trend from February 2010 onward to see how effective the remedial measures have been. See Section 2.3.3 and Appendix C for results of groundwater monitoring.

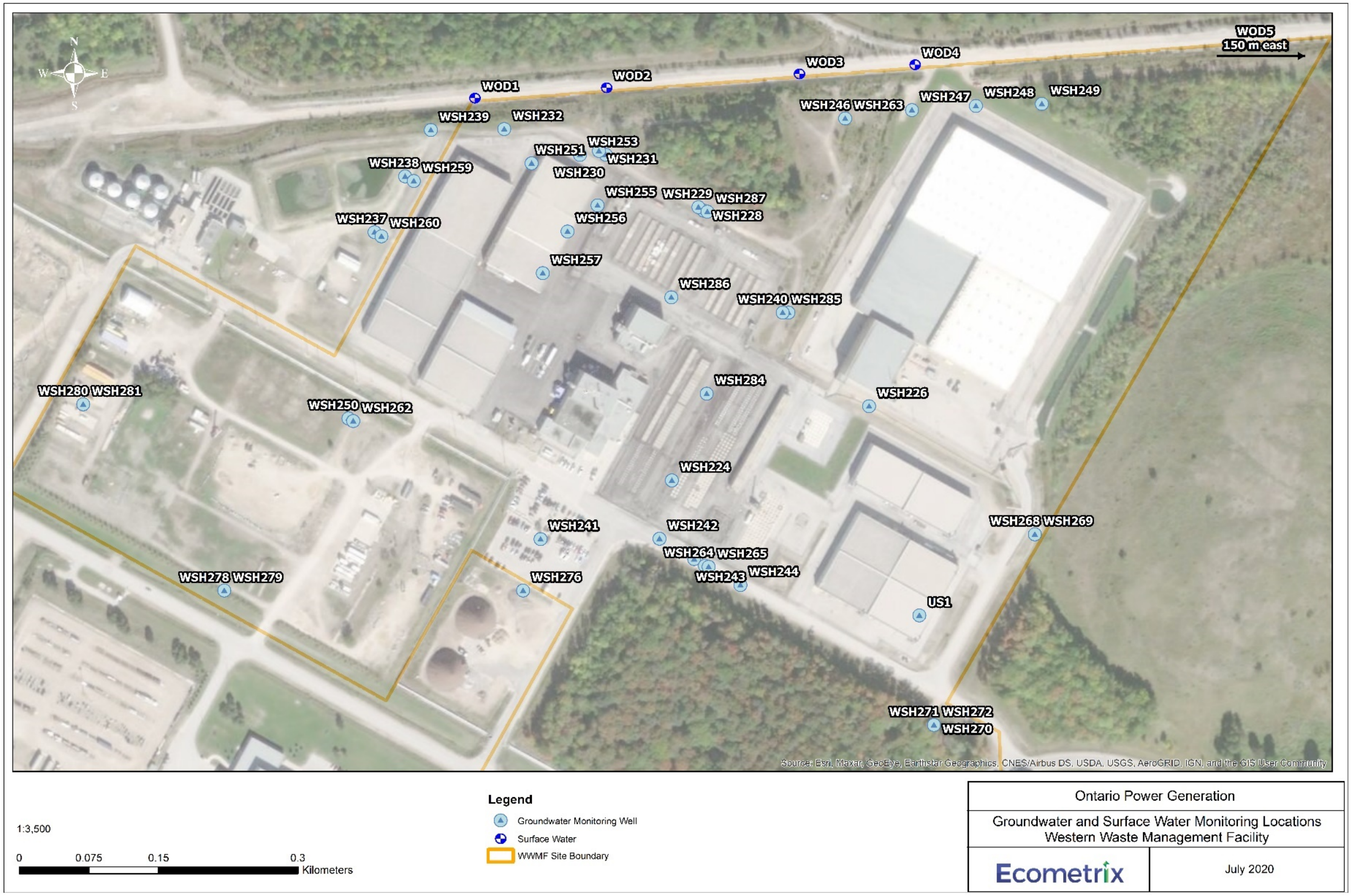

Figure 2.3: Monitoring Well Network at the WWMF

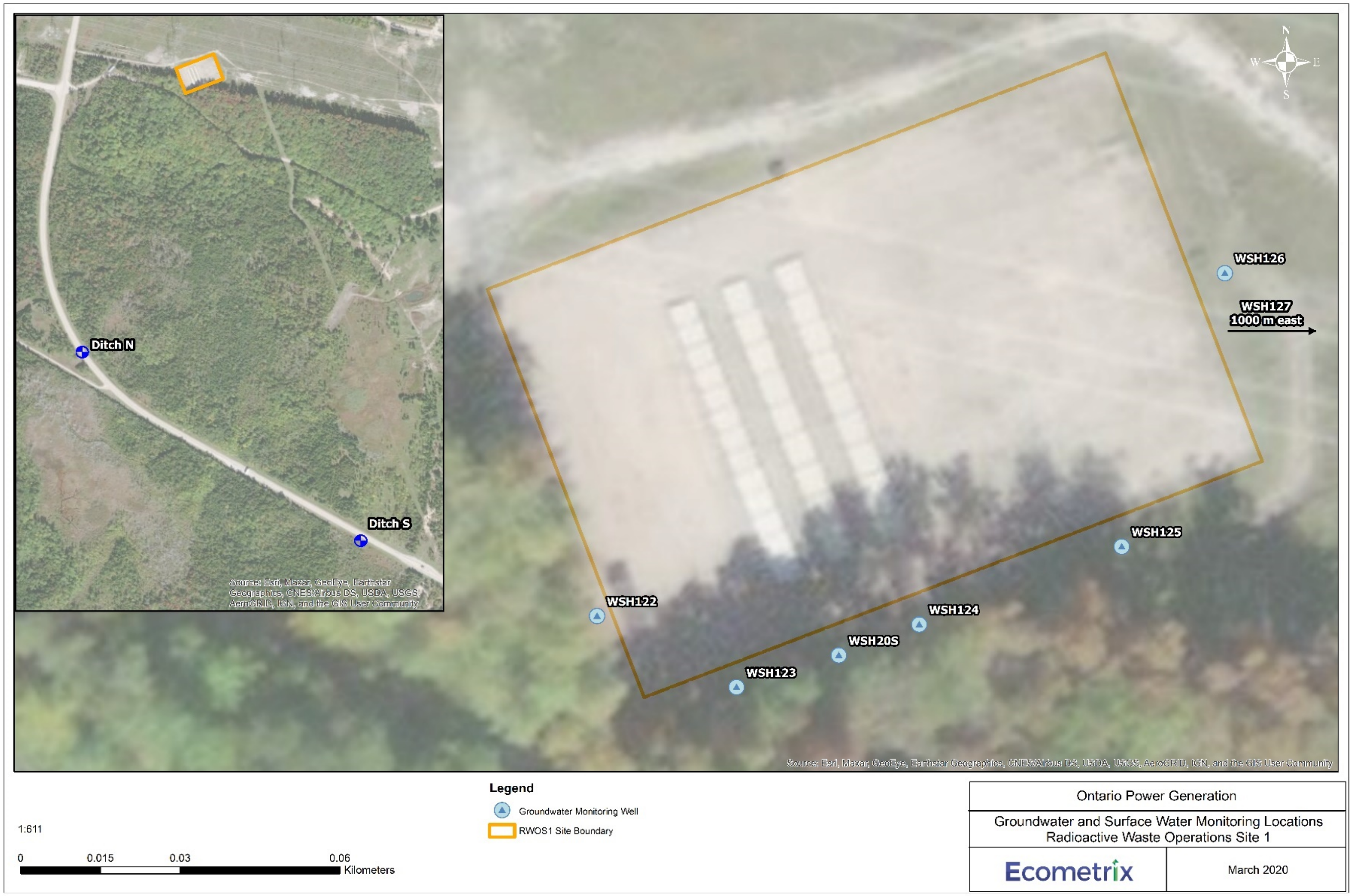

Figure 2.4: Monitoring Well Network at the RWOS 1

2.2.5 Verify Predictions Made by Environmental Risk Assessment

The EMP design report recommended a supplementary study to monitor water and sediment quality in the grassed swale and wetland at the east side of the WWMF to verify ERA predictions of no significant adverse effects. Samples of water and sediment were taken in the South Railway Ditch just north of the UFDSF (upstream of the grassed swale and wetland), in the grassed swale/wetland close to the stormwater discharge point from the east side of the WWMF site, and at the east end of the railway ditch, east of the WWMF site downstream of the wetland. Samples were taken in spring, summer and fall. Water and sediment samples were analyzed for metals (metal scan) and gamma emitters (gamma scan). Water samples were also analyzed for HTO, C-14 and gamma emitters. This supplementary study was completed in 2013. The WWMF ERA concluded that there was no risk, with the exception of benthic invertebrates, where copper and zinc exceeded sediment TRVs. Copper and zinc are not associated with WWMF operations [R-7]. However, zinc levels in the South Railway Ditch and WWMF drainage measured as part of a groundwater monitoring well network assessment in 2016 were above what was assessed in the ERA, and suggest that the zinc concentrations in the South Railway Ditch are influenced by the WWMF drainage system [R-5].

2.2.6 Water in South Railway Ditch

The South Railway Ditch has been monitored routinely for tritium since 2010 and was also monitored in 2013 as part of the WWMF EMP supplementary studies [R-7]. The study was completed in 2013. A review of the results indicated that no conclusions could be made about changes in tritium in the South Railway Ditch as compared with tritium levels measured in WSH 231 over the same period. Routine monitoring of the ditch continues at four locations (WOD1, WOD2, WOD4 and WOD5) each quarter.

2.2.7 HTO in Precipitation

The EMP design report recommended a supplementary study to investigate maximum tritium concentrations in precipitation on the WWMF site in order to compare these levels to those in groundwater and to determine if tritium in precipitation may be a source of elevated tritium in groundwater [R-4]. This supplementary study was completed in July 2014. The results suggested that tritium levels were too low to account for increased tritium at WSH 231, but may account for tritium levels in other near-surface sampling locations. The study also concluded that there was no significant decrease in tritium concentration between WWMF and RWOS 1 or between the WWMF perimeter and the incinerator. It was concluded that elevated tritium concentrations are mainly a result of emissions from the Bruce Nuclear Generating Station [R-6].

Routine precipitation monitoring has continued on the site of the WWMF with two reference locations. Samples were taken in four locations at the WWMF at the corners of the WWMF and at the site boundary (WS1-4). This was to detect any increased concentrations that may occur close to the incinerator and WVRB ventilation exhausts. One reference sample was located at RWOS 1 (WS-B) and the second reference location was south of Bruce A Switchyard, 700m north of the WWMF(WS-A). Sampling locations are shown in Figure 2.5. Precipitation was collected continuously with rain gauges and was analyzed for HTO. The target precipitation sampling frequency is bi-weekly, with the criteria being 30 times per year. Due to low precipitation event frequency 18 samples were collected in 2019.

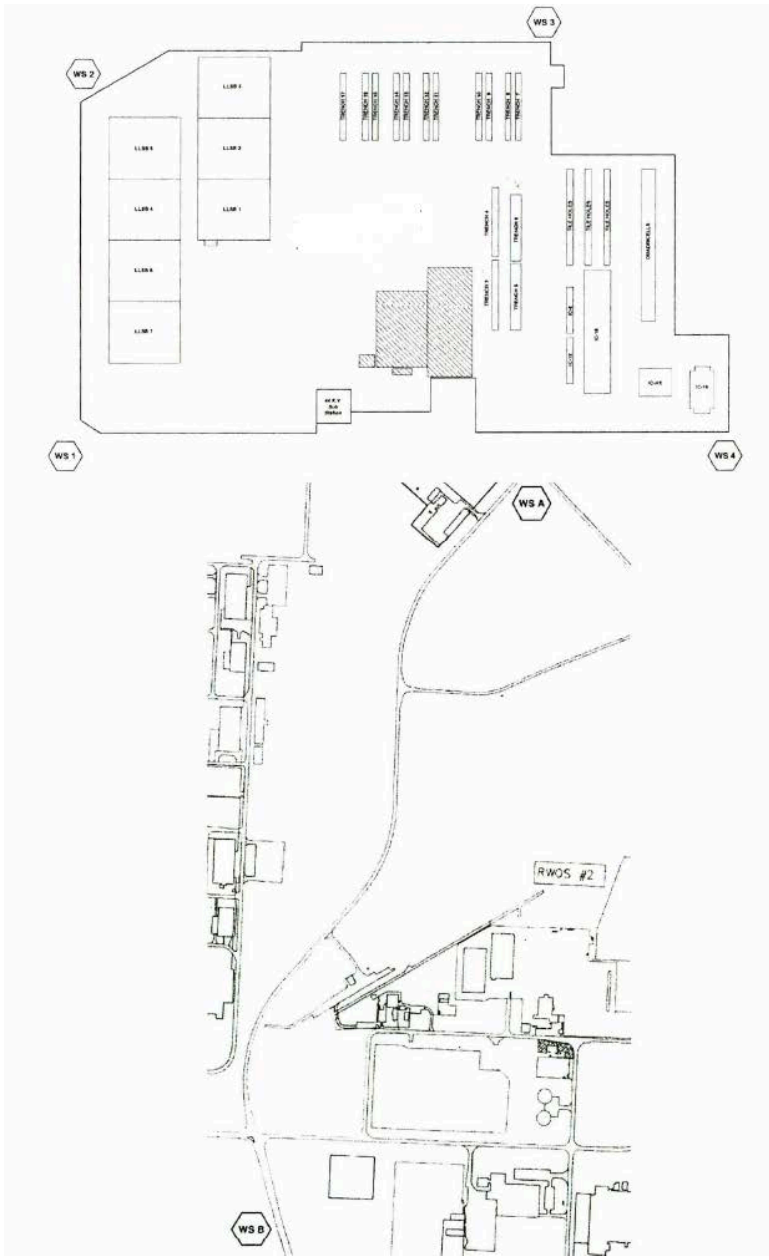

Figure 2.5: Sampling Locations for Routine Precipitation HTO Monitoring.

2.2.8 Other

2.2.8.1 C-14 in Air

Elevated C-14 in air on the WWMF site was identified in the 2013 EMP Report [R-7] and an integration into routine sampling was recommended. Bruce Power nuclear site passive C-14 samplers are shown in Figure 2.6. In 2019, passive sampler results from Bruce Power indicated higher levels than provincial locations. Highest concentrations were localized at WWMF, Bruce A and Bruce B and measured levels neared provincial levels at the site boundary [R-8].

The C-14 passive samplers consist of mixed soda lime pellets to absorb CO_2 from air at a controlled rate. The CO_2 is released from the pellets in the laboratory by titration with acid, then collected and analyzed by liquid scintillation counting for C-14 content. Twenty samplers are positioned on the area of the WWMF for passive monitoring, as shown in Figure 2.7. The samples are collected and analyzed quarterly.

As a result of the effluent assessment project initiated in 2018, elevated concentrations of C-14 were detected at the WWMF. Their source was traced to the spent resin storage area, specifically the IC-12s and IC-18s in-ground containers. The fugitive emissions reassessment (“Phase 3”) is 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 “Phase 3” was completed in 2019. Both environmental and health physics monitoring support that there is no significant impact on workers, the public, or the environment.

