ONTARIO POWER GENERATION

Report

Public Information	
Document Number: N-REP-03443-10019	Usage Classification: Information
Sheet Number: N/A	Revision: R000

Title:
2018 RESULTS OF ENVIRONMENTAL MONITORING PROGRAMS

© Ontario Power Generation Inc., 2019. This document has been produced and distributed for Ontario Power Generation Inc. purposes only. No part of this document may be reproduced, published, converted, or stored in any data retrieval system, or transmitted in any form or by any means (electronic, mechanical, photocopying, recording, or otherwise) without the prior written permission of Ontario Power Generation Inc.

2018 Results Of Environmental Monitoring Programs

N-REP-03443-10019-R000
2019-04-15

Order Number: N/A
Other Reference Number:

Public Information

Prepared By: Margo Curtis April 15/19
Margo Curtis Date
Environmental Advisor
Nuclear Environment

Verified By: EcoMetrix Incorporated

Reviewed By: Shirley Leung April 15/19
Shirley Leung Date
Environmental Advisor
Nuclear Environment - Projects

Reviewed By: RMcCalla Apr 15/19
Raphael McCalla Date
Director
Nuclear Environment

Approved By: RMcCalla for Apr 15/19.
Connie Hergert Date
Vice President
Real Estate & Environment

Table of Contents

Page

List of Tables and Figures 5
Revision Summary 8
Executive Summary 9

1.0 INTRODUCTION 11

1.1 Program Objectives 11
1.2 Overview of Pickering and Darlington Nuclear Sites 12
1.2.1 Site Description 12
1.2.2 Nuclear Generation Performance 13

2.0 EFFLUENT MONITORING PROGRAM 14

2.1 Radiological Emissions 14
2.1.1 Radiological Emissions Graphs 15
2.1.2 OPG Nuclear Carbon-14 Inventory Data 19
2.2 Conventional Emissions 19

3.0 ENVIRONMENTAL MONITORING PROGRAM 21

3.1 Design of EMPs 21
3.1.1 Environmental Risk Assessments 21
3.2 EMP Sampling Plan 22
3.2.1 Radiological Contaminants 22
3.2.2 Conventional Contaminants 24
3.3 Environmental Monitoring Program Results 25
3.3.1 Protocol for Reporting Data and Uncertainties 25
3.3.2 Atmospheric Sampling 26
3.3.2.1 Tritium Oxide 26
3.3.2.2 Carbon-14 27
3.3.2.3 Noble Gas Detectors 28
3.3.3 Terrestrial Sampling 30
3.3.3.1 Fruits and Vegetables 30
3.3.3.2 Milk and Animal Feed 32
3.3.3.3 Eggs and Poultry 35
3.3.3.4 Soil Sampling 36
3.3.4 Aquatic Sampling 36
3.3.4.1 Water Supply Plants 36
3.3.4.2 Well Water 39
3.3.4.3 Lake Water 40
3.3.4.4 Fish 41
3.3.4.5 Beach Sand 44
3.3.4.6 Sediment 45

3.4 Supplementary Studies....45
3.5 Other Studies....45
3.5.1 Potassium in Lake Water....45
3.6 Areas of Regulatory Interest and Other Monitoring Programs....46
3.6.1 Thermal Monitoring Program....46
3.6.2 Impingement and Entrainment Monitoring Program....48
3.6.3 Groundwater Monitoring Program....48

4.0 ASSESSMENT OF RADIOLOGICAL DOSE TO THE PUBLIC....48

4.1 Modelling....49
4.1.1 Integrated Model for Probabilistic Assessment of Contaminant Transport (IMPACT)....49
4.1.2 Calculated Atmospheric Dispersion Factors....50
4.1.3 Meteorological Data....51
4.2 Critical Group Dose....52
4.2.1 Exposure Pathways....54
4.2.2 Age Classes....54
4.2.3 Basis of Dose Calculation....54
4.2.4 Uncertainty in Dose Calculation....54
4.3 Darlington Nuclear Public Dose....54
4.3.1 Darlington Nuclear Potential Critical Groups....54
4.3.2 Dose Calculation Results....55
4.3.3 Discussion of Results....56
4.4 Pickering Nuclear Public Dose....57
4.4.1 Pickering Nuclear Potential Critical Groups....57
4.4.2 Dose Calculation Results....57
4.4.3 Discussion of Results....59
4.5 Natural and Anthropogenic Data....60

5.0 QUALITY ASSURANCE AND PERFORMANCE....60

5.1 Laboratory Quality Assurance and Quality Control....61
5.1.1 Laboratory Quality Control....61
5.1.2 Laboratory Performance Testing....61
5.2 Equipment Calibrations/Maintenance....62
5.3 Program Quality Assurance....63
5.3.1 Audits....63
5.3.2 Self-Assessments....63
5.4 Third-Party Verification of Annual EMP Report....64
5.5 Program Performance....64
5.5.1 Sample Unavailability....64
5.6 Annual Assessment of the EMPs....67
5.6.1 Summary of Darlington Results....67
5.6.2 Summary of Pickering Results....67

6.0 OUTLOOK FOR 2019....68

7.0 REFERENCES 69

Appendix A: Radiological Units and Conversions 73

Appendix B: Glossary of Acronyms and Symbols 74

Appendix C: Maps of Environmental Monitoring and Critical Group Locations 77

Appendix D: Environmental Monitoring Data 81

Appendix E: Potential Critical Group Descriptions 93

Appendix F: Dose Calculation Procedure and Concentrations 97

Appendix G: Tables of Public Doses by Radionuclide, Pathway and Age Group for Darlington Nuclear and Pickering Nuclear Potential Critical Groups 104

Appendix I: Compliance with Regulatory Document REGDOC-3.1.1 109

List of Tables and Figures

Page

Figure 2-1: Darlington Nuclear Airborne Elemental Tritium Emissions 15
Figure 2-2: Darlington Nuclear Tritium Oxide Air Emissions 16
Figure 2-3: Pickering Nuclear Tritium Oxide Air Emissions....16
Figure 2-4: Darlington Nuclear C-14 Air Emissions 17
Figure 2-5: Pickering Nuclear C-14 Air Emissions....17
Figure 2-6: Darlington Nuclear Tritium Oxide Water Emissions....18
Figure 2-7: Pickering Nuclear Tritium Oxide Water Emissions 18
Figure 2-8: Darlington Nuclear Gross Beta-Gamma Water Emissions 19
Figure 2-9: Pickering Nuclear Gross Beta-Gamma Water Emissions....19
Figure 3-1: DN Annual Average HTO in Air....27
Figure 3-2: PN Annual Average HTO in Air....27
Figure 3-3: DN Annual Average C-14 in Air....28
Figure 3-4: PN Annual Average C-14 in Air....28
Figure 3-5: PN Annual Average Ar-41 Dose Rate in Air 30
Figure 3-6: DN Annual Average HTO in Vegetation 31
Figure 3-7: PN Annual Average HTO in Vegetation 31
Figure 3-8: DN Annual Average C-14 in Vegetation 32
Figure 3-9: PN Annual Average C-14 in Vegetation 32
Figure 3-10: DN Annual Average HTO in Milk....33
Figure 3-11: PN Annual Average HTO in Milk 33
Figure 3-12: DN Annual Average C-14 in Milk....34
Figure 3-13: PN Annual Average C-14 in Milk....34
Figure 3-14: DN Annual Average HTO in Eggs 35
Figure 3-15: DN Annual Average C-14 in Eggs....35
Figure 3-16: DN Annual Average HTO in Poultry 35
Figure 3-17: DN Annual Average C-14 in Poultry....35
Figure 3-18: Bowmanville WSP – Annual Average HTO in Water 38
Figure 3-19: Newcastle WSP – Annual Average HTO in Water....38
Figure 3-20: Oshawa WSP – Annual Average HTO in Water....38
Figure 3-21: Ajax WSP – Annual Average HTO in Water 38
Figure 3-22: Scarborough Horgan WSP – Annual Average HTO in Water 38
Figure 3-23: Toronto Harris WSP – Annual Average HTO in Water 38
Figure 3-24: Whitby WSP – Annual Average HTO in Water 39
Figure 3-25: DN Annual Average HTO in Well Water....40
Figure 3-26: PN Annual Average HTO in Well Water 40
Figure 3-27: DN Annual Average HTO in Lake Water 41
Figure 3-28: PN Annual Average HTO in Lake Water 41
Figure 3-29: DN Annual Average HTO in Fish....42
Figure 3-30: PN Annual Average HTO in Fish....42
Figure 3-31: DN Annual Average C-14 in Fish 43
Figure 3-32: PN Annual Average C-14 in Fish....43
Figure 3-33: DN Annual Average Cs-137 in Fish....44
Figure 3-34: PN Annual Average Cs-137 in Fish....44
Figure 3-35: Long Term Trends in Lake Ontario Winter Temperatures (Dec 1st to March 31st) 47

Figure 3-36: Long Term Trends in Lake Ontario Winter Temperatures (Dec 15th to January 15th) 47
Figure 4-1: Model of Exposure Pathways from Site Emissions....49
Figure 4-2: Darlington Nuclear Annual Public Dose Trend 56
Figure 4-3: Comparison of Darlington Nuclear Public Dose to Background Dose....57
Figure 4-4: Pickering Nuclear Annual Public Dose Trend....59
Figure 4-5: Comparison of Pickering Nuclear Public Dose to Background Dose 59

Table 1-1: OPG Public Dose Estimates - 2017....10
Table 2-1: DN and PN Annual Site Radiological Emissions 2017....14
Table 2-2: DN and PN Annual Total Site Emissions of Conventional Hazardous Substances – 2016....20
Table 3-1: Routine Environmental Samples Used for the DN and PN EMPs 24
Table 3-2: Water Supply Plants Monitored and Distance from Stations....36
Table 4-1: Darlington Nuclear Annual Boundary Dispersion Factors – 2017 50
Table 4-2: Pickering Nuclear Annual Boundary Dispersion Factors – 2017....51
Table 4-3: Darlington and Pickering Nuclear – 2017 Annual Average Wind Frequency by Direction (at 10 m height)....52
Table 4-4: 2017 Annual Darlington Nuclear Critical Group Doses 55
Table 4-5: 2017 Darlington Nuclear Public Dose....56
Table 4-6: 2017 Annual Pickering Nuclear Critical Group Doses....58
Table 4-7: 2017 Pickering Nuclear Public Dose 58
Table 4-8: Typical Doses from Exposure to Natural and Anthropogenic Sources....60
Table 4-9: Naturally Occurring Annual Public Effective Doses 60
Table 5-1: Summary of Analytics Performance Test Results – 2017 62
Table 5-2: Unavailability of EMP Sample Data Used for Dose Calculation Purposes 66

Acknowledgement

Ontario Power Generation would like to thank the residents of the local communities in the vicinity of Pickering Nuclear and Darlington Nuclear stations and throughout the province of Ontario, who voluntarily participate in our environmental monitoring programs. Their support in allowing OPG to maintain air monitoring equipment on their properties and in supplying samples of vegetables, fruits, animal feed, milk, eggs, poultry, and water helps to ensure that the annual public dose estimates are realistic.

Revision Summary

Revision Number	Date	Comments
R000	2019-04-15	Initial issue.

Executive Summary

Ontario Power Generation (OPG) maintains Environmental Monitoring Programs (EMPs) in the vicinity of Darlington Nuclear (DN) and Pickering Nuclear (PN) stations in accordance with operating licence requirements. The EMPs comply with the Canadian Standards Association (CSA) N288.4-10 standard for Environmental Monitoring Programs at Class I Nuclear Facilities and Uranium Mines and Mills. 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 DN and PN sites, including the on-site waste management facilities.

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 on 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.

Additionally, environmental sampling and analyses for the EMPs support the calculation of annual public dose resulting from operation of OPG nuclear facilities, as required by Canadian Nuclear Safety Commission (CNSC) REGDOC-3.1.1, Reporting Requirements for Nuclear Power Plants.

The 2018 program results contained in this report include concentrations of radionuclides in the air, water, milk, vegetation, animal feed, eggs, poultry, beach sand, and fish samples taken in the vicinity of DN and PN, and the associated public radiation dose assessments. Samples from provincial-background locations were used to determine background radiation levels in areas considered to be outside the influence of the nuclear stations.

In 2018, OPG operated nine of ten nuclear reactors, producing 41.0 terawatt hours (TWh) of electricity. Unit 2 at DN was under refurbishment in 2018. Site radiological emissions remained at a very small fraction of their licensed Derived Release Limits (DRLs).

A total of 985 laboratory analyses were performed on a variety of environmental media used for the annual public dose calculation. The availabilities of PN and DN samples analyzed for the dose calculation met the annual performance requirements.

IMPACT 5.4.0 software was used for the dose calculations and is consistent with the method of dose calculation described in the CSA N288.1-08 standard, Guidelines for Calculating Derived Release Limits for Radioactive Material in Airborne and Liquid Effluents for Normal Operation of Nuclear Facilities.

The 2018 critical group doses resulting from the operation of the DN and PN sites continue to be a very small fraction of both the annual legal limit of 1,000 microsieverts (µSv) and the estimated annual average background radiation dose around DN and PN of 1,400 µSv. The 2018 public doses for the DN and PN sites are similar to those observed in 2017 and are summarized in Table 1-1:

Table 1-1: OPG Public Dose Estimates - 2018

Site	Critical Group (Receptor)	Effective Dose (*µ*Sv)	Percentage of Legal Limit (%)	Percentage of Background Radiation around DN and PN (%)
Darlington Nuclear	Farm (adult)	0.8	0.1	< 0.1
Pickering Nuclear	Urban Resident (Adult)	2.1	0.2	0.1

1.0 INTRODUCTION

Ontario Power Generation (OPG) owns and operates the Pickering Nuclear (PN) and Darlington Nuclear (DN) Generating Stations. To ensure nuclear activities at these sites are conducted in a manner that minimizes any adverse impact on the public and the natural environment, OPG has established an Environmental Management Program that is consistent with the Canadian Nuclear Safety Commission (CNSC) Regulatory Document REGDOC-2.9.1 [R- 1] at both stations. Additionally, this program is registered to the International Organization for Standardization (ISO) 14001 Environmental Management Systems standard.

As part of this program, each site has an Environmental Monitoring Program (EMP), which identifies the contaminants and physical stressors to be monitored and conducts monitoring in the environment surrounding the site. The EMP designs use a risk-based approach and rely on the results of site Environmental Risk Assessments (ERAs), as described in Section 3.1.1. Locations considered to be outside the influence of PN and DN site operations are also monitored to allow for a baseline comparison with background values.

The EMPs are maintained in accordance with the operating licences issued to PN and DN and are required to comply with the Canadian Standards Association (CSA) N288.4-10 standard, Environmental Monitoring Programs at Class I Nuclear Facilities and Uranium Mines and Mills[R- 2] . This report is prepared and submitted to the CNSC in accordance with their Regulatory Document REGDOC-3.1.1, Reporting Requirements for Nuclear Power Plants [R- 3]. It is also made available to the public.

The emissions and environmental data collected for each site during the 2018 sampling year, data interpretations, and the estimates of radiation doses to the public resulting from the operation of PN and DN sites are provided in this report.

Emissions and environmental data are summarized in Sections 2.0 and 3.0, respectively. Assessment of the doses to the public is provided in Section 4.0.

1.1 Program Objectives

The PN and DN EMPs are designed to satisfy the following primary objectives:

(a) To assess the impact on human health and the environment of contaminants and physical stressors of concern resulting from operation of OPG nuclear facilities.

(b) To demonstrate compliance with limits on the concentration and/or intensity of contaminants and physical stressors in the environment or assess their effect on the environment.

(c) To demonstrate the effectiveness of containment and effluent control, and provide public assurance of the effectiveness of containment and effluent control, independent of effluent monitoring.

(d) To verify predictions made by ERAs, refine the models used in ERAs, or reduce uncertainty in the predictions made by ERAs.

The EMPs are also designed to facilitate realistic estimates of radiation doses to the public resulting from the operation of PN and DN sites, and to demonstrate that these doses remain below the regulatory limit specified in the current Radiation Protection Regulations under the Nuclear Safety and Control Act [R- 4].

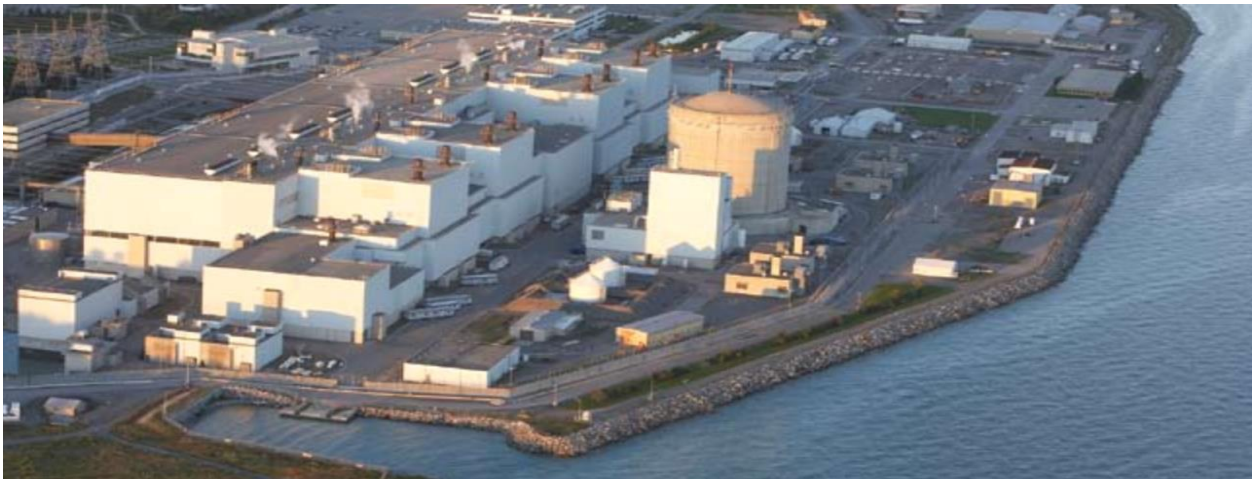
1.2 Overview of Pickering and Darlington Nuclear Sites

1.2.1 Site Description

DN and PN Generating Stations have a combined generating capacity of about 6,600 megawatts (MW). A brief description of the two stations is as follows:

Darlington Nuclear

The DN Generating Station is an OPG CANDU (CANadian Deuterium Uranium) nuclear generating station. It is a four-unit station with a total output of 3,500 MW and is located on the shores of Lake Ontario in the Municipality of Clarington in Durham Region.



The DN site also contains the Tritium Removal Facility (TRF), where tritium is extracted from tritiated heavy water, and the Darlington Waste Management Facility (DWMF) for used fuel dry storage and processing. The EMP encompasses all the facilities on the DN site.

The immediate area around the Darlington station is mostly rural and farm lands with some industrial/commercial areas. The urban residential locations of Oshawa, Bowmanville and West/East Beach are more than 3 km from the site.

Based on the results of site-specific surveys, the residents around DN are grouped into categories which best represent their locations and/or lifestyle characteristics. The categories are known as potential critical groups and are further described in Appendix

E, Section E.1.0. The DN EMP design focuses primarily on the farm, dairy farm, and rural resident potential critical groups, as described in Section 4.0.

Pickering Nuclear

The PN site is located on the shores of Lake Ontario, in the city of Pickering. The site contains the PN Generating Stations and the Pickering Waste Management Facility (PWMF) which consists of sites located inside and outside of the station protected area. The EMP encompasses all the facilities on the PN site.



PN has six operating CANDU reactors. This station has a total output of 3,100 MW. PN Units 2 and 3 are in a safe storage state.

Unlike DN, the area around PN is mainly urban residential and industrial/commercial. The closest farm lands are more than 6 km from the station.

Based on the results of site-specific surveys, the residents around PN are grouped into categories which best represent their locations and/or lifestyle characteristics. The categories are known as potential critical groups and are further described in Appendix E, Section E.2.0. The PN EMP design focuses primarily on the urban resident, dairy farm, industrial/commercial worker, and correctional institute occupant potential critical groups, as described in Section 4.0.

1.2.2 Nuclear Generation Performance

In 2018, OPG operated nine of ten nuclear reactors that produced 41.0 terawatt hours (TWh) of electricity. This production is broken down as follows:

Darlington Nuclear: Net electrical output in 2018 was 20.2 TWh.

Pickering Nuclear: Net electrical output in 2018 was 20.8 TWh.

2.0 EFFLUENT MONITORING PROGRAM

2.1 Radiological Emissions

The radiological emissions from DN and PN sites in 2018 remain at a very small fraction of the site Derived Release Limits (DRLs). These licensing limits represent radionuclide release rates that correspond to an exposure at the legal public dose limit of 1,000 microsieverts per year (µSv/year) for the most affected critical group. See Section 4.0 for the description of a critical group.

Table 2-1 shows the 2018 total airborne and waterborne emissions for radionuclides measured at the DN and PN sites, including the waste management facilities, and the percentage of their respective DRLs.

Table 2-1: DN and PN Annual Site Radiological Emissions 2018

Site Emissions[d]	DN		PNA (Units 1-4)		PNB (Units 5-8)	
	Bq	%DRL	Bq	%DRL	Bq	%DRL
AIR						
Tritium Oxide	2.1E+14	0.36	3.0E+14	0.25	3.2E+14	0.17
Elemental Tritium [a]	4.7E+13	<0.01	NA	NA	NA	NA
Noble Gas [b]	4.7E+13	0.10	1.2E+14	0.36	5.0E+12	0.01
I-131[c]	1.4E+08	<0.01	7.0E+06	<0.01	4.7E+06	<0.01
Particulate	2.5E+07	<0.01	4.2E+06	<0.01	3.5E+06	<0.01
C-14	8.4E+11	0.24	2.3E+12	0.11	1.4E+12	0.07
WATER						
Tritium Oxide	2.2E+14	<0.01	1.4E+14	0.04	2.8E+14	0.04
Gross Beta/Gamma	2.6E+10	3.7E-02	9.3E+09	0.54	3.4E+10	1.08
C-14[e]	1.2E+09	<0.01	NA	NA	1.1E+09	<0.01

NOTES: NA = Not Applicable, Bq = Bequerels

(a) Emissions from Darlington Tritium Removal Facility

(b) Units for noble gas emissions are Bq-MeV

(c) Weekly samples are usually < Method Detection Limit (MDL)

(d) Annual air emissions are the sum of continuous samples analysed weekly.
Note that if interim Noble Gas sampling is in place, samples may not be continuous.
Annual water emissions are the sum of monthly composite samples for C-14, and weekly composite samples for tritium oxide and gross beta/gamma.

(e) While reported under PNB emissions in this table, the 2018 C-14 waterborne emission value is the total for all Pickering units.

2.1.1 Radiological Emissions Graphs

Graphs displaying the past ten years of tritium and C-14 emissions to air and tritium emissions to water from DN and PN are provided in Figures 2-1 to 2-7. DN and PN gross beta-gamma emissions to water are provided in Figures 2-8 and 2-9. Given that the reported noble gas stack emissions are often below the instrument detection limits, the results of environmental noble gas monitors are used to trend the station noble gas emissions as described in Section 3.3.2.3. Iodine and particulate in airborne emissions and C-14 waterborne emissions are not graphed because their contribution to the overall public dose is minimal.

Elemental Tritium Airborne Emissions

DN – Figure 2-1

As indicated in Figure 2-1, the elemental tritium (HT) emissions from DN have remained at low levels. As of 2017, these emissions include HT emissions from the powerhouse. However, the increase in elemental tritium emissions observed in 2017 is primarily attributed to a valve that was inadvertently opened and vented to the TRF stack. Corrective actions were immediately taken to redirect residual elemental tritium to the Air Clean up System and a procedure update was subsequently initiated to rectify the deficiencies. In 2018, the HT emissions were 4.7 x 10^{13} becquerels (Bq).

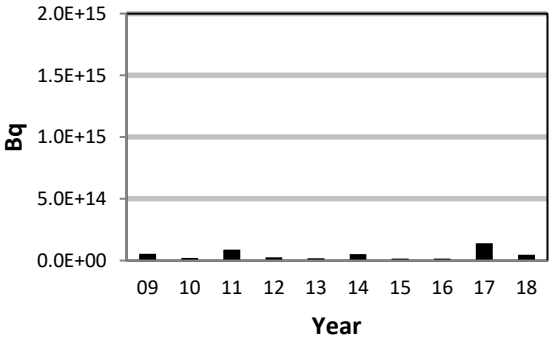


Figure 2-1: Darlington Nuclear Airborne Elemental Tritium Emissions

PN

PN does not experience substantial HT emissions as it does not have a TRF.

Tritium Oxide Airborne Emissions

DN – Figure 2-2

In 2014, a small increase was observed in DN tritium oxide (HTO) airborne emissions, which was attributed to both dryer performance and TRF restart activities. During 2015 and 2016, work plans were executed to refurbish dryers throughout the station

resulting in a decrease in emissions. Airborne HTO emissions in 2018 were 2.1 x 10^{14} Bq.

PN – Figure 2-3

PN HTO airborne emissions decreased from 2008 to 2010 and again in 2013 as a result of improvements in emissions management, reliability and operation of vapour recovery dryers, and reduction of HTO source terms. The increase in 2016 was primarily attributed to the presence of tritiated water in a Fuel Transfer Conveyor Tunnel, and the resulting airborne HTO emissions being vented to a monitored stack. Mitigating actions were taken to reduce HTO airborne emissions from this source. The slight increase observed in 2017 was primarily attributed to dryer performance issues and a rupture disk failure on Unit 1, which has since been corrected. Further improvements in airborne tritium management were made in 2018 and airborne HTO emissions in 2018 were 6.2 x 10^{14} Bq.

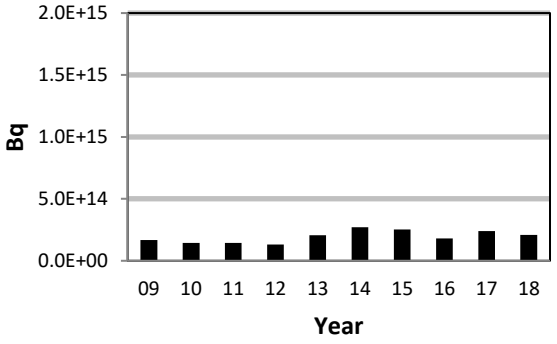


Figure 2-2: Darlington Nuclear Tritium Oxide Air Emissions

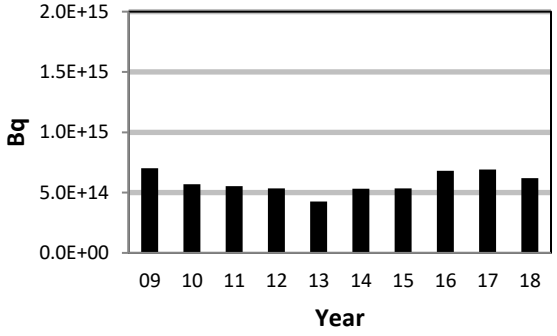


Figure 2-3: Pickering Nuclear Tritium Oxide Air Emissions

Carbon-14 Airborne Emissions

DN – Figure 2-4

DN C-14 airborne emissions remain stable. The 2018 C-14 airborne emissions were 8.4 x 10^{11} Bq.

PN – Figure 2-5

PN C-14 airborne emissions were 3.7 x 10^{12} Bq in 2018. This increase observed in 2018 was due to work associated with the moderator purification system on Units 1 and 6.

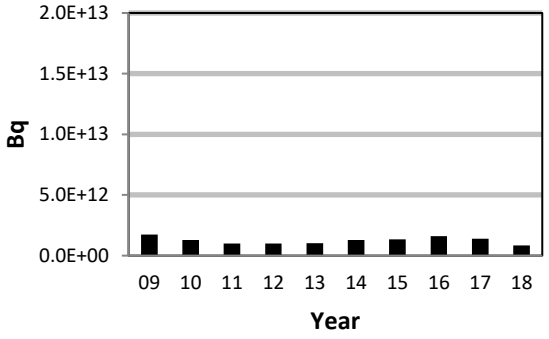


Figure 2-4: Darlington Nuclear C-14 Air Emissions

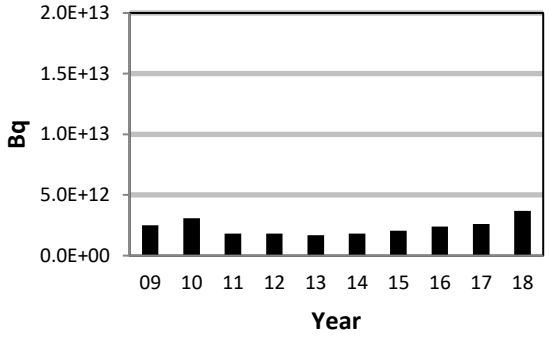


Figure 2-5: Pickering Nuclear C-14 Air Emissions

Tritium Oxide Waterborne Emissions

DN – Figure 2-6

The 2015 DN vacuum building outage (VBO) required system drainage in 2014 and 2015, which resulted in slightly elevated DN HTO to water emissions during these years. The increases in emissions observed in 2016 and 2017 are primarily attributed to the processing and discharge of condensate from reactor building air conditioning units (ACUs) through the active liquid waste system. In 2018, the majority of ACU coils were replaced during unit outages. The 2018 DN tritium to water emission was 2.2 x 10^{14} Bq.

PN – Figure 2-7

The PN waterborne HTO emissions remain stable. The slightly elevated emissions in 2009 were due to a small Unit 1 boiler tube leak. The slight increase observed in 2017 is attributed to a leak in the Unit 5 moderator pit. Tritiated water from the moderator room was processed and discharged through the active liquid waste system. Sealing and repair work to the moderator pit was completed in April 2017. The PN tritium to water emission in 2018 was 4.2 x 10^{14} Bq.

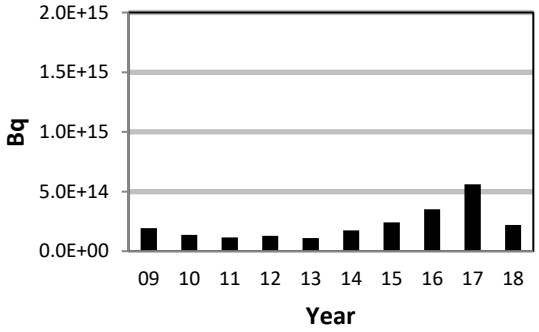


Figure 2-6: Darlington Nuclear Tritium Oxide Water Emissions

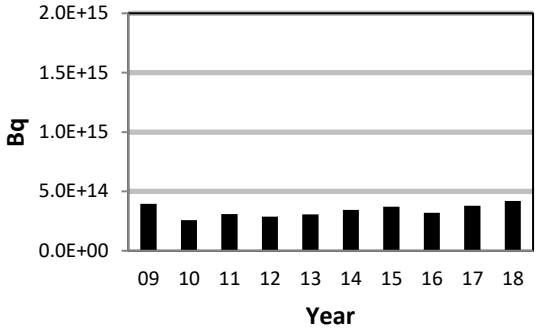


Figure 2-7: Pickering Nuclear Tritium Oxide Water Emissions

Gross Beta-Gamma Waterborne Emissions

DN – Figure 2-8

The DN gross beta-gamma emissions to water remain low. The slightly elevated emission values in 2015 and 2016 do not reflect a true increase in emissions, but rather the use of an alternate counter with a higher detection limit than the main counter. The main counter was returned to service in November 2016. The 2018 gross beta-gamma water emission was 2.6 x 10^{10} Bq.

PN – Figure 2-9

The PN gross beta-gamma emissions to water remain low. The increases in 2009 and 2010 were due to anomalously high activity of several samples. Mitigating actions from OPG's investigation and third-party review of this matter have been implemented. Since 2011, the emissions have generally returned to pre-2009 levels, as shown in Figure 2-9. The increase in gross beta-gamma waterborne emissions seen in 2016 was primarily attributed to spontaneous release of concentrated, entrained active lake sediment materials from the Reactor Building Service Water system, and not a station generated source of activity. In 2018, gross beta-gamma water emission were 4.3 x 10^{10} Bq.

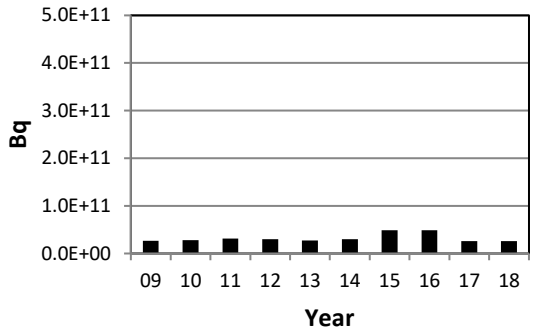


Figure 2-8: Darlington Nuclear Gross Beta-Gamma Water Emissions

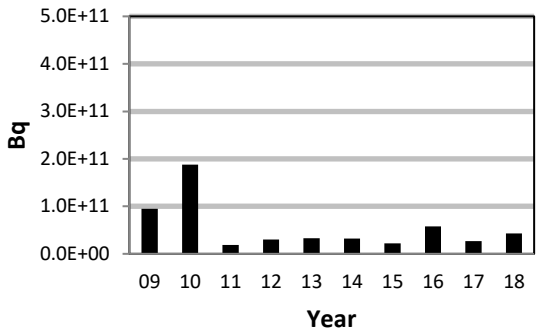


Figure 2-9: Pickering Nuclear Gross Beta-Gamma Water Emissions

2.1.2 OPG Nuclear Carbon-14 Inventory Data

The C-14 inventories within the DN and PN stations are included in this report to fulfill a regulatory commitment to the CNSC [R- 5]. The 2018 estimates of C-14 inventory within the DN and PN stations are 7.1 $x10^{14}$ Bq and 9.0 $x10^{14}$ Bq, respectively [R- 6].

2.2 Conventional Emissions

OPG monitors conventional substances emitted to air and water as a result of DN and PN site operations. Reports on emissions of both conventional hazardous and non-hazardous substances are prepared in accordance with regulatory requirements and submitted to provincial and federal agencies throughout the year. As the submission of 2018 reports continues through 2019, conventional hazardous substances released from DN and PN sites in 2017, as required under National Pollutant Release Inventory (NPRI), is provided in Table 2-2. 2018 emissions will be summarized in the 2019 EMP report.

Table 2-2: DN and PN Annual Total Site Emissions of Conventional Hazardous Substances – 2017

Hazardous Material [a]	DN	PN
	Mg	Mg
AIR		
SO_2 to Air[b][c]	1.8E+00	9.8E-01
NO_2 to Air[c]	3.8E+01	2.1E+01
CO_2 to Air[b][c]	1.4E-01	7.8E-02
Ammonia to Air	9.8E+00	6.2E+00
Hydrazine to Air[d]	3.0E-02	5.5E-03
Ozone Depleting Substances (ODS) Releases[e]	8.0E-02	4.4E-02
WATER		
Ammonia to Water	3.5E+00	7.1E-01
Hydrazine to Water[d]	6.8E-01	2.6E-01

NOTES:

Mg = Megagrams

(a) Hazardous Materials as calculated for NPRI reporting requirements

(b) Reported in OPG Sustainable Development Report as an OPGN aggregate value.

(c) Based on annual fuel consumption.

(d) Based on annual consumption.

(e) Based on estimated quantity when a release occurs.

Sulphur Dioxide, Nitrogen Oxides and Carbon Dioxide Emissions

DN and PN have standby diesel generators to provide back-up electrical power to the station if required. These generators are routinely tested to ensure availability, which accounts for sulphur dioxide, nitrogen oxides and carbon dioxide emissions. There were no regulatory non-compliances associated with the air emissions from these generators in 2017 from DN or PN.

Hydrazine and Ammonia

Hydrazine and ammonia are used in station water systems to prevent corrosion. These chemicals are released when steam is vented to the atmosphere and when water is drained to Lake Ontario. There were no regulatory non-compliances associated with hydrazine and ammonia emissions in 2017 for DN or PN.

Ozone Depleting Substances

Ozone-depleting substances (ODS) are used in refrigeration systems. Refrigerant leaks to air are minimized through routine inspections and maintenance of equipment. There were no releases of ODS that were reportable as spills in 2017 for DN or PN. ODS releases between 10 kg and 100 kg are reported in semi-annual halocarbon release reports.

3.0 ENVIRONMENTAL MONITORING PROGRAM

3.1 Design of EMPs

The EMP designs were developed using the guidance in CSA N288.4-10 to address site specific objectives covering the aspects of regulatory requirements, ERA results, confirmation of effluent control, areas of regulatory interest, and stakeholder commitments.

3.1.1 Environmental Risk Assessments

The PN and DN site ERAs assess 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 ERAs help to identify which monitoring to include in the EMPs.

The most recent DN ERA was completed at the end of 2016 [R- 53] in accordance with the requirements of CSA N288.6-12, Environmental Risk Assessments at Class I Nuclear Facilities and Uranium Mines and Mills [R- 7] and concluded that the DN site is operating in a manner that is protective of human and ecological receptors residing in the surrounding area.

The 2016 DN ERA identified a recommendation to sample lake water at the outlet of the DN diffuser and analyze the samples using a lower detection limit for hydrazine as part of a supplementary study. The purpose of the study is to reduce uncertainty surrounding human exposure to hydrazine through drinking water and fish ingestion. This supplementary study is scheduled to take place in 2019.

The 2016 DN ERA also identified a recommendation to collect filtered and unfiltered aluminum effluent samples in the CCW to clarify the risks to ecological receptors in Lake Ontario. Sample collection for this supplementary study is scheduled to commence in 2019.

The PN ERA was updated in 2017 [R- 52] in accordance with the requirements of CSA N288.6-12 [R- 7] and concluded that the PN site is operating in a manner that is protective of human and ecological receptors residing in the surrounding area.

The 2017 PN ERA identified a recommendation to conduct a thermal monitoring study in the vicinity of the CCW discharge over two winter seasons, to further assess the

potential for thermal effects to Round Whitefish embryos in the thermal plume over the period of continued operation of PN. The thermal monitoring study and any future scientific advances in the understanding of thermal impacts on Round Whitefish survival will be incorporated into the next ERA update.

Beyond obtaining data to clarify potential risks identified by the ERAs, the EMPs also fulfill the CSA N288.4-10 and regulatory requirements of estimating public dose from radiological emissions, confirming effluent control, clarifying risks and refining ERA models and predictions.

3.2 EMP Sampling Plan

The EMP sampling plan outlines the contaminants monitored, the sampling locations, the sample types, and the frequency of collection. Samples collected, analyses performed, and data interpreted aim to support the EMP objectives as follows:

1) Public Dose Calculation

   To ensure that the public dose estimation from radiological emissions is as realistic as possible, various exposure pathways, such as food ingestion, inhalation, and water ingestion are assessed for radionuclide concentrations resulting from site operations. Samples are collected at site boundary locations as well as at potential critical group locations. A description of critical groups is provided in Section 4.0, Assessment of Radiological Dose to the Public. For sample types that are not available at potential critical group locations, contaminant concentrations are estimated from concentrations measured at the boundary locations using ratios of modeled atmospheric dispersion factors.

2) Demonstration of Emissions Control

   To meet this objective, environmental measurements at the site boundary are used to confirm that concentrations are as expected based on effluent monitoring. Similarly, lake water/drinking water monitoring demonstrates waterborne emissions are properly controlled. Environmental monitoring provides an independent ongoing check on the effectiveness of containment and effluent control.

3) Refining ERA Models and Predictions

   Sampling to verify ERA predictions and to assist in refining models used in the ERAs is included in the EMP designs and handled through supplementary studies, which are documented in the annual EMP report.

3.2.1 RadiologicalContaminants

Radionuclides that are emitted as a result of PN and DN site operations and monitored in the EMPs are listed below. They are identified through the pathway analyses as discussed in Section 4.2 of this document. The routine sample analyses used in the public dose calculation are indicated in Table 3-1.

Carbon-14 (C-14) – is produced from the operation of nuclear stations. It is also a naturally occurring radionuclide and a by-product of past nuclear weapons testing with average background concentrations between 220 becquerels per kilogram carbon (Bq/kg-C) and 250 Bq/kg-C for air. C-14 values detected above background are included in the dose calculations.

Tritiated Water (HTO) – is a normal station emission of CANDU plants. Concentrations measured in plants and animals refer to the HTO concentration in the free water portion of the sample.

Tritiated Hydrogen Gas (HT) – is emitted to air primarily as a result of the operation of the TRF at DN. HT concentration in air is modeled from emissions and not monitored in the environment. However, much of the HT is converted to HTO in the environment, and this HTO is monitored.

Organically Bound Tritium (OBT) – is tritium that is bound to the organic molecules in organisms and is not readily exchanged with other hydrogen atoms. In accordance with CSA N288.1-08, OBT concentrations used in the dose calculation are modeled from HTO concentrations measured in sample media at each potential critical group location and in fish. OPG dose calculations incorporate dose from OBT via intake of terrestrial plants and animal products, and from fish. OBT is measured in a few environmental samples for informational purposes and these results are presented in Appendix D.

Noble Gases – Radioactive noble gases released from the DN and PN plants are mostly Argon-41 (Ar-41), Xenon-133 (Xe-133) and Xenon-135 (Xe-135). The environmental detectors that measure noble gas doses may also detect Iridium-192 (Ir-192) skyshine from industrial radiography carried out in the stations.

Iodine-131 – The dose from radioiodine emissions is modeled from I-131 emissions, with the assumption that I-131 emissions are accompanied by an equilibrium mixture of other short lived iodine fission products (i.e., I-132, I-133, I-134 and I-135) or mixed fission products [I(mfp)].

Particulates and gross beta-gamma – Atmospheric particulate emissions are represented by Cobalt-60 (Co-60) and liquid effluent beta-gamma emissions are represented by Cesium-137 (Cs-137) as this provides the most conservative assignment of dose based on the pathway analyses in the program design reviews [R-48][R- 49]. Cs-137 is also present in the environment as a result of historic weapons testing. Co-60 and Cesium-134 (Cs-134) are representative of station emissions and are analyzed together with Cs-137, which helps distinguish between the Cs-137 resulting from station operations with that from past weapons testing.

Table 3-1: Routine Environmental Samples Used for the DN and PN EMPs

Environmental Medium of Interest	Monitored For	Sampling Frequency	Analyses Frequency
SAMPLES USED FOR PUBLIC DOSE CALCULATIONS			
Atmospheric Sampling			
Air	HTO (active monitor)	Continuous	Monthly
Air	C-14 (passive monitor)	Continuous	Quarterly
Air	Noble gases (Ar-41, Xe-133, Xe-135), Ir-192[(a)]	Continuous	Reported monthly
Terrestrial Sampling			
Fruits and Vegetables[(c)]	HTO and C-14	3 grab samples/year	3 times/year
Animal Feed	HTO and C-14	Bi-annual grab samples	Bi-annual
Eggs	HTO and C-14	Quarterly grab samples	Quarterly
Poultry	HTO and C-14	Annual grab samples	Annual
Milk[(b)]	HTO and C-14	Monthly grab samples	Monthly
Aquatic Sampling			
Municipal Drinking Water	HTO	2-3 grab samples/day	Weekly composite
Well Water	HTO	Monthly grab samples	Monthly
Lake Water	HTO	Monthly grab samples	Monthly
Fish	HTO, C-14, Cs-137, Cs-134, Co-60	Annual grab samples	Annual
Beach Sand	Cs-137, Cs-134, Co-60	Annual grab samples	Annual
SAMPLES FOR OTHER EMP OBJECTIVES			
Vegetables	OBT	Annual grab samples	Annual
Soil	Cs-137, Cs-134, Co-60	Grab samples every five years	Every five years
Milk	OBT	Monthly grab samples	Monthly
Municipal Drinking Water	Gross beta	2-3 grab samples/day	Monthly composite
Fish	OBT	Annual grab samples (composite)	Annual
Sediment	C-14, Cs-137, Cs-134, Co-60	Grab samples every five years (composite)	Every five years
Lake water	Potassium	Grab samples every three years (composite)	Every three years

(a) Air kerma is measured and converted to external air immersion dose.
(b) Sampling frequency is quarterly for provincial-background locations.
(c) Sampling frequency is annual for provincial-background locations.

3.2.2 Conventional Contaminants

Conventional contaminants emitted as a result of PN and DN operations may be monitored in the environment as part of the EMPs for ERA confirmation and/or demonstration that concentrations fall below benchmark values. The monitoring of these contaminants is achieved through supplementary studies.

No supplementary studies were conducted in 2018.

3.3 Environmental Monitoring Program Results

This section contains the results of the EMPs for the DN and PN sites and those of the provincial-background locations. All sampling locations are shown in Appendix C, Figures C1 to C3, and are selected based on the pathway analyses and site specific survey reviews as described in Section 4.2 of this report.

3.3.1 Protocol for Reporting Data and Uncertainties

Statistical analyses typically performed on datasets include determination of the mean and standard deviation, trend analysis, demonstration that the concentrations of contaminants are below the benchmark value, and dataset comparison.

Trend analysis is performed on most EMP data, however, it is more meaningful when sampling locations and frequencies remain consistent throughout the trending period. As the air monitors around the site boundary are sensitive to changes in location, only locations that were active for the entire trending period are used in the trend analysis of boundary air data. For other sample media, all locations that are currently active are included in the trend analysis. Fruits and vegetables are the exception in that all sample locations, both current and historical, are included in the trend analysis since these sample locations change frequently. Therefore, for the trend analysis of EMP environmental sample media other than air, there is a degree of inaccuracy when comparing year to year averages since the same set of locations may not have been used for the entire trending period.

Radionuclide concentrations 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) or critical level (Lc).

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- 2]. 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- 2]. 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.

See Appendix F.2.0 for treatment of background data for dose calculation purposes.

3.3.2 Atmospheric Sampling

Samples of air are collected to monitor the environment around the DN and PN sites. Background samples are also collected to allow determination of net values for dose calculations. The radionuclide analyses performed and the sample collection frequency are detailed in Table 3-1 and results are summarized in Sections 3.3.2.1 to 3.3.2.3. Detailed data are given in Appendix D, Environmental Monitoring Data, Tables D1 to D3.

3.3.2.1 Tritium Oxide

The active tritium-in-air sampler collects water vapour by passing air continuously at a steady rate through two molecular sieve canisters in series. The active samplers are located at six site boundary EMP monitoring locations around DN (D1, D2, D5, D9, D10 and D11) and six around PN (P2, P3, P4, P6, P10, and P11), as identified in Figures C1 and C2 in Appendix C. These samples are collected and analyzed monthly.

The background concentration of HTO in air is measured at Nanticoke, which is considered to be far from the influence of nuclear stations. The annual average HTO in air measured at the background location in recent years has been at or below the active sampler detection limit of 0.2 Bq/m^3. In 2018, HTO in air measured at Nanticoke was 0.67 Bq/m^3. Since this value is notably higher than in previous years, a value of zero was used for the background concentration of HTO in air in the dose calculation to maintain conservatism.

The 2018 annual average results of airborne HTO at the DN, PN, and background monitoring locations are summarized in Appendix D, Table D1. The levels of HTO observed in the environment depend on station emissions, wind direction, wind speed, ambient humidity, and seasonal variations. As such, fluctuations from year to year are expected even if site HTO emissions remain constant.

For the purpose of statistical trend analyses, Figures 3-1 and 3-2 utilize only locations which were active for all of the last 10 years in order to provide a representative year to year comparison. For DN this includes locations D1, D2, and D5. For PN this includes locations P2, P3, P4, P6, P10 and P11.

DN – Figure 3-1

The 2018 HTO in air annual average concentrations measured at DN boundary locations ranged from 0.6 to 1.6 Bq/m^3, with an average concentration of 1.1 Bq/m^3. A Mann-Kendall trend analysis at the 95% confidence level does not indicate any statistically significant trend over the past 10 years.

PN – Figure 3-2

The 2018 HTO in air annual average concentrations measured at PN boundary locations ranged from 3.6 to 16.5 Bq/m^3, with an average concentration of 8.9 Bq/m^3. A Mann-Kendall trend analysis at the 95% confidence level does not indicate any statistically significant trend over the past 10 years.

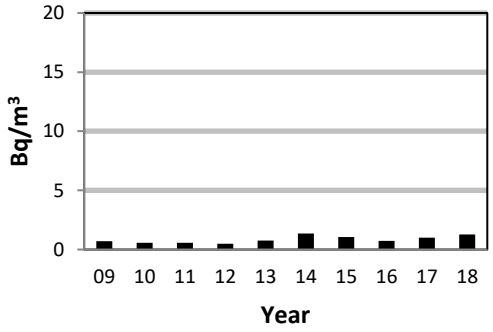


Figure 3-1: DN Annual Average HTO in Air

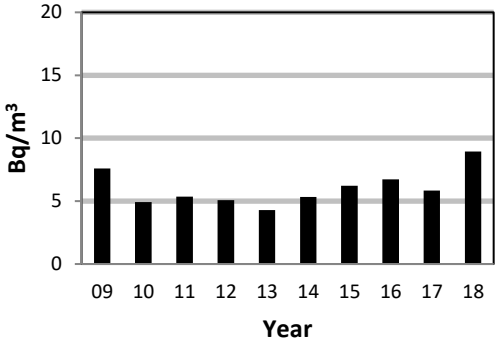


Figure 3-2: PN Annual Average HTO in Air

3.3.2.2 Carbon-14

C-14 in air is sampled using passive sampling technology. The passive C-14 sampler works by absorption of CO_2 in air into soda lime pellets exposed for a period of an annual quarter. Samples are analyzed after each quarter.

C-14 is naturally occurring in the environment but is also a by-product of past nuclear weapons testing from the early 1960s. C-14 background concentrations around the world are decreasing as weapons test C-14 levels naturally decay over time. Pre-atmospheric weapons test levels were measured at 226 Bq/kg-C [R- 9]. The

annual average C-14 in air concentration observed at the Nanticoke EMP background location in 2018 was 233 Bq/kg-C.

In the EMP designs, C-14 in air is monitored at four boundary locations for DN (D1, D2, D5, and D10) and four boundary locations for PN (P3, P4, P6, and P10). Appendix D, Table D2, provides the 2018 annual averages of airborne C-14 measured at the DN, PN, and background sampling locations.

For the purpose of statistical trend analyses, Figures 3-3 and 3-4 utilize only locations which were active for all of the last 10 years in order to provide a representative year to year comparison. For DN this includes locations D1, D2, and D10. For PN this includes locations P6 and P10.

DN – Figure 3-3

The 2018 annual average C-14 in air concentrations measured at DN boundary locations ranged from 244 to 253 Bq/kg-C, with an average concentration of 247 Bq/kg-C. A Mann-Kendall trend analysis at the 95% confidence level does not indicate any statistically significant trend over the past 10 years.

PN – Figure 3-4

The 2018 annual average C-14 in air concentrations measured at PN boundary locations ranged from 259 to 462 Bq/kg-C, with an average concentration of 344 Bq/kg-C. A Mann-Kendall trend analysis at the 95% confidence level does not indicate any statistically significant trend over the past 10 years.

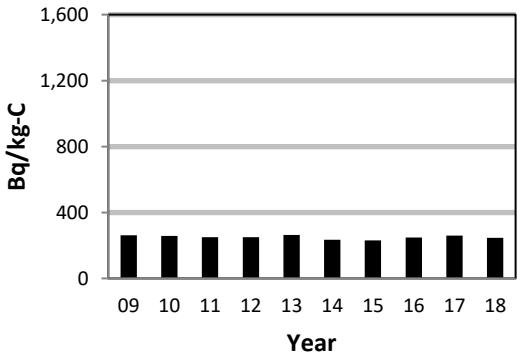


Figure 3-3: DN Annual Average C-14 in Air

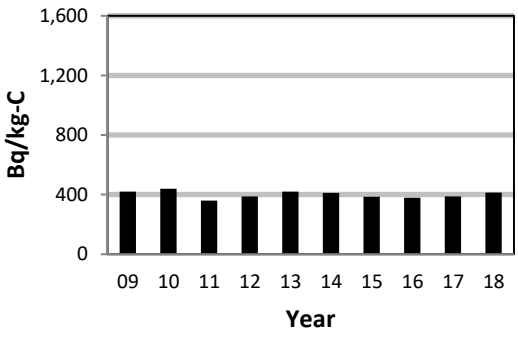


Figure 3-4: PN Annual Average C-14 in Air

3.3.2.3 Noble Gas Detectors

Under a Memorandum of Understanding (MOU) between OPG and Health Canada (HC), established in 2009, HC operates and maintains OPG's network of noble gas detectors. In exchange, OPG allows HC to release the detector results on their public website as part of their Fixed Point Surveillance (FPS) network [R- 10].

In years past, OPG and HC would each calculate noble gas dose from raw data using different analysis and processing software, yielding comparable results. Starting in 2014, OPG began using the noble gas dose results generated by HC for calculation of the annual public dose. Noble gas data generated by HC is reviewed by OPG on a quarterly basis.

External gamma radiation doses from noble gases and Ir-192 are measured using sodium iodide (NaI) spectrometers set up around the DN and PN sites. There are a total of eight detectors around the DN site and eight detectors around the PN site that monitor the dose rate continuously. Natural background dose has been subtracted from noble gas detector results.