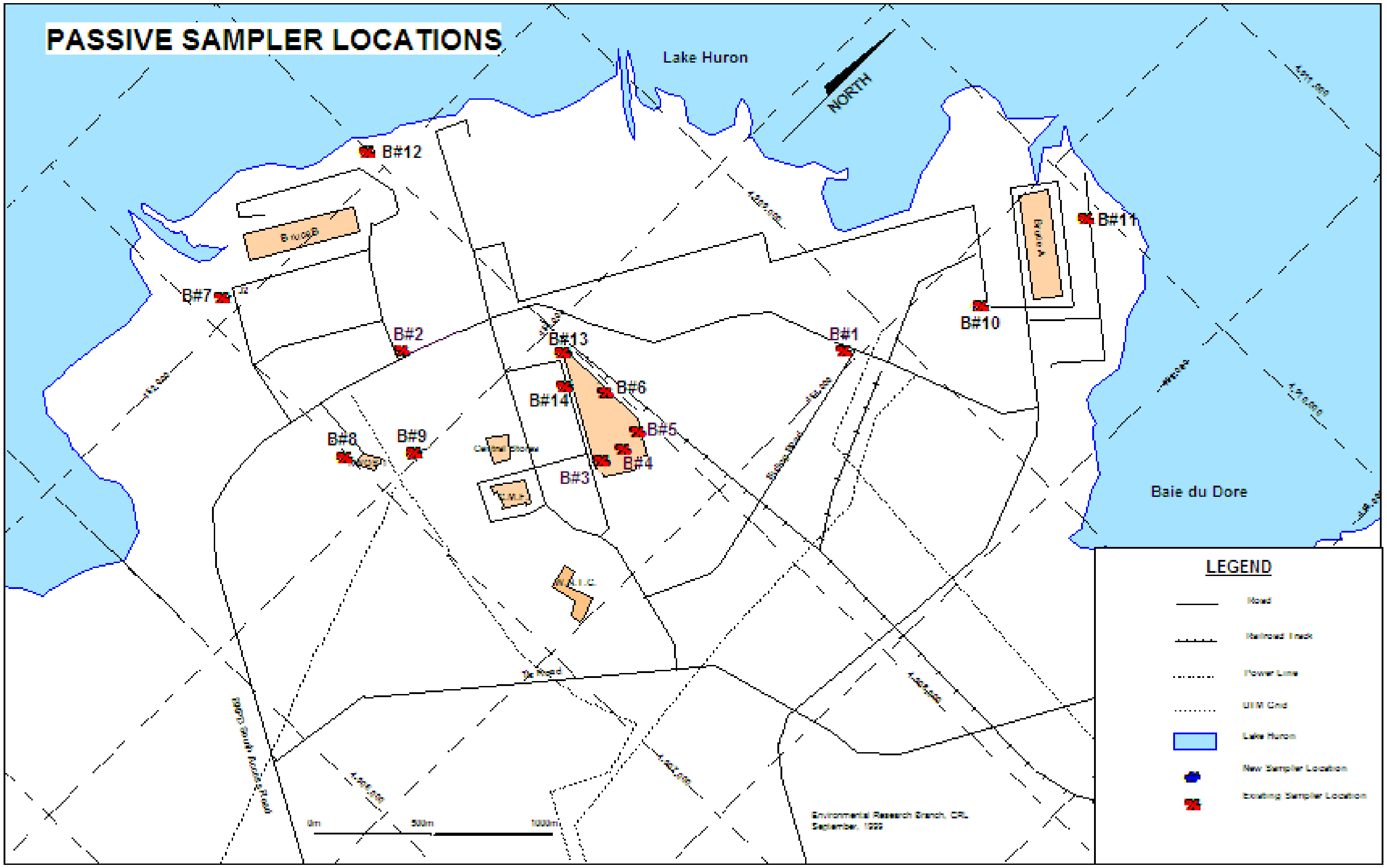

Figure 2.6: BP Site C-14 Passive Sampler Locations

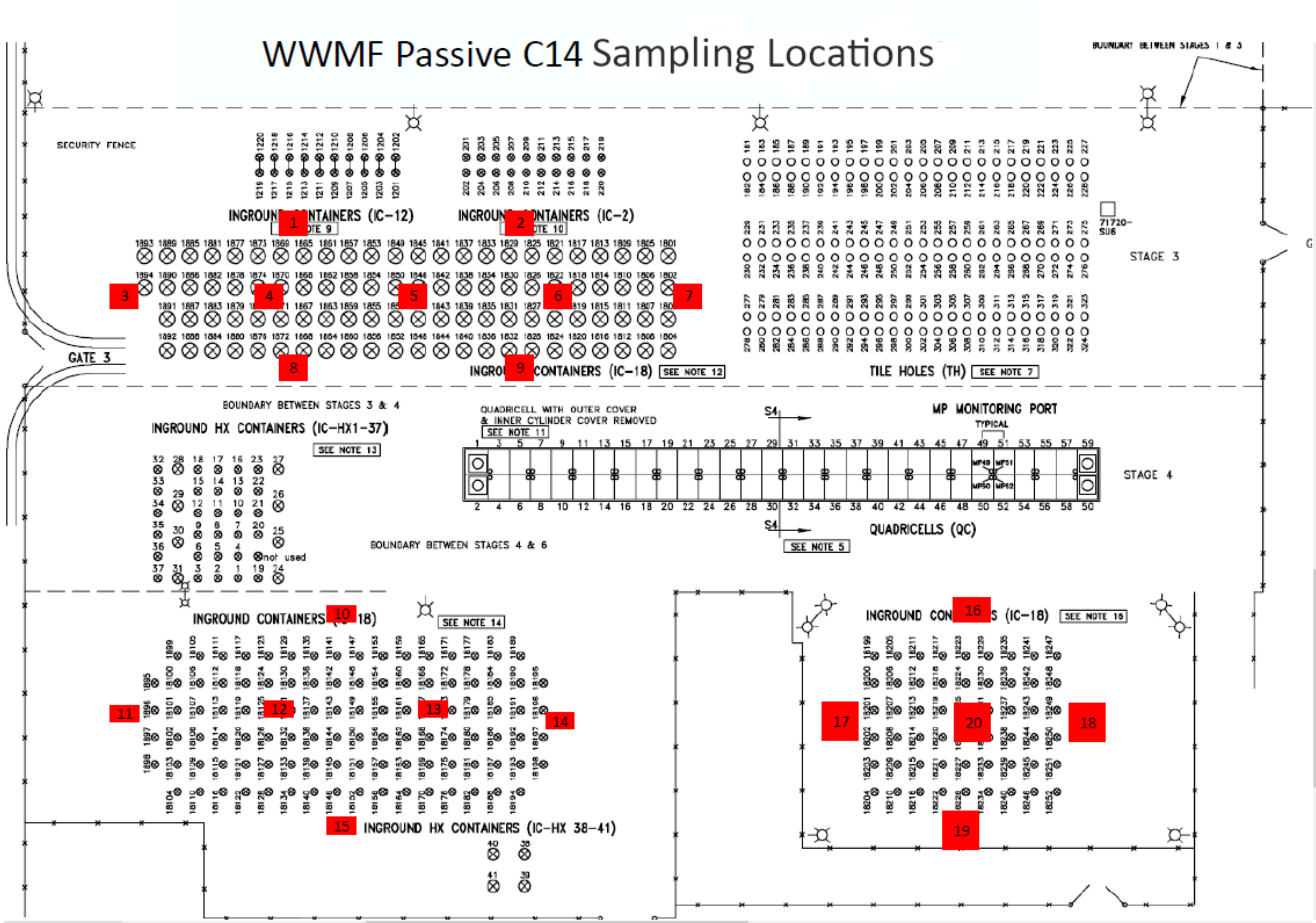

Figure 2.7: Sampling Locations of the Passive Air Samplers at the WWMF

2.3 EMP Results

This section contains the 2019 results of the EMP for the WWMF and RWOS 1. Sampling methods, analyses, and QA/QC measures are identified along with figures showing all sampling locations.

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 calculations for datasets with non-detects and analysis for trends were performed using ProUCL, an approved statistical software package developed by the U.S. Environmental Protection Agency (EPA) [R-12].

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 [R-1]. The EMPs use a probability of 5%. For the EMPs, 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 [R-1]. The EMPs use a probability of 5%.

When reporting the analytical data in Appendix D tables, 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 particular 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 WWMF and RWOS 1.

The dosimeters are changed every quarter and shipped back to the OPG Whitby Health Physics laboratory for readout. For QC, transport dosimeters always accompany the field dosimeters on the trip to and from the field locations, in order to monitor and account for extraneous radiation dose received in transit. Additional information on the TLDs and the readout procedure can be found in the EGM System Overview [R-9].

The 2019 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 WWMF, including the UFDS area, are well below the derived dose rate limit of 0.5 µGy/h. A graphical representation of the 2019 results is shown in Figure 2.8.

Looking at the 6-year history of TLD results, only TLD 28 reaches 0.1 µGy/h annual average rate (Figure 2.9). All TLD locations were analyzed for any statistically significant trends at the 95% significance level using the Mann-Kendall Test in EPA's ProUCL software [R-12]. Most locations did not show any changes or trends that would warrant further investigation. Even though the dose at the TLD 28 location increased from 2014 to 2015, there was a decreasing trend over the 6-year period. TLDs 12 and 24, that were noted to previously have rates close to 0.1 µGy/h [R-7] showed statistically significant decreasing trends over the last 6 years. TLDs 25, 26 and 27 at the Western Low and Intermediate Level Waste Storage Facility (WLILWSF) showed statistically significant increasing trends over the last 6 years with a maximum quarterly dose rate of 0.083 µGy/h. Statistically increasing dose rates were also observed at multiple locations of the Western Used Fuel Dry Storage Facility (UFDSF) with the highest dose rate being 0.097 µGy/h at DFSW-1 in the fourth quarter of 2018. However, the dose rate at this location decreased in 2019.

Table 2.1: 2019 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	0.056	0.044	0.056	0.056	0.053	0.012
1A	0.060	0.046	0.060	0.061	0.057	0.014
2	0.060	0.046	0.060	0.062	0.057	0.015
2A	0.059	0.048	0.058	0.059	0.056	0.011
3	0.054	0.042	0.054	0.056	0.052	0.013
4	0.053	0.041	0.054	0.057	0.051	0.014
4A	0.057	0.044	0.059	0.058	0.055	0.014
			WLILWSF[1]			
5	0.058	0.042	0.055	0.058	0.053	0.015
8	0.067	0.051	0.063	0.068	0.062	0.016
10	0.055	0.044	0.056	0.058	0.053	0.013
11	0.069	0.046	0.058	0.080	0.063	0.029
12	0.063	0.053	0.062	0.061	0.060	0.009
15	0.068	0.052	0.064	0.065	0.062	0.014
16	0.073	0.055	0.071	0.075	0.069	0.018
17	0.067	0.051	0.063	0.067	0.062	0.015
18	0.070	0.056	0.065	0.067	0.065	0.012
19	0.070	0.055	0.065	0.066	0.064	0.013
20	0.059	0.049	0.064	0.061	0.058	0.013
21	0.067	0.050	0.062	0.067	0.062	0.016
22	0.059	0.046	0.058	0.059	0.056	0.013
23	0.072	0.052	0.071	0.073	0.067	0.020
24	0.068	0.054	0.068	0.070	0.065	0.015
25	0.081	0.067	0.074	0.078	0.075	0.012
26	0.083	0.067	0.078	0.080	0.077	0.014
27	0.077	0.066	0.077	0.078	0.075	0.011
28	0.098	0.084	0.097	0.092	0.093	0.013
29	0.067	0.056	0.070	0.067	0.065	0.012
			UFDSF[2]			
DFSN-1	0.086	0.077	0.091	0.087	0.085	0.012
DFSN-2	0.096	0.079	0.095	0.096	0.092	0.017
DFSN-3	0.085	0.078	0.088	0.090	0.085	0.011
DFSN-4	0.065	0.053	0.066	0.065	0.062	0.012
DFSS-1	0.074	0.057	0.072	0.076	0.070	0.017
DFSS-2	0.076	0.062	0.072	0.078	0.072	0.014

TLD - Average Air Kerma Rates (µGy/h)						
TLD Location	**Q1**	**Q2**	**Q3**	**Q4**	**Annual Average**	**2*SD[3]**
DFSS-3	0.074	0.062	0.074	0.078	0.072	0.014
DFSS-4	0.067	0.057	0.072	0.071	0.067	0.014
DFSE-1	0.071	0.059	0.071	0.075	0.069	0.014
DFSE-2	0.094	0.081	0.092	0.097	0.091	0.014
DFSE-3	0.089	0.078	0.088	0.092	0.087	0.012
DFSE-4	0.064	0.056	0.067	0.067	0.064	0.010
DFSW-1	0.086	0.079	0.089	0.089	0.086	0.009
DFSW-2	0.085	0.069	0.079	0.085	0.080	0.015
DFSW-3	0.082	0.069	0.079	0.085	0.079	0.014
DFSW-4	0.059	0.053	0.060	0.065	0.059	0.010