The annual boundary average noble gas dose rate is estimated from the monthly data from each detector. Results obtained in 2018 from the noble gas detectors are summarized in Appendix D, Table D3 and discussed below.

DN

Due to a different station design, DN does not experience the same level of noble gas emissions as PN. The DN boundary average dose rates for Ar-41, Xe-133, Xe-135, and Ir-192 are typically below the detection limits. Therefore, no trend graph is presented for DN.

PN – Figure 3-5

Ar-41 is the predominant radionuclide measured in noble gas around PN followed by Xe-133 and Xe-135. The PN boundary average Ar-41 dose in air was 290 nanogray (nGy)/month in 2018.

Figure 3-5 illustrates the boundary average Ar-41 dose rate for PN from 2009 to 2018 in units of nGy/month. A Mann-Kendall trend analysis at the 95% confidence level indicates an increasing trend over the past 10 years for Ar-41. Ar-41 emissions are largely related to the number of operating days of PN Units 1 and 4, therefore higher Ar-41 in the environment is typically attributed to a higher number of operating days from these two units. The increases observed in 2016 and 2017 are attributed to air ingress through the Unit 4 calandria vault dryers. Repairs to address this were completed in October 2017. Ar-41 emissions remain high in 2018 due to a substantial increase in operating time of Units 1 and 4, compared to previous years.

In 2018, Xe-135 remained below the detection limit, <3 nGy/month. Xe-133 was, at times, measured above the detection limit at PN. The measured boundary average value for Xe-133 was 7.8 nGy/month. No Ir-192 was detected at PN in 2018.

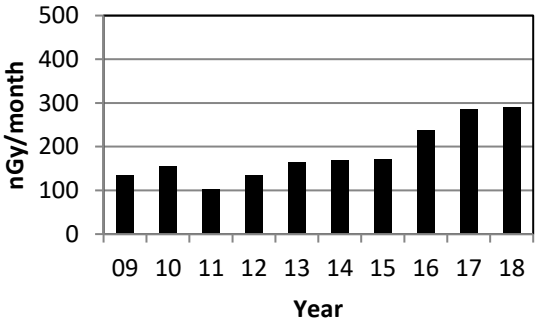


Figure 3-5: PN Annual Average Ar-41 Dose Rate in Air

3.3.3 Terrestrial Sampling

Terrestrial biota receive exposure from both airborne and waterborne emissions as indicated in Figure 4-1. Cow's milk, for example, is affected by the air, plants, and water sources that the cow consumes. It is therefore important to consider the combined effect of all these pathways when assessing the station impact on terrestrial samples.

Samples of soil, fruits, vegetables, animal feed, milk, eggs, and poultry are collected to support the public dose calculation for DN and PN sites. Background samples are also collected for calculating net concentrations for dose calculations. The radionuclides monitored and the sample collection frequencies are summarized in Table 3-1 and the 2018 results are discussed in the following sections. Detailed data are given in Appendix D, Tables D4 to D7.

3.3.3.1 Fruits and Vegetables

In the EMP designs, fruits and vegetables are sampled three times from each location for a representation of the entire growing season. Each sample is analysed for C-14 and HTO. Sampling locations for 2018 are shown in Appendix C.

A total of seven fruit and vegetable locations were sampled around DN and nine locations were sampled around PN. Fruits and vegetables were sampled from four background locations.

The results for vegetation are provided in Appendix D, Table D4.

Tritium Oxide

HTO concentrations in vegetation around the nuclear sites tend to vary from year to year due to prevailing winds, HTO emissions, humidity, etc. Furthermore, the number of samples and their locations change over the years. These variations should be considered when reviewing the following graphs and trend analysis results.

The average HTO concentrations measured in fruits and vegetables from the background locations in 2018 were < 2.3 Bq/L.

DN – Figure 3-6

The 2018 average concentration for HTO was 15.9 Bq/L in fruits and 14.7 Bq/L in vegetables. Figure 3-6 illustrates the combined DN fruit and vegetable annual average HTO results over the past 10 years. A Mann-Kendall trend analysis at the 95% confidence level does not indicate any statistically significant trend.

PN – Figure 3-7

The 2018 average concentration for HTO was 99.0 Bq/L in fruits and 85.4 Bq/L in vegetables. Figure 3-7 illustrates the combined PN fruit and vegetable annual average HTO results over the past 10 years. A Mann-Kendall trend analysis at the 95% confidence level does not indicate any statistically significant trend.

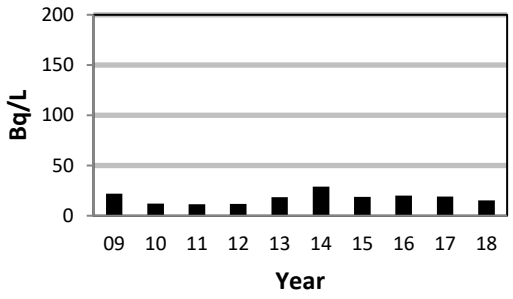


Figure 3-6: DN Annual Average HTO in Vegetation

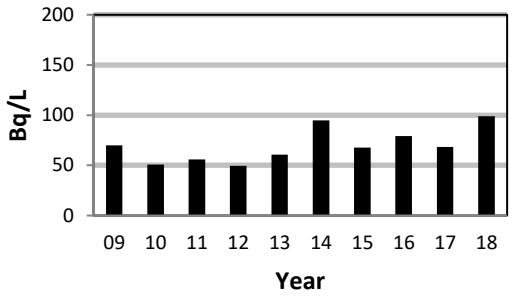


Figure 3-7: PN Annual Average HTO in Vegetation

Carbon-14

The number of fruit and vegetable samples, their locations, and sampling frequencies have changed over the years, which should be considered when reviewing the following graphs and trend analysis results.

The average C-14 concentrations measured in fruits and vegetables from the background locations in 2018 were 232 Bq/kg-C and 247 Bq/kg-C respectively.

DN – Figure 3-8

The 2018 average concentration of C-14 was 235 Bq/kg-C in fruits and 237 Bq/kg-C in vegetables. Figure 3-8 illustrates the combined DN fruit and vegetable annual average C-14 results over the past 10 years. A Mann-Kendall trend analysis at the 95% confidence level does not indicate any statistically significant trend.

PN – Figure 3-9

The 2018 average concentration of C-14 at PN locations was 285 Bq/kg-C in fruits and 264 Bq/kg-C in vegetables. Figure 3-9 illustrates the combined PN fruit and vegetable annual average C-14 results over the past 10 years. A Mann-Kendall trend analysis at the 95% confidence level does not indicate any statistically significant trend.

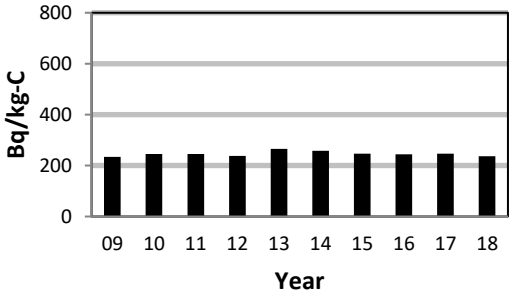


Figure 3-8: DN Annual Average C-14 in Vegetation

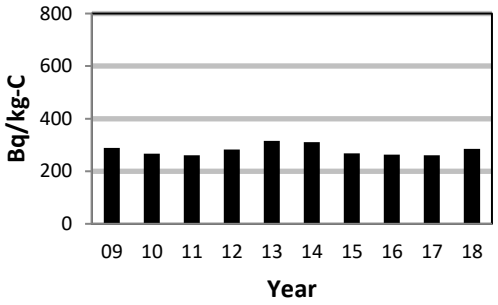


Figure 3-9: PN Annual Average C-14 in Vegetation

3.3.3.2 Milk and Animal Feed

Milk sampling is used to estimate the portion of dose received from milk ingestion for the Dairy Farm potential critical group. Milk consumed by other members of the public comes from commercial dairies whose products consist of composites from many dairy farms across Ontario. Values in this report are only applicable to residents of the surrounding dairy farms who consume raw milk and are not representative of milk that is sold at a grocery store.

Milk samples are collected on a monthly basis from dairy farms around DN and PN and analysed for HTO and C-14. Samples are collected from three dairy farms around DN and two dairy farms located around PN. Quarterly milk samples are collected from a background location with three replicates collected per quarter.

Locally grown animal feed is collected from four dairy farms around DN, twice a year, with two replicates collected per visit. Animal feed is collected from one dairy farm around PN and one dairy farm from a background location twice a year, with four replicates collected per visit. Since 2013, dry feed (grains, hay, etc.) and wet feed (forage) are collected separately. Animal feed is analysed for HTO and C-14.

Annual average values of HTO and C-14 in animal feed and milk are provided in Appendix D, Table D5 and D6, respectively.

The annual average HTO and C-14 in milk measurements around the nuclear sites vary from year to year due to changes in prevailing winds, emissions, humidity, cow's diet, feed sources, and water sources. These variations should be considered when reviewing the following graphs.

Tritium Oxide

The background average HTO in milk concentration was < 2.3 Bq/L and HTO in animal feed was 6.3 Bq/L for dry feed, and 2.9 Bq/L for wet feed (forage).

DN – Figure 3-10

The 2018 average concentration of HTO in milk was 4.8 Bq/L based on three dairy farms around DN. Figure 3-10 illustrates DN HTO in milk results over the past 10 years. A Mann-Kendall trend analysis at the 95% confidence level does not indicate any statistically significant trend.

The average HTO concentration in animal feed was 12.0 Bq/L for wet feed (forage). No dry feed samples were available in 2018. No trend analysis was performed on animal feed since, beginning in 2013, wet feed and dry feed have been sampled separately, resulting in changes to sampling frequency and replicates.

PN – Figure 3-11

The 2018 average concentration of HTO in milk was 18.0 Bq/L based on two dairy farms located within 12 km of PN. Figure 3-11 illustrates PN HTO in milk results over the past 10 years. A Mann-Kendall trend analysis at the 95% confidence level indicates a decreasing trend for PN HTO in milk.

The average HTO concentration in animal feed was 27.7 Bq/L for wet feed (forage). No dry feed samples were available in 2018. No trend analysis was performed on animal feed since, beginning in 2013, wet feed and dry feed have been sampled separately, resulting in changes to sampling frequency and replicates.

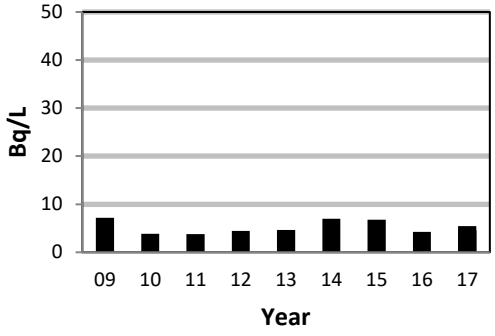


Figure 3-10: DN Annual Average HTO in Milk

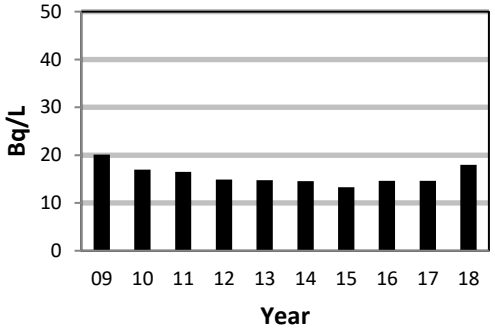


Figure 3-11: PN Annual Average HTO in Milk

Carbon-14

The background average C-14 in milk was 234 Bq/kg-C. C-14 in dry feed was 231 Bq/kg-C and C-14 in wet feed (forage) was 240 Bq/kg-C.

The C-14 level in animal feed consumed by the cows is the main contributing factor to the C-14 levels in milk. Animal feed contains C-14 from the previous year when it was grown, therefore emissions from the previous year would affect the C-14 values measured in milk in the current year for cows consuming local feed.

DN – Figure 3-12

The 2018 average concentration of C-14 in milk from dairy farm locations in the vicinity of DN was 237 Bq/kg-C. Figure 3-12 illustrates that C-14 levels in milk around DN have been stable and near background levels for the past 10 years. A Mann-Kendall trend analysis at the 95% confidence level does not indicate any statistically significant trend.

The average C-14 concentration in animal feed was 236 Bq/kg-C for wet feed (forage). No dry feed samples were available in 2018. No trend analysis was performed on animal feed since, beginning in 2013, wet feed and dry feed have been sampled separately, resulting in changes to sampling frequency and replicates.

PN – Figure 3-13

The 2018 average concentration of C-14 in milk from dairy farm locations in the vicinity of PN was 234 Bq/kg-C. Figure 3-13 illustrates that C-14 levels in milk around PN have been near background levels for the past 10 years. A Mann-Kendall trend analysis at the 95% confidence level indicates a decreasing trend for PN C-14 in milk.

The average C-14 concentration in animal feed was 240 Bq/kg-C for wet feed (forage). No dry feed samples were available in 2018. No trend analysis was performed on animal feed since, beginning in 2013, wet feed and dry feed have been sampled separately, resulting in changes to sampling frequency and replicates.

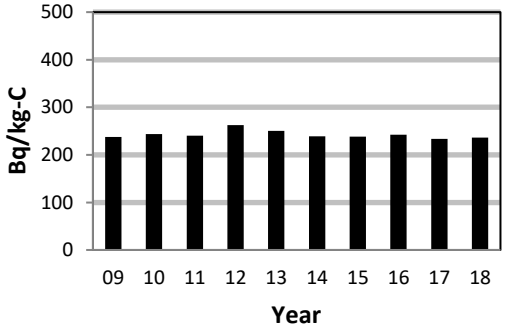


Figure 3-12: DN Annual Average C-14 in Milk

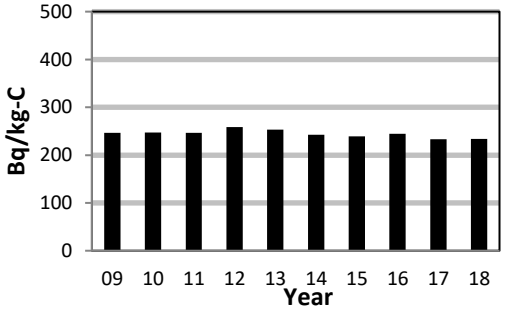


Figure 3-13: PN Annual Average C-14 in Milk

3.3.3.3 Eggs and Poultry

Eggs are sampled on a quarterly basis and three sample replicates are collected per visit. Poultry is collected annually with eight sample replicates collected per visit. Both eggs and poultry are analysed for HTO and C-14.

One farm location around DN is sampled for eggs (D10) and one farm location is sampled for poultry (F16). No farm location selling fresh eggs and poultry could be found in the PN vicinity, and therefore these pathways are modeled for PN. One background location is sampled for both eggs and poultry.

The background concentration of HTO was <2.3 Bq/L for eggs and <2.3 Bq/L for poultry. The background concentration of C-14 was 236 Bq/kg-C for eggs and 231 Bq/kg-C for poultry.

The concentration of HTO in DN eggs was 2.5 Bq/L and HTO in poultry was 7.1 Bq/L. C-14 in DN eggs was 233 Bq/kg-C and C-14 in poultry was 227 Bq/kg-C. Refer to Table D7 in Appendix D for detailed data. No trend analysis was performed as only five years of data have been collected from these locations thus far.

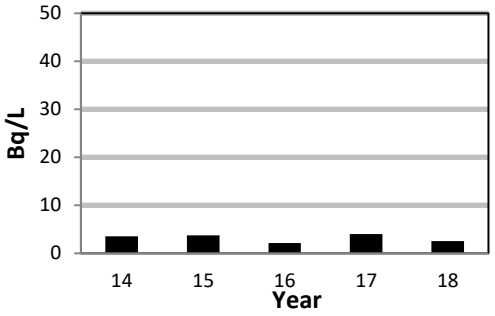


Figure 3-14: DN Annual Average HTO in Eggs

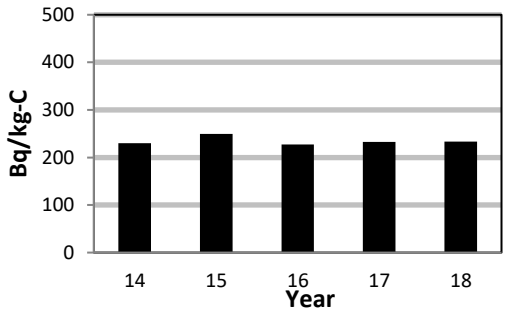


Figure 3-15: DN Annual Average C-14 in Eggs

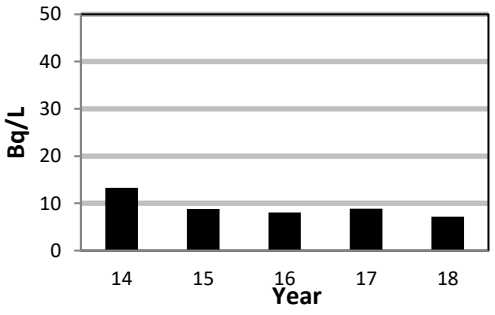


Figure 3-16: DN Annual Average HTO in Poultry

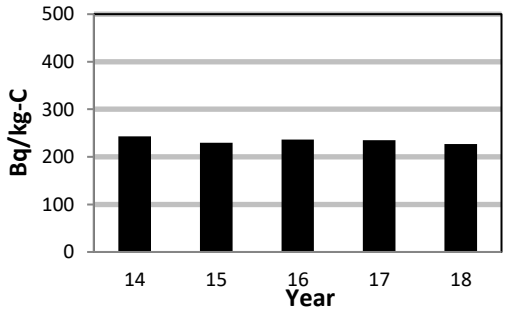


Figure 3-17: DN Annual Average C-14 in Poultry

3.3.3.4 Soil Sampling

Soil is sampled every five years to identify possible radionuclide accumulation over time. The last sampling took place in 2017. Therefore, no sampling of soil was conducted in 2018. The 2017 results for soil sampling are provided in the 2017 Results of Radiological Environmental Monitoring Programs report [R- 11].

3.3.4 Aquatic Sampling

Samples of drinking water sources (municipal and well water), lake water, lake sediment, beach sand and fish are collected to monitor the aquatic environment around the DN and PN sites. Background samples are also collected to provide a comparison benchmark and to allow determination of net values for dose calculations. The radionuclides monitored and the sample collection frequencies are detailed in Table 3-1. Detailed data for the results of aquatic sampling are given in Appendix D, Tables D8 to D10, and discussed in the following sections.

3.3.4.1 Water Supply Plants

Samples of drinking water are taken during each 8-12 hour shift at water supply plants (WSPs) that supply water to Durham Region and the City of Toronto. Weekly composites of these samples are analyzed for HTO and monthly composites are analyzed for gross beta activity.

The locations of the WSPs sampled relative to the nearest nuclear station discharge are indicated in Table 3-2. The results of water sampled are provided in Appendix D, Table D8.

Table 3-2: Water Supply Plants Monitored and Distance from Stations

	Distance from Site
DN AREA WSPs	
Bowmanville WSP	7 km ENE of DN
Newcastle WSP	13 km E of DN
Oshawa WSP	8 km W of DN
PN AREA WSPs	
R.C. Harris WSP	22 km WSW of PN
Horgan WSP	11 km SW of PN
Ajax WSP	7 km ENE of PN
Whitby WSP	12 km ENE of PN

The impact of HTO emissions from OPG stations on the nearby WSPs varies depending upon distance from the station, lake current direction, location and depth of the WSP intake pipe and general dispersion conditions. Annual average HTO levels at

all WSPs are well below the Ontario Drinking Water Quality Standard of 7,000 Bq/L [R-12].

A single sample hypothesis test was performed to demonstrate that the annual average at each WSP is below OPG's commitment to maintain HTO in drinking water below 100 Bq/L. Results from Ajax, Bowmanville, Whitby, Oshawa, Harris, Horgan, and Newcastle WSPs all showed annual averages < 100 Bq/L.

Tritium Oxide

HTO in Lake Ontario, along with all the Great Lakes, originates from several sources: natural cosmogenic tritium, residual tritium fallout from atmospheric weapons testing, current emissions from nuclear plants, and residual HTO from past emissions of nuclear plants. For the purpose of calculating public dose resulting from OPG operations, the sum of contributions from current emissions and residual HTO from past emissions was used. The background HTO value, subtracted from HTO measurements, includes only natural cosmogenic tritium and residual weapons fallout tritium. This produces a conservative estimate of dose from tritium in lake water. This Lake Ontario background component for 2018 was conservatively estimated to be 1.25 Bq/L, using the Great Lakes Time-Concentration Tritium Model [R- 13].

The WSPs annual average concentrations of tritium in drinking water are shown in Figures 3-18 through 3-24. A statistical trend analysis was performed for each WSP over a 10-year period.

DN – Figures 3-18 to 3-20

Annual average HTO concentrations measured at the Bowmanville, Newcastle, and Oshawa WSPs ranged from 4.7 to 7.0 Bq/L. Based on the past 10 years of data, a Mann-Kendall trend analysis at the 95% confidence level indicates a significant upward trend at Oshawa WSP. There is no statistically significant trend for HTO at the remaining DN WSP locations.

PN – Figure 3-21 to 3-24

Annual average HTO concentrations measured at the Ajax, Horgan, Harris, and Whitby WSPs ranged from 3.9 to 6.3 Bq/L. Based on the past 10 years of data, a Mann-Kendall trend analysis at the 95% confidence level does not indicate any statistically significant trend for HTO at any PN WSP location.

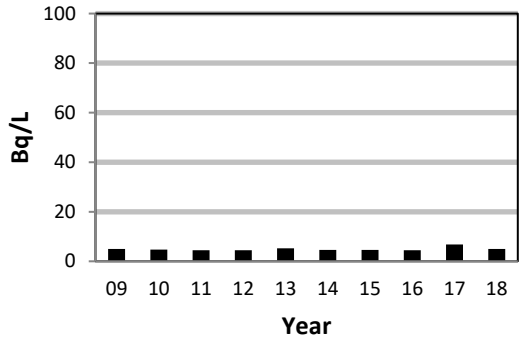


Figure 3-18: Bowmanville WSP – Annual Average HTO in Water

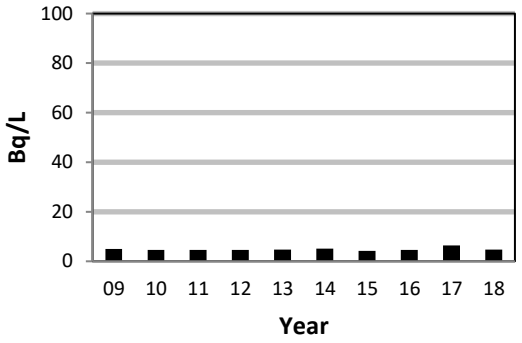


Figure 3-19: Newcastle WSP – Annual Average HTO in Water

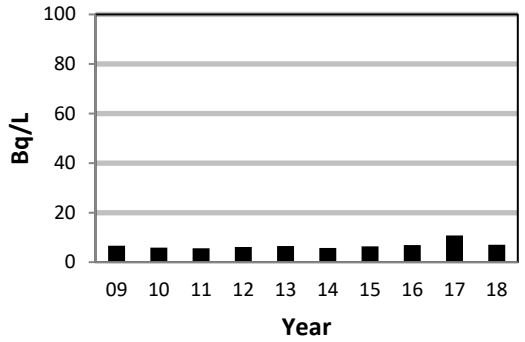


Figure 3-20: Oshawa WSP – Annual Average HTO in Water

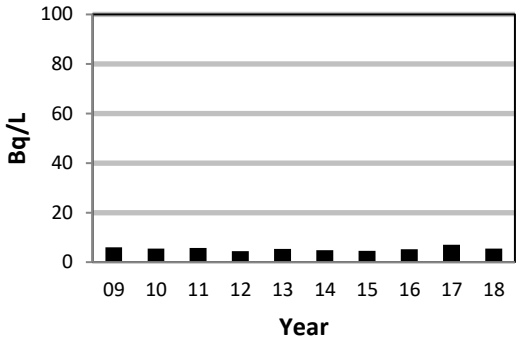


Figure 3-21: Ajax WSP – Annual Average HTO in Water

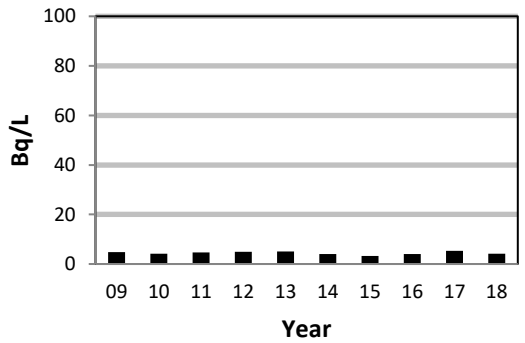


Figure 3-22: Scarborough Horgan WSP – Annual Average HTO in Water

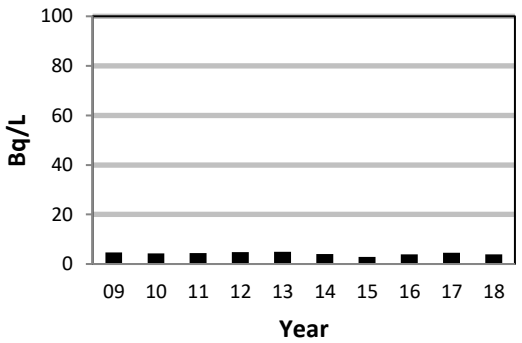


Figure 3-23: Toronto Harris WSP – Annual Average HTO in Water

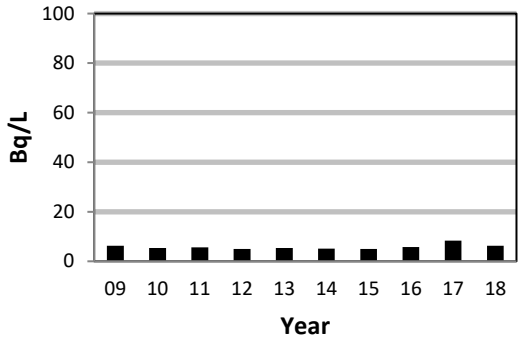


Figure 3-24: Whitby WSP – Annual Average HTO in Water

Gross Beta

For both DN and PN, annual average gross beta activity levels across all samples from area WSPs were 0.11 Bq/L. This is well below the gross beta activity screening level of 1 Bq/L, which is both an internal OPG level and a drinking water level recommended by Health Canada [R- 14].

3.3.4.2 Well Water

Monthly well water samples are collected from four wells around the DN area and two wells around the PN area. The wells sampled represent the potential critical groups for which the annual public dose is calculated under the EMP designs. Samples are analyzed monthly for HTO. Analytical results are provided in Appendix D, Table D8.