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

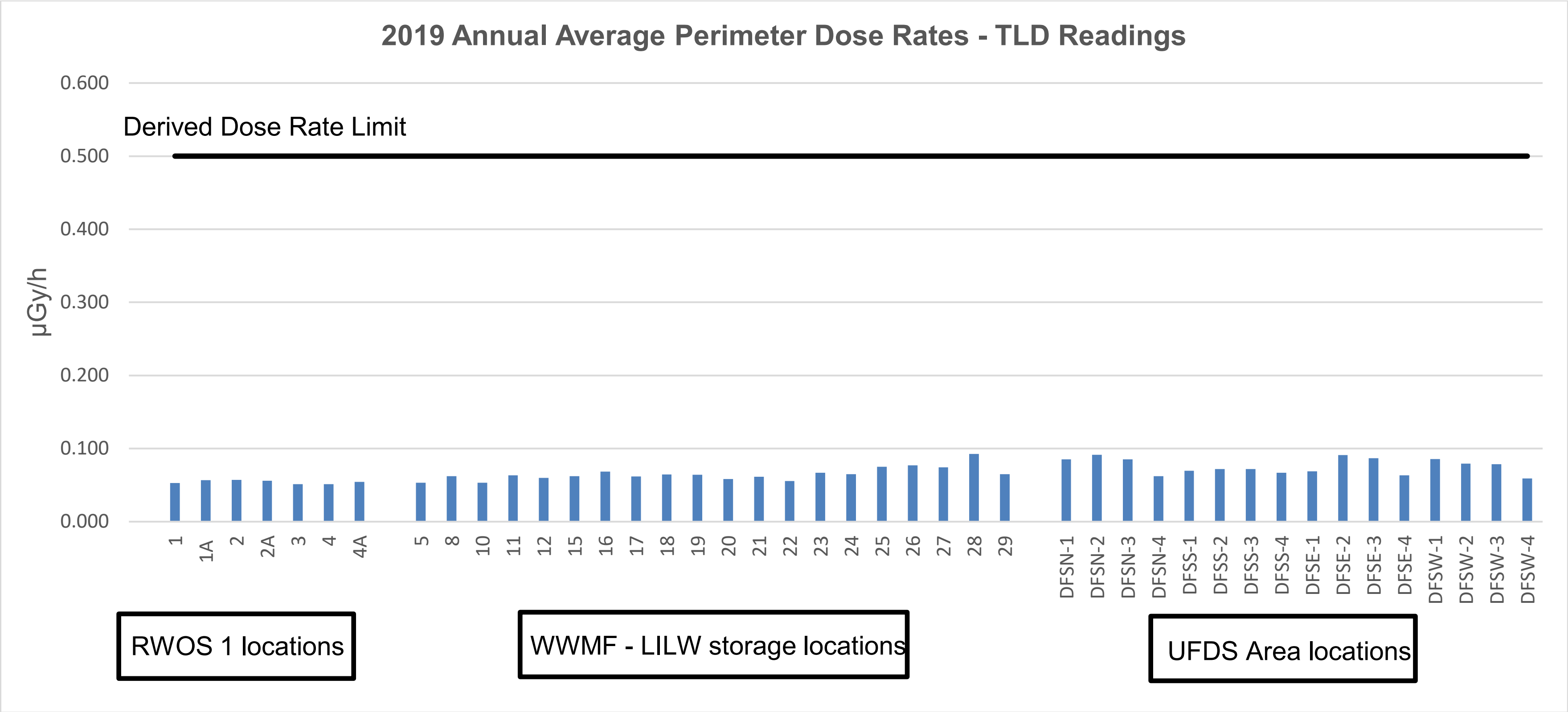

Figure 2.8: 2019 TLD Results

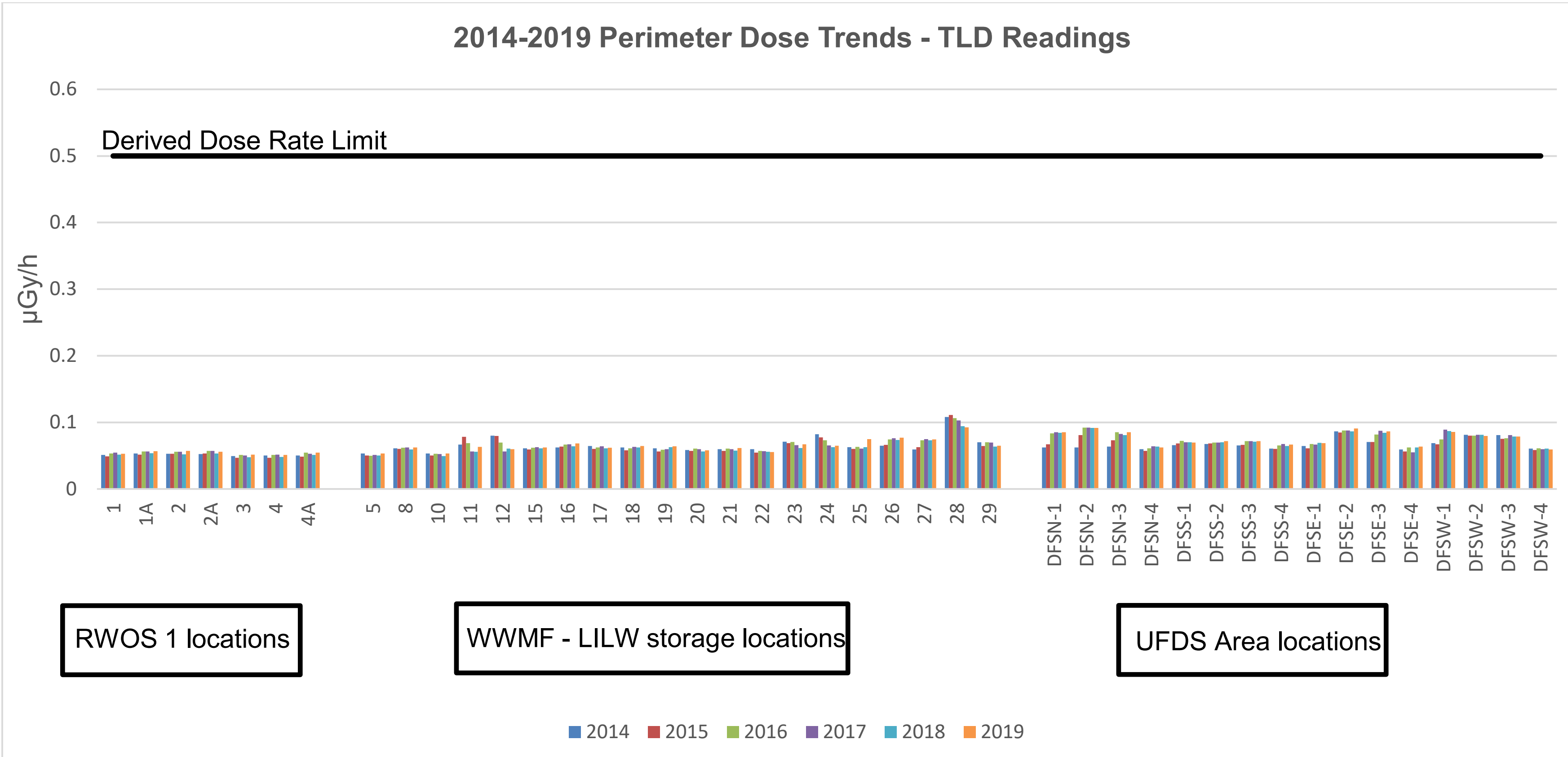

Figure 2.9: 2014-2019- TLD Results

2.3.3 Groundwater Monitoring Results

Of the 42 wells at WWMF monitoring the bedrock and the MSA, 20 wells are monitored for tritium and gross β activity quarterly except WSH 224 which is only monitored for C-14. WSH 226 is monitored for tritium and gross β activity quarterly and for C-14 monthly. Monitoring of WSH US6 was discontinued in 2017. Analysis results for all of these wells are shown in Table 2.2 on a quarterly and annual average basis. Wells that are monitored annually are shown in Table 2.3. Table 2.4 shows the monthly results from WSH 231. In RWOS 1 the bedrock aquifer is monitored for tritium and gross β activity quarterly in seven wells and two surface water locations (Ditch N, Ditch S), shown in Table 2.2 and Table 2.5 respectively. All of these wells are also monitored each quarter for C-14.

In 2019, all but five wells of the WWMF had tritium concentrations in groundwater below 500 Bq/L. Tritium in WSH 231 which characterizes the MSA averaged 13,193 Bq/L over the year, and never exceeded the level of 60,000 Bq/L at which OPG has committed to notify the CNSC. The highest concentration of tritium was measured in WSH 253, located close to WSH 231 with an annual average of 29,825 Bq/L. Monitoring of this well started in 2017 and no statistically significant trend was identified (Figure 2.10).

Annual average gross β levels in RWOS 1 groundwater were generally below 0.1 Bq/L and average annual gross β levels in WWMF groundwater were generally under 0.2 Bq/L. WSH 238 and WSH 239 had higher gross β levels than most other WSHs, at just below 0.7 Bq/L in 2019. For WSH 238 this is consistent with past values at this location and is still low, such that further investigation is not warranted. In the case of WSH 239, annual monitoring only started in 2017. The 2019 tritium in groundwater results for all WSHs are shown in Figure 2.11, and Figure 2.12 shows the gross β results.

Historic data for tritium and gross β activity in the WSHs of both sites from 2014 to 2019 was analyzed for the presence of statistically significant trends over this 6 year period. The Mann-Kendall test was used for trend analysis in EPA's ProUCL software, and tested for evidence of a statistical increasing or decreasing trend at the 95% confidence level. The results of the trend analyses indicated that five WWMF WSHs (WSH 230, WSH 242, WSH 264, WSH 279 and WSH 283) showed a slightly increasing trend in tritium, but levels remained below 200 Bq/L, except for WSH 230 where the tritium concentration was 508 Bq/L. Of the remaining WWMF wells, nine had a slightly decreasing tritium trend (WSH 226, WSH 228, WSH 232, WSH 240, WSH 246, WSH 248, WSH 249, WSH 250, WSH 251) and the remainder had no statistically significant trend. Most wells in the WWMF had no statistically significant trend for gross β. One well (WSH 226) showed a statistically significant increasing trend and eight showed statistically significant decreasing trends (WSH 230, WSH 251, WSH 253, WSH 255, WSH 283, WSH 284, WSH 285, WSH 286).

The RWOS 1 wells showed increasing tritium trends in all wells except WSH 122, WSH 123 and WSH 20S, which showed no trend. Gross β in the RWOS 1 wells showed no significant trends. The graphs where statistically significant increasing trends were detected along with

WSH 231 and WSH 253 are shown in Appendix C. No statistically significant trends were noted for the surface water sampling locations of RWOS 1.

These results indicate that there are no significantly elevated radionuclide concentrations in groundwater leaving the WWMF in the bedrock aquifer. However, the localized elevated tritium in WSH 231 and WSH 253 indicate that there is 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 from waste stored in the LLSBs. [R-5]. 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. Additionally, the tritium inventory continues to decrease due to decay and off-gassing. Tritium levels in WSH 231 were analyzed for trends over the 6 year period 2014-2019 using EPA's ProUCL software [R-12]. The Mann-Kendall trend test indicated that there was a significant decreasing trend at the 95% confidence level over this period. WSH 231 and the neighbouring WSH 253 annual averages over this period are plotted in Figure 2.10

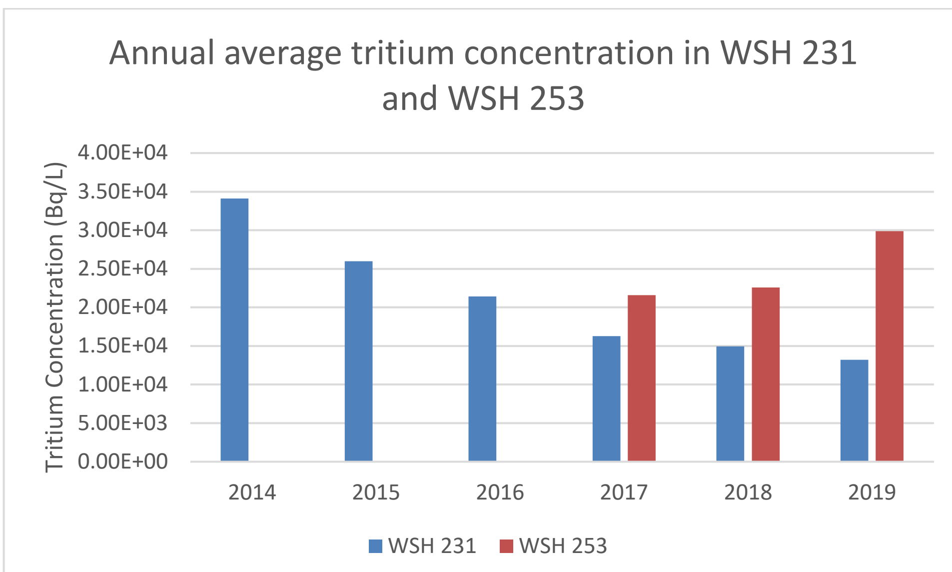

Figure 2.10: Annual Average Concentration of Tritium in Groundwater at Well WSH 231 and WSH 253

Table 2.2: 2019 Groundwater Monitoring Results (Bq/L)

	Q1			Q2			Q3			Q4			Annual Average				
WSH	HTO	Gross β	C-14 (1)	HTO	Gross β	C-14 (1)	HTO	Gross β	C-14 (1)	HTO	Gross β	C-14 (1)	HTO	Uncertainty (2)	Gross β	Uncertainty (2)	C-14 (3)
RWOS 1																	
122	2.15E+02	0.18	<0.1	7.13E+02	0.08	<0.1	2.07E+02	**0.07**	<0.1	9.51E+01	0.07	<0.12	5.52E+02	5.52E+02	0.11*	0.06	<0.12
123	**3.20E+02**	0.09	<0.1	2.66E+02	**0.08**	<0.1	4.58E+02	**0.06**	1.50	3.46E+02	0.10	<0.11	3.48E+02	1.62E+02	$<L_d$		1.5
20S	3.17E+02	0.10	<0.1	1.75E+02	**0.09**	0.12	2.68E+02	0.11	<0.1	3.73E+02	**0.07**	<0.14	2.83E+02	1.68E+02	0.09*	2.00	0.12
124	1.29E+02	**0.06**	<0.1	1.59E+02	**0.09**	<0.1	2.19E+02	**0.07**	<0.1	1.91E+02	**0.07**	<0.1	1.75E+02	7.80E+01	$<L_d$		<0.1
125	1.45E+02	**0.08**	<0.1	1.67E+02	**0.09**	<0.1	1.84E+02	**0.07**	<0.1	1.40E+02	**0.08**	<0.13	1.59E+02	4.08E+01	$<L_d$		<0.13
126	1.27E+02	**0.13**	<0.1	1.10E+02	**0.08**	<0.1	1.86E+02	**0.07**	<0.1	1.46E+02	**0.04**	<0.14	1.42E+02	6.53E+01	$<L_d$		<0.14
127	7.50E+01	**0.07**	<0.1	2.25E+02	**0.14**	<0.1	1.23E+02	**0.06**	<0.1	1.25E+02	**0.06**	<0.12	1.37E+02	1.26E+02	$<L_d$		<0.12
WWMF																	
224			<0.1			<0.1			<0.1			<0.1					<0.1
226	**9.59E+00**	0.09	<0.1	4.41E+02	0.17	<0.1	**1.02E+01**	**0.18**	<0.1	**9.25E+00**	0.17	<0.3	1.18E+02	4.31E+02	0.15*	0.05	<0.3
228	1.76E+02	**0.08**	<0.1	2.03E+02	0.08	<0.1	1.44E+02	0.13	<0.1	1.92E+02	0.29	<0.1	1.79E+02	5.14E+01	0.15*	0.11	<0.1
229	5.38E+02	**0.08**	<0.1	7.33E+02	0.25	0.16	5.51E+02	0.13	14.9**	4.32E+02	0.14	0.60	5.64E+02	2.50E+02	0.15*	0.08	14.9**
230	4.97E+02	**0.08**	<0.1	4.94E+02	0.17	<0.1	5.09E+02	0.08	<0.1	5.30E+02	**0.07**	<0.1	5.08E+02	3.27E+01	0.1*	0.06	<0.1
240	**9.54E+00**	**0.08**	<0.1	1.36E+01	0.31	<0.1	**9.52E+00**	0.14	8.7**	**1.01E+01**	**0.06**	<0.1	1.07E+01	3.92E+00	0.14*	0.14	8.7**
242	4.92E+01	0.10	N/A	5.66E+01	0.17	N/A	4.59E+01	**0.18**	N/A	4.60E+01	0.14	N/A	4.94E+01	1.00E+01	0.14*	0.04	
243	4.19E+02	0.17	<0.1	3.98E+02	0.14	<0.1	4.04E+02	0.25	<0.1	3.81E+02	0.18	<0.2	4.01E+02	3.14E+01	0.18	0.09	<0.2
253	2.77E+04	**0.10**	N/A	2.98E+04	**0.13**	N/A	2.91E+04	**0.24**	N/A	3.27E+04	**0.09**	N/A	2.98E+04	4.21E+03	$<L_d$		N/A
255	3.62E+03	0.12	N/A	3.13E+03	**0.11**	N/A	3.60E+03	0.28	N/A	3.17E+03	0.11	N/A	3.38E+03	5.32E+02	0.15*	0.09	N/A
264	3.00E+01	0.13	<0.1	5.08E+01	0.15	<0.1	3.00E+01	0.39	<0.1	3.85E+01	0.13	<0.09	3.73E+01	1.97E+01	0.20	0.25	<0.1
265	4.56E+02	0.25	0.12	5.34E+02	0.34	<0.1	5.17E+02	0.35	<0.1	3.83E+02	0.23	0.30	4.73E+02	1.37E+02	0.29	0.12	0.3
269	4.75E+02	**2.73**	N/A	1.19E+01	**3.22**	N/A	3.15E+02	0.36	N/A	2.79E+02	**0.11**	N/A	2.70E+02	3.84E+02	$<L_d$		N/A
282	8.07E+02	0.46	<0.1	6.91E+02	0.58	<0.1	5.86E+02	0.24	<0.1	5.31E+02	0.51	<0.11	6.54E+02	2.44E+02	0.45	0.29	<0.11
283	2.57E+02	0.42	<0.1	1.64E+02	**0.39**	<0.1	1.61E+02	0.29	<0.1	1.34E+02	0.30	<0.2	1.79E+02	1.07E+02	0.32*	0.06	<0.2
284	5.94E+02	0.33	<0.1	5.22E+02	0.10	<0.1	4.73E+02	0.34	<0.1	3.89E+02	0.22	<0.2	4.95E+02	1.72E+02	0.25	0.23	<0.2
285	2.92E+02	0.10	0.17	2.57E+02	0.31	0.23	2.99E+02	0.27	<0.1	2.76E+02	0.17	<0.1	2.81E+02	3.73E+01	0.21	0.19	0.23
286	2.94E+02	0.41	<0.1	2.82E+02	0.41	<0.1	2.57E+02	0.35	<0.1	2.37E+02	0.33	<0.2	2.68E+02	5.10E+01	0.37	0.09	<0.2
287	2.85E+02	0.34	<0.1	3.14E+02	0.55	0.10	2.63E+02	0.54	0.14	3.13E+02	0.36	<0.1	2.94E+02	4.90E+01	0.45	0.23	0.1

(1) 0.10 Bq/L is the minimum detectable limit for C-14.
(2) Uncertainty is presented as ±2 standard deviations. Where Kaplan-Meyer Means are calculated, uncertainty is presented as ±2 Kaplan- Meyer standard deviations
(3) For C-14 the annual maximum is shown
* Kaplan-Meyer Mean
** Elevated C-14 levels found in samples from WSH229 and WSH240 are believed to be erroneous, as C-14 does not migrate through the ground quickly and samples taken in Q4 2019 show that C-14 returned down to normal levels.
Bolded values indicate measurements under the detection limit

Table 2.3: Annual Tritium, Gross β and C-14 in Yearly Monitored Groundwater Wells (Bq/L)

	Q3 (Bq/L)		
WSH	HTO	Gross β	C-14
WWMF			
224	5.42E+01	1.37E-01	<0.1
232	**9.56E+00**	1.90E-01	<0.1
237	**1.09E+01**	3.18E-01	<0.1
238	**1.05E+01**	6.49E-01	0.21
239	**1.04E+01**	6.23E-01	<0.1
244	1.54E+01	3.54E-01	N/A
246	**9.40E+00**	1.99E-01	N/A
248	**9.31E+00**	**1.96E-01**	N/A
249	**9.40E+00**	2.29E-01	N/A
250	1.80E+02	**2.11E-01**	<0.1
251	2.57E+03	1.37E-01	N/A
257	1.93E+03	2.69E-01	N/A
259	7.86E+02	1.90E-01	N/A
260	1.79E+01	1.85E-01	N/A
262	2.95E+01	**2.05E-01**	<0.1
263	7.60E+01	**1.94E-01**	N/A
268	**9.55E+00**	**1.69E-01**	N/A
270	**9.51E+00**	**1.79E-01**	N/A
271	**5.61E+00**	**1.99E-01**	N/A
272	2.62E+02	**1.81E-01**	N/A
278	3.95E+01	**1.91E-01**	N/A
279	2.41E+02	**1.84E-01**	N/A

Bolded values indicate measurements under the detection limit.

Table 2.4: Monthly Tritium and Gross β Concentration in WSH 231 (Bq/L)

Date	HTO	Gross β
2019-12-19	1.16E+04	**0.09**
2019-11-05	7.81E+03	0.19
2019-10-22	1.46E+04	0.19
2019-09-12	1.69E+04	0.13
2019-08-19	1.53E+04	**0.20**
2019-07-15	**1.41E+04**	0.17
2019-06-10	**1.32E+04**	0.21
2019-05-21	**1.30E+04**	**0.08**
2019-04-08	**1.17E+04**	0.07
2019-03-13	1.31E+04	**0.10**
2019-02-14	1.35E+04	0.09
2019-01-15	1.35E+04	**0.07**
annual average	1.32E+04	1.31E-01

Bolded values indicate measurements under the detection limit.

Table 2.5: 2019 Groundwater Monitoring Results RWOS 1 Surface Water (Bq/L)

	Q1			Q2			Q3			Q4			Annual Average				
RWOS1	HTO	Gross β	C-14 (1)	HTO	Gross β	C-14 (1)	HTO	Gross β	C-14 (1)	HTO	Gross β	C-14 (1)	HTO	Uncertainty (2	Gross β	ncertainty	C-14 (3)
RWOS 1 Surface Water																	
Discharge Ditch (N)	2.23E+02	0.22	N/A	2.25E+02	0.14	N/A	2.50E+02	0.15	N/A	2.85E+02	**7.00E-02**	N/A	5.78E+01	5.78E+01	0.14*	0.11	N/A
Discharge Ditch (N)	2.25E+02	0.10	N/A	2.64E+02	0.11	N/A	2.02E+02	**0.21**	N/A	2.41E+02	1.91E-01	N/A	2.33E+02	5.23E+01	0.13*	0.08	N/A
Discharge Ditch (N)	2.26E+02	0.10	N/A	2.58E+02	0.08	N/A	2.78E+02	0.17	N/A	1.84E+02	1.68E-01	N/A	2.37E+02	8.21E+01	0.11	0.16	N/A
Discharge Ditch (S)	1.90E+02	0.04	N/A	2.28E+02	0.13	N/A	2.07E+02	0.09	N/A	1.97E+02	**6.79E-02**	N/A	2.06E+02	3.31E+01	0.08*	0.07	N/A
Discharge Ditch (S)	1.49E+02	0.08	N/A	2.31E+02	0.10	N/A	1.73E+02	**0.21**	N/A	1.17E+02	2.06E-01	N/A	1.68E+02	9.63E+01	0.13*	0.11	N/A
Discharge Ditch (S)	1.92E+02	0.09	N/A	2.41E+02	0.06	N/A	7.01E+01	0.08	N/A	9.23E+01	7.27E-02	N/A	1.49E+02	1.62E+02	0.06	0.08	N/A

(1) 0.10 Bq/L is the minimum detectable limit for C-14.
(2) Uncertainty is presented as ±2 standard deviations. Where Kaplan-Meyer Means are calculated, uncertainty is presented as ±2 Kaplan- Meyer standard deviations
(3) For C-14 the annual maximum is shown
* Kaplan-Meyer Mean

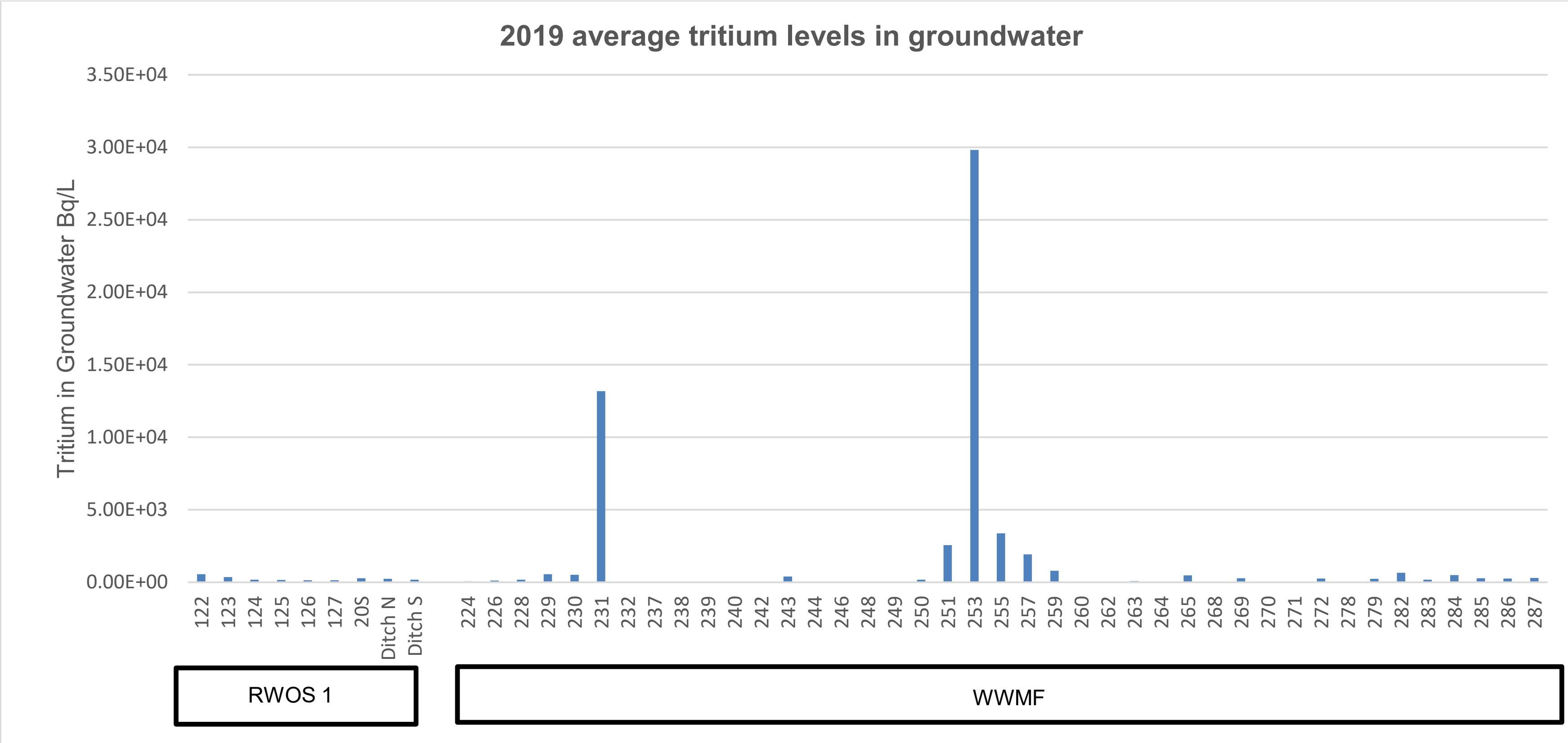

Figure 2.11: 2019 Average Annual Tritium Levels in Groundwater Monitoring Wells

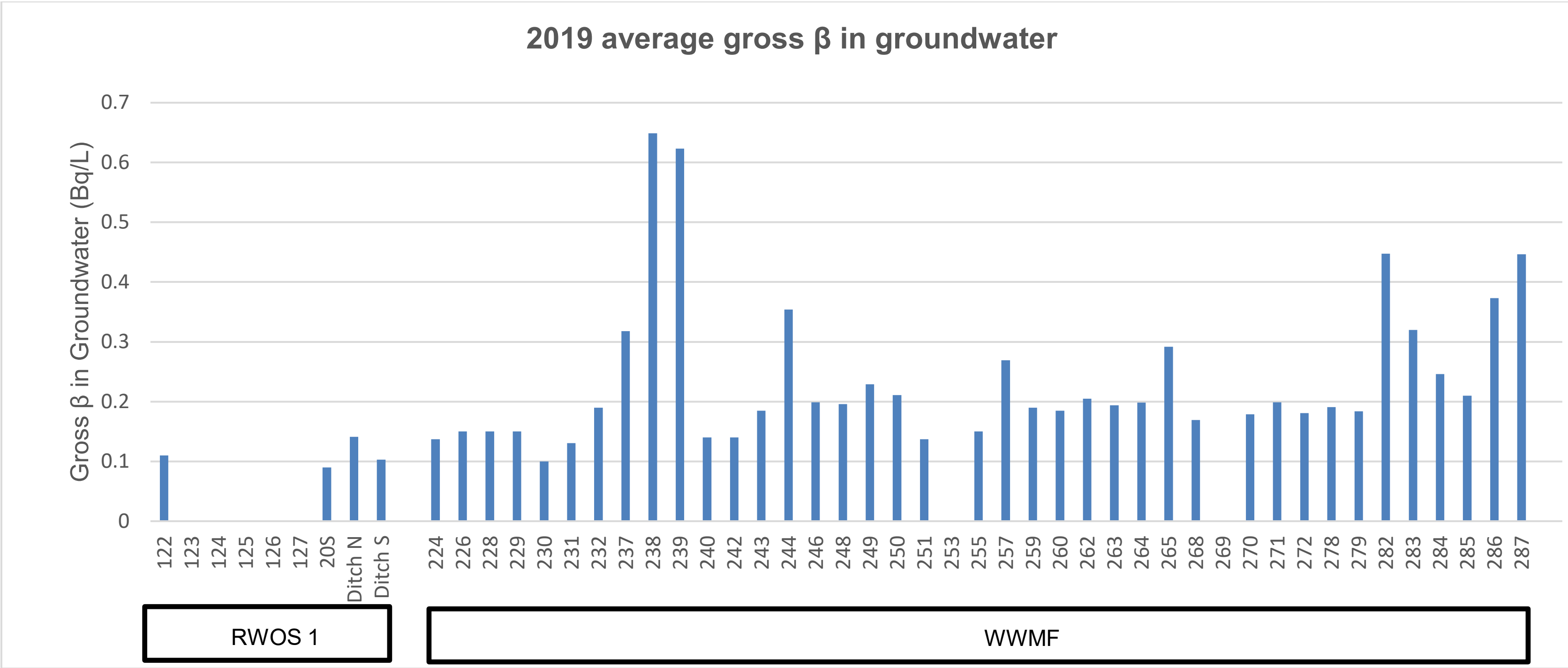

Figure 2.12: 2019 Average Annual Gross β Concentration in Groundwater Monitoring Wells.

2.3.4 Water in South Railway Ditch

Tritium concentrations in the South Railway Ditch were measured quarterly in 2019. Results of the mean annual concentration at each location are shown in Table 2.6. All locations were analyzed for statistically significant trends at the 95% significance level using the Mann-Kendall Test. Using measured tritium concentrations from 2014 to 2019 for WOD1, WOD2 and WOD4 no statistically significant trend was detected. Monitoring in WOD5 began in 2016 and this location indicated a statistically significant decreasing trend (Figure 2.13).

Table 2.6: Mean annual tritium concentration in 2019 at Railway Ditch

	HTO (Bq/L)	Uncertainty *
WOD1	5.61E+02	1.46E+03
WOD2	7.52E+02	3.18E+02
WOD4	7.47E+02	2.82E+02
WOD5	6.33E+02	4.22E+02

*Uncertainty is given as ±2 standard deviations.

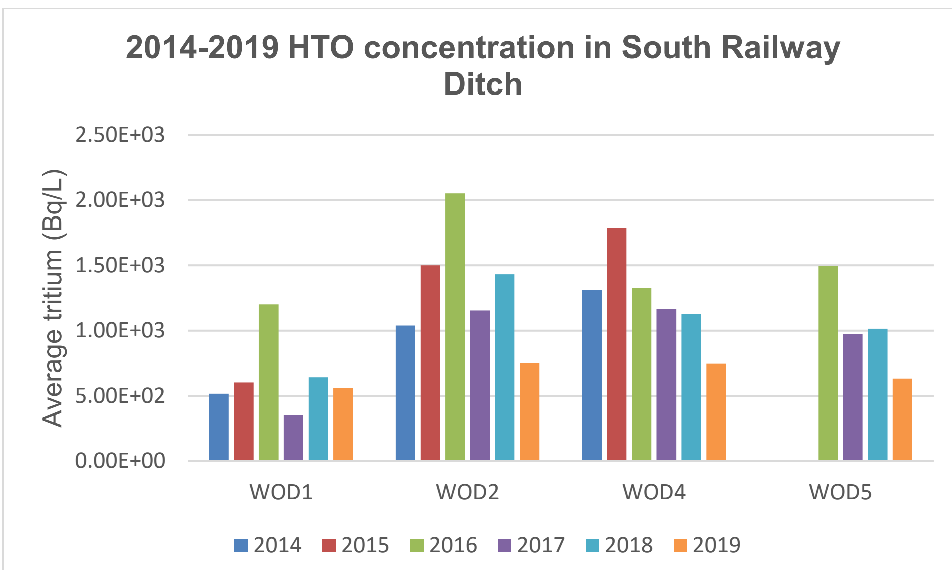

Figure 2.13: 2014-2019 Average Annual Tritium at Surface Water Sampling Locations in South Railway Ditch

2.3.5 HTO in Precipitation

Eighteen precipitation samples were collected in 2019 from four locations at the perimeter of the WWMF (WS1-4) and two reference locations (WSA-B) and were analyzed for tritium concentrations. The average tritium concentration in 2019 was 546 Bq/L in the samples from WS1-4 and 648 Bq/L at the reference locations. The Mann-Kendall Test for the last 5 years showed no statistically significant trend in either the WWMF or the reference locations (Figure 2.14).

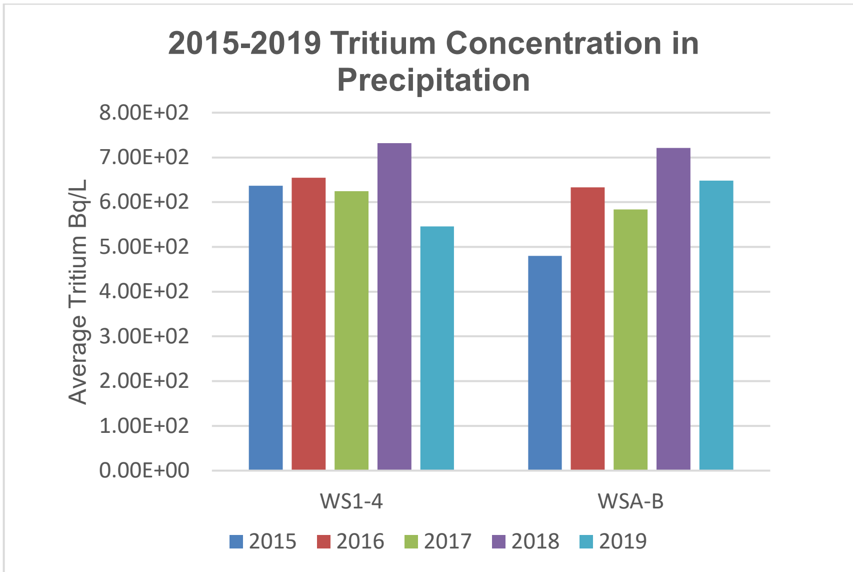

Figure 2.14: Average Annual Tritium Concentration in Precipitation Samples.

2.3.6 Other

2.3.6.1 Passive Carbon-14 sampling

Twenty passive monitors are used to determine C-14 in air at the WWMF on a quarterly basis. Figure 2.15, shows the results of the second quarter measurements. Quarterly and annual results from the passive monitors are shown in Table 2.7.

The elevated concentrations of C-14 are attributed to spent moderator ion exchange (IX) resin stored in the IC-12s and IC-18s and those are investigated separately. As a result, C-14 concentration in air is highest in Area 1 (samplers 1-9), which has 63% and 98% higher concentration than Areas 2 and 3 respectively. Figure 2.16 shows C-14 concentrations from a sampler close to the IC-18s (i.e., B#3, Figure 2.6) and one representing background (i.e., B#13, Figure 2.6) for comparison. Measurements from the IC-18s show a statistically significant increasing trend using UCLPro's Mann-Kendall Test, whereas the sampler representing background shows no trend. Additional field sampling to update the estimated fugitive tritium and C-14 emissions from the site and determine if additional monitoring is warranted was completed as part of Phase 3 of the fugitive emissions reassessment.