Tritium Oxide

HTO concentrations in well water depend on the depth of the well and thus the amount of time it takes for precipitation to reach the aquifer from where the well draws its water. Radioactive decay of the tritium during its transit time to the aquifer determines the residual activity level in the well water. Deeper wells tend to have lower HTO concentrations. Well water HTO concentrations reflect the level of past atmospheric HTO releases because of the time it takes for precipitation to reach the well.

DN – Figure 3-25

The 2018 annual average HTO concentration observed in well water samples collected from the DN area was 10.7 Bq/L. Based on the past 10 years of data, a Mann-Kendall trend analysis at the 95% confidence level does not indicate any statistically significant trend for DN HTO in well water.

PN – Figure 3-26

The 2018 annual average HTO concentration observed in well water samples collected from the PN area was 15.7 Bq/L. Based on the past 10 years of data, a

Mann-Kendall trend analysis at the 95% confidence level does not indicate any statistically significant trend for PN HTO in well water.

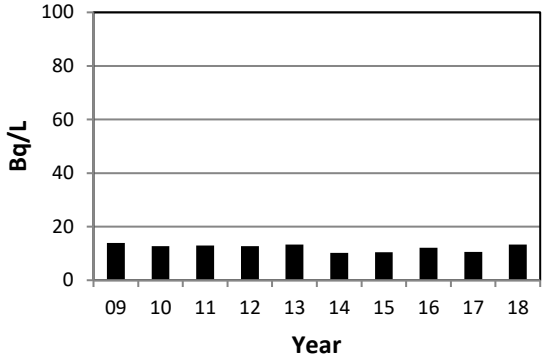


Figure 3-25: DN Annual Average HTO in Well Water

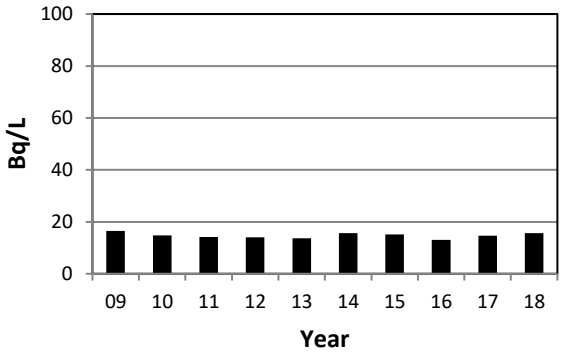


Figure 3-26: PN Annual Average HTO in Well Water

3.3.4.3 Lake Water

Lake water (non-drinking water) is sampled from two beaches in the vicinity of DN and three beaches in the vicinity of PN on a monthly basis and analysed for HTO. It is used to assess the water immersion dose exposure pathway from swimming in lake water. Sampling of lake water is not required during the winter months as it is not representative of public exposure. Analytical results are provided in Appendix D, Table D8.

DN – Figure 3-27

The 2018 annual average HTO concentration observed in lake water samples collected from two beaches in the DN area was 22.8 Bq/L. Based on the past 10 years of data, a Mann-Kendall trend analysis at the 95% confidence level does not indicate any statistically significant trend for DN HTO in lake water.

PN – Figure 3-28

The 2018 annual average HTO concentration observed in lake water samples collected from three beaches in the PN area was 29.8 Bq/L. Based on the past 10 years of data, a Mann-Kendall trend analysis at the 95% confidence level does not indicate any statistically significant trend for PN HTO in lake water.

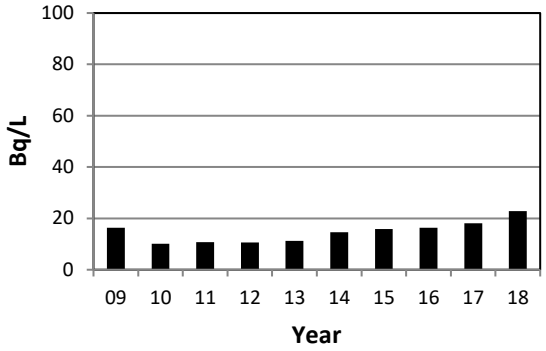


Figure 3-27: DN Annual Average HTO in Lake Water

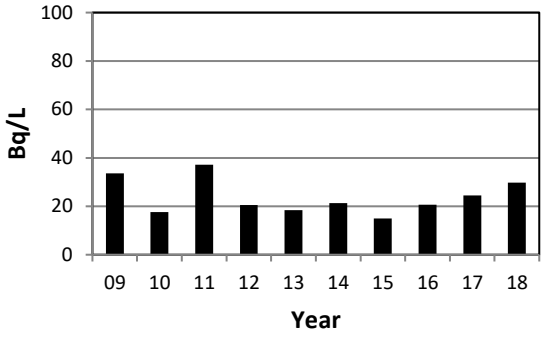


Figure 3-28: PN Annual Average HTO in Lake Water

3.3.4.4 Fish

At the DN site, fish sampling takes place over the cooling water discharge diffuser. At the PN site, the sampling location is in the PN outfall. Background samples are taken from the Bay of Quinte area of Lake Ontario.

The target fish species to be collected at DN, PN, and at background locations is White Sucker, with Brown Bullhead as the backup species. Eight replicate fish samples are collected and analyzed at each location. A sample consists of the fish muscle tissue only, and excludes the head, skin, fins, and as many bones as possible. HTO, C-14, Co-60, Cs-134, Cs-137, and Potassium-40 (K-40) measurements are performed on each fish sample.

The results for fish are provided in Appendix D, Table D9.

Tritium Oxide

The HTO levels in fish change quickly in response to changes in water HTO levels from waterborne emissions. Thus, HTO concentrations measured in fish tissue reflect the HTO concentration in the water in the few hours before they were sampled. Long-term graphs of fish HTO levels for PN and DN are provided in Figures 3-29 and 3-30. In 2018, the HTO in Lake Ontario background fish samples averaged 2.9 Bq/L.

DN – Figure 3-29

The HTO levels in the DN diffuser fish samples averaged 9.2 Bq/L. Based on the past 10 years of data, a Mann-Kendall trend analysis at the 95% confidence level does not indicate any statistically significant trend for HTO in DN fish.

PN – Figure 3-30

The HTO concentration in the PN outfall fish samples averaged 3.1 Bq/L. Based on the past 10 years of data, a Mann-Kendall trend analysis at the 95% confidence level indicates a decreasing trend for HTO in PN fish.

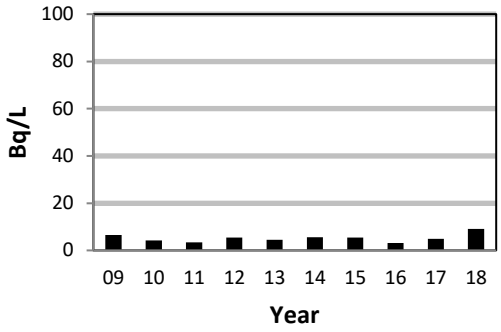


Figure 3-29: DN Annual Average HTO in Fish

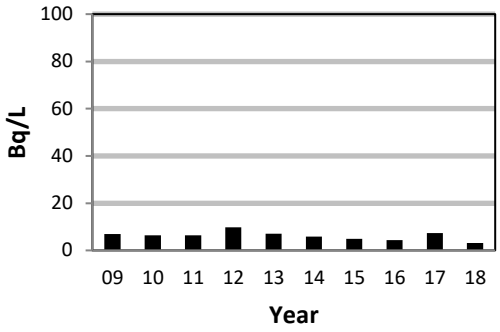


Figure 3-30: PN Annual Average HTO in Fish

Carbon-14

The average C-14 level in fish measured at a background Lake Ontario location was 229 Bq/kg-C in 2018.

The concentrations of C-14 in fish at both DN and PN are consistent with past years and comparable to background levels, as shown in Figures 3-31 and 3-32.

DN – Figure 3-31

The 2018 annual average C-14 level in DN fish was 256 Bq/kg-C. Based on the past 10 years of data, a Mann-Kendall trend analysis at the 95% confidence level does not indicate any statistically significant trend for C-14 in DN fish.

PN – Figure 3-32

The 2018 annual average C-14 level in PN fish was 255 Bq/kg-C. Based on the past 10 years of data, a Mann-Kendall trend analysis at the 95% confidence level does not indicate any statistically significant trend for C-14 in PN fish.

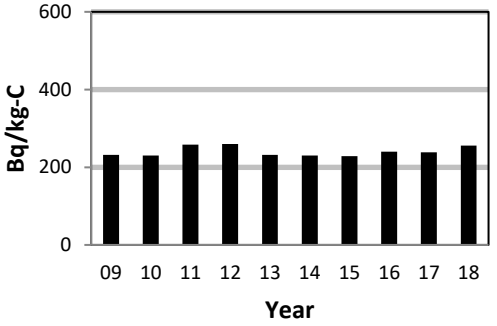


Figure 3-31: DN Annual Average C-14 in Fish

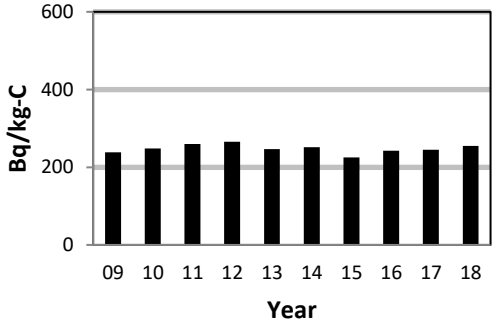


Figure 3-32: PN Annual Average C-14 in Fish

Gamma Spectrometry

The majority of the gamma activity in fish is naturally occurring K-40. A small amount of Cs-137 is usually present which is primarily due to nuclear weapons testing and not reactor operation given that Cs-134 and Co-60, which are indicative of reactor operation, were not detected.

The average Cs-137 value for background Lake Ontario fish was 0.2 Bq/kg.

DN – Figure 3-33

The average Cs-137 value for DN fish was 0.1 Bq/kg. Given the level of uncertainty at such low concentrations, this is not distinguishable from background. Cs-134 and Co-60, which are indicative of reactor operation, were not detected in any fish samples at DN site in 2018.

PN – Figure 3-34

The average Cs-137 value for PN fish was 0.2 Bq/kg. Given the level of uncertainty at such low concentrations, this is not distinguishable from background. Cs-134 and Co-60, which are indicative of reactor operation, were not detected in any fish samples at PN site in 2018.

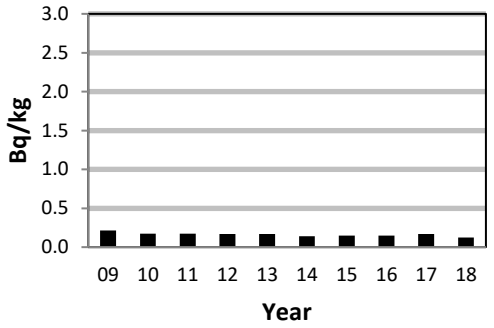


Figure 3-33: DN Annual Average Cs-137 in Fish

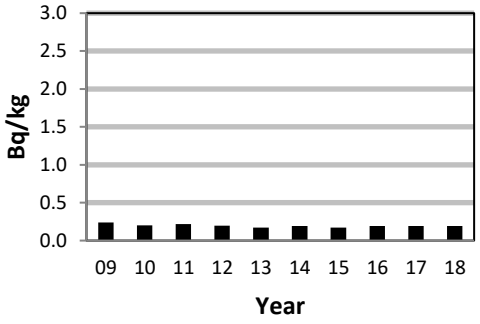


Figure 3-34: PN Annual Average Cs-137 in Fish

3.3.4.5 Beach Sand

Sand from three beaches around DN and three beaches around PN is collected annually to represent a potential pathway for external dose. Eight replicates are collected per sampling location. Gamma spectrometry is performed on these samples.

Beach sand samples were collected at Cobourg to determine the Cs-137 concentration in Lake Ontario background sand due to atmospheric weapons test fallout.

The results for beach sand are provided in Appendix D, Table D10.

Gamma Spectrometry

Background Cs-137 concentrations in beach sand samples measured at Cobourg averaged 0.3 Bq/kg in 2018. These values are consistent with values observed over the past five years.

DN

The average concentration of Cs-137 measured at DN area beaches ranged from below detection (< 0.1) to 0.3 Bq/kg in 2018. Similar to previous years, there was no Co-60 or Cs-134 detected in any of the samples.

PN

The average concentration of Cs-137 measured at PN area beaches ranged from 0.4 to 0.5 Bq/kg. Similar to previous years, there was no Co-60 or Cs-134 detected in the samples.

Wave action continuously moves the beach sand around, disturbing the original deposition patterns. This range of Cs-137 values is similar to the background values measured and, without the presence of other radionuclides such as Co-60 or Cs-134 that are more closely related to reactor operation, the Cs-137 measured along the shoreline cannot be confirmed to be the result of OPG operations.

3.3.4.6 Sediment

Lake sediment is sampled every five years to identify possible radionuclide accumulation over time. The last sampling was conducted as part of a study commissioned by the CANDU Owners Group (COG) and took place in 2011 [R- 15]. The 2011 results for sediment sampling are provided in the 2014 Results of Environmental Monitoring Programs report [R- 16]. While EMP sediment sampling was scheduled to take place in 2016, it was deferred to 2019 as sampling was conducted only one year prior, in 2015, in support of the PN Safe Storage ERA [R- 52]. The details and results of the 2015 sediment sampling is provided in section 3.4.3 of the 2017 Results of Radiological Environmental Monitoring Programs report [R- 11]. Station and background sediment sampling in support of the EMP will be conducted in 2019.

3.4 Supplementary Studies

CSA N288.4-10 specifies that supplementary studies can occasionally be conducted as part of the EMPs to achieve specific, well-defined objectives such as:

- providing the data required to reduce uncertainty and confounding factors in the risk assessment;
- increasing knowledge of the behaviour of contaminants and physical stressors in the environment (e.g., refining environmental transfer parameters);
- investigating specific EMP findings; and
- follow-up monitoring of mitigation activities implemented following an EA.

Supplementary studies are site-specific and as such may vary between nuclear facilities. These studies become part of the EMPs until the objective of the study has been achieved. At that time, the supplementary study is terminated.

In 2018, no supplementary studies were conducted. See section 3.1 for future recommended supplementary studies as identified in the program design reviews.

3.5 Other Studies

3.5.1 Potassium in Lake Water

Concentrations of potassium in lake water around PN and DN are monitored to support validation of the CSA N288.1-08 [R- 18] default cesium bioaccumulation factor (Cs BAF) for fish of 3,500, which is used for the calculation of DRLs. The Cs-BAF value is based on an equation recommended by the International Atomic Energy Agency (IAEA) in the Technical Report Series (TRS)-472 report, which considers the relationship of the Cs BAF to lake water concentrations of potassium [R- 19]. This study is conducted once every three years. The next potassium in lake water measurements will take place in 2019.

3.6 Areas of Regulatory Interest and Other Monitoring Programs

While the primary focus of this report is the results of 2018 monitoring conducted in support of the annual public dose calculation, the overall EMPs encompass several other OPG monitoring programs, which are described in Sections 3.6.1 to 3.6.3. Due to differences in reporting requirements and schedules, the information in the following sections is the most recent information available. Some 2018 information is based on preliminary data and/or reports as the finalized reports have not been issued at the time of this report's preparation.

3.6.1 Thermal Monitoring Program

The discharge of warm water through operation of the condenser cooling water (CCW) system has the potential to impact the spawning success and larvae development of round whitefish. As a result of the CNSC's comments on a study completed in 2010 on the impact of PN thermal discharge on round whitefish spawning[R- 20], a COG study on the effects of fixed and fluctuating temperatures on mortality and hatch of round whitefish and lake whitefish eggs was initiated and issued in 2014 [R- 21]. This study prompted OPG to perform a re-assessment of the impacts of the thermal emissions from DN and PN on the survival of round whitefish eggs in Lake Ontario.

The COG study indicated that round whitefish are not as sensitive to thermal impact as previously suggested. Both station re-assessments concluded that the risk of thermal emissions on round whitefish is low and no further mitigation or offsetting is warranted. However, OPG made a commitment in the Darlington Refurbishment Environmental Assessment to monitor ambient substrate lake temperature during the winter months, and worked with Environment and Climate Change Canada and the CNSC to develop the monitoring program [R- 22].

The program primarily uses the Darlington lake current monitor, with the Pickering lake current monitor as a backup. The objective is to examine the trend in winter water temperatures to inform an adaptive management program to protect round whitefish, should the potential effects of climate change cause significant increases in winter season lake bottom temperatures.

Whitefish spawn in late fall on coarse substrates (gravel or cobble) between the depths of 3 to 12 m. The embryos develop over the winter and hatch in spring. Suitable spawning habitat is present near the Darlington CCW discharge. Temperature impacts egg development in two ways: 1) increased temperature may lead to direct mortality of the eggs; and 2) increased temperature shortens the gestation period, leading to earlier hatch. The average winter temperature between December 1st and March 31st is compared to a threshold of 6.0° C, with the intention of implementing an adaptive management program if the 6.0° C threshold were to be exceeded [R- 23].

The average lake temperature at the Darlington Lake Current Monitor between December 1st 2017 and March 31st 2018 was 2.3°C. Therefore no additional actions are required. Long term trends are provided in Figure 3-35 below. There is no indication of a warming trend which would approach the threshold in the near term.

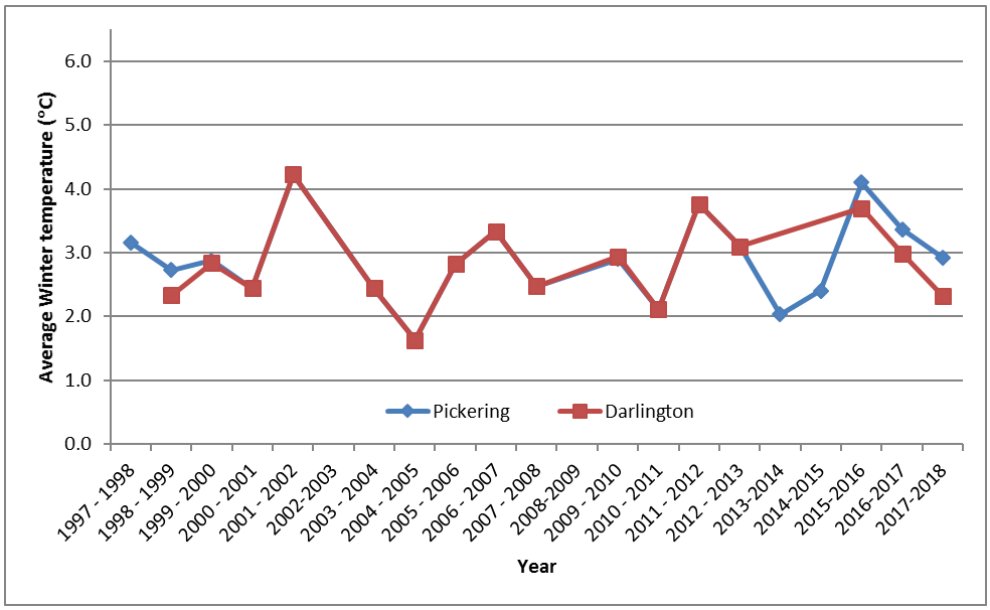


Figure 3-35: Long Term Trends in Lake Ontario Winter Temperatures (Dec 1st to March 31st)

Whitefish eggs may also be susceptible to temperature during the early phase of embryo development [R- 24]. Environment and Climate Change Canada requested that OPG trend temperatures during the first month of egg development. Long term trends are provided in Figure 3-36 below. There is no indication of a warming trend approaching the threshold that would require adaptive management.

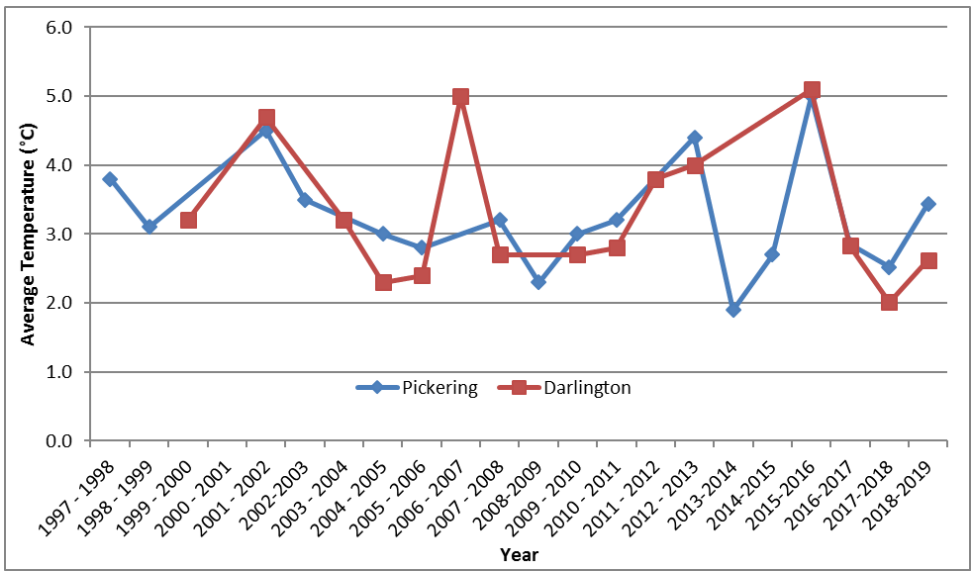


Figure 3-36: Long Term Trends in Lake Ontario Winter Temperatures (Dec 15th to January 15th)

3.6.2 Impingement and Entrainment Monitoring Program

Since 2009, OPG has seasonally installed a Fish Diversion System (FDS) at PN to reduce impingement. Annual reporting of fish impingement is required by the CNSC to ensure ongoing compliance with targets. In January 2018 Pickering received an Authorization under Section 35 of the Fisheries Act for the impingement and entrainment of fish resulting from the water taking for the operation of the CANDU reactors. The Authorization requires OPG to offset all fish impacted by the intake of station cooling water.

Results of the 2017 monitoring program are presented in the Pickering Nuclear 2017 Impingement Monitoring Report [R- 25]. The biomass impinged in 2017 was estimated to be 25,217 kg, or 4.99 kg/million m^3 of station flow. An impingement event occurred on November 16-18, 2017 during which 24,000 kg of Alewife were impinged. This occurred after the FDS was removed for the winter per its design requirements, and following an upwelling event in Lake Ontario which caused a rapid change in water temperature. Alewife are known to be adversely affected by such events.

3.6.3 Groundwater Monitoring Program

In 2018, PN and DN completed annual groundwater monitoring programs to evaluate groundwater quality and flow across the sites and to detect any emergent issues.

The groundwater monitoring programs occur from January 1 to December 31 of each year with 227 groundwater monitoring locations sampled in 2018 for tritium, the key parameter of concern. Annual water level measurement events were also conducted for each site. Within certain areas, samples were also analyzed for petroleum hydrocarbons (PHCs).

In general, tritium trends over time show levels for the most part that have remained nearly steady or have decreased, indicating stable or improved environmental performance. There are isolated cases where tritium concentrations have shown increases. Expected increases occur when tritium is migrating as a plume. Where unexpected tritium concentrations are identified, investigations are completed to determine the root cause and to implement corrective measures. Ongoing results confirm that tritium in groundwater is mainly localized within the station protected area and the site perimeter tritium concentrations remain low.

4.0 ASSESSMENT OF RADIOLOGICAL DOSE TO THE PUBLIC

This section contains an assessment of doses to the public resulting from the operation of OPG's PN and DN sites. The effective dose limit for members of the public as set out in the Radiation Protection Regulations [R- 26] is 1,000 µSv/year. The environmental samples collected and analysed through the PN and DN EMPs are used to produce realistic estimates of radiation doses to the public resulting from the operation of PN and DN sites, and to demonstrate that these doses remain below the regulatory limit.

The doses are heavily based on environmental concentrations of radionuclides measured at the potential critical group locations and surrounding environment. For the radionuclides and pathways where environmental measurements are not available, dose is modeled from emissions.

The dose calculation follows the method described in OPG's Methodology for Data Analysis and Public Dose Determination for the Environmental Monitoring Program [R- 27]. Assumptions, model parameters, and mean intake rates are used in accordance with CSA N288.1-08 [R- 18]. Annual average meteorological data are used along with local intake fractions and representative locations for potential critical groups identified in the site-specific survey reviews [R- 28][R- 29]. Appendix F provides details on how the data are used.

Figure 4-1 represents the model of exposure pathways to human receptors used for public dose calculation.

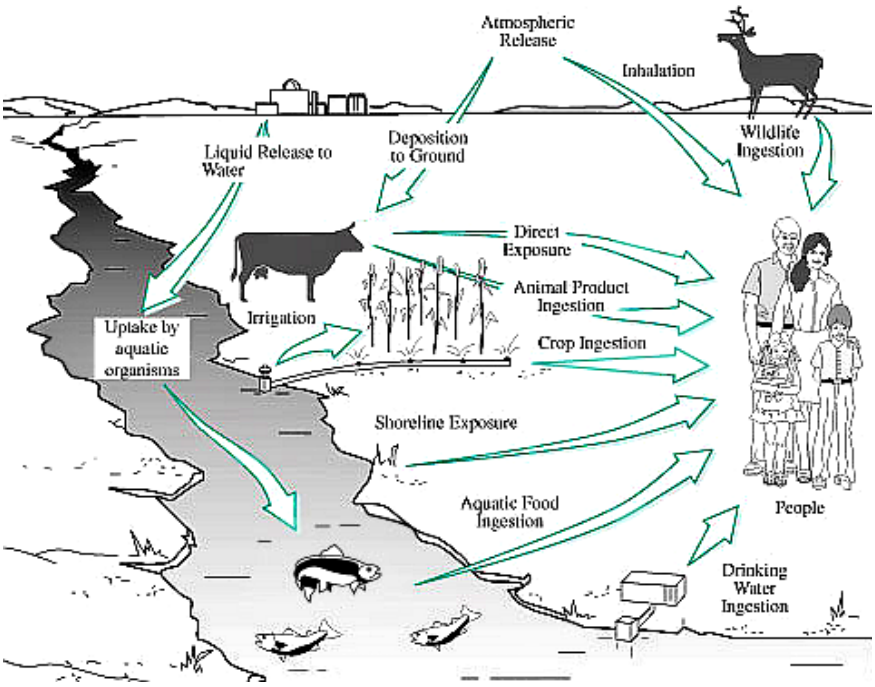


Figure 4-1: Model of Exposure Pathways from Site Emissions

Source: Based on United States Department of Energy/Hanford Site

4.1 Modelling

4.1.1 Integrated Model for Probabilistic Assessment of Contaminant Transport (IMPACT)

The IMPACT version 5.4.0 software was used to calculate doses to the potential critical groups using 2018 environmental monitoring data. Where measured environmental data is not available, IMPACT calculates the doses from emissions.