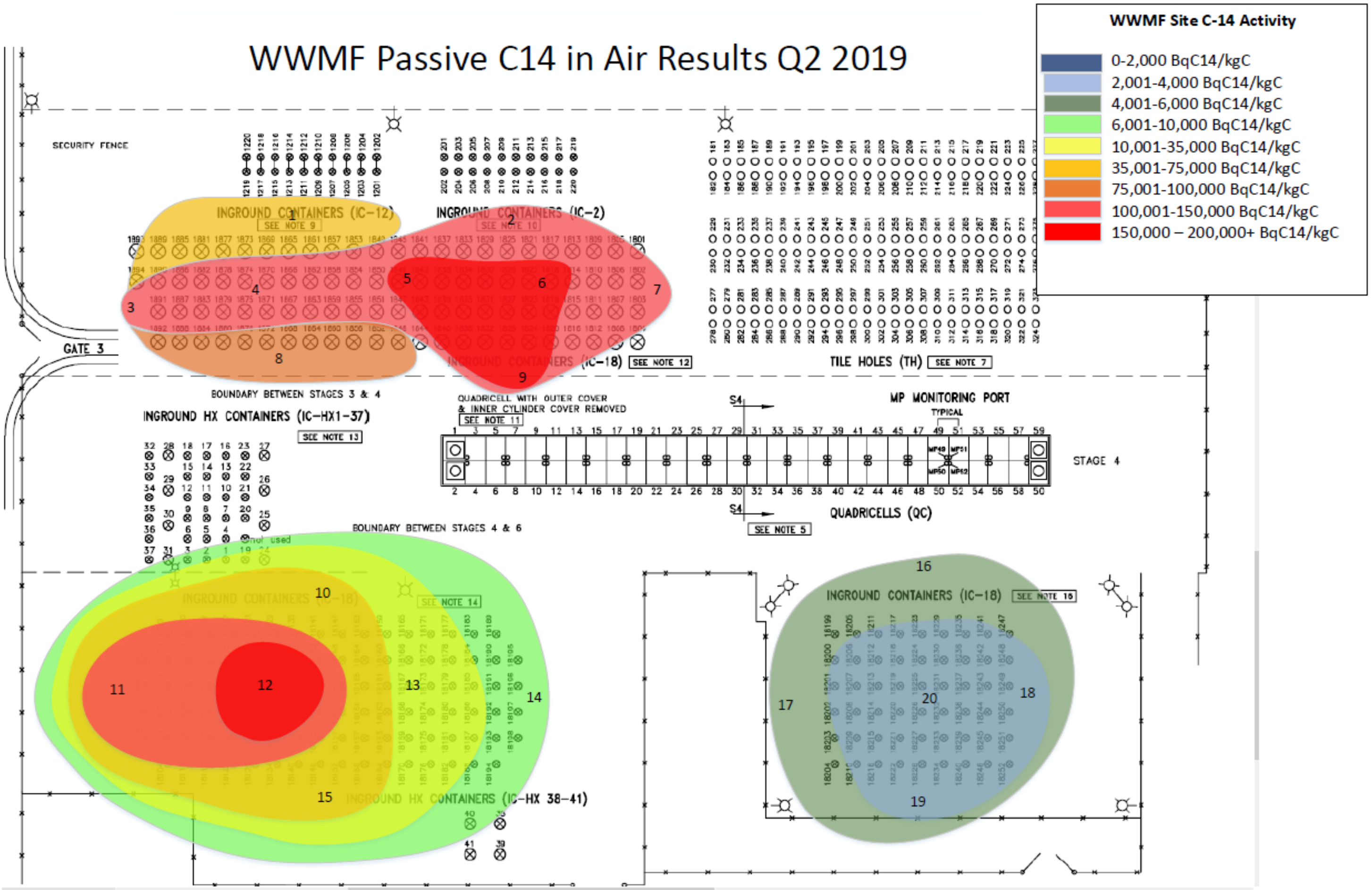

Figure 2.15: WWMF Passive C-14 Sampling Locations and Results for Q2

Table 2.7: 2019 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* (Bq C-14 /kgC)
			Area 1 : Phase I-III			
#1	7.40E+04	6.88E+04	2.02E+04	5.56E+04	5.46E+04	4.85E+04
#2	1.52E+05	1.23E+05	9.41E+04	1.33E+05	1.25E+05	4.84E+04
#3	1.63E+05	1.20E+05	2.72E+04	1.22E+05	1.08E+05	1.15E+05
#4	1.16E+05	1.25E+05	3.43E+04	7.60E+04	8.79E+04	8.34E+04
#5	1.08E+05	1.54E+05	6.99E+04	1.08E+05	1.10E+05	6.87E+04
#6	2.27E+05	2.14E+05	1.04E+05	1.99E+05	1.86E+05	1.12E+05
#7	1.97E+05	1.34E+05	1.23E+05	1.74E+05	1.57E+05	6.94E+04
#8	1.15E+05	8.97E+04	3.07E+04	7.67E+04	7.80E+04	7.07E+04
#9	3.03E+05	1.85E+05	1.41E+05	2.60E+05	2.22E+05	1.45E+05
			Area 2 : Stage 6			
#10	1.88E+05	7.44E+04	3.09E+04	1.16E+05	1.02E+05	1.34E+05
#11	2.75E+05	1.31E+05	4.02E+04	1.48E+05	1.49E+05	1.93E+05
#12	6.48E+05	1.63E+05	1.08E+05	3.29E+05	3.12E+05	4.86E+05
#13	1.03E+05	3.14E+04	1.95E+04	8.36E+04	5.94E+04	8.05E+04
#14	2.48E+04	9.50E+03	4.80E+03	1.58E+04	1.37E+04	1.73E+04
#15	1.04E+05	3.87E+04	2.80E+04	6.00E+04	5.77E+04	6.73E+04
			Area 3 : Batch 5			
#16	9.46E+03	5.20E+03	3.36E+03	1.19E+04	7.48E+03	7.80E+03
#17	6.45E+03	4.41E+03	2.05E+03	4.50E+03	4.35E+03	3.60E+03
#18	7.79E+03	2.20E+03	2.32E+03	6.39E+03	4.67E+03	5.70E+03
#19	4.71E+03	2.43E+03	1.75E+03	3.53E+03	3.11E+03	2.59E+03
#20	5.71E+03	2.59E+03	2.00E+03	4.09E+03	3.60E+03	3.32E+03

*Uncertainty is given as ±2 standard deviations.

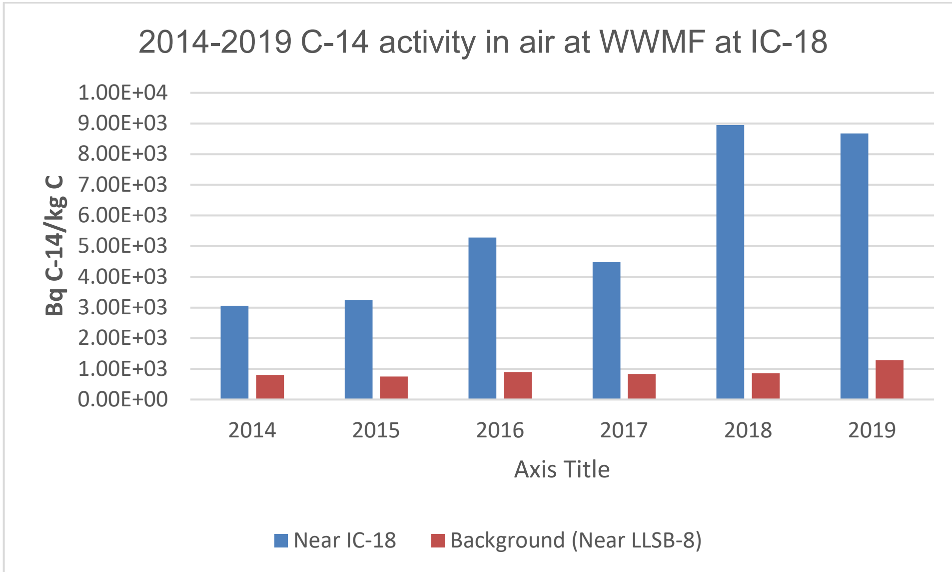

Figure 2.16: 2014-2019 C-14 Total Annual Concentration at WWMF for Samplers B#3 (Near IC-18) and B#13 (Background)

3.0 RADIOLOGICAL DOSE TO THE PUBLIC

One WWMF EMP objective is to demonstrate that the radiological risk to the public due to the operation of the WWMF is low and well within the relevant regulatory dose limit. Members of the public are exposed to radiation or radionuclides that are released as a result of WWMF operations. Non-NEWs on site may be exposed to direct/in-direct radiation from 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 the level 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 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 [R-13]. Public dose is calculated using mostly concentrations of radionuclides measured 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 [R-8].

3.1.2 Public Dose from WWMF Operations

Bruce Power reported the annual public dose to be 1.5 µSv in 2019 based on results from their 2019 EMP [R-8]. This is approximately three orders of magnitude below the public dose limit of 1 mSv/a. The public dose arising from WWMF operations is a small fraction of the 1.5 µSv value since WWMF radiological emissions are no more than 1.6% of the combined site emissions (Table 3.1). Thus, the dose to members of the public from WWMF operations is well below the regulatory limit.

3.2 Tritium Levels at Nearby Water Supply Plants

The WSPs influenced by WWMF tritium emissions are the same as those monitored by the Bruce Power EMP, i.e. the Kincardine WSP and the Southampton WSP. For 2019, Bruce Power reported that the annual average tritium in drinking water at these WSPs was 4.3 Bq/L at the Kincardine WSP and 11.6 Bq/L at the Southampton WSP [R-8]. These are well below the Ontario Drinking Water Standard for tritium of 7,000 Bq/L, and also meet OPG's commitment to keep these levels below 100 Bq/L on an annual average basis. Waterborne tritium releases from the WWMF are only 0.01% of the Bruce nuclear site total waterborne tritium emissions, so the contribution from the WWMF is extremely low. Waterborne emissions from the WWMF consist of releases from the surface and subsurface engineered drainage systems that contain mostly precipitation.

3.3 Direct Gamma Radiation Exposure

The WWMF facilities, including the UFDS facility and RWOS 1 are relatively far from the Bruce nuclear site boundaries. Gamma radiation and skyshine from the 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 WWMF facility boundaries to ensure that non-NEWs did not receive doses in excess of the regulatory limit. The TLD measurements for 2019 showed that doses at all locations around the facility boundaries were within 0.1 µGy/h, compared to the derived dose rate limit of 0.5 µGy/h.

3.4 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 2.16) the dose in a worst-case scenario to a non-NEW worker at the fenceline of the WWMF can be estimated. In the case of 8-hour occupancy year-round, the expected dose due to C-14 inhalation is estimated to 0.03 µSv/a. This is well below the public dose limit of 1mSv/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 in the immediate vicinity of the C-14 emission was estimated. Calculated dose rates to grasses were determined to be 5.9E-4mGy/day, well below the benchmark of 2.4 mGy/day [R-14].

3.5 Discussion of Results

All direct and indirect estimations of radiological dose to members of the public, including non-NEW, and keeping tritium levels at WSPs below 100 Bq/L as a result of the operation of the WWMF and RWOS 1, produced results well within the regulatory limits and OPG's commitments, and indicated that the WWMF was meeting its EMP objectives in these areas.

Table 3.1: Radiological Emissions from Bruce Nuclear Site Facilities (Bq/year)[1]

	Bruce A	Bruce B	CMLF	WWMF	CNL	Kinectrics KI [3]	Total	%WWMF
				Airborne Emissions (Bq/year)				
Tritium Oxide	4.63E+14	3.30E+14	2.23E+10	1.03E+13	2.41E+11	1.88E+11	8.04E+14	1.3%
Noble gas[1]	7.07E+13	3.39E+13	N/A	N/A	N/A	N/A	1.05E+14	N/A
I-131	4.17E+07	4.40E+05	2.52E+04	0.00E+00	N/A	N/A	4.22E+07	0.0%
Particulate Gamma	1.97E+06	4.76E+06	0.00E+00[4]	6.52E+02	N/A	N/A	6.73E+06	0.0%
Particulate Gross Beta	N/A	N/A	N/A	N/A	3.90E+04	N/A	3.90E+04	N/A
Particulate-Gross Alpha	2.43E+04	2.63E+04	0.00E+00*	N/A	4.90E+03	N/A	5.55E+04	N/A
C-14	1.34E+12	1.08E+12	N/A	2.62E+09	N/A	N/A	2.42E+12	0.1%
				Waterborne Emissions (Bq/year)				
Tritium Oxide	2.12E+14	8.82E+14	N/A	1.60E+11	3.73E+10	N/A	1.09E+15	0.01%
C-14	8.17E+08	4.68E+09	N/A	N/A	N/A	N/A	5.50E+09	N/A
Gross β/ γ	2.13E+09	2.26E+09	N/A	N/A	N/A	N/A	4.39E+09	N/A
Gross β			N/A	7.08E+07	4.52E+07	N/A	1.16E+08	1.6%[2]
Gross α	<Ld	<Ld	N/A		6.75E+06	N/A	6.75E+06	N/A

1) Noble gas emissions are in units of Bq-MeV/year.
2) %Gross β = WWMF Gross β/(total Gross β/ γ + WWMF Gross β).
3) This is the net airborne emission from KI North Facility for the period of Dec 27, 2018 to Jan 23, 2020.
4) Natural occurring radionuclide material detected in gamma spectrum analysis is not reported.

4.0 QUALITY ASSURANCE AND PERFORMANCE

The WWMF EMP design report recommends that a QA/QC program for the WWMF EMP be implemented and that it should be based on OPG's existing EMP QA manual (for Darlington and Pickering EMPs) [R-15], with adjustments for the specific characteristics of the WWMF site and operations. The program would encompass all activities in field sample collection, laboratory analysis, laboratory quality control, and external laboratory comparison. 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 Health Physics Laboratory (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 2019, the OPG EGM system met these accuracy and precision requirements. Results of its QA testing for 2019 were satisfactory and are documented in its annual QA report [R-16].

The OPG HPL has a commitment to perform a minimum of one independent audit each year of the quality system used for dosimetry and environmental measurement services. These may not always be related to the EMPs. In 2019, an HPL QA audit was conducted on the Personal Air Sampler (PAS) Process. This audit identified two good practices, and three recommendations. The recommendations are being addressed through the AR 28229006. [R-16]. There were no significant adverse findings or conditions arising from this self-assessment that affected the quality of results and measurements in the dosimetry and environmental laboratory.

The Ministry of the Environment, Conservation and Parks performed audits of the Health Physics Laboratory in February and July, 2019. There were no non-compliant findings for either audit. Overall, the Inspection rating for the July audit was 100%. [R-16].

Environmental tritium and gross β analysis in water samples are performed for the WWMF by the Bruce Power Health Physics laboratory. The Bruce Power Health Physics Lab operates a comprehensive QA program in accordance with ISO 17025, 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, surface water, and precipitation sample analyses, i.e. HTO and gross β activity in water, met requirements, including accuracy and precision as per external laboratory testing. Bruce Power HPL had one audit in 2019, performed by the internal Audit department. The scope included the laboratory quality management system, and a selection of dosimetry and radiological analysis methods.

Kinectrics performs C-14 analysis for the WWMF. The Kinectrics laboratory operates a comprehensive QA program which includes proficiency testing for C-14 analysis using a service provided by the National Research Council Canada (NRC). Kinectrics is accredited by The Standards Council of Canada for radiochemical tests, including C-14 in water [R-17].

4.2 Program Quality Assurance

EMP program QA generally includes self-assessments and audits as per the requirements of CSA N288.4-10 [R-3]. There were no assessments or audits in 2019.

4.3 Program Performance

4.3.1 Sample Unavailability

TLD deployment and analysis and groundwater sampling and analysis are done on a planned schedule. All data were examined to determine the unavailability for 2019. Unavailability is the fraction of the total planned samples that were missed or produced invalid results. The WWMF does not currently have unavailability targets for EMP samples.

A total of 172 TLD samples were planned for 2019, consisting of quarterly samples at seven locations at RWOS 1, quarterly samples at 20 locations at the WWMF/LILW storage area, and quarterly samples at 16 locations at the WWMF/UFDSF. All 172 results were obtained and valid (see Table 2.1), producing an overall unavailability of 0%.

Bi-weekly sampling was planned for precipitation monitoring in 2019, weather permitting. A total of 108 samples were collected for the 2019 tritium monitoring in precipitation, consisting of six samples on 18 sampling dates. All 108 results were valid, producing a total unavailability of 0%.

Table D.1 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. An overall unavailability of 0% was achieved for the existing groundwater monitoring plan.

A total of 80 C-14 samples were planned for 2019, consisting of quarterly samples at 20 locations at WWMF. All 80 results were obtained and valid (see Table 2.7), producing an overall unavailability of 0%.

5.0 OVERALL SUMMARY OF EMP

An EMP detailed design was developed for the WWMF in 2012 [R-4]. The design recommended in the detailed EMP design report was followed in 2019. The primary objectives of the EMP concerning public and worker safety and demonstrating containment of radioactivity were met in 2019. Operation of the WWMF resulted in extremely low public dose, well within regulatory limits. The potential exposure of non-NEWs near WWMF facilities was low and well within the derived dose rate limit. Waterborne tritium emissions from the WWMF were shown to be very low and acceptable with respect to the commitment by OPG to keep its impact on tritium levels at nearby WSPs below 100 Bq/L on an annual average basis (Objectives 1 and 7).

Measurements of TLDs around the WWMF and RWOS 1 (Objective 2) are well under the Derived Dose Rate Limit of 0.5 μSv/h. TLDs that were previously noted to be close to 0.1 μSv/h showed a statistically significant decreasing trend. Despite the increasing trend in some locations no TLD exceeded 0.1 μSv/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. Six wells at the WWMF and four wells at the RWOS 1 showed statistically significant increasing trends in tritium or gross β, however they remain well below the level of 60,000 Bq/L at which OPG has committed to notify the CNSC. The majority of wells that show an increasing trend have concentrations below 200 Bq/L and 0.2 Bq/L for tritium and gross β respectively. Surface water sampling for the WWMF at the South Railway Ditch shows no statistically significant trends except for one location where a decreasing trend can be detected. Surface water sampling at the RWOS 1, shows no statistically significant trends.

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. The annual average concentration of tritium in WSH 231 in 2019 was lower than in the previous year and shows a decreasing trend for the last 6 years. However, a neighbouring well WSH 253 shows an increasing trend since 2017. Comparing to the Ontario Drinking Water Quality Standards for tritium (7,000 Bq/L) and gross β activity (1 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 is currently being updated as part of N288.7 implementation for December 31, 2021.