IMPACT 5.4.0 is consistent with the method of dose calculation described in the CSA N288.1-08 standard [R- 18].

IMPACT 5.5.1, an updated version of IMPACT 5.4.0, has been released and is consistent with the revised CSA N288.1-14 standard [R- 51]. IMPACT 5.5.1 has been used to update the DN and PN DRLs. Following implementation of these updated DRLs, IMPACT 5.5.1 will be used for the 2019 public dose calculations.

4.1.2 Calculated Atmospheric Dispersion Factors

Atmospheric dispersion factors (Ka) provide a measure of the dilution of station radiological stack emissions to the atmosphere. Ka values are used to estimate radionuclide concentrations in air at the boundary monitor locations when local measured values are not available. Details of how and when the Ka values are used are provided in Appendix F, Dose Calculation Procedure and Concentrations.

Factors influencing atmospheric dispersion at a specific location include wind speed and direction, as well as the level of turbulence in the atmosphere.

Ka values are calculated from the measured HTO in air concentrations and HTO emissions using the relationship:

$Ka = C/Q\ (s/m^3)$

Where C is the annual average HTO in air concentration (Bq/m^3) above background measured outside the site boundary, and Q is the average annual HTO release rate (Bq/s) measured by stack monitors at the point of release. The release rate is determined by dividing the total annual emission of HTO as given in Table 2-1 by 3.16×10^7 seconds per year.

Ka values have been calculated using HTO in air concentrations from the active samplers at the boundary locations. These values are listed in Tables 4-1 and 4-2 for DN and PN, respectively.

Table 4-1: Darlington Nuclear Annual Boundary Dispersion Factors – 2018

INDICATOR SITES	Measured Average Airborne Tritium Concentration (Bq/m^3)	Measured Ka (s/m^3)
D1 – Southeast Fence	1.63	2.4E-07
D2 – East Fence	1.32	1.9E-07
D5 – Knight Road	0.90	1.3E-07
D9- Courtice WPCP	1.23	1.80E-07
D10 – Holt Road	0.62	9.14E-08
Average		**1.7E-07**

NOTE: The measured annual HTO to air emission is used together with the measured levels of HTO in the environment to calculate Ka.

Table 4-2: Pickering Nuclear Annual Boundary Dispersion Factors – 2018

INDICATOR SITES	Measured Average Airborne Tritium Concentration (Bq/m^3)	Measured Ka (s/m^3)
P2 – Montgomery Park Rd.	16.49	8.4E-07
P3 – Sandy Beach Rd.	5.07	2.6E-07
P4 – Liverpool Rd.	3.55	1.8E-07
P6 – East Boundary	9.25	4.7E-07
P10 – Central Maintenance –East	14.59	7.5E-07
P11 – Alex Robertson Park	4.63	2.4E-07
Average		**4.6E-07**

NOTE: The measured annual HTO to air emission is used together with the measured levels of HTO in the environment to calculate Ka.

4.1.3 Meteorological Data

Wind speed, direction and frequency are measured continuously at meteorological towers at each nuclear site. The average annual wind frequencies at a 10 m height in 2018 for the DN and PN sites are presented in Table 4-3 for 16 wind sectors.

The meteorological data are used in the IMPACT program to model radionuclide concentrations at the potential critical group locations where measured data is not available (such as pathways for I(mfp), Co-60, Cs-137+ and HT). In 2018, the DN Meteorological tower exceeded unavailability limits as defined for the program. Therefore, meteorological data from the PN site was used for both nuclear sites.

In 2018, the landward wind sector which the wind predominantly blew towards was SW. Table 4-3 indicates the wind frequencies blowing from each direction.

Table 4-3: Darlington and Pickering Nuclear – 2018 Annual Average Wind Frequency by Direction (at 10 m height)

Direction Wind Blowing From	Darlington Nuclear* Wind Frequency (%)	Pickering Nuclear Wind Frequency (%)
N	7.84	7.84
NNE	7.84	7.84
NE	3.85	3.85
ENE	4.81	4.81
E	7.07	7.07
ESE	6.38	6.38
SE	4.11	4.11
SSE	2.06	2.06
S	2.70	2.70
SSW	8.13	8.13
SW	**8.19**	**8.19**
WSW	5.29	5.29
W	5.48	5.48
WNW	7.15	7.15
NW	10.43	10.43
NNW	8.70	8.70
Total	100.00	100.00

NOTES:

* Darlington Nuclear Meteorological Tower did not meet unavailability limits in 2018. Therefore, data from the Pickering Nuclear Meterological Tower was used.

- Shaded fields indicate landward wind sectors.

- Bolded values indicate landward wind sectors with the highest wind frequency.

4.2 Critical Group Dose

The calculation of public dose in this report is intended to be realistic, using the potential critical group lifestyles and attributes collected in the DN and PN site-specific surveys [R- 28][R- 29][R- 30][R- 31]. The site specific surveys identify the potential critical groups for DN and PN as discussed in Appendix E. Approximately, every five years the site specific surveys and pathway analyses are reviewed to ensure the public dose accurately represents the public living near the nuclear generating stations.

Current EMP designs are based on the 2006 site specific survey information. Site specific surveys were most recently reviewed in 2018 and pathway analyses were updated in 2016, however these did not identify any significant changes with the potential to substantially alter the predictions of the ERAs or the implementation of the EMPs. Therefore, in accordance with CSA N288.4-10 Clause 5.3, no immediate action or change is required to the EMP designs. Recommendations from these

studies were incorporated into EMP design reviews undertaken in 2018 [R- 54][R- 55] and necessary program changes will be implemented in 2019.

In public dose assessments, “critical groups” are used to estimate the mean realistic impacts of emissions on the most affected individuals. An individual with the average characteristics of the group is known as the “Representative Person” as described in CSA N288.1-08 [R- 18]. Dose estimates are calculated for a number of potential critical groups for each site, and for three age classes within each potential critical group; adult, child, and infant. The group and age class with the highest dose is reported as the site public dose for the given year.

Doses are reported for each of the top three potential critical groups at DN and PN, i.e. the three potential critical groups for each site which yield the highest dose estimates based on the pathway analyses. For DN these groups are currently the Dairy Farm, the Farm, and the Rural Resident. As a result of the recent EMP design review [R- 54], these groups will become the Farm, Rural Resident and West/East Beach Resident for DN, beginning with the 2019 dose calculation. For PN these groups are currently the Industrial/Commercial Worker, the Urban Resident, and the occupants of a Correctional Institute. As a result of the recent EMP design review [R- 55], these groups will become the Urban Resident, Sport Fisher and Industrial Worker, beginning with the 2019 dose calculation. Additionally, the annual public dose is also calculated for the PN Dairy Farm potential critical group as this group is exposed to the most media types and pathways. Including the Dairy Farm assures that any future changes in emissions, environmental transfer factors, exposure factors, and dosimetry, and changes in the distribution of radionuclides released will be captured. The EMP sampling plan is designed to monitor for these potential critical groups. No changes to routine sampling were identified in the recent EMP design reviews [R- 54][R- 55].

For groups that occupy a relatively small geographic area, radionuclide measurements taken at that location are used in the potential critical group calculations. For groups such as the Farm, Dairy Farm or Urban Resident that are spread over much wider geographic areas, air concentrations are determined for a single conservative representative location, and group average values are used for terrestrial samples and water sources.

A small fraction of the adult residents living near DN or PN also work within 5 km of the stations, thereby receiving a different dose while at work and at home. Similarly, a small fraction of the Industrial/Commercial potential critical group workers live near DN or PN station and continue to receive a dose while at home. As a result, the dose estimates for these potential critical groups have been adjusted to account for this portion of the population.

The following sections provide the basis for the dose calculation, results, and interpretation of the public dose for DN and PN. Details on the calculations, how the radionuclide concentrations are determined, background subtractions, and whether data is measured or modeled are provided in Appendix F. Tables of doses calculated for all the potential critical groups are provided in Appendix G, Tables of Public Doses by Radionuclide, Pathway and Age Group for Darlington Nuclear and Pickering Nuclear Potential Critical Groups.

4.2.1 Exposure Pathways

The dose calculations include all pathways of radionuclide uptake or external exposure by humans, as illustrated previously in Figure 4-1. The dose contribution from each pathway was estimated with IMPACT 5.4.0 either using direct measurements in the environment or by modelling from emissions.

4.2.2 Age Classes

In accordance with CSA N288.1-08 [R- 18], three age classes are used for estimating annual dose to the representative person. The three age classes are 0-5 years (infant), 6-15 years (child), and 16-70 years (adult). The dose estimates to these three age groups are sufficient to characterize doses to the public. For practical implementation in dose calculations, the dose coefficients and characteristics for a one-year old infant, a 10-year old child, and an adult are used to represent the three age classes [R- 32].

4.2.3 Basis of Dose Calculation

- For each potential critical group, the annual average concentration of each environmental medium sampled from that group is used for the dose calculation with the background subtracted.

- OBT doses from terrestrial animals, plants, and fish are modeled from measured HTO concentrations in terrestrial media and fish.

- Doses from HTO, noble gases, and C-14 in air (where samplers are not at potential critical group locations) are estimated based on measurements at the fence line boundary and applying a calculated air dispersion ratio for the potential critical group location.

- Doses from the remaining radionuclide pathways for I(mfp), Co-60, and HT, are modeled from emissions applying the Ka dispersion factor as well as the calculated air dispersion ratio for the potential critical group location (see Appendix F)

4.2.4 Uncertainty in Dose Calculation

As described previously, the public dose estimates use a combination of measured and modeled environmental concentrations of radionuclides. A study was completed through COG to quantify the uncertainties associated with public dose estimation. This study concluded that dose estimates which start with concentration measurements in environmental media for the important exposure pathways, such as OPG's EMP dose estimates, tend to have uncertainties in the order of ±30% [R- 33].

4.3 Darlington Nuclear Public Dose

4.3.1 Darlington Nuclear Potential Critical Groups

The three potential critical groups at DN for which doses are calculated in this report are shown in Figure C1, Appendix C and are described in Appendix E, Potential

Critical Group Descriptions. The potential critical groups and their representative locations are primarily based on the DN site-specific survey review [R- 28][R- 30] and modified, if required, if significant changes occur ahead of the next site-specific survey review.

4.3.2 Dose Calculation Results

For 2018, the limiting critical group at DN was the Farm adult, with a dose of 0.8 µSv/year, as indicated in Table 4-4.

The Farm critical group represents agricultural farms located within approximately 10 km of the DN site. The representative location of this critical group is the most affected farm which is in the WNW wind sector about 2 km from the site. Members of this group obtain their water supply mostly from wells and use it for drinking, bathing, irrigation, and watering livestock. They also obtain a large fraction of their annual fruit, vegetable and animal product consumption from locally grown products, consume a small amount of locally caught fish, and are exposed to beach sand at local beaches. The results of the 2018 DN public dose calculation are presented in Table 4-4.

Table 4-4: 2018 Annual Darlington Nuclear Critical Group Doses

Potential Critical Group	Dose per Age Class (microsieverts)		
	Adult	Child (10-year old)	Infant (One-year old)
Dairy Farm Residents	0.5	0.5	0.5
Farm Residents	**0.8**	0.7	0.5
Rural Residents	0.4	0.3	0.2

Table 4-5 illustrates the dose contribution from each radionuclide for the Farm adult and percent contribution to the total dose. C-14, HTO, and noble gases contribute over 95% of the total dose.

Table 4-5: 2018 Darlington Nuclear Public Dose

Radionuclide	Dose (µSv/a)	% Dose Contribution
C-14	9.4E-02	12.2%
Co-60	1.3E-02	1.6%
Cs-137+	3.2E-05	0.0%
HT	4.7E-06	0.0%
HTO	5.2E-01	66.6%
Noble Gases	1.3E-01	16.5%
OBT	1.6E-02	2.1%
I (mfp)	7.0E-03	0.9%
Total	7.7E-01	100%

NOTE: "+" indicates that contributions from progeny are included.

This distribution of dose by radionuclides reflects the characteristics of the Farm group. C-14 dose is mostly from ingestion of terrestrial plants and animal products. A large portion of the animal products, fruits, and vegetables consumed by the Farm group is from local sources. Dose from HTO is attributed to air inhalation and ingestion of local well water, terrestrial plants and animal products. The public dose trend for DN is presented on a logarithmic scale in Figure 4-2. The DN dose remains essentially unchanged over the last ten years and is below 1% of the legal limit.

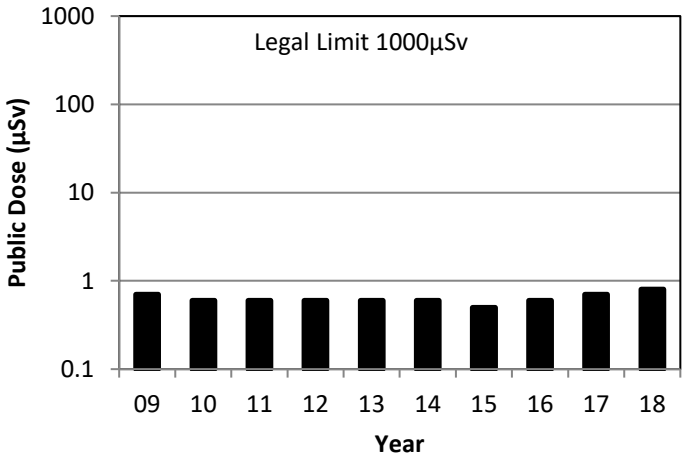


Figure 4-2: Darlington Nuclear Annual Public Dose Trend

4.3.3 Discussion of Results

The 2018 DN site public dose of 0.8 µSv, as represented by the Farm adult, is about 0.1% of the 1,000 µSv/year legal limit for a member of the public. The DN dose for

2018 is essentially unchanged from the 2017 site dose of 0.7 µSv for the Dairy Farm infant.

The DN dose for 2018 is less than 0.1% of the estimated average background dose around DN, from naturally occurring and anthropogenic (man-made) radiation, of about 1,400 µSv/year (excluding medical doses, refer to Section 4.5). Figure 4-3 is a graphical representation of critical group dose compared to background radiation around DN. As an additional source of comparison, Table 4-8 provides examples of typical doses from exposure to natural and anthropogenic sources.

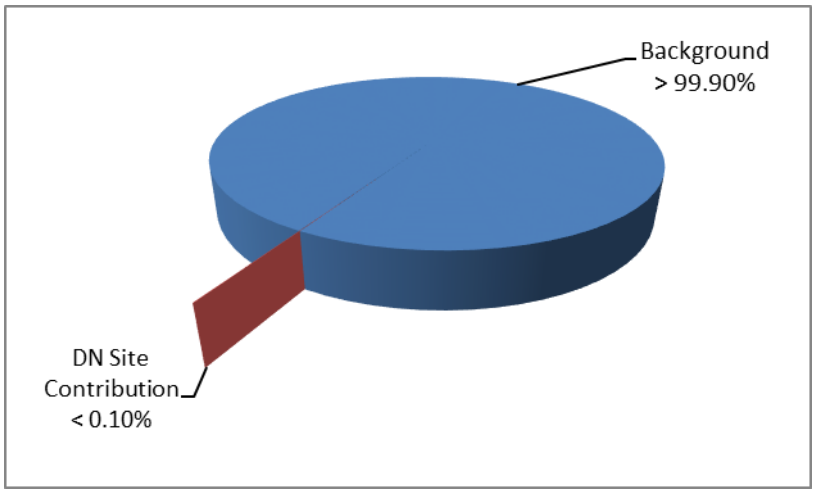


Figure 4-3: Comparison of Darlington Nuclear Public Dose to Background Dose

4.4 Pickering Nuclear Public Dose

4.4.1 Pickering Nuclear Potential Critical Groups

The four potential critical groups at PN for which doses are calculated in this report are shown in Figure C2, Appendix C and are described in Appendix E. The potential critical groups and their representative locations are primarily based on the site-specific survey review conducted in 2005 [R- 29] and modified, if required, if significant changes occur ahead of the next site-specific review cycle.

4.4.2 Dose Calculation Results

For 2018, the limiting critical group at PN was the Urban Resident adult, with a dose of 2.1 µSv/year, as indicated in Table 4-6.

The Urban Resident critical group consists of Pickering and Ajax residents in the areas surrounding the PN site. Members of this group drink mostly water from Ajax WSP and also consume a diet comprised in part of locally grown produce and some locally

caught fish. Members of this group are also externally exposed to beach sand at local beaches.

A fraction of adult residents within the Urban Resident critical group also work within 5 km of PN station and receive some dose from the station while at work. The average dose for the Urban Resident Adult has been adjusted to account for these residents.

The results of the 2018 PN public dose calculation are presented in Table 4-6.

Table 4-6: 2018 Annual Pickering Nuclear Critical Group Doses

Potential Critical Group	Dose per Age Class (microsieverts)		
	Adult	Child (10-year old)	Infant (One-year old)
Dairy Farm Residents	0.5	0.4	0.4
Urban Residents	2.1	2.1	2.0
C2 Correctional Institution	1.4	1.5	
Industrial Workers	1.6		

Table 4-7 illustrates the dose from each radionuclide and percent contribution to the total dose. HTO and noble gases contribute over 95% of the total dose.

Table 4-7: 2018 Pickering Nuclear Public Dose

Radionuclide	Dose (µSv/a)	% Dose Contribution
C-14	9.3E-03	0.4%
Co-60	3.4E-03	0.2%
Cs-137+	5.1E-02	2.4%
HTO	9.6E-01	45.0%
Noble Gases	1.1E+00	52.0%
OBT	2.4E-03	0.1%
I (mfp)	4.9E-05	0.0%
Total	2.1E+00	100%

NOTE: "+" indicates that contributions from progeny are included.

This distribution of dose by radionuclides reflects the characteristics of the Urban Resident group since their exposure is mainly from inhalation of HTO and external exposure to noble gases. The public dose trend for PN is presented on a logarithmic scale in Figure 4-4. The PN dose remains below 1% of the legal limit.

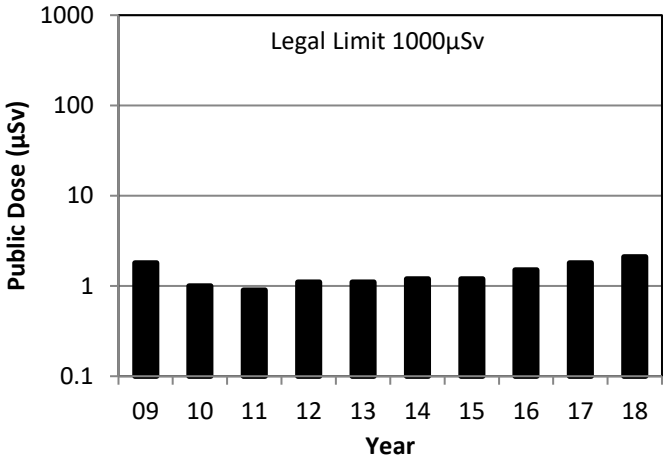


Figure 4-4: Pickering Nuclear Annual Public Dose Trend

4.4.3 Discussion of Results

The 2018 PN site public dose of 2.1 µSv, as represented by the Urban Resident adult, is 0.2% of the 1,000 µSv/year legal limit for a member of the public. The critical group has remained unchanged.

The PN dose for 2018 was equivalent to 0.15% of the estimated background dose around PN of 1,400 µSv/year, from naturally occurring and anthropogenic (man-made) radiation (excluding medical doses, refer to Section 4.5). Figure 4-5 is a graphical representation of critical group dose compared to background radiation around PN. As an additional source of comparison, Table 4-8 provides examples of typical doses from exposure to natural and anthropogenic sources.

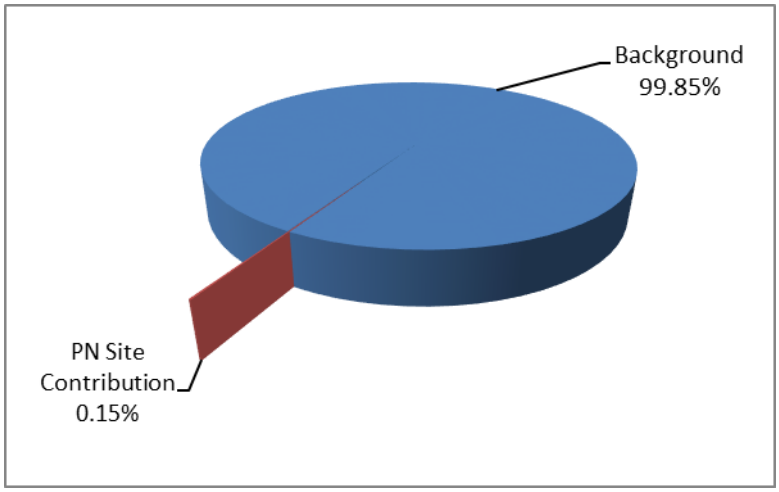


Figure 4-5: Comparison of Pickering Nuclear Public Dose to Background Dose

4.5 Natural and Anthropogenic Data

Table 4-8 provides some typical doses received by members of the public from exposure to natural and anthropogenic sources.

Table 4-8: Typical Doses from Exposure to Natural and Anthropogenic Sources

Source of Exposure	Effective Dose (µSv)
Annual External Exposure during Precipitation Events (Gamma Radiation from Naturally Occurring Radon Gas Decay Products) [R- 34]	4
Chest X-Ray (single film) [R- 35]	10
Airplane Travel (two hour flight) [R- 36]	12

Information on Canadian public doses from naturally occurring sources, including data from ground gamma surveys in four major Canadian cities, was provided in 2002 [R-37][R- 38]. Results are summarized in Table 4-9, where it can be seen that most of the variation is due to the inhalation dose from Radon-222 (Rn-222).

Table 4-9: Naturally Occurring Annual Public Effective Doses

Radiation Source	Worldwide Average (µSv)	Canada (µSv)	Toronto (µSv)	Montreal (µSv)	Winnipeg (µSv)	Pickering Nuclear Site (µSv)	Darlington Nuclear Site (µSv)
Cosmic	380	318	313	313	315	313	313
Internal	306	306	306	306	306	306	306
Inhalation[(a)]	1,256	926	757	667	3,225	565	565
External	480	219	178	278	176	154	154
Total[(b)]	**2,400**	**1,800**	**1,600**	**1,600**	**4,000**	**1,300**	**1,300**

(a) Mostly from Rn-222.
(b) Total doses have been rounded to two significant figures to reflect the inherent uncertainty. Some components are based on direct measurements and others are estimated from related measurements.

In addition to naturally occurring radiation, the public also receives about 70 µSv/year effective dose from anthropogenic sources such as nuclear weapon test fallout, and exposures from technological processes and consumer products and services, excluding medical sources. Thus, the total background dose around PN and DN from naturally occurring and anthropogenic sources is 1,400 µSv/year. Furthermore, the average Canadian dose from medical sources averages 1,100 µSv/year per person. The legal limit of 1,000 µSv per year from licensed industrial practices is over and above the dose the public already receives from the natural environment and from medical procedures [R- 39].

5.0 QUALITY ASSURANCE AND PERFORMANCE

The Quality Assurance (QA) program for the EMPs encompasses all activities from sample collection, laboratory analysis, laboratory quality control and external laboratory comparison, to program audits, self-assessments, and dose verifications. The objectives include ensuring that EMP samples are representative and their

analytical results are accurate such that best estimates of radiation doses to the public can be provided, as well as complying with procedures and program quality requirements. This section provides an overview of quality assurance activities that are critical to ensuring the quality of the EMP data and processes.

5.1 Laboratory Quality Assurance and Quality Control

The OPG Health Physics Laboratory (HPL) is accredited for radioanalysis of drinking water and soil by the Canadian Association for Laboratory Accreditation (CALA). The accreditation is based on demonstrated compliance with ISO 17025, General Requirements for the Competence of Testing and Calibration Laboratories. HPL is also licensed for radioanalysis of drinking water by the Province of Ontario's Ministry of the Environment, Conservation and Parks. HPL performs laboratory activities in accordance with the OPG Dosimetry and Radiological Environmental Measurement Services Quality Assurance Manual [R- 40].

5.1.1 Laboratory Quality Control

Quality Control (QC) samples are used to estimate the precision and accuracy of analytical results and to examine any sources of error introduced by laboratory practices which require corrective actions. Two types of QC samples are used to accompany the analyses of the environmental samples collected for the EMPs:

(a) Process control samples are 'dead water' (radiation-free water/blank) samples that go through the same handling process as the real samples.

(b) QC standards are samples with predetermined values (usually traceable standards) that go through the same handling process as the real samples. The analysis of the environmental sample is considered valid when the results of the accompanying QC samples are within the expected set limits, depending on the analysis type.

For 2018, the results for the QC samples were all within the required range. These results provide confidence in the quality of data for the program and the consistency of laboratory measurements.

5.1.2 Laboratory Performance Testing

The main purpose of the laboratory performance testing programs is to provide assurance to OPG Nuclear and the CNSC of the laboratory's analytical proficiency (i.e., the accuracy of the measurements). The testing programs provide a quality check on laboratory operations including equipment calibration, analytical procedures, data review and internal QC. These testing programs are a crucial part of the laboratory QA program to demonstrate that the laboratory is performing within the acceptable limits as measured against external unbiased standards.

For 2018, OPG Nuclear participated in a laboratory performance testing program that included the measurement of tritium in water, gross beta in water, and gamma emitters in water, soil and milk.

QA test samples were supplied on a quarterly basis by Eckert and Ziegler Analytics [R-41]. Results of analyses were reported back to Eckert and Ziegler Analytics who then provide performance reports for each of the analytical types. The performance test limits were as follows:

$$-25\% \leq \text{Relative Difference} \leq +50\%$$

$$\text{Relative Precision} \leq 40\%$$

These test limits are adapted from the *in vitro* accuracy specifications of the CNSC's Regulatory Standard S-106 Revision 1, Technical and Quality Assurance Requirements for Dosimetry Services [R- 42].

All QA performance test results in 2018 met the specified limits. The maximum and minimum Relative Difference and Relative Precision are summarized for each sample type and presented in Table 5-1.

Table 5-1: Summary of Analytics Performance Test Results – 2018

Sample Types	Relative Difference (%)		Relative Precision (%)	
	High	Low	High	Low
Tritium in Water	0	-6	2	2
Gross Beta in Water	9	1	10	8
Gamma in Water	28	-4	11	1
Gamma in Soil	15	-13	5	1
Gamma in Milk	19	-12	5	1

5.2 Equipment Calibrations/Maintenance

Equipment calibrations and maintenance are conducted in accordance with the Environmental Monitoring Program Equipment Maintenance Manual [R- 43].