Monitoring of HTO in precipitation (Objective 4) is incorporated in the routine sampling program. Precipitation samples are taken at the four indicated locations around the WWMF and at two reference locations as precipitation events allow. The supplementary study conducted in 2013 concluded that the HTO concentration was not correlated with operation of the incinerator and was too low to account for elevated levels in MSA wells. No statistically significant trend for 2014 – 2019 was observed. The supplementary study on HTO concentration in precipitation will be repeated to support the 2021 ERA.

Monitoring in the South Railway Ditch (Objective 5) is done as part of the routine sampling. Surface water in the South Railway Ditch is monitored quarterly. The supplementary study conducted in 2013, concluded that the WWMF runoff/groundwater has a negligible influence on tritium concentrations and found no statistically significant trends. No statistically significant trends were observed in the monitored locations for 2014 – 2019 either, except for WOD5, which showed a decreasing trend. The supplementary study on HTO concentrations in the South Railway Ditch will be repeated for the 2021 ERA.

Sediment and water in the wetland areas of the WWMF (Objective 6) were monitored in a supplementary study conducted in 2013-2014. Acceptable water and sediment quality were demonstrated in the 2016 ERA [R-6]. No effect due to exposure to radiological or non-radiological contaminants was identified. The only risk identified was a low to moderate risk to benthic invertebrates due to exposure to copper and zinc in sediment. This study will be repeated to support the 2021 ERA.

Increasing C-14 concentration in air at the WWMF has been attributed to moderator exchange resin stored in Area 1. A fugitive emissions reassessment is currently underway to address this finding and the final report is currently targeted to be completed in Q3 2020. Scrubbers to reduce the amount of fugitive emissions are scheduled to be installed in Q4 of 2020 to help mitigate this trend. Despite these emissions, both environmental and health physics monitoring support that there is no significant impact on workers, the public, or the environment.

Overall, the results of the 2019 WWMF EMP indicate confirmation of adequate protection of public, workers and the environment.

6.0 OUTLOOK FOR EMP

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

- Reviews and Audits: Perform EMP review (internal), self-assessments, and audits according to N288.4-10
- RWOS 1 groundwater monitoring grid: review and document the objectives and rationale of this monitoring grid, including monitoring of surface water in the North and South ditches. Note any licence requirements or commitments to CNSC, and if appropriate, determine and document criteria for when to stop monitoring. This is currently addressed as part of the N288.7 implementation planned for December 31, 2021.
- WWMF groundwater: prepare a groundwater protection program and groundwater monitoring program compliant with CSA N288.7-15. This is currently addressed as part of the N288.7 implementation planned for December 31, 2021.
- Precipitation: Routine and supplementary monitoring concluded that tritium in precipitation is not the likely source of tritium in groundwater. The supplementary study will be completed in 2020-21 to support the 2021 ERA update. Following this assessment, the precipitation sampling should be reviewed and modifications made to the EMP design.
- Surface Water: The South Railway Ditch routine and supplementary studies indicated little impact from the WWMF and tritium concentrations in WOD5 are trending downwards. The supplementary study will be repeated in 2020-21 in support of the 2021 ERA update after which the frequency and timing of this sampling should be reviewed and modifications made to the EMP design.
- Wetland sampling: The East Wetland will be sampled in 2020-21 as part of a repeat of supplementary studies to support the ERA. If the results indicate no ecological impacts from contaminants related to WWMF operation then the frequency of this sampling should be re-evaluated and modifications made to the EMP design.
- C-14 monitoring: To be continued as currently implemented with a focus on the upward trend close to IC-18. Scrubbers will be installed in Q42020 and therefore results for 2021 onward should indicate if this mitigation is sufficient to address the recently observed upward trend.

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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

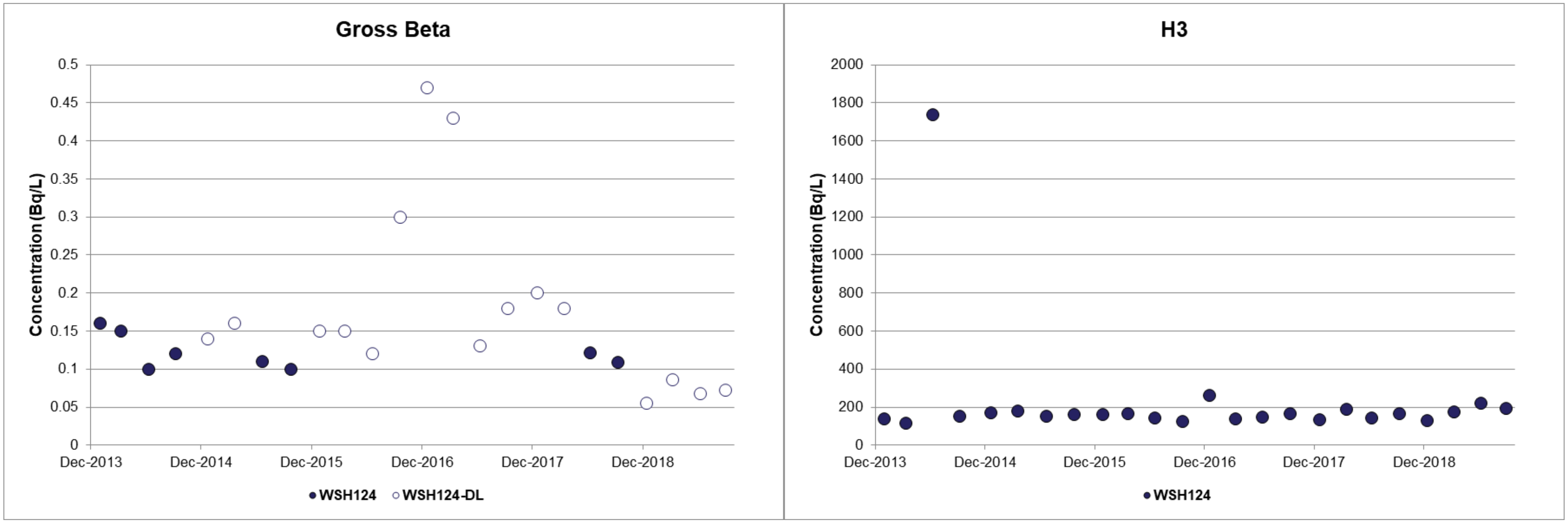
Acronyms and Abbreviations

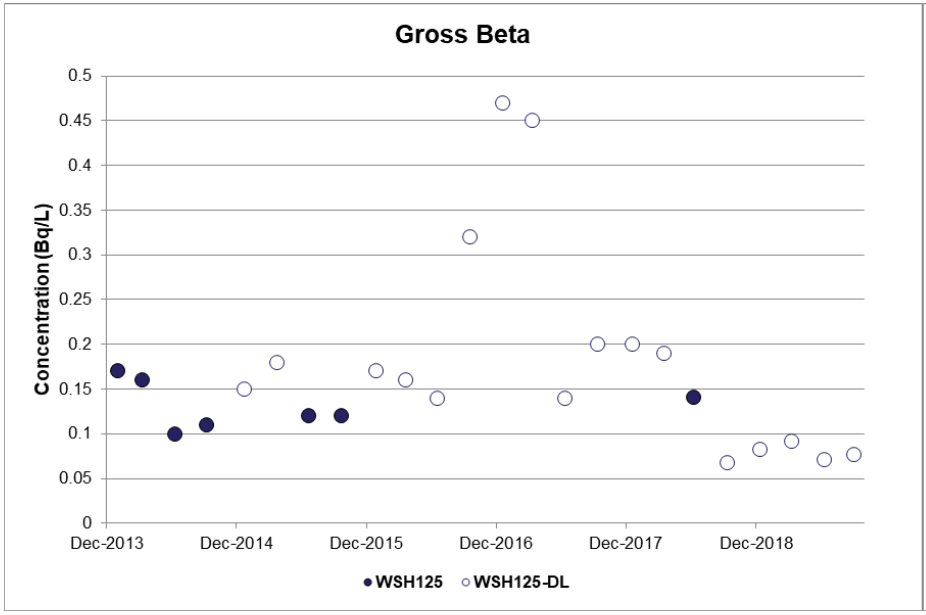
AECL	Atomic Energy of Canada Limited
CMLF	Central Maintenance and Laundry Facility
CNSC	Canadian Nuclear Safety Commission
CNL	Canadian Nuclear Laboratories
CSA	Canadian Standards Association
DN	Darlington Nuclear
EGM	Environmental Gamma Monitors
EMP	Environmental Monitoring Program
EPA	Environmental Protection Agency
ERA	Environmental Risk Assessment
HPL	OPG Health Physics Laboratory
IAEA	International Atomic Energy Agency
ICs	Inground storage containers
IC-12	12 m3 capacity ICs
IC-18	18 m3 capacity ICs
ISO	International Organization for Standardization
Lc	Critical Level
Ld	Limit of Detection
LILW	Low and Intermediate Level Waste
LLSB	Low Level Storage Building
MSA	Middle Sand Aquifer
NRC	National Research Council of Canada

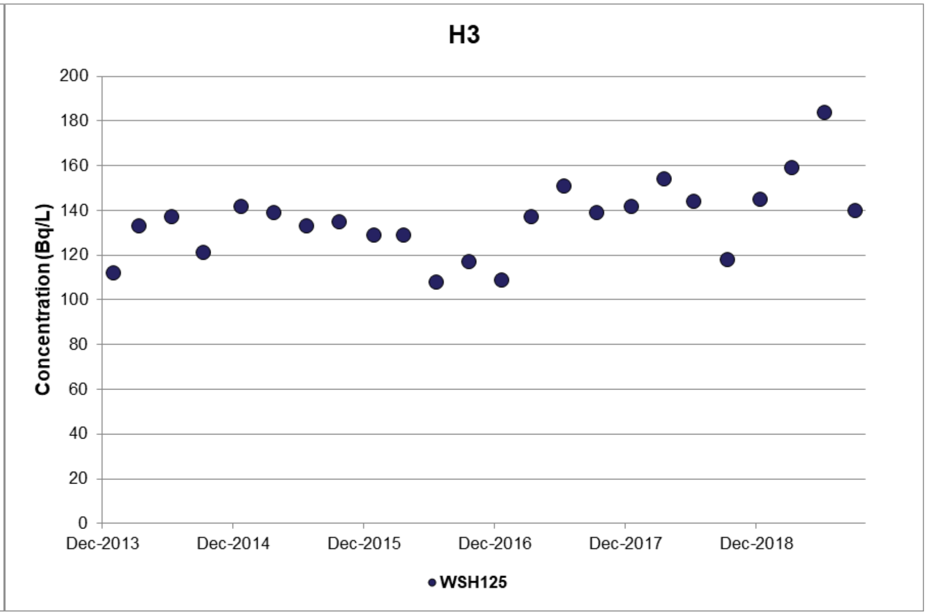
NEW	Nuclear Energy Worker
OPG	Ontario Power Generation
QA	Quality Assurance
QC	Quality Control
QOR	WWMF Quarterly Operations Report
RWOS 1	Radioactive Waste Operations Site 1
SSTF	Spent Solvent Treatment Facility
TLD	thermo luminescent dosimeter
TPMB	Transportation Maintenance Building
UFDSF	Used Fuel Dry Storage Facility
WSH	Water Sampling Hole
WSP	Water Supply Plant
WVRB	Waste Volume Reduction Building
WWMF	Western Waste Management Facility

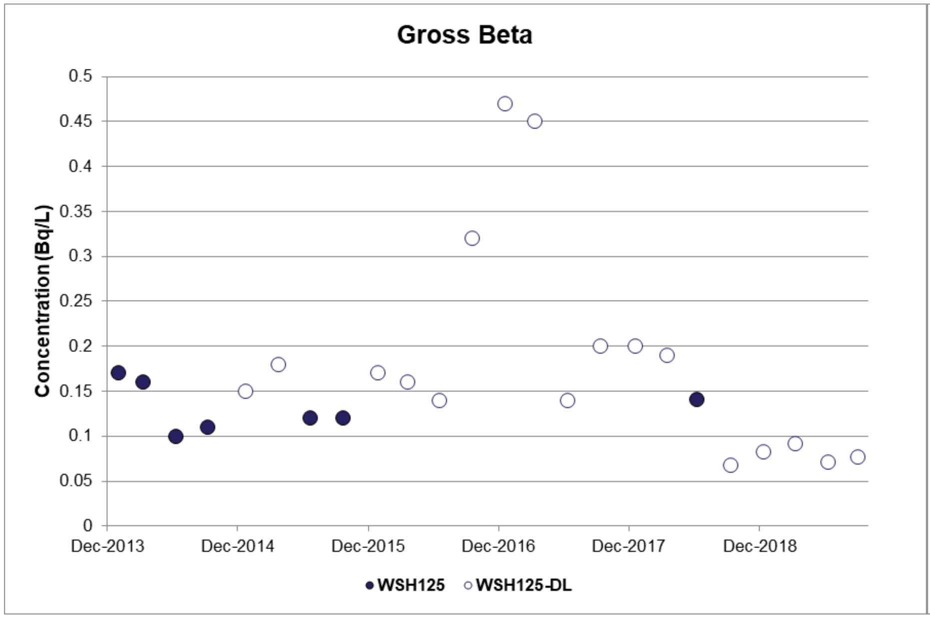
Appendix C Tritium and Gross Beta in Groundwater 2014-2019

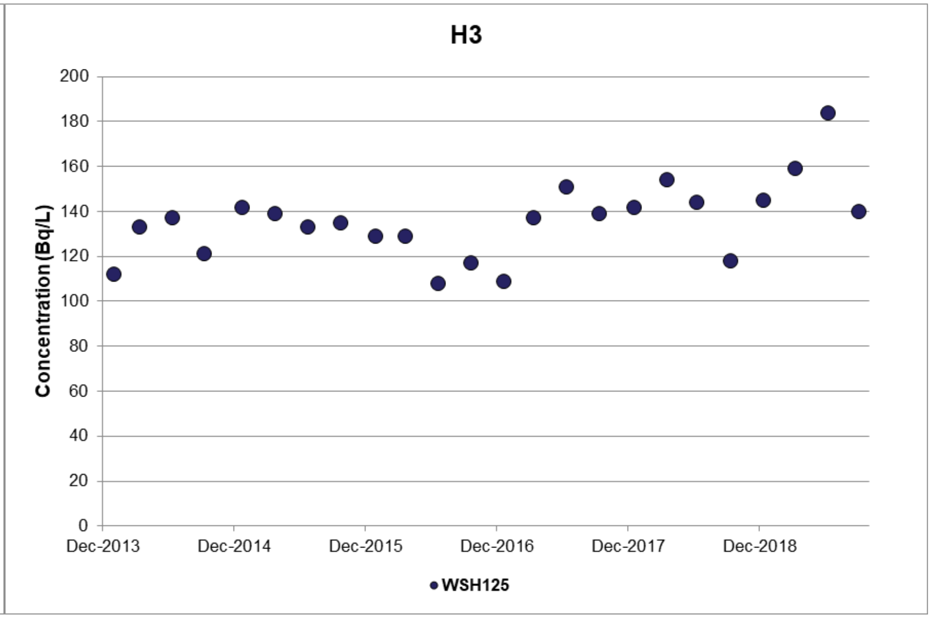
This appendix contains the plots of tritium and gross beta activity with statistically significant increase in either tritium or gross beta over the 5 year period 20014-2019. All datasets were also analyzed for the presence of statistically significant trends using EPA's ProUCL software, and results of the trend analyses are reported in Section 2.3.3.

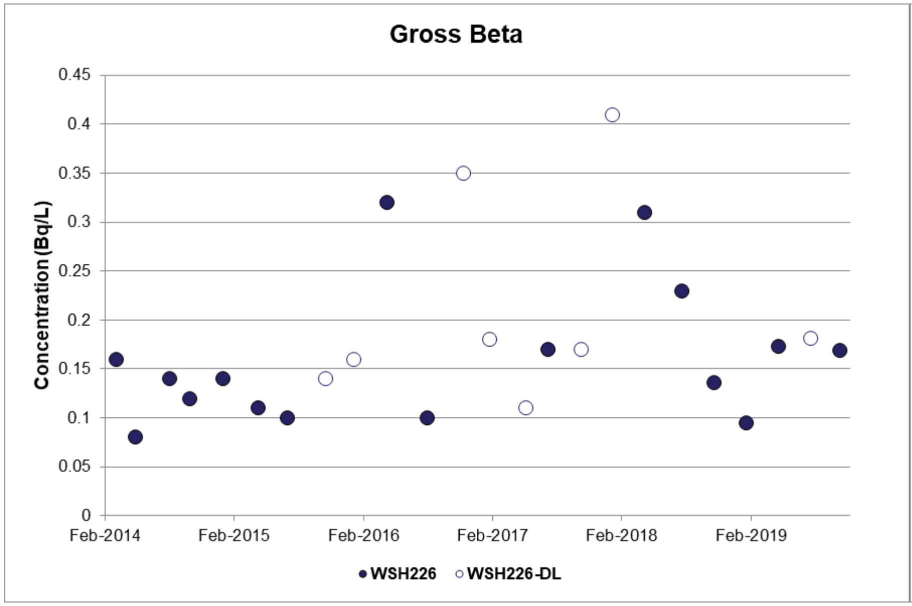


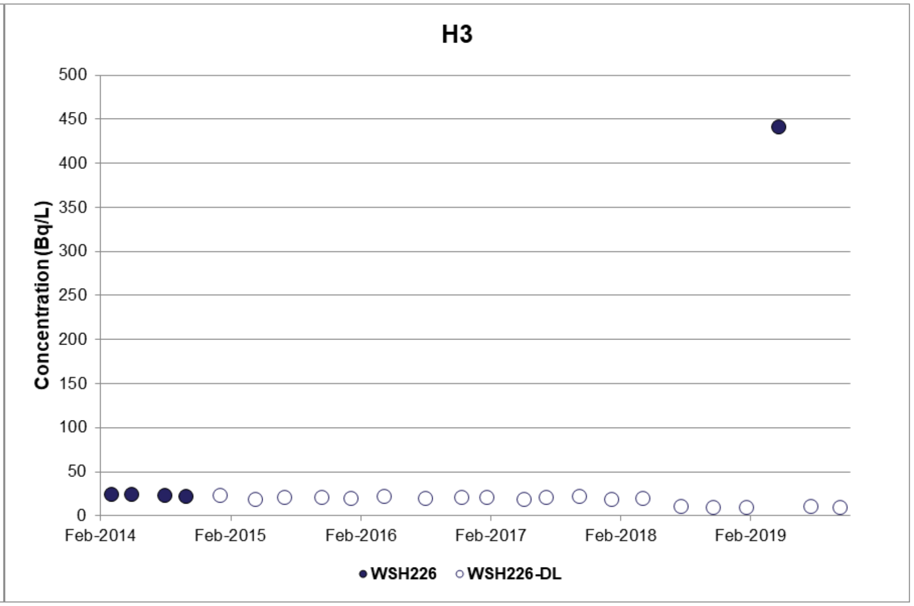

Gross Beta
Concentration (Bq/L)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Dec-2013
Dec-2014
Dec-2015
Dec-2016
Dec-2017
Dec-2018
WSH125
WSH125-DL

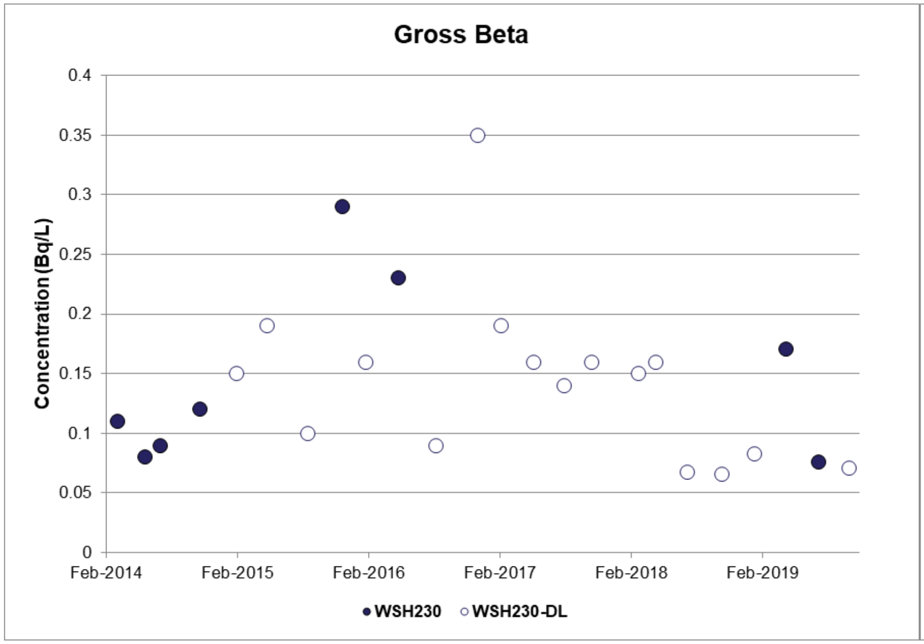

H3
Concentration (Bq/L)
0
20
40
60
80
100
120
140
160
180
200
Dec-2013
Dec-2014
Dec-2015
Dec-2016
Dec-2017
Dec-2018
WSH125

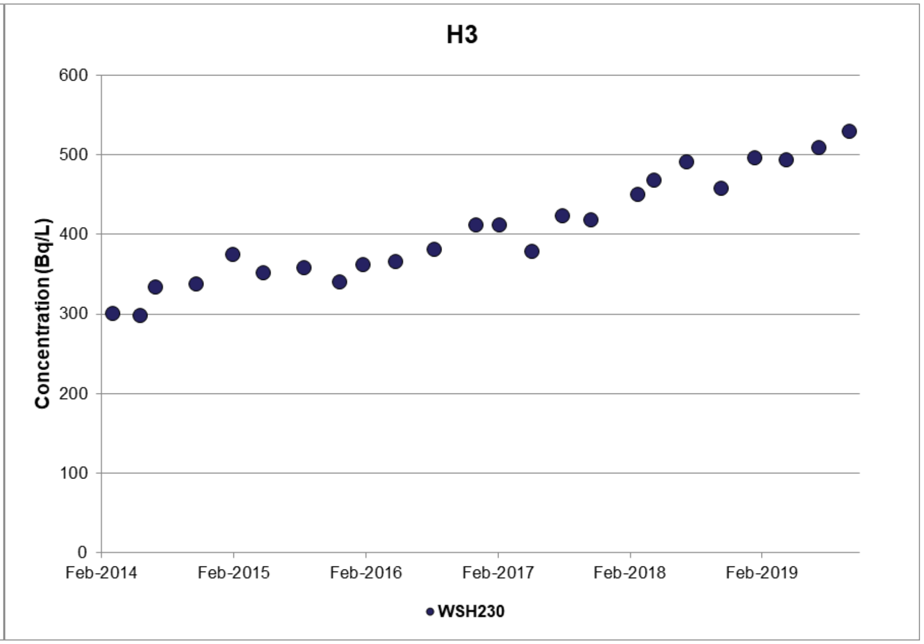

Gross Beta
Concentration (Bq/L)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Dec-2013
Dec-2014
Dec-2015
Dec-2016
Dec-2017
Dec-2018
WSH125
WSH125-DL

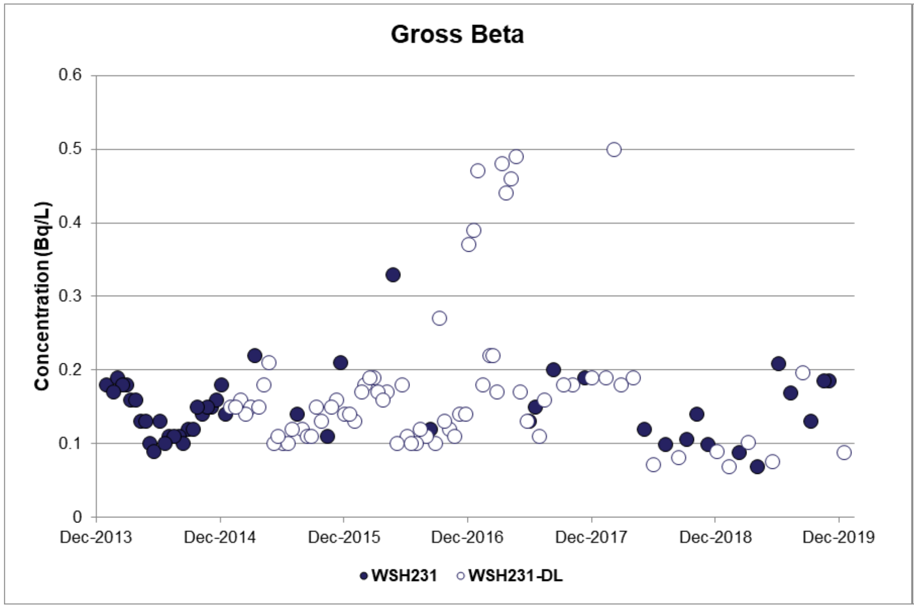

H3
Concentration (Bq/L)
200
180
160
140
120
100
80
60
40
20
0
Dec-2013
Dec-2014
Dec-2015
Dec-2016
Dec-2017
Dec-2018
WSH125

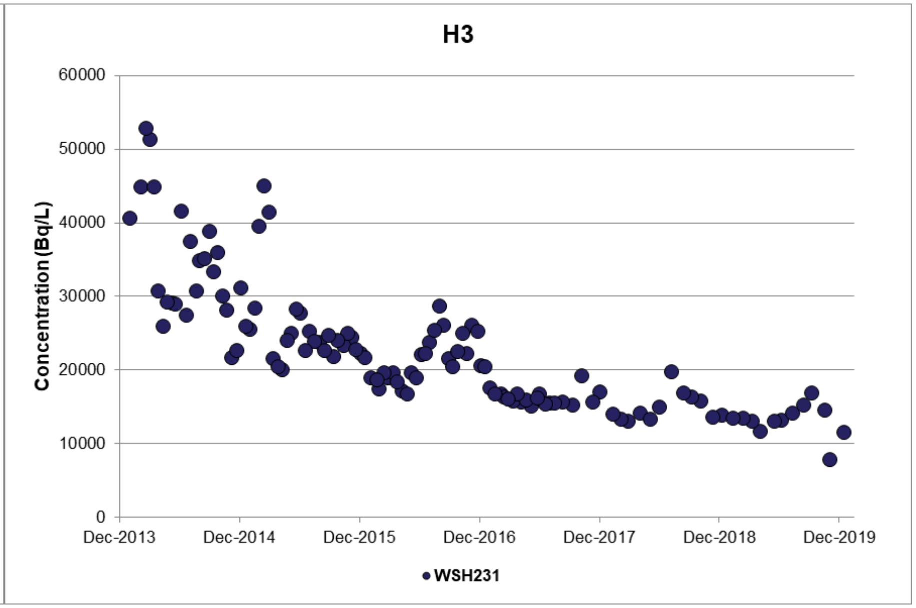

Gross Beta
Concentration (Bq/L)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Feb-2014
Feb-2015
Feb-2016
Feb-2017
Feb-2018
Feb-2019
WSH226
WSH226-DL

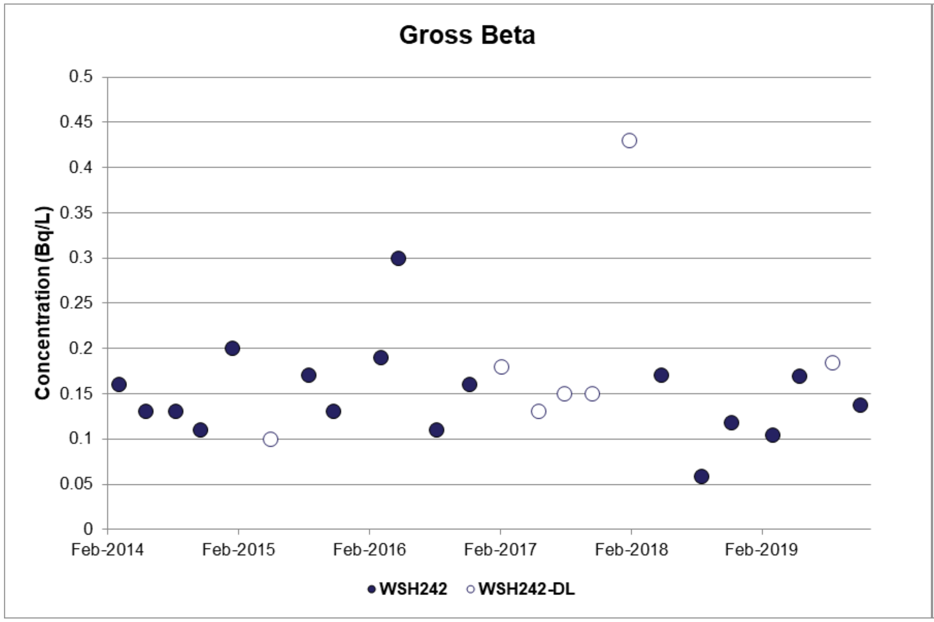

H3
Concentration (Bq/L)
500
450
400
350
300
250
200
150
100
50
0
Feb-2014
Feb-2015
Feb-2016
Feb-2017
Feb-2018
Feb-2019
WSH226
WSH226-DL

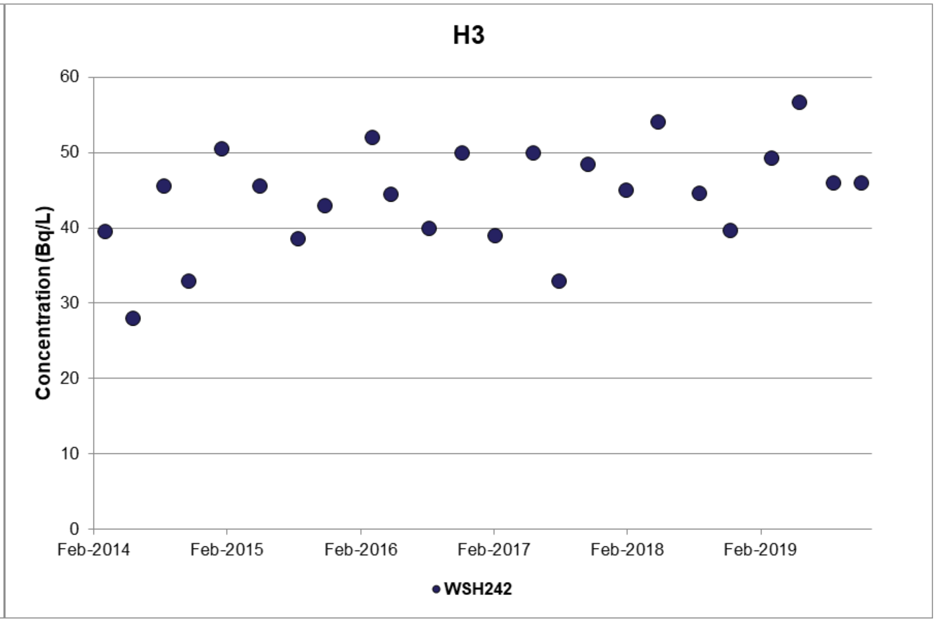

Gross Beta
Concentration (Bq/L)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Feb-2014
Feb-2015
Feb-2016
Feb-2017
Feb-2018
Feb-2019
WSH230
WSH230-DL

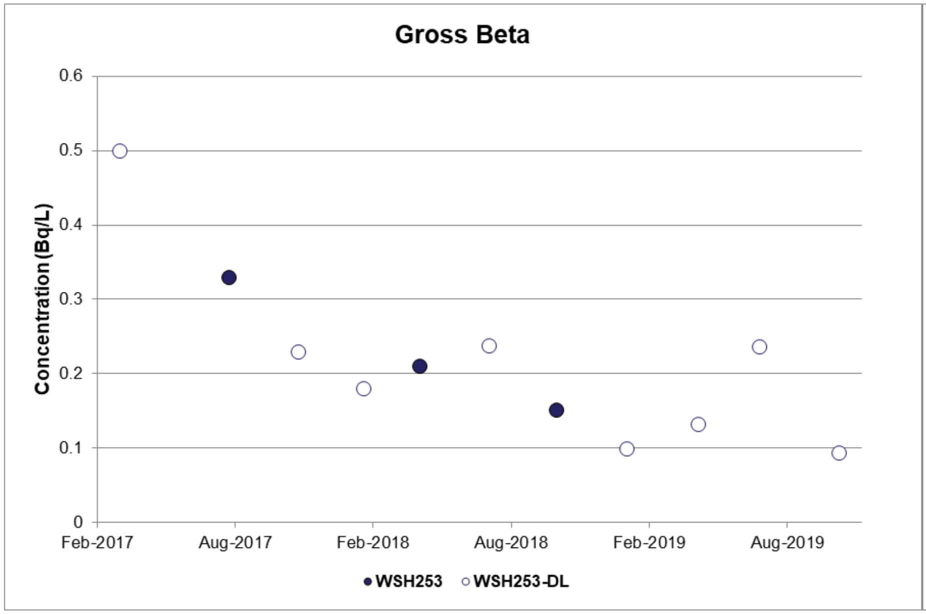

H3
Concentration (Bq/L)
600
500
400
300
200
100
0
Feb-2014
Feb-2015
Feb-2016
Feb-2017
Feb-2018
Feb-2019
WSH230