From May to December of 2018, the processing of environmental water samples was shifted to the Berthold #2 counter to accommodate the installation of a new sample changer on Berthold #1 counter. Subsequent issues with the installation triggered an investigation by the Environment Health Physicist, where it was determined that the calibration reports indicated that only Berthold #1 was calibrated to count Environment water samples. As a result, monthly WSP gross beta results from April to October 2018 and quarterly provincial WSP gross beta results for Q2 and Q3 were over reported by approximately 5%. This positive bias in reporting remains within the range of uncertainty for gross beta in water results and therefore, does not negatively impact the dose calculation.

In addition, annual sensitivity checks are performed on the noble gas detectors to quantify the sensitivity of the sodium iodide crystal in each detector. The 2018 results indicate that detectors are functioning at acceptable levels of sensitivity [R- 44].

5.3 Program Quality Assurance

5.3.1 Audits

An independent audit, also referred to as a performance based assessment, of the EMPs is conducted once every five years in accordance with CSA N288.4-10 [R- 2]. The last audit of the EMPs was performed in 2014 by OPG's Nuclear Oversight department.

The OPG HPL also 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 2018, an HPL QA audit was conducted on worker qualifications in the dosimetry section, including the Health Physics Laboratory. 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. There were three minor findings and one observation and have been assigned and will be tracked to completion [R- 41].

Additionally, The Ministry of the Environment, Conservation and Parks performed an audit at the Health Physics Laboratory in July, 2018. A non-compliant finding identified that a training record required under the Safe Drinking Water Act was missing. The finding was resolved by providing a copy of the necessary training record. Overall, the Inspection rating for this audit was 98.82%. [R- 41]

In 2018, there were three CNSC Field Inspections held at the Health Physics Laboratory (Whitby). The first field inspection, conducted August 1, 2018 identified a Human Performance finding on Personnel Training. Specifically, a worker had completed required training, but the paperwork to credit the employee with the training had not yet been processed in the training system. The finding was resolved by uploading the required training record. Field inspections conducted on August 30 and December 4, 2018 found no adverse conditions. [R- 41]

5.3.2 Self-Assessments

In 2018, two self-assessments were performed on different elements of the EMPs.

(a) Field Verification of Lab Procedures for Free Water Extraction by Passive Distillation and Tritium Analysis

The focus of this self-assessment was to verify procedural use of Free Water Extraction by Passive Distillation and Tritium analysis procedures by HPL staff. OPG Environment staff observed HPL staff perform tritium analysis on fruit samples according to approved program procedures. HPL staff were found to be knowledgeable and competent in performing free water extraction by passive distillation tritium analysis of fruit samples, and followed lab procedures adequately. This self-assessment is documented in the OPG Self Assessment Database under COE18-001571-S.

(b) Annual Performance Assessment

Self-assessment COE18-001375-SA was completed for the EMP Annual Performance Assessment. The assessment confirmed that all EMP design objectives were met. Required equipment repairs and maintenance to EMP stations have been carried out. Revisions required for various EMP procedures and documents were completed.

5.4 Third-Party Verification of Annual EMP Report

An independent third-party verification of the annual dose calculations and this report was carried out by EcoMetrix Incorporated. Verification was done on the methodology used, assumptions made, input parameter values and data used. This involved checking the dose calculations, IMPACT scenarios, and performing independent replicate IMPACT model runs and hand calculations to validate the results obtained by OPG. Any necessary changes identified by the third-party verification have been addressed and incorporated in this report.

5.5 Program Performance

5.5.1 Sample Unavailability

A total of 985 laboratory analyses were performed for the 2018 dose calculation. The analyses covered HTO, C-14, and gamma scan. The PN site accounted for 36% of these sample analyses, while the DN and provincial-background programs accounted for 49% and 15% respectively. Table 5-2 shows the sample types, number of locations, number of samples used for the dose calculation, and the unavailability of each sample type.

The unavailability indicator tracks the performance of sample collection and analysis for the EMPs. The sampling portion of the EMPs is designed to collect representative field samples from selected pathways near each nuclear site and from background locations, in order to meet the program objectives as defined in Section 1.1. The sample unavailability percentage is determined by dividing the number of missed or invalid sample analyses by the number of planned sample analyses for each EMP site.

An important objective of the EMP is to estimate the doses to the public based on environmental data measured in the public domain. In accordance with the EMP governing document [R- 45], the requirement to meet unavailability limits is specific to the analysis of samples used in the dose calculation. These limits are applied to the PN, DN and provincial-background EMPs separately.

The unavailability limits for samples used in the dose calculation are provided in Table 5-2 and range from 10 to 25%. The unavailability limits were derived based on the relative contributions to total dose, therefore higher dose contributors have a lower unavailability limit. The overall unavailability for PN, DN and provincial-background EMPs was 1%, 2% and 1%, respectively.

Though not exceeded, the unavailability limit of 20% for DN fruits was reached in 2018. This was due to the fact that fruit samples were not available at one location in 2018. Eighty percent of DN fruit were available and considered representative of critical group locations. Therefore, these samples were used in the dose calculation.

Table 5-2: Unavailability of EMP Sample Data Used for Dose Calculation Purposes

Sample Types	Collection Frequency	Pickering Nuclear				Darlington Nuclear				Provincial Background				Unavailability Limit [d]
		Locations	Planned Analyses	Actual Analyses	Unavailability	Locations	Planned Analyses	Actual Analyses	Unavailability	Locations	Planned Analyses	Actual Analyses	Unavailability	
Tritium														
Tritium in Air (Molecular Sieve)	Monthly/Quarterly	6	72	72	0%	6	72	68	6%	1	12	11	8%	10%
Water Supply Plants	Weekly Composite	1	48	48	0%	2	96	96	0%					15%
Residential Wells	Monthly	2	24	21	13%	4	48	48	0%					15%
Milk	Monthly	2	24	24	0%	3	36	36	0%					25%
Milk	Quarterly									1	12	11	8%	25%
Lake Water	Monthly [a]	3	24	23	4%	2	16	16	0%					25%
Fruits	Annual	5	15	15	0%	5	15	12	20%	4	8	8	0%	20%
Vegetables	Annual	5	15	15	0%	4	12	12	0%	4	8	8	0%	20%
Animal Feed	Annual	1	8	8	0%	4	16	16	0%	1	8	8	0%	25%
Poultry	Annual					1	8	8	0%	1	8	8	0%	25%
Eggs	Quarterly					1	12	12	0%	1	12	12	0%	25%
Fish	Annual	1	8	8	0%	1	8	8	0%					25%
Carbon-14														
Carbon-14 in Air	Quarterly	4	16	16	0%	4	16	16	0%	1	4	4	0%	25%
Milk	Monthly	2	24	24	0%	3	36	36	0%					10%
Milk	Quarterly									1	12	11	8%	25%
Fruits	Annual	5	15	15	0%	5	15	12	20%	4	8	8	0%	20%
Vegetables	Annual	5	15	15	0%	4	12	12	0%	4	8	8	0%	20%
Animal Feed	Annual	1	8	8	0%	4	16	16	0%	1	8	8	0%	25%
Poultry	Annual					1	8	8	0%	1	8	8	0%	25%
Eggs	Quarterly					1	12	12	0%	1	12	12	0%	25%
Fish	Annual	1	8	8	0%	1	8	8	0%	1	8	8	0%	25%
Noble Gases														
External Gamma (Noble Gas Monitors) [b]	Continuous	6	NA	NA	1%	5	NA	NA	3%					25%
Gamma														
Fish	Annual	1	8	8	0%	1	8	8	0%	1	8	8	0%	25%
Beach Sand	Annual	3	24	24	0%	3	24	24	0%	1	8	8	0%	25%
Overall dose sample Unavailability [c]			356	352	**1%**		494	484	**2%**		152	149	**1%**	

Notes: NA = Not Applicable.

(a) For safety considerations, samples are not required during the winter months (Dec. - Mar.).

(b) Noble gas detector unavailability is based on an average of actual run time of all monitors for PN and DN.

(c) Unavailability defined as an average of the percent unavailability of all sample types.

(d) Unavailability limit for all Provincial samples types is 25%.

5.6 Annual Assessment of the EMPs

The annual assessment of OPG's 2018 EMPs is summarized as follows:

- Overall, the EMPs met their objectives as defined in Section 1.1.
- A total of 985 environmental data analyses were completed for samples collected around DN and PN sites and at various Ontario background locations in support of the radiological dose calculations. The overall unavailabilities were 1%, 2%, and 1% for the PN, DN, and provincial-background EMPs, respectively.
- Two self assessments were completed this year for the EMPs. No significant findings were identified.
- An independent third-party verification of the annual dose calculations and this report was carried out by EcoMetrix Incorporated.

5.6.1 Summary of Darlington Results

- Site emissions remained at very small fractions of their respective DRLs.
- Boundary noble gas detector dose rates remained below detection limits.
- As indicated in Figure 2-1, the HT emissions from DN have remained at low levels. In 2018, the HT emissions were 4.7×10^{13} becquerels (Bq). As of 2017, these emissions include HT emissions from the powerhouse.
- Annual average tritium concentrations in drinking water from the nearby water supply plants were well below OPG's commitment of 100 Bq/L. The annual average HTO activity in well water was 10.7 Bq/L.
- Concentrations of HTO and C-14 in air, vegetation, milk, and fish and Cs-137 in fish were in line with levels seen over the last ten years. Eggs and poultry sampling resulted in concentrations for HTO and C-14 that were similar to those in 2017.
- The 2018 public dose for the DN site was 0.8 µSv and was represented by the adult of the Farm critical group. The 2018 site public dose remains a small fraction of both the annual legal dose limit and the annual natural background radiation in the area.

5.6.2 Summary of Pickering Results

- Site emissions remained at a very small fraction of their respective DRLs.
- The PN waterborne HTO emissions remain stable. The PN tritium to water emission in 2018 was 4.2×10^{14} Bq.

- Annual average tritium concentrations in drinking water from the nearby water supply plants were below OPG's commitment of 100 Bq/L. The annual average HTO activity in well water was 15.7 Bq/L.

- Concentrations of HTO and C-14 in air, vegetation, milk, and fish, and Cs-137 in fish were in line with levels seen over the last ten years.

- The PN boundary average Ar-41 dose in air was 290 nanogray (nGy)/month in 2018. The increases observed in 2016 and 2017 are attributed to air ingress through the Unit 4 calandria vault dryers. Repairs to address this were completed in October 2017. However, Ar-41 emissions remain high in 2018 due to a substantial increase in operating time of Units 1 and 4, compared to previous years.

- The 2018 public dose for the PN site was 2.1 µSv and was represented by the adult of the Urban Resident group. The 2018 site public dose remains a small fraction of both the annual legal dose limit and the annual natural background radiation in the area.

6.0 OUTLOOK FOR 2019

The most recent program design reviews on the PN and DN EMPs were undertaken in 2018 and issued in 2019. The design reviews incorporated the most recent ERA results, updated pathway analyses, and the results of the latest site specific survey reviews. No changes to routine sampling were identified in the reviews [R- 54][R- 55]. However, beginning in 2019, the dose calculation will use Cs-134, rather than Cs-137+, as the surrogate for gross beta-gamma in water releases to align with recently implemented DRLs. Additionally, the top three potential critical groups at DN and PN for which doses are reported will reflect those which yielded the highest dose estimates based on the most recent pathway analyses, as summarized in section 4.2.

A 2019 supplementary study will be conducted to sample lake water at the outlet of the DN diffuser and analyze samples using a lower detection limit for hydrazine to reduce uncertainty surrounding human exposure to hydrazine through drinking water and fish ingestion.

An additional supplementary study will be conducted to collect filtered and unfiltered effluent samples for analysis of aluminum in the DN CCW to clarify the risks to ecological receptors in Lake Ontario.

Finally, an independent audit of the EMPs will be conducted in 2019 in accordance with CSA N288.4-10 [R- 2]. This audit will be performed by OPG's Nuclear Oversight department.

7.0 REFERENCES

[R- 1] Canadian Nuclear Safety Commission, Regulatory Document REGDOC-2.9.1, Environmental Protection Policies, Programs and Procedures, September 2013.

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

[R- 3] Canadian Nuclear Safety Commission, Regulatory Document REGDOC-3.1.1, Reporting Requirements for Nuclear Power Plants, May 2014.

[R- 4] Government of Canada, Nuclear Safety and Control Act S.C. 1997, c.9, last amended January 2017.

[R- 5] OPG letter, Mr. G. C. Andognini to Dr. M.P. Measures, “Carbon-14 Management Plan”, N-CORR-00531-00541, December 16, 1999.

[R- 6] OPGN Carbon-14 Inventory 2018, N-REP-03400.1-0752413, March 2019.

[R- 7] Canadian Standards Association, Environmental Risk Assessments at Class I Nuclear Facilities and Uranium Mines and Mills, CSA N288.6-12, June 2012.

[R- 8] EcoMetrix Incorporated, Pickering Nuclear Environmental Risk Assessment, P-REP-07010-10012, January 2014.

[R- 9] Beninson, D., Gonzalez, A.J., Application of the Dose Limitation System to the Control of 14C Releases from Heavy-Water-Moderated Reactors, IAEA-SM-258/53, 1982.

[R- 10] Health Canada. Environmental Workplace and Health, Fixed Point Surveillance Network, Accessed 2019-04-05 http://www.hc-sc.gc.ca/ewh-semt/contaminants/radiation/surveill/index-eng.php

[R- 11] Ontario Power Generation, 2017 Results of Radiological Environmental Monitoring Programs, N-REP-03443-10017, April 03, 2018.

[R- 12] Ontario Drinking Water Quality Standards, Safe Drinking Water Act, O. Reg 169/3, 2002.

[R- 13] King-Sharp, K.J. and Klukas, M.H., Great Lakes Time-Concentration tritium Model: Using 2008 Tritium Data and Updated Emissions to 2007, COG Report: OP-08-3040, December 2008.

[R- 14] Health Canada, Guidelines for Canadian Drinking Water Quality: Guideline Technical Document, Radiological Parameters, May 2009.

[R- 15] Hart, D. and Petersen, K., Results of Site Specific Sampling and Analysis of Sediments near Canadian CANDU Facilities, COG-12-3045, April 2013.

[R- 16] Cautillo, C., 2014 Results of Radiological Environmental Monitoring Programs, N-REP-03443-10014, April 20, 2015.

[R- 17] Radiation Solutions Inc. Report: Air Kerma Rate Analysis for Pickering Nuclear Generating Station, N-REP-03443-10018, March 2018

[R- 18] Canadian Standards Association, Guidelines for Calculating Derived Release Limits for Radioactive Material in Airborne and Liquid Effluents for Normal Operation of Nuclear Facilities, CAN/CSA-N288.1-08, September 2008.

[R- 19] International Atomic Energy Agency, “Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments” Technical Reports Series No. 472, January 2010.

[R- 20] Brown, D., Impact of PNGS Thermal Discharge During the Winter of 2010 on Potential Round Whitefish Spawning, P-REP-07250-00001, Aug 12, 2010.

[R- 21] Patrick, P. et al, Effects of Fixed and Fluctuating Temperatures on Mortality and Hatch of Round Whitefish and Lake Whitefish Eggs, COG-13-3025, October 2014.

[R- 22] Ontario Power Generation, Darlington Nuclear Refurbishment and Continued Operation Environmental Assessment Follow-up Program, NK38-REP-07730-10022, September 2013.

[R- 23] Thermal Monitoring Plan For The Darlington Nuclear Follow Up Monitoring Program, NK38-PLAN-07250-00001-R000, February 2017.

[R- 24] Griffiths, J.S., Potential Effects of Unstable thermal discharges on Incubation of round Whitefish Eggs. Ontario Hydro Research Division Report 80-140-K, 1980.

[R- 25] Wright, J. and Brown, D., Pickering Nuclear 2017 Impingement Monitoring Report, P-REP-07263-00011, April 16, 2018.

[R- 26] Radiation Protection Regulations, Nuclear Safety and Control Act, SOR/2000-203.

[R- 27] Cautillo, C., Methodology for Data Analysis and Public Dose Determination for the Environmental Monitoring Program, N-INS-03443-00001, Dec 2015.

[R- 28] Curtis, M., Review of the Darlington Nuclear Site Specific Survey, OPG Report, NK38-REP-03443-10004-R000, December 20, 2018.

[R- 29] Curtis, M., Review of Pickering Nuclear Site Specific Survey, OPG Report, P-REP-03443-10003-R000, December 20, 2018.

[R- 30] Schweinsberg, S., Site-Specific Survey for the Darlington Nuclear Site, OPG Report, NK38-REP-03443-10001-R00, December 14, 2001.

[R- 31] Schweinsberg, S., Site-Specific Survey for the Pickering Nuclear Site, OPG Report, P-REP-03443-10001-R00, December 16, 1999.

[R- 32] ICRP, Assessing Dose of the Representative Person for the Purpose of Radiation Protection of the Public and the Optimization of Radiological Protection: Broadening the Process, ICRP Publication 101, Elsevier, 2005.

[R- 33] Hart, D., Uncertainty in Dose Estimates Based on Environmental Monitoring Results, COG-07-3043I, January 2010.

[R- 34] Grasty, R.L., The Annual Effective Dose from Natural Sources of Radiation in the Ground – Pickering Area, Gamma-Bob Report 01-2, 2001.

[R- 35] Moeller, D. W., Environmental Health, 3rd Edition, Harvard University Press, 2005.

[R- 36] World Health Organization, Cosmic Radiation and Air Travel Information Sheet, November 2005.

[R- 37] Grasty, R.L., The Annual Effective Dose from Natural Sources of Ionizing Radiation in Canada, Gamma-Bob Report 02-6, December 2002.

[R- 38] Grasty, R.L., LaMarre, J.R., The Annual Effective Dose from Natural Sources of Ionizing Radiation in Canada, Radiation Protection Dosimetry, Volume 108 No. 3, pages 215 to 226, Oxford University Press, 2004.

[R- 39] Aldrich, J.E., et al, Radiation Doses from Medical Diagnostic Procedures in Canada, ACRP-9, AECB-INFO-0670, March 1997.

[R- 40] OPG, Dosimetry and Radiological Environmental Measurement Services Quality Assurance Manual, N-MAN-03416.3-0020, February 2015.

[R- 41] Guindon, A., Annual Summary 2018 – Health Physics Laboratory Environmental Measurement Quality Assurance Program, OPG Report, N-REP-03443.8-10013, February 18, 2019.

[R- 42] Canadian Nuclear Safety Commission, Regulatory Standard S-106 Revision 1, Technical and Quality Assurance Requirements for Dosimetry Services, May 2006.

[R- 43] Cautillo, C., Environmental Monitoring Program Equipment Maintenance Manual, N-MAN-03443-10007, December 2016.

[R- 44] Exploranium, GR150 Sensitivity Check Procedure, 26006-1, October 20th, 2005.

[R- 45] OPG, Management of the Environmental Monitoring Programs, N-PROC-OP-0025 December 2015.

[R- 46] Hart, D., Derived Release Limits Guidance, COG-06-3090-R2-I, November 2008.

[R- 47] ICRP Publication 74, Conversion Coefficients for use in Radiological Protection Against External Radiation, September 1995.

[R- 48] Brown, A., Pickering Radiological Environmental Monitoring Program (REMP) Review – 2006, OPG Report, P-REP-03481-00002-R000, October 2007.

[R- 49] Borromeo, J., Darlington Radiological Environmental Monitoring Program (REMP) Review, OPG Report, NK38-REP-03481-10003-R000, June 2008.

[R- 50] OPG letter, Mr. T.N. Mitchell to Mr. T.E. Schaubel and Mr. G.R. Schwartz, “Gross Alpha Maximum Probable Emission Rate Calculations for Airborne Effluents and Closure of the CNSC Action Item No.2005-4-11”, N-CORR-00531-04072, December 20, 2007.

[R- 51] Canadian Standards Association, Guidelines for Calculating Derived Release Limits for Radioactive Material in Airborne and Liquid Effluents for Normal Operation of Nuclear Facilities, CAN/CSA-N288.1-14, March 2014.

[R- 52] Ecometrix Inc. and Golder Associates, Environmental Risk Assessment Report for Pickering Nuclear. P-REP-07701-00001-R001, April 2017

[R- 53] EcoMetrix Inc. Darlington Nuclear Environmental Risk Assessment. NK38-REP-07701-00001. November 2016

[R- 54] Curtis, M. Darlington Environmental Monitoring Program (EMP) Review, OPG Report, NK38-REP-03443-10003-R001, April 2019

[R- 55] Curtis, M. Pickering Environmental Monitoring Program (EMP) Review, OPG Report, P-REP-03443-00004-R001, April 2019

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

Ar-41	Argon-41
C-14	Carbon-14
CO_2	Carbon Dioxide
Co-60	Cobalt-60
Cs-134	Cesium-134
Cs-137	Cesium-137
Cs-137+	Cesium-137 including progeny
HT	Elemental Tritium
HTO	Tritium Oxide
I(mfp)	Mixed Fission Products Radioiodines
I-131	Iodine-131
Ir-192	Iridium-192
K-40	Potassium-40
Rn-222	Radon-222
Xe-133	Xenon-133
Xe-135	Xenon-135
µGy	microgray
µSv	microsievert
Bq	becquerel
Bq/kg-C	becquerels per kilogram carbon
Ci	Curie
Gy	Gray
kg	kilogram
L	Litre
mGy	milligray
mSv	millisievert
nGy	nanogray
Sv	Sievert

Acronyms and Abbreviations

ACU	Air Conditioner Unit
BAF	Bioaccumulation Factor
CALA	Canadian Association for Laboratory Accreditation
CANDU	Canada Deuterium Uranium
CCW	Condenser Cooling Water
CNSC	Canadian Nuclear Safety Commission
COG	CANDU Owners Group
CSA	Canadian Standards Association
DN	Darlington Nuclear
DRL	Derived Release Limit
DWMF	Darlington Waste Management Facility
E	East wind sector
EA	Environmental Assessment
EcoRA	Ecological Risk Assessment
EMP	Environmental Monitoring Program

ENE	East North East wind sector
EPA	Environmental Protection Agency
ERA	Environmental Risk Assessment
ESE	East South East wind sector
FDS	Fish Diversion System
FPS	Fixed Point Surveillance
HC	Health Canada
HPL	Health Physics Laboratory
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IMPACT	Integrated Model for Probabilistic Assessment of Contaminant Transport
ISO	International Organization for Standardization
Ka	Atmospheric Dispersion Factor (s/m^3)
Kerma	Kinetic Energy Released in Matter
Lc	Critical Level (≈0.5Ld)
Ld	Limit of Detection
MOECC	Ministry of Environment and Climate Change
MOEE	Ministry of Environment and Energy
MOU	Memorandum of Understanding
MW	Megawatts
N	North wind sector
NaI	Sodium Iodide
NE	North East wind sector
NND	New Nuclear at Darlington
NNE	North North East wind sector
NNW	North North West wind sector
NW	North West wind sector
OBT	Organically Bound Tritium
ODS	Ozone Depleting Substances
OPG	Ontario Power Generation
PHC	Petroleum Hydrocarbon
PN	Pickering Nuclear
PWMF	Pickering Waste Management Facility
PWQO	Provincial Water Quality Objective
QA	Quality Assurance
QC	Quality Control
QOR	Quarterly Operations Report
REMP	Radiological Environmental Monitoring Program
S	South wind sector
SE	South East wind sector
SOR	Statement of Requirements
SSE	South South East wind sector
SSW	South South West wind sector
SW	South West wind sector
TOC	Total Organic Carbon
TRC	Total Residual Chlorine
TRCA	Toronto and Region Conservation Authority
TRF	Tritium Removal Facility

TRS	Technical Report Series
TRV	Toxicity Reference Value
TWh	Terawatt Hour
UFDS	Used Fuel Dry Storage
VOC	Volatile Organic Compounds
VBO	Vacuum Building Outage
W	West wind sector
WNW	West North West wind sector
WPCP	Water Pollution Control Plant
WSP	Water Supply Plant

Appendix C: Maps of Environmental Monitoring and Critical Group Locations

(This page has been intentionally left blank)

Figure C1 Darlington Nuclear Site Critical Groups and Environmental Monitoring Locations

0 1 2 3 4 km

- MILK
- FRUIT / VEGETABLES
- WELL WATER
- LAKE WATER
- WATER SUPPLY PLANT
- POULTRY/EGGS
- PASSIVE C-14 (AIR)
- ACTIVE TRITIUM (AIR) / NOBLE GAS
- ANIMAL FEED
- BEACH SAND
- FISH NETTING LOCATIONS
- HOSPITAL
- TRANSMISSION LINES
- RAILROAD LINES
- Urban area
- Large industrial/ commercial buildings
- Potential Critical Group

NOTE: 1) Air Monitoring Stations 3 and 8 contain only a Noble Gas monitor
2) Soil sampling performed every five years.

Data as of March 2019

DF18 (13 km NNW of DN site)

10.0 km

5.0 km

N NNE NE ENE E ESE SE SSE S SSW SW WSW W WNW NW NNW

DN

DF9 (13 km ENE of DN site)

Newcastle WSP (13 km ENE of DN site)

Oshawa WSP

Bowmanville WSP

RURAL RESIDENT

NON-DAIRY FARM

DAIRY FARM

D10

F16

F18

R2

R16

R27

R329

R336

R316

R275

3

5

8

9

17

Oshawa

North Oshawa

Taunton

Mitchell's Corners

Harmony Valley Conservation Area

Kingsway College

Courtice

Darlington Station

Darlington Provincial Park

McLaughlin Point

Lakeview Park

Cedar Dale

Gaud Corners

Maple Grove

Bowmanville

Bowmanville Harbour Conservation Area

Port Darlington

East Beach

West Beach

Thurne Parks Valley Conservation Area

Darlington Generating Station

Raby Head

Second Marsh

Harmony Creek

Black Creek

Soper Creek

Darlington Creek

Robinson Creek

Tooley Creek

Darlington West Side Ck

Pacific Canadian

CN

Oil Gas

Auto Wrecker

Motel

Reservoir

Airfield Condition Unknown

Tanks

Waste

Cement Plant

Hospital

Police

Museum

Zoo

Arena

Shopping Centre

Marina

Lumber Yard

Senior Citizens Homes

Community Centre

Dump

Water

Weigh Scale

Harmony

Simcoe

Taunton

Mitchell's

Darlington

Second

Lakeview

Cedar

Gaud

Maple

Bowmanville

Port

Thurne

Courtice

Oshawa

Newcastle

Figure C2 Pickering Nuclear Site Critical Groups and Environmental Monitoring Locations

2 4 km

- MILK
- FRUIT / VEGETABLES
- WELL WATER
- LAKE WATER
- WATER SUPPLY PLANT
- PASSIVE C-14 (AIR)
- ACTIVE TRITIUM (AIR) / NOBLE GAS
- ANIMAL FEED
- BEACH SAND
- FISH NETTING LOCATIONS
- HOSPITAL
- TRANSMISSION LINES
- RAILROAD LINES
- Urban area
- Large industrial/ commercial buildings
- Potential Critical Group

NOTE: 1) Air Monitoring Stations 7 and 8 contain only a Noble Gas monitor
2) Sediment and Soil sampling performed every five years.

Data as of March 2019

DF3 (18 km NW of PN site)

DAIRY FARM

URBAN RESIDENT

CORRECTIONAL INSTITUTION 2

INDUSTRIAL COMMERCIAL

PN

10 km

5.0 km

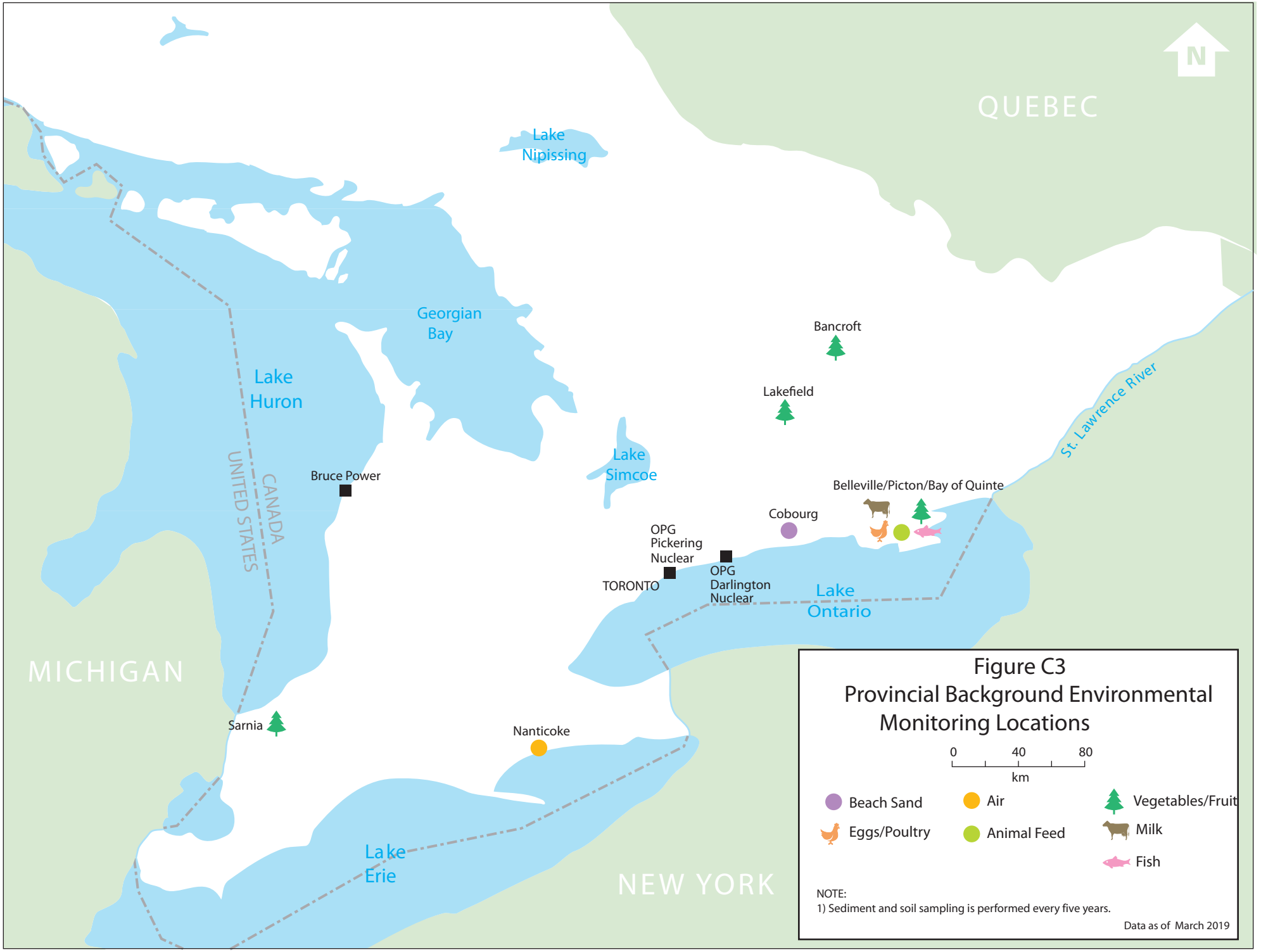
N NNE NE ENE E ESE SE SSE S SSW SW WSW W WNW NW NNW

F.J. Horgan WSP

R.C. Harris WSP (22 km WSW of PN site)

Ajax WSP

Whitby WSP (12 km ENE of PN site)


N
QUEBEC
Lake Nipissing
Georgian Bay
Lake Huron
CANADA
UNITED STATES
MICHIGAN
Bruce Power
Lake Simcoe
Bancroft
Lakefield
St. Lawrence River
Belleville/Picton/Bay of Quinte
Cobourg
OPG Pickering Nuclear
TORONTO
OPG Darlington Nuclear
Lake Ontario
Sarnia
Nanticoke
Lake Erie
NEW YORK
Figure C3
Provincial Background Environmental Monitoring Locations
0
40
80
km
Beach Sand
Air
Vegetables/Fruit
Eggs/Poultry
Animal Feed
Milk
Fish
NOTE:
1) Sediment and soil sampling is performed every five years.
Data as of March 2019

Appendix D: Environmental Monitoring Data

Table D-1: Annual Average Concentrations of Tritium-in-Air – 2018

Molecular Sieve Tritium-in-Air											
DN EMP Locations	N	Location Average (Bq/m^3)[a]	Uncertainty ($\pm 2\sigma$)[b]	PN EMP Locations	N	Location Average (Bq/m^3)[a]	Uncertainty ($\pm 2\sigma$)[b]	Background Locations	N	Location Average (Bq/m^3)[a]	Uncertainty ($\pm 2\sigma$)[b]
D1	11	1.6	2.6	P2	12	16.5	24.6	Nanticoke	11	0.67	2.00
D2	12	1.3	1.8	P3	12	5.1	12.8				
D5	12	0.9	1.6	P4	12	3.6	9.6				
D9	12	1.2	2.0	P6	12	9.3	15.8				
D10	9	0.6	1.4	P10	12	14.6	29.2				
D11	12	1.0	2.0	P11	12	4.6	10.8				
Annual Average[c]	68	1.1	2.0	Annual Average[c]	72	8.9	20.6				

NOTES:

Refer to Section 3.3.1 for complete list of reporting conventions.

N = number of samples.

Bolded values are greater than Lc but less than Ld. "<" indicates less than Lc.

(a) Molecular Sieve Tritium Ld = 0.2 Bq/m^3 and Lc = 0.1 Bq/m^3.

(b) Averages of datasets are reported. 2σ denotes tw o times the standard deviation of the dataset.

(c) Annual averages are calculated using the entire dataset.

Table D-2: Annual Average Concentrations of Carbon-14 in Air – 2018

Passive Sampler C-14 in Air											
DN EMP Locations	N	Location Average (Bq/kg-C)[a]	Uncertainty (±2σ)[b]	PN EMP Locations	N	Location Average (Bq/kg-C)[a]	Uncertainty (±2σ)[b]	Background Locations	N	Location Average (Bq/kg-C)[a]	Uncertainty (±2σ)[b]
D1	4	244	48	P3	4	289	53	Nanticoke	4	233	12
D2	4	253	55	P4	4	259	45				
D5	4	245	50	P6	4	365	84				
D10	4	244	67	P10	4	462	243				
Annual Average[c]	16	247	50	Annual Average[c]	16	344	201				

NOTES:

Refer to Section 3.3.1 for complete list of reporting conventions.

N = number of samples.

(a) Bq/kg-C (Bq per kg of carbon). Ld for C-14 = 40 Bq/kg-C.

(b) Averages of datasets are reported. 2σ denotes tw o times the standard deviation of the dataset.

(c) Annual averages are calculated using the entire dataset.

Table D-3: Annual Average Dose Rates of Noble Gases and Ir-192 Skyshine in Air – 2018

DN EMP	N	Air Kerma Rates							
		Ar-41[c]		Ir-192		Xe-133		Xe-135	
		Location Average (nGy/month)	Uncertainty (±2σ)	Location Average (nGy/month)	Uncertainty (±2σ)	Location Average (nGy/month)	Uncertainty (±2σ)	Location Average (nGy/month)	Uncertainty (±2σ)
D1	12	<6	NA	ND	NA	3.1*	0.7	< 3	NA
D2	12	<6	NA	ND	NA	3.0*	0.2	< 3	NA
D3	12	<6	NA	ND	NA	3.1*	0.7	< 3	NA
D5	12	<6	NA	ND	NA	3.1*	0.5	< 3	NA
D8	12	<6	NA	ND	NA	< 3	NA	< 3	NA
D9	12	<6	NA	ND	NA	< 3	NA	< 3	NA
D10	10	<6	NA	ND	NA	< 3	NA	< 3	NA
D11	12	<6	NA	ND	NA	3.1*	2.3	< 3	NA
Annual Average[b]	94	<6	NA	ND	NA	0.2*	1.8	< 3	NA
PN EMP	**N**	**Ar-41**		**Ir-192**		**Xe-133[c]**		**Xe-135**	
		Location Average (nGy/month)	Uncertainty (±2σ)[a]	Location Average (nGy/month)	Uncertainty (±2σ)	Location Average (nGy/month)	Uncertainty (±2σ)[a]	Location Average (nGy/month)	Uncertainty (±2σ)[a]
P2	12	520	549	ND	NA	17*	16	< 3	NA
P3	12	203	263	ND	NA	4.9*	5.5	< 3	NA
P4	12	134	173	ND	NA	4.0*	3.1	< 3	NA
P6	12	256	308	ND	NA	9.9*	10	< 3	NA
P7	12	336	462	ND	NA	9.0*	11	< 3	NA
P8	12	121	129	ND	NA	4.2*	3.2	< 3	NA
P10	12	591	657	ND	NA	17*	19	< 3	NA
P11	12	161	201	ND	NA	5.1*	5.3	< 3	NA
Annual Average[b]	96	290	502	ND	NA	7.8*	16	< 3	NA

NOTES:

Refer to Section 3.3.1 for complete list of reporting conventions.

N = number of samples.

"<" indicates less than Ld. NA= Not Applicable. ND = Not Detected.

* indicates that dataset contains both detected and censored non-detected values

(a) Averages of datasets are reported. 2σ denotes tw o times the standard deviation of the dataset.

(b) Annual averages are calculated using the entire dataset.

(c) For datasets partially composed of values censored at the Ld, the Kaplan-Meier methodology is used to determine the mean and standard deviation of the dataset.

Table D-4: Fruits and Vegetables – 2018

Darlington EMP						
Location	Sample Type	N	HTO (Bq/L)[a]		C-14 (Bq/kg-C)[a]	
			Location Average	Uncertainty (±2σ)[c][d]	Location Average	Uncertainty (±2σ)[c][d]
DF9	Fruit	3	9.0	3.6	239	17
F18	Fruit	3	11.3	1.7	227	10
R19	Fruit	0	NA	NA	NA	NA
R27	Fruit	3	26.3	6.3	244	23
R335	Fruit	3	17.0	6.1	232	26
Annual Average[b]	Fruit	12	15.9	14.5	235	22
F16	Vegetables	3	7.8	3.6	248	34
R19	Vegetables	3	21.7	28.7	238	32
R275	Vegetables	3	19.0	20.2	225	17
R335	Vegetables	3	10.2	3.5	237	6
Annual Average[b]	Vegetables	12	14.7	19.4	237	27

NOTES:

Refer to Section 3.3.1 for complete list of reporting conventions.

N = number of samples. NA = not applicable.

Bolded values are greater than Lc but less than Ld. "<" indicates less than Lc.

(a) Ld for tritium = 4.5 Bq/L and Lc = 2.3 Bq/L. Ld for C-14 = 40 Bq/kg-C.

(b) Annual averages are calculated using the entire dataset.

(c) Averages of datasets are reported. 2σ denotes two times the standard deviation of the dataset.

(d) For datasets of a single measured value, associated uncertainty is the laboratory analytical uncertainty for that sample

Table D-4: Fruits and Vegetables – 2018 (Continued)

Pickering EMP								
Location	Sample Type	N	HTO (Bq/L)[a]		C-14 (Bq/kg-C)[a]		OBT (Bq/L (w.e.))[d]	
			Location Average	Uncertainty (±2σ)[c]	Result	Uncertainty (±2σ)[c]	Result	Uncertainty (±2σ)[b]
DF3	Fruit	3	15.1	4.5	232	13		
F10	Fruit	3	30.2	6.4	253	7	42.1	6.6
LOC10	Fruit	3	156.1	55.6	338	31		
LOC35	Fruit	3	163.1	130	295	18		
LOC7	Fruit	3	305.6	9.2	131	4		
Annual Average[b]	Fruit	15	99.0	141.9	285	80	42.1	6.6
DF1	Vegetables	3	25.5	10.5	238	20		
DF3	Vegetables	3	8.8	4.1	233	28		
P11	Vegetables	3	173.6	102.2	320	42		
P9	Vegetables	3	107.6	95.3	259	32		
R144	Vegetables	3	111.5	75.4	268	41		
Annual Average[b]	Vegetables	15	85.4	139.3	264	70		

NOTES:

Refer to Section 3.3.1 for complete list of reporting conventions.

N = number of samples. NA= not applicable.

Bolded values are greater than Lc but less than Ld. "<" indicates less than Lc.

(a) Ld for tritium = 4.5 Bq/L and Lc = 2.3 Bq/L. Ld for C-14 = 40 Bq/kg-C.

(b) Annual averages are calculated using the entire dataset.

(c) Averages of datasets are reported. 2σ denotes two times the standard deviation of the dataset.

(d) w.e. = water equivalent.

Table D-4: Fruits and Vegetables – 2018 (Continued)

Background Locations								
Location	Sample Type	N	HTO (Bq/L)(a)		C-14 (Bq/kg-C)[a]		OBT (Bq/L (w.e.))[d]	
			Result	Uncertainty (±2σ)[b]	Result	Uncertainty (±2σ)[b]	Result	Uncertainty (±2σ)[b]
F1 | Bancroft- Sample A	Fruit	1	<2.3	2.3	226	21	NR	NR
F1 | Bancroft- Sample B	Fruit	1	<2.3	2.3	238	22		
F2 | Lakefield- Sample A	Fruit	1	<2.3	2.4	230	21		
F2 | Lakefield- Sample B	Fruit	1	<2.3	2.4	228	21		
F3 | Picton- Sample A	Fruit	1	<2.3	2.4	224	20		
F3 | Picton- Sample B	Fruit	1	<2.3	2.3	225	21		
F4 | Sarnia- Sample A	Fruit	1	<2.3	2.3	245	22		
F4 | Sarnia- Sample B	Fruit	1	<2.3	2.4	242	21		
Annual Average[c]		8	<2.3	1.5	232	16		
F1 | Bancroft- Sample A	Vegetables	1	<2.3	2.3	250	21	18.3	5.4
F1 | Bancroft- Sample B	Vegetables	1	<2.3	2.3	253	21	NR	NR
F2 | Lakefield- Sample A	Vegetables	1	<2.3	2.3	250	21	13.2	5.1
F2 | Lakefield- Sample B	Vegetables	1	<2.3	2.4	236	20	NR	NR
F3 | Picton- Sample A	Vegetables	1	<2.3	2.3	244	20	12.8	5.1
F3 | Picton- Sample B	Vegetables	1	<2.3	2.4	239	21	NR	NR
F4 | Sarnia- Sample A	Vegetables	1	<2.3	2.3	258	21	16.3	5.3
F4 | Sarnia- Sample B	Vegetables	1	<2.3	2.3	244	21	NR	NR
Annual Average[c]		8	<2.3	1.3	247	15	15.1	5.2

NOTES:

Refer to Section 3.3.1 for complete list of reporting conventions.

N = number of samples. NA= not applicable. NR = not required by program.

Bolded values are greater than Lc but less than Ld. "<" indicates less than Lc.

(a) Ld for tritium = 4.5 Bq/L and Lc = 2.3 Bq/L. Ld for C-14 = 40 Bq/kg-C.

(b) Individual analytical results are reported. 2σ denotes the laboratory uncertainty of the individual sample.

(c) Averages of datasets are reported. 2σ denotes two times the standard deviation of the dataset.

(d) w.e. = water equivalent.

Table D-5: Animal Feed – 2018

Animal Feed[b]							
Location	Sample Type	N	HTO (Bq/L)[a]		N	C-14 (Bq/kg-C)[a]	
			Location Average	Uncertainty (±2σ)[d]		Location Average	Uncertainty (±2σ)[d]
Darlington EMP							
DF18	Forage	4	7.5	10.5	4	226	17
DF7	Forage	4	9.6	11.7	4	250	16
DF8	Forage	4	18.6	16.5	4	239	39
DF9	Forage	4	12.4	3.4	4	229	30
Annual Average[c]	Forage	16	12.0	13.5	16	236	32
Pickering EMP							
DF8	Forage	8	27.7	18.4	8	240	29
Background Locations							
Belleville	Forage	4	**2.9**	1.1	4	240	33
Belleville	Generic Feed	4	6.3	2.3	4	231	23

NOTES:

Refer to Section 3.3.1 for complete list of reporting conventions.

N = number of samples. NA = not applicable.

Generic Feed = dry feed, Forage = wet feed

Bolded values are greater than Lc but less than Ld. "<" indicates less than Lc.

(a) Ld for tritium = 4.5 Bq/L and Lc = 2.3 Bq/L. Ld for C-14 = 40 Bq/kg-C.

(b) Animal feed is collected semi-annually. This table depicts the average of the results for each sampling location.

(c) Annual averages are calculated using the entire dataset.

(d) Averages of datasets are reported. 2σ denotes two times the standard deviation of the dataset. However, where N < 3, Individual sample results are reported and 2σ denotes the laboratory uncertainty of the individual sample.

Table D-6: Annual Average Concentrations in Milk – 2018

Location	N	HTO (Bq/L)[a]		C-14 (Bq/kg-C)[a]		OBT (Bq/L w.e.)	
		Location Average	Uncertainty (±2σ)[b]	Location Average	Uncertainty (±2σ)[b]	Location Average	Uncertainty (±2σ)[b]
DN EMP							
DF18	12	5.1	3.3	238	18		
DF9	12	**3.5**	3.2	235	18		
DF8	12	5.6	3.7	237	21		
Annual Average[c]	36	4.8	3.8	237	18		
PN EMP							
DF1	12	13.2	3.2	232	19	NR	NR
DF8	12	22.7	12.9	236	22	27.5	11.5
Annual Average[c]	24	18.0	13.3	234	21	27.5	11.5
Background Locations							
Belleville	11	<2.3	2.5	234	23	NR	NR

NOTES:

Refer to Section 3.3.1 for complete list of reporting conventions.

N = number of samples. NA = not applicable. NR = not required by program.

Bolded values are greater than Lc but less than Ld. "<" indicates less than Lc.

(a) Ld for tritium = 4.5 Bq/L and Lc = 2.3 Bq/L. Ld for C-14 = 40 Bq/kg-C.

(b) Averages of datasets are reported. 2σ denotes two times the standard deviation of the dataset.

(c) Annual averages are calculated using the entire dataset.

Table D-7: Annual Average Concentrations in Eggs and Poultry – 2018

Location	Sample Type	N	HTO (Bq/L)[a]		C-14 (Bq/kg-C)[a]	
			Location Average	Uncertainty (±2σ)[b]	Location Average	Uncertainty (±2σ)[b]
Darlington EMP						
F16	Poultry	8	7.1	1.4	227	17
D10	Eggs	12	**2.5**	1.9	233	18
Background						
Picton	Poultry	8	<2.3	1.9	231	26
Picton	Eggs	12	<2.3	2.1	236	28

NOTES:

Refer to Section 3.3.1 for complete list of reporting conventions.

N = number of samples

Bolded values are greater than Lc but less than Ld. "<" indicates less than Lc.

Egg and poultry sampling not required for PN EMP.

(a) Ld for tritium = 4.5 Bq/L and Lc = 2.3 Bq/L. Ld for C-14 = 40 Bq/kg-C.

(b) Averages of datasets are reported. 2σ denotes two times the standard deviation of the dataset.

Table D-8: Annual Average Drinking Water and Lake Water Concentrations – 2018

DN EMP							PN EMP						
	Tritium Concentration			Gross Beta Activity Concentration				Tritium Concentration			Gross Beta Activity Concentration		
Location	N	Location Average (Bq/L)[b]	Uncertainty (±2σ)[c]	N	Location Average (Bq/L)[a]	Uncertainty (±2σ)[c]	Location	N	Location Average (Bq/L)[b]	Uncertainty (±2σ)[c]	N	Location Average (Bq/L)[a]	Uncertainty (±2σ)[c]
WSP							**WSP**						
Bowmanville WSP	48	5.0	5.9	12	0.11	0.04	Ajax WSP	48	5.5	6.4	12	0.11	0.03
Newcastle WSP	48	4.7	5.3	12	0.11	0.02	F. J. Horgan WSP	48	**4.1**	4.0	12	0.11	0.04
Oshawa WSP	48	7.0	8.5	12	0.12	0.04	R.C. Harris WSP	48	**3.9**	3.5	12	0.10	0.03
							Whitby WSP	48	6.3	7.4	12	0.11	0.03
Annual Average[d]	144	5.6	7.0	36	0.11	0.03	Annual Average[d]	192	4.9	5.9	48	0.11	0.03
Well Water							**Well Water**						
DF18	12	**2.9**	2.8				DF8	12	10.8	2.8			
R2	12	21.5	4.6				R143	12	20.5	5.0			
R316	12	5.5	2.3										
R329	12	13.0	3.7										
Annual Average[d]	48	10.7	15.0				Annual Average[d]	24	15.7	10.6			
Lake Water							**Lake Water**						
Courtice Road Beach	8	14.3	24.6				Beachfront Park	8	31.1	50.3			
McLaughlin Bay	8	31.4	14.1				Frenchman's Bay	7	35.7	15.7			
							Squires Beach	8	23.2	80.7			
Annual Average[d]	16	22.8	26.2				Annual Average[d]	23	29.8	55.2			

NOTES:

Refer to Section 3.3.1 for complete list of reporting conventions.

N = number of samples. NR = not required by program.

Bolded values are greater than Lc but less than Ld. "<" indicates less than Lc.

(a) Ld for gross beta = 0.03 Bq/L and Lc = 0.02 Bq/L.

(b) Ld for tritium = 4.5 Bq/L and Lc = 2.3 Bq/L.

(c) Averages of datasets are reported. 2σ denotes tw o times the standard deviation of the dataset.

(d) Annual averages are calculated using the entire dataset.

(e) Samples are not required during the w inter months.

Table D-9: Lake Fish – 2018

	Sample Type	N	HTO		C-14		Co-60	Cs-134	Cs-137		K-40		OBT composite[e]	
			Result (Bq/L)[a]	Uncertainty (±2σ)[c]	Result (Bq/kg-C)[a]	Uncertainty (±2σ)[c]	Result (Bq/kg fw)[b]	Result (Bq/kg fw)[b]	Result (Bq/kg fw)[b][d]	Uncertainty (±2σ)[c]	Result (Bq/kg fw)	Uncertainty (±2σ)[c]	Result (Bq/L) w.e.	Uncertainty (±2σ)[c]
DN EMP - Locations														
Darlington Diffuser	White sucker	8	9.2	7.9	256	23	< 0.1	< 0.1	0.1*	0.05	100	74	24.8	2.9
PN EMP - Locations														
Pickering 5-8 Outfall	White sucker	8	**3.1**	3.0	255	27	< 0.1	< 0.1	0.2*	0.1	125	11	14.9	2.6
Background Locations														
Lake Ontario (USA) Far Field	White sucker	8	**2.9**	1.2	229	24	< 0.1	< 0.1	0.2*	0.1	113	15	33.5	3.1

NOTES:

Refer to Section 3.3.1 for complete list of reporting conventions.

N = number of samples

fw = fresh weight

w.e. = water equivalent

(a) Ld for tritium = 4.5 Bq/L and Lc = 2.3 Bq/L. Ld for C-14 = 40 Bq/kg-C. Bolded values are greater than Lc but less than Ld. "<" indicates less than Lc.

(b) For gamma analysis (Co-60, Cs-134, Cs-137, K-40), "<" indicates less than Ld.

(c) Averages of datasets are reported. 2σ denotes two times the standard deviation of the dataset.

(d) For datasets partially composed of values censored at the Ld, the Kaplan-Meier methodology is used to determine the mean and standard deviation of the dataset. This is indicated by "*".

(e) Where individual analytical results are reported, 2σ denotes the laboratory uncertainty of the individual sample.

Table D-10: Beach Sand – 2018

Beach Sand	N	Gamma Analysis (Bq/kg dw)[a]					
		Co-60 Result	Cs-134 Result	Cs-137[c]		K-40	
				Result	Uncertainty (±2σ)[b]	Result	Uncertainty (±2σ)[b]
DN EMP - Locations							
Courtice Road Beach	8	< 0.1	< 0.1	< 0.1	NR	231	13
McLaughlin Bay	8	< 0.1	< 0.2	< 0.1	NR	258	55
West/East Beach	8	< 0.1	< 0.2	0.3	0.1	407	60
PN EMP - Locations							
Beachfront Park	8	< 0.1	< 0.1	0.5	0.1	382	15
Beachpoint Promenade	8	< 0.1	< 0.2	0.4	0.1	216	74
Squire Beach	8	< 0.1	< 0.1	0.4	0.07	423	34
Background Locations							
Cobourg	8	< 0.1	< 0.2	0.3	0.1	341	62

Refer to Section 3.3.1 for complete list of reporting conventions.

N = number of samples. NR = not required by program.

(a) For gamma analysis "<" indicates less than Ld.

(b) Averages of datasets are reported. 2σ denotes two times the standard deviation of the dataset.

Appendix E: Potential Critical Group Descriptions

E.1.0 DARLINGTON NUCLEAR POTENTIAL CRITICAL GROUPS

Nine potential critical groups are identified for Darlington Nuclear. The annual public dose is calculated for the top three DN potential critical groups only, which have yielded the highest dose estimates in recent years. These are the Dairy Farm, the Farm, and the Rural Resident, as shown in Figure C1 (see Appendix C, Maps of Environmental Monitoring and Critical Group Locations). The EMP sampling plan is structured around monitoring for these three potential critical groups. These groups can change based on the updated pathway analysis results. For informational purposes, descriptions for all nine potential critical groups considered are provided below.