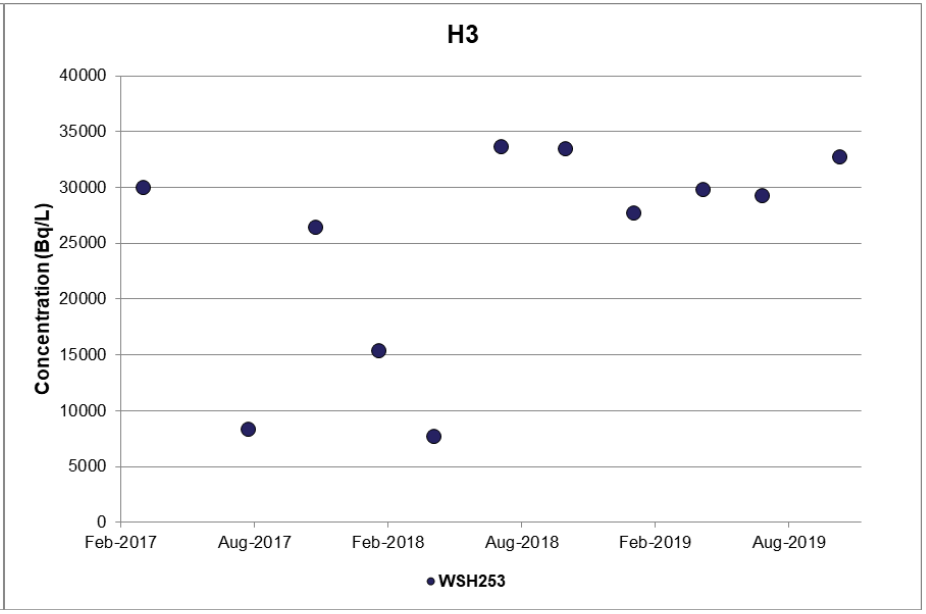

Gross Beta
Concentration (Bq/L)
0
0.1
0.2
0.3
0.4
0.5
0.6
Dec-2013
Dec-2014
Dec-2015
Dec-2016
Dec-2017
Dec-2018
Dec-2019
WSH231
WSH231-DL

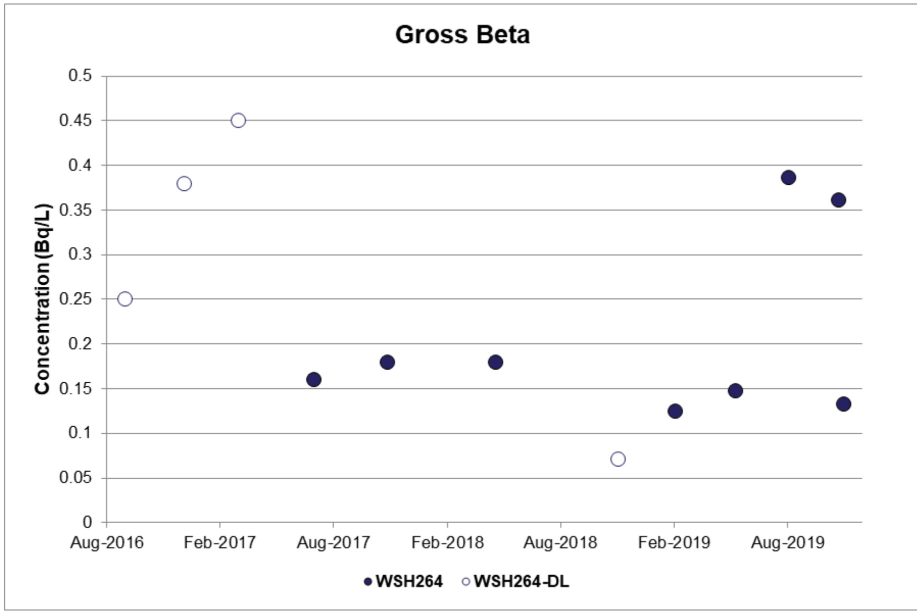

H3
Concentration (Bq/L)
0
10000
20000
30000
40000
50000
60000
Dec-2013
Dec-2014
Dec-2015
Dec-2016
Dec-2017
Dec-2018
Dec-2019
WSH231

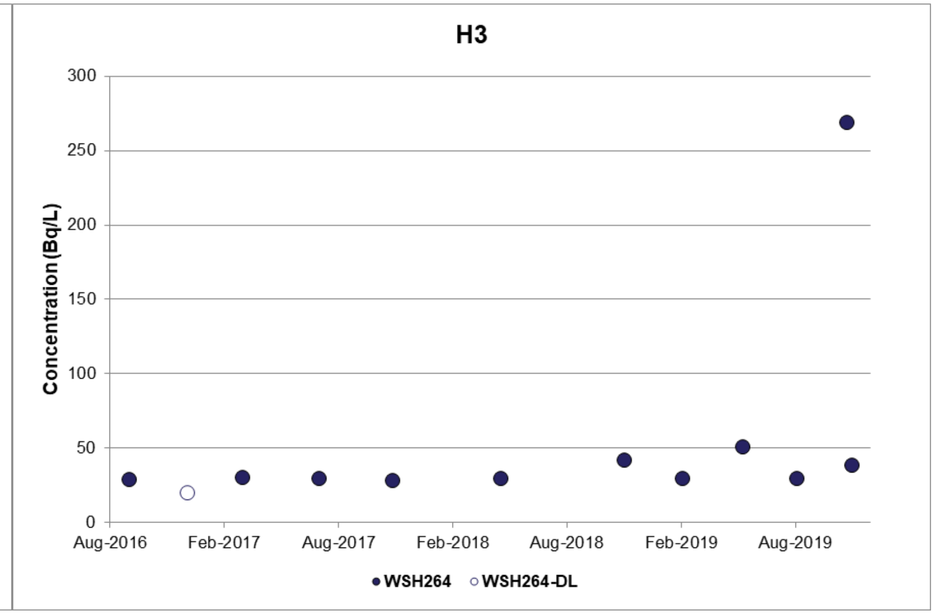

Gross Beta
Concentration (Bq/L)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Feb-2014
Feb-2015
Feb-2016
Feb-2017
Feb-2018
Feb-2019
WSH242
WSH242-DL

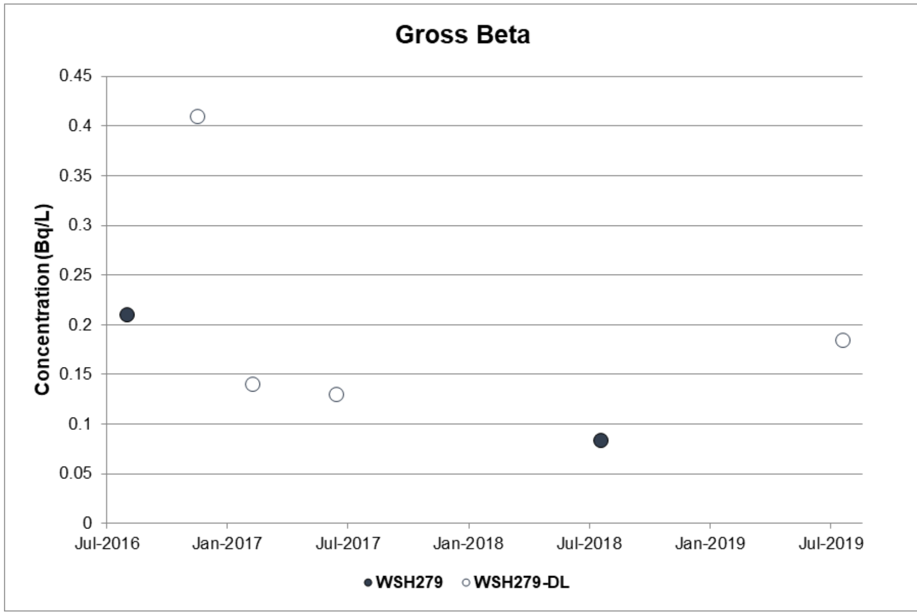

H3
Concentration (Bq/L)
60
50
40
30
20
10
0
Feb-2014
Feb-2015
Feb-2016
Feb-2017
Feb-2018
Feb-2019
WSH242

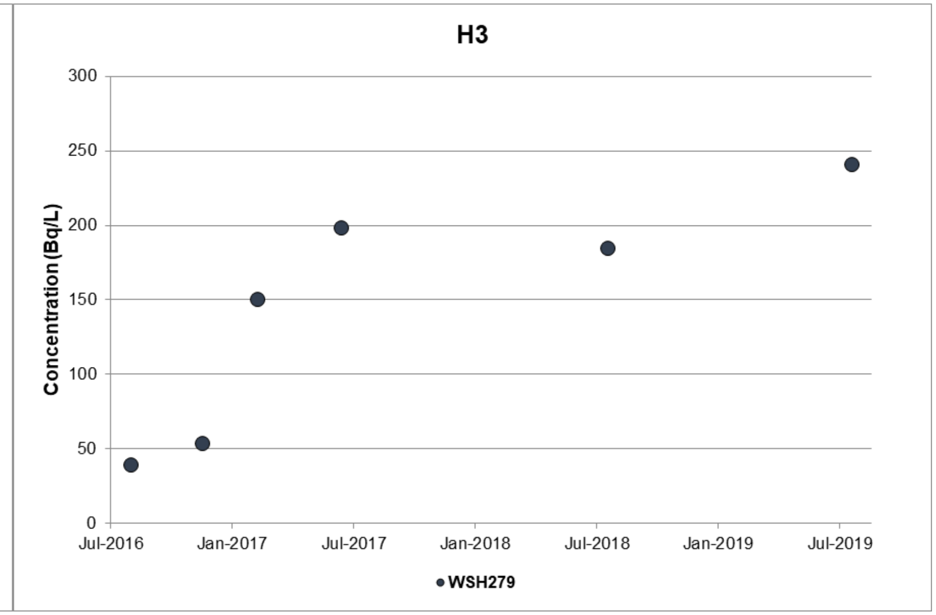

Gross Beta
Concentration (Bq/L)
0.6
0.5
0.4
0.3
0.2
0.1
0
Feb-2017
Aug-2017
Feb-2018
Aug-2018
Feb-2019
Aug-2019
WSH253
WSH253-DL

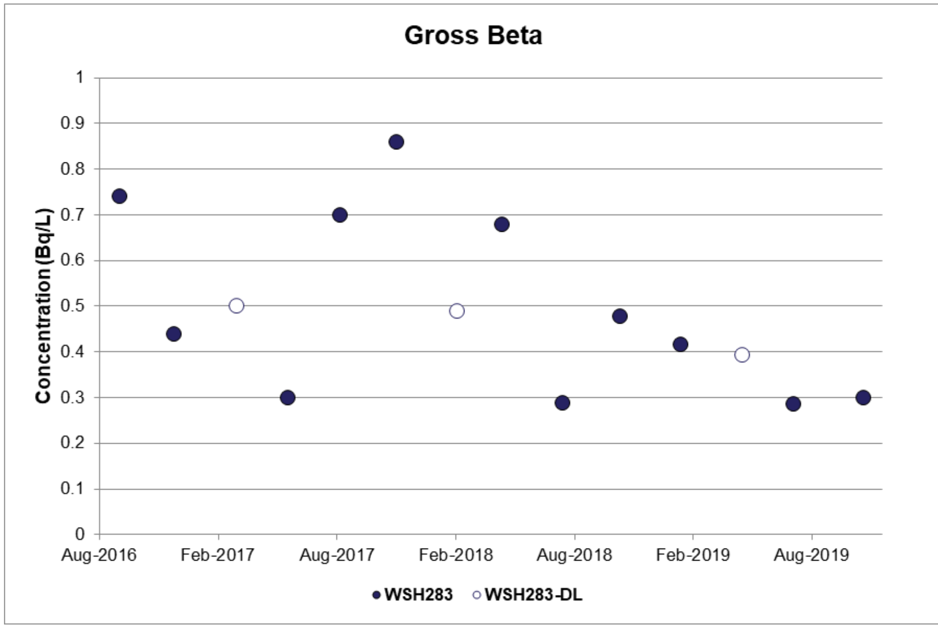

H3
Concentration (Bq/L)
40000
35000
30000
25000
20000
15000
10000
5000
0
Feb-2017
Aug-2017
Feb-2018
Aug-2018
Feb-2019
Aug-2019
WSH253

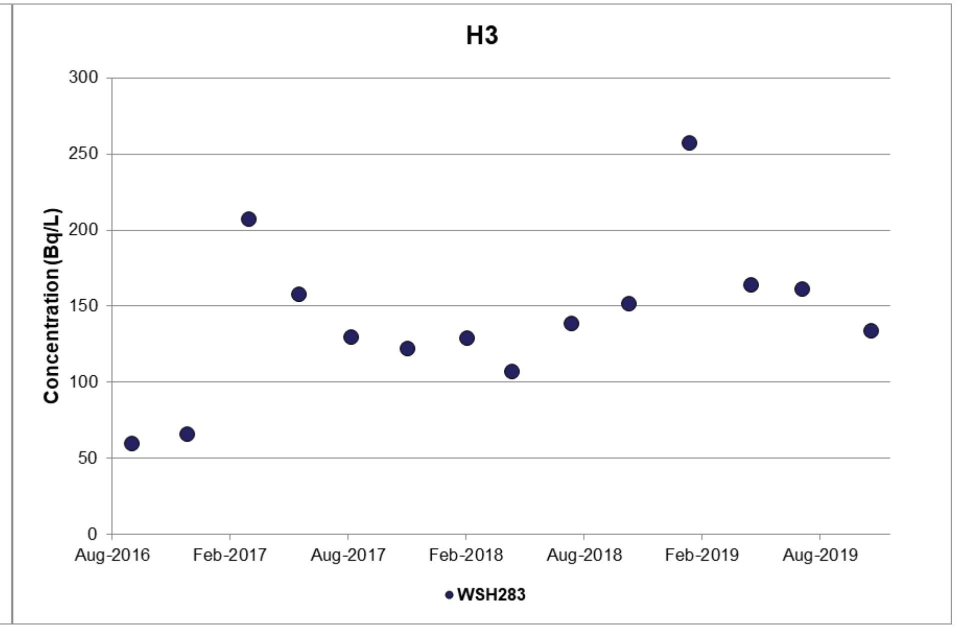

Gross Beta
Concentration (Bq/L)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Aug-2016
Feb-2017
Aug-2017
Feb-2018
Aug-2018
Feb-2019
Aug-2019
WSH264
WSH264-DL


H3
Concentration (Bq/L)
300
250
200
150
100
50
0
Aug-2016
Feb-2017
Aug-2017
Feb-2018
Aug-2018
Feb-2019
Aug-2019
WSH264
WSH264-DL


Gross Beta
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Concentration (Bq/L)
Jul-2016
Jan-2017
Jul-2017
Jan-2018
Jul-2018
Jan-2019
Jul-2019
WSH279
WSH279-DL


H3
300
250
200
150
100
50
0
Concentration (Bq/L)
Jul-2016
Jan-2017
Jul-2017
Jan-2018
Jul-2018
Jan-2019
Jul-2019
WSH279


Gross Beta
Concentration (Bq/L)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Aug-2016
Feb-2017
Aug-2017
Feb-2018
Aug-2018
Feb-2019
Aug-2019
WSH283
WSH283-DL


H3
Concentration (Bq/L)
300
250
200
150
100
50
0
Aug-2016
Feb-2017
Aug-2017
Feb-2018
Aug-2018
Feb-2019
Aug-2019
WSH283

Appendix D Groundwater and Ditch Surface Sample Unavailability

Table D.1: 2019 Planned and Actual Samples and Analyses for Groundwater and Ditch Surface Water at WWMF and RWOS 1

	Planned Samples												Total Planned	Total Actual	% Unavailability
	HTO				Gross β				C-14						
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4			
	RWOS 1														
122	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
123	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
20S	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
124	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
125	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
126	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
127	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
	WWMF														
224			1				1						2	2	0.0
226	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
228	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
229	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
230	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
231	3	3	3	3	3	3	3	3					28	28	0.0
240	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
242	1	1	1	1	1	1	1	1					8	8	0.0
243	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
253	1	1	1	1	1	1	1	1					8	8	0.0
255	1	1	1	1	1	1	1	1					8	8	0.0
264	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
265	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0

	Planned Samples														
	HTO				Gross β				C-14				Total	Total	%
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Planned	Actual	Unavailability
269	1	1	1	1	1	1	1	1					8	8	0.0
282	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
283	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
284	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
285	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
286	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
287	1	1	1	1	1	1	1	1	1	1	1	1	12	12	0.0
	WWMF Annual monitoring														0.0
232			1				1				1		3	3	0.0
237			1				1				1		3	3	0.0
238			1				1				1		3	3	0.0
239			1				1				1		3	3	0.0
244			1				1						2	2	0.0
246			1				1						2	2	0.0
248			1				1						2	2	0.0
249			1				1						2	2	0.0
250			1				1				1		2	2	0.0
251			1				1						2	2	0.0
257			1				1						2	2	0.0
259			1				1						2	2	0.0
260			1				1						2	2	0.0
262			1				1				1		3	3	0.0
263			1				1						2	2	0.0
268			1				1						2	2	0.0
270			1				1						2	2	0.0

	Planned Samples												Total Planned	Total Actual	% Unavailability
	HTO				Gross β				C-14						
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4			
271			1				1						2	2	0.0
272			1				1						2	2	0.0
278			1				1						2	2	0.0
279			1				1						2	2	0.0
	Railway Ditch													0	0.0
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