All of the potential critical groups, with the exception of the Industrial/Commercial group, consume some locally caught fish near the DN diffuser. All potential critical groups with the exception of the Sport Fisher and Industrial/Commercial groups are assumed to be exposed to local beach sand. The one-year old infant is assumed to drink cow's milk and water (not infant formula). For all potential critical groups except the dairy farm infant, who drinks fresh local cow's milk, the assumption is made that the milk consumed is a composite from dairy farms all over Ontario which are not affected by station operations.

Based on the site-specific survey review [R-30], a small fraction of residents from the Oshawa/Courtice, Bowmanville, West/East Beach, and Rural Resident potential critical groups work within 5 km of DN. In addition, a small fraction of the Industrial/Commercial potential critical group resides close to DN. Therefore, the average Adult dose for the Rural Resident potential critical group has been adjusted to account for the exposure this portion of the population receives while at work and at home.

The DN potential critical groups are described as follows:

(c) The **Oshawa/Courtice** potential critical group consists of urban residents in Oshawa and in the community of Courtice within the Municipality of Clarington located to the W and WNW of the site starting at about 6 km from the site. These residents obtain drinking water from the Oshawa WSP, and grow a small percentage of their annual fruit and vegetable consumption in gardens.

(d) The **Bowmanville** potential critical group consists of urban residents located to the NE and NNE of the site at distances from 4 to 7 km from DN. These residents obtain drinking water from the Bowmanville WSP, and grow a small percentage of their annual fruit and vegetable consumption in gardens. They also purchase a small percentage of their annual meat, poultry and egg consumption from local farms.

(e) The **West/East Beach** potential critical group consists of urban residents located to the ENE of the site at distances from 3.5 km to 7 km. These residents obtain their drinking water from both wells and the Bowmanville WSP, and grow a small percentage of their annual fruit and vegetable consumption in gardens. They also purchase a small percentage of their annual poultry and egg consumption from local farms.

(f) The **Farm** potential critical group consists of agricultural farms (but not dairy farms) located in all landward wind sectors around the DN site at distances from 1.5 km to 10 km. The closest is in the WNW wind sector. Members of this group obtain their water supply mostly from wells and use it for drinking, bathing, irrigation and watering livestock. They also obtain a large fraction of their annual fruit, vegetable and animal product consumption from locally grown products.

(g) The **Dairy Farm** potential critical group consists of dairy farms located in all landward wind sectors around the DN site at distances from 3 km to over 10 km. The closest is in the N wind sector. Members of this group obtain their water supply from wells and use it for drinking, bathing, irrigation, and livestock watering. They also obtain a large fraction of their annual fruit, vegetable and animal product consumption, including fresh cow's milk, from locally grown products.

(h) The **Rural Residents** potential critical group consists of residents in rural areas in all landward wind sectors around the site at distances of about 2 km to 5 km. Members of this group obtain about half of their water supply from wells and half from the Bowmanville WSP, and use it for drinking, bathing, and irrigation. They obtain a moderate fraction of their annual fruits, vegetables, poultry and eggs from locally grown products.

(i) The **Industrial/Commercial** potential critical group consists of adult workers whose work location is close to the nuclear site. The closest location for this group is the St. Mary's cement plant about 1.8 km NE of the site, however, the most affected location due to updated meteorological data is the Courtice Water Pollution Control Plant about 2 km W of DN. Members of this group are typically at this location about 23% of the time. They consume water from the Bowmanville WSP.

(j) The **Sport Fisher** potential critical group is comprised of non-commercial individuals fishing near the DN site discharge, about 0.5 km S of the DN site. Members of this group were conservatively assumed to obtain their entire amount of fish for consumption from the vicinity of the DN site and spend 1% of their time at the discharge location where atmospheric exposure occurs.

(k) The **Camper** potential critical group consists of campers at the Darlington Provincial Park, located from 4 to 6 km W of the site at the lakeshore, and includes McLaughlin Bay, a shallow water body where some fishing takes place. The campers are assumed to be in the park no more than six months of the year. They consume drinking water from the Oshawa WSP, and purchase a small fraction of their annual fruits, vegetables, meat, poultry, and eggs from locally grown sources.

E.2.0 PICKERING NUCLEAR POTENTIAL CRITICAL GROUPS

Six potential critical groups are identified for Pickering Nuclear. Note that the annual public dose is calculated for the top three PN potential critical groups, which have yielded the highest dose estimates in recent years. These are the Industrial Worker, the Urban Resident, and the inhabitants of a Correctional Institution. In addition, PN dose is calculated for the Dairy Farm potential critical group since it is exposed to the most media/pathways. Including the Dairy Farm group assures that any future changes in emissions, environmental transfer factors, exposure factors, and dosimetry, and changes in the distribution of radionuclides released will be captured. Refer to Figure C2 in Appendix C, Maps of Environmental Monitoring and Critical Group Locations.

The annual sampling plan is structured around monitoring for these four potential critical groups. These groups can change based on the updated pathway analysis results. For informational purposes, descriptions for all six potential critical groups considered are provided below.

The one-year old infant is assumed to drink cow's milk and water (not infant formula). For all potential critical groups except the dairy farm infant, who drinks fresh local cow's milk, the assumption is made that the milk is a composite from dairy farms all over Ontario which are not affected by station operations.

Based on the site-specific survey [R-31], a small fraction of Industrial/Commercial workers reside close to PN. Similarly, a fraction of residents from the Urban Resident potential critical group work within 5 km of PN. Therefore, the average Adult doses for these groups have been adjusted to account for the exposure this portion of the population receives while at work and at home.

The PN potential critical groups are described as follows:

(l) The **C2** potential critical group consists of inhabitants at a correctional institute, located approximately 3 km NNE of the PN Site. The C2 group obtains drinking water from the Ajax WSP and does not consume locally grown fruits or vegetables. The C2 resident is conservatively assumed to be at this location 100 percent of the time over the full year.

(m) The **Industrial/Commercial** potential critical group consists of adult workers whose work location is close to the nuclear site. Members of this group are typically at this location about 23% of the time. They consume water from the Ajax WSP. The closest location for this group is about 1 km NNE of the site.

(n) The **Urban Residents** potential critical group consists of Pickering and Ajax area residents which surround the PN Site (e.g., Fairport, Fairport Beach, Rosebank, Liverpool, Pickering Village, etc.). The members of this group mostly consume water from the Ajax WSP and also consume a diet composed in part of locally grown produce and some locally caught fish. Members of this potential critical group are also externally exposed to beach sand at local beaches (Beachpoint Promenade, Beachfront Park, or Squires Beach).

(o) The **Farm** potential critical group consists of residents of agricultural farms (but not dairy farms) within a 10 km radius of the PN Site. Members of this group obtain most of their water supply from wells but also a portion from the Ajax WSP. Members of this potential critical group consume locally grown produce and animal products, as well as locally caught fish. They are also externally exposed to beach sand at local beaches (Beachpoint Promenade, Beachfront Park, or Squires Beach).

(p) The **Dairy Farm** potential critical group consists of residents of dairy farms within a 20 km radius of the PN Site. This group obtains most of their water supply from local wells. They also consume locally grown fruit and vegetables and locally produced animal products, including fresh cow's milk. Members of this potential critical group are also externally exposed to beach sand at local beaches (Beachpoint Promenade, Beachfront Park, or Squires Beach).

(q) The **Sport Fisher** potential critical group is comprised of non-commercial individuals fishing near the PN site outfalls, 0.5 km S of the PN site. Members of this group were conservatively assumed to obtain their entire amount of fish for consumption from the vicinity of the PN site and spend 1% of their time at the outfall location where atmospheric exposure occurs.

Appendix F: Dose Calculation Procedure and Concentrations

F.1.0 CRITICAL GROUP DOSE CALCULATION PROCEDURE

The dose calculations were performed according to N-INS-03443-00001, Methodology for Data Analysis and Public Dose Determination for the Environmental Monitoring Program [R-29]. Deviations from this methodology are listed below. The methodology used and software used for dose calculation, IMPACT 5.4.0, are consistent and compliant with CSA N288.1-08 [R-20]. As mentioned in Section 4.1.1, the recently released IMPACT 5.5.1, which is compliant with CSA N288.1-14 [R-56], will be used first to update DN and PN DRLs before it is applied to public dose calculations.

- An update to N288.1-08 was issued in 2011. Only one change in this update affects the dose calculation and it is related to the parameters used for beef cattle consuming dry feed. Given that the use of the existing parameters produces a conservative dose estimate, this change will not be applied at this time.

- OBT doses from terrestrial animals and terrestrial plants were modeled using HTO concentrations measured in terrestrial samples at the potential critical groups. OBT doses from fish were modeled from HTO concentrations in fish.

- HTO and C-14 concentrations in terrestrial animal products other than milk, eggs, and poultry are modeled from measured concentrations of HTO and C-14 in animal feed, forage, air and water. The concentrations are used to calculate the dose from ingestion of animal products. The dose resulting from I(mfp) and particulate is modeled from emissions and empirical Ka values and the ratio of modeled Ka values for the boundary monitor location and the potential critical group location.

- Location specific measures of each radionuclide were used in the potential critical group calculations where the group occupied a relatively small geographic location. Some groups such as the Farm, Dairy Farm or Urban Resident are spread over much wider geographic areas, and for these groups air concentrations were determined for a single conservative representative location, and group average values were used for terrestrial samples and water sources.

- Only dairy farm residents ingest local cow's milk.

- People are generally assumed to be at the potential critical group location 100% of the time, with the exception of the Industrial/Commercial group. Details are provided in Appendix E. Based on the site specific surveys, a small fraction of residential potential critical group members at both PN and DN work within 5 km of the station. In addition, a small fraction of Industrial/Commercial workers reside close to the station at both PN and DN. Therefore, the average Adult doses for these groups have been adjusted at both PN and DN to account for the exposure this portion of the population receives while at work and at home.

- No local grain products are consumed by humans.

F.2.0 PROVINCIAL-BACKGROUND DATA

Treatment of provincial-background data for public dose calculation purposes is as follows:

- If the mean (arithmetic or Kaplan-Meier) is below the Lc, a concentration of 0 (zero) is used for the dose calculation in order to be conservative, i.e. no background concentration is subtracted from the concentration measured around PN or DN.

- If all values in a dataset are below the Ld, a concentration of 0 (zero) is used for the dose calculation in order to be conservative.

- If there are not enough samples collected in a given year to accurately reflect the background dose in a particular sample media, 0 (zero) is used for HTO and gamma in order to be conservative. Previous sampling years may be consulted to arrive at an estimated C-14 concentration in the affected media as background values are not expected to vary significantly from year to year.

F.3.0 POTENTIAL CRITICAL GROUP RADIONUCLIDE CONCENTRATIONS AND BACKGROUND SUBTRACTIONS

The following section details how the radionuclide concentrations are determined, whether they are measured or modeled, and any calculations made to obtain results.

A summary on the radionuclides and pathways measured and modeled in the dose calculation is presented in Table F-1. DRL Guidance document [R-49] provides a description of each pathway.

Table F-1: Radionuclides and Pathways Measured and Modeled in the Dose Calculation

Pathway	Radionuclide	Modeled[a]	Measured
Air Inhalation	HTO	✓(Fisher)	✓[c]
	HT	✓ [b]	
	C-14	✓ [b]	✓
	I(mfp)	✓ [b]	
	Co-60	✓ [b]	
Air External Exposure	Noble Gas		✓ [c]
	C-14	✓ [b]	✓
	I(mfp)	✓ [b]	
	Co-60	✓ [b]	
Soil External Exposure	C-14	✓	
	I(mfp)	✓	
	Cs-137+, Co-60	✓	
Sand External Exposure	C-14	✓	
	Cs-137+		✓
Water External Exposure (Lakes, WSPs, Wells)	HTO	✓ (wells)	✓
	C-14	✓	
	I(mfp)	✓	
	Cs-137+	✓	
Terrestrial Animals Ingestion	HTO	✓	✓ (milk, eggs, poultry)
	C-14	✓	✓ (milk, eggs, poultry)
	I(mfp)	✓	
	Cs-137+, Co-60	✓	
	OBT	✓ [d]	
Terrestrial Plants Ingestion	HTO		✓
	C-14		✓
	I(mfp)	✓	
	Cs-137+, Co-60	✓	
	OBT	✓ [d]	
Aquatic Animals Ingestion	HTO		✓
	C-14		✓
	I(mfp)	✓	
	Cs-137+		✓
	OBT	✓ [d]	
Sand and Soil Incidental Ingestion	HTO	✓	
	C-14	✓	
	I(mfp)	✓ (soil)	
	Cs-137+, Co-60	✓	✓ (sand)
Water Ingestion (WSPs, Wells)	HTO		✓
	C-14	✓	
	I(mfp)	✓	
	Cs-137+	✓	

"+" indicates that contributions from progeny are included.

(1) Modeling is based on emissions or from local air measurements where they are available.

(2) Concentrations are modeled from emissions and adjusted using empirical Ka determined for each potential critical group location.

(3) Doses are measured directly at the site boundary and adjusted to potential critical group locations using the ratio of modeled air dispersion factors for the boundary monitor and potential critical group.

(4) OBT dose is modeled from HTO concentration in terrestrial plants, terrestrial animals, or fish respectively.

F.3.1 Tritium

For the purpose of estimating the critical group dose, the concentrations used in the corresponding pathways were determined as follows:

Air – Tritium-in-air is measured at boundary locations with measured background tritium-in-air subtracted, and these values are used to estimate concentrations at each potential critical group location using the ratio of modeled atmospheric dispersion factors for the boundary monitor location and the potential critical group location (except for the Fisher potential critical group where it is modeled from emissions).

Concentrations of radionuclides in air that are not monitored at boundary sites or potential critical groups are obtained for the potential critical group location as follows:

The concentrations at the boundary monitor sites are estimated using their emissions data and empirical Ka values obtained from HTO emissions and HTO boundary monitor measurements. The concentrations at potential critical group locations are modeled from the empirically estimated boundary location concentration by using the ratio of modeled air dispersion factors for the boundary monitor location and the potential critical group location.

- **Water** – Drinking water is sampled and measured at the local WSPs and also at wells where local residents obtain their water. For the WSPs, the annual average concentration is used with background tritium concentration subtracted. The background tritium concentration is calculated for natural and weapons fallout contributions using the Great Lakes Time-Concentration Tritium Model [R-15]. For wells, the average concentration found at each potential critical group is used and background is assumed to be zero. Tritium concentration in wells used for purposes other than drinking water is modeled. Lake water HTO concentrations are measured monthly and used to calculate the dose from water immersion. Background HTO concentrations from the Great Lakes Time-Concentration Tritium model [R-15], are subtracted.

- **Milk** – Milk from local dairy farms is sampled on a monthly basis. The annual average of all the dairy farms is used for the dose calculation, with background tritium in milk concentration subtracted. Only dairy farm residents drink local milk since it is illegal to sell unprocessed milk.

- **Poultry** – Poultry from a local farm is sampled on an annual basis. The annual average is used for the dose calculation, with background values subtracted. Since the farm where poultry is sampled is located in close proximity to the dairy farm, it is assumed that there is not a large difference in radionuclide concentrations in poultry obtained from the local farm vs. the local dairy farm. Therefore, the poultry samples taken are applied to both the Farm and Dairy Farm potential critical groups.

- **Eggs** – Eggs from a local farm are sampled on a quarterly basis. The annual average is used for the dose calculation, with background values subtracted. Since the farm where eggs are sampled is located in close proximity to the dairy farm, it is assumed that there is not a large difference in radionuclide concentrations in eggs obtained from the local farm vs. the local dairy farm. Therefore, the egg samples taken are applied to both the Farm and Dairy Farm potential critical groups.

- **Fruits and Vegetables** – Fruit and vegetable tritium concentrations are measured at each potential critical group location and the background tritium concentration is subtracted. The average concentration from all samples measured for each potential critical group is used in the dose calculation.

- **Animal Feed** – The animal feed (wet and dry) is collected from dairy farms bi-annually and is usually from the previous year's harvest. The annual averages of wet and dry feed are used for the dose calculation with background values subtracted.

- **Fish** – The radionuclide concentrations used for locally caught fish are the average measured values in the fish samples, minus background tritium in water. The background tritium in water concentration is for natural and weapons fallout contributions only, as calculated using the Great Lakes Time-Concentration Tritium Model [R-15].

F.3.2 Carbon-14

For the purpose of estimating the critical group dose, the concentrations used in the corresponding pathways were determined as follows:

(a) **Air** – C-14 via air inhalation is monitored at boundary locations for about half the landward wind sectors. Where C-14 in air measurements are available, the concentration of C-14 in air is based on the annual average of measurements for each potential critical group location. If more than one sample location is used to represent one potential critical group, then the maximum of the annual averages is taken. Where C-14 in air measurements are not available C-14 in air is modeled from emissions and adjusted using the empirical Ka as described in Section 4.1.2. For all measurements, the average background C-14 concentration in air is subtracted.

(b) **Water** – Concentrations of C-14 in well water are modeled from measured local air concentrations at each potential critical group location, and concentrations in the WSPs and lake water are modeled from site waterborne emissions.

(c) **Terrestrial media** – The concentrations of C-14 in terrestrial media (plants, milk, animal feed, eggs, and poultry) are based on the average of the measurements for each sample type for each potential critical group, minus the average C-14 concentration measured in background media. Where average measurements for a sample type are less than average concentrations in background media, C-14 is conservatively modeled.

(d) **Fish** – For fish, the average C-14 concentration of all samples per site is used, minus the average concentration of C-14 in Lake Ontario fish measured in background locations.

F.3.3 Noble Gases and Skyshine

The noble gas detectors measure the air kerma rate, which is converted to effective dose using appropriate age-specific conversion factors (effective dose/air kerma rate) [R-50] and standard occupancy and shielding factors for air immersion dose as described in CSA N288.1-08 [R-20].

Noble gas dose is measured directly in most landward wind sectors around the DN and PN site boundaries, and adjusted to the potential critical group location using calculated air dispersion ratios.

The air kerma rate from the PWMF at the PN site was measured in June 2017 over water on Lake Ontario [R-19]. The results showed a rapid drop in the measured air kerma rate with distance, such that it is below the detection limit (0.33 nGy/h) at a distances greater than 400 m from the storage areas. At 1 km distance, the air kerma rate is estimated to be negligible. The skyshine dose from this source is, therefore, not significant for potential critical groups outside the 1 km boundary, which are all the potential critical groups except the Fisher which is assumed to be located 500 m south of PN in Lake Ontario. Skyshine doses from the PWMF are estimated and included in the total noble gas dose for all potential critical groups. Skyshine doses from the DWMF are negligible as all potential critical groups are located beyond 1 km from the DWMF.

Ir-192 skyshine doses from radiography conducted at DN and PN stations are estimated and included in the potential critical group noble gas doses. Skyshine doses are found to be negligible for all potential critical groups.

F.3.4 Radioiodines

Radioiodine emissions are assumed to have an equilibrium mixture of radioiodines based on I(mfp). This is to account for short-lived radioiodines which may be emitted along with I-131. Emissions for each short-lived radioiodine are incorporated into the dose model based on its equilibrium ratio to the measured I-131 emission. Doses are modeled for the individual radioiodines and summed for the total I(mfp) dose. Due to the very short half-lives of some of these radioiodines, this calculation may overestimate the doses.

Radioiodines are an airborne emission and concentrations at potential critical group locations are modeled using emissions, the empirical Ka at each potential critical group location and modeled atmospheric dispersion factors.

F.3.5 Particulates and Gross-Beta Gamma

Both airborne particulates and waterborne gross-beta emissions represent a mixture of beta and gamma emitting radionuclides. In order to obtain conservative doses for

these mixtures, they are represented by the most limiting radionuclides typically found in the mixtures. According to the pathway analyses [R-53][R-54], the most limiting radionuclide for atmospheric particulate emissions is Co-60 and for liquid effluent beta-gamma emissions it is Cs-137. There was no analysis for alpha radioactivity because alpha radionuclide emissions from the stations are extremely low [R-55].

For airborne particulates, concentrations in air are modeled using emissions, the empirical Ka at each potential critical group location and modeled atmospheric dispersion factors. Concentrations in terrestrial media are subsequently modeled from the airborne concentrations. These concentrations are used to calculate doses to potential critical groups.

For waterborne gross-beta gamma, potential critical group doses are directly modeled from emissions in aquatic media where no local measurements are available. The only pathways used for dose calculation in which gross beta-gamma activity is measured in environmental samples are fish and beach sand. Background values of activity in Lake Ontario fish and beach sand are subtracted from these measurements.

F.3.6 Elemental Tritium

For HT, the inhalation pathway is the only direct pathway to humans resulting in dose. Concentrations in air are modeled using emissions, the empirical Ka at each potential critical group location and modeled atmospheric dispersion factors. HT converts into HTO through interaction with microbes in the soil. The resultant HTO is routinely measured in air and local biota around nuclear sites.

Appendix G: Tables of Public Doses by Radionuclide, Pathway and Age Group for Darlington Nuclear and Pickering Nuclear Potential Critical Groups

Table G-1: Darlington Nuclear – Farm Doses – 2018

HumanType	Radionuclide	Unit	Air (inhalation)	Air (external)	Water (ingestion)	Water (external)	Soil (ingestion)	Soil (external)	Sediment (ingestion)	Sediment (external)	Aquatic plants	Aquatic animals	Terrestrial plants	Terrestrial animals	Total
Adult	C-14	uSv/a	1.67E-04	1.92E-07	2.63E-06	3.79E-11	0.00E+00	0.00E+00	1.00E-10	6.42E-12	0.00E+00	4.46E-04	4.71E-02	4.66E-02	9.44E-02
	Co-60	uSv/a	1.25E-05	4.74E-07	2.71E-07	3.67E-08	1.21E-08	1.25E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.40E-04	4.38E-06	1.27E-02
	Cs-137+	uSv/a	0.00E+00	0.00E+00	2.78E-05	4.07E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.19E-05
	HT	uSv/a	4.71E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.71E-06
	HTO	uSv/a	3.21E-01	0.00E+00	1.42E-01	5.68E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.83E-05	2.97E-02	1.67E-02	5.16E-01
	NobleGases	uSv/a	0.00E+00	1.28E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.28E-01
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.21E-05	4.60E-03	1.18E-02	1.64E-02
	I (mfp)	uSv/a	2.13E-04	1.58E-05	1.76E-06	9.23E-09	1.10E-09	4.84E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.51E-03	1.22E-03	7.00E-03
	Total	uSv/a	3.22E-01	1.28E-01	1.42E-01	5.69E-03	1.32E-08	1.26E-02	1.00E-10	6.42E-12	0.00E+00	4.87E-04	8.71E-02	7.63E-02	7.74E-01
Child-10y	C-14	uSv/a	2.39E-04	1.92E-07	1.86E-06	3.79E-11	0.00E+00	0.00E+00	5.54E-10	6.42E-12	0.00E+00	2.64E-04	3.60E-02	2.91E-02	6.56E-02
	Co-60	uSv/a	1.78E-05	4.74E-07	4.51E-07	3.67E-08	1.57E-07	1.25E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.27E-04	7.37E-06	1.28E-02
	Cs-137+	uSv/a	0.00E+00	0.00E+00	1.10E-05	4.07E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.51E-05
	HT	uSv/a	5.61E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.61E-06
	HTO	uSv/a	3.82E-01	0.00E+00	9.15E-02	4.74E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.51E-05	1.99E-02	9.38E-03	5.07E-01
	NobleGases	uSv/a	0.00E+00	1.28E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.28E-01
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.12E-06	3.51E-03	7.05E-03	1.06E-02
	I (mfp)	uSv/a	4.83E-04	1.58E-05	2.14E-06	9.23E-09	1.04E-08	4.84E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.49E-03	1.87E-03	8.91E-03
	Total	uSv/a	3.83E-01	1.28E-01	9.16E-02	4.74E-03	1.67E-07	1.26E-02	5.54E-10	6.42E-12	0.00E+00	2.86E-04	6.61E-02	4.74E-02	7.33E-01
Infant_1y	C-14	uSv/a	1.63E-04	1.92E-07	0.00E+00	1.17E-11	0.00E+00	0.00E+00	1.11E-09	6.42E-12	0.00E+00	1.55E-04	3.12E-02	2.44E-02	5.59E-02
	Co-60	uSv/a	1.31E-05	6.16E-07	0.00E+00	4.78E-08	3.84E-07	1.63E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.21E-04	1.01E-05	1.65E-02
	Cs-137+	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	HT	uSv/a	3.84E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.84E-06
	HTO	uSv/a	2.62E-01	0.00E+00	0.00E+00	2.19E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.44E-06	1.83E-02	7.92E-03	2.90E-01
	NobleGases	uSv/a	0.00E+00	1.57E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.57E-01
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.32E-06	3.00E-03	5.33E-03	8.33E-03
	I (mfp)	uSv/a	5.65E-04	2.06E-05	0.00E+00	1.20E-08	3.63E-08	6.29E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.01E-03	5.01E-03	1.47E-02
	Total	uSv/a	2.62E-01	1.57E-01	0.00E+00	2.19E-03	4.21E-07	1.64E-02	1.11E-09	6.42E-12	0.00E+00	1.69E-04	6.18E-02	4.27E-02	5.42E-01

Table G-2: Darlington Nuclear – Dairy Farm Doses – 2018

HumanType	Radionuclide	Unit	Air (inhalation)	Air (external)	Water (ingestion)	Water (external)	Soil (ingestion)	Soil (external)	Sediment (ingestion)	Sediment (external)	Aquatic plants	Aquatic animals	Terrestrial plants	Terrestrial animals	Total
Adult	C-14	uSv/a	1.50E-04	1.73E-07	3.47E-06	3.51E-11	0.00E+00	0.00E+00	1.00E-10	6.42E-12	0.00E+00	8.88E-05	2.62E-02	1.17E-01	1.43E-01
	Co-60	uSv/a	5.23E-06	1.98E-07	0.00E+00	0.00E+00	2.65E-09	2.75E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.76E-05	1.07E-05	2.83E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	0.00E+00	4.07E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.07E-06
	HT	uSv/a	1.97E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.97E-06
	HTO	uSv/a	1.35E-01	0.00E+00	2.97E-02	1.76E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.62E-06	3.47E-02	3.30E-02	2.34E-01
	NobleGases	uSv/a	0.00E+00	7.66E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.66E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.41E-06	5.47E-03	1.43E-02	1.97E-02
	I (mfp)	uSv/a	8.95E-05	6.36E-06	0.00E+00	0.00E+00	4.48E-10	1.98E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.44E-03	4.29E-03	6.85E-03
	Total	uSv/a	1.35E-01	7.66E-02	2.97E-02	1.77E-03	3.10E-09	2.77E-03	1.00E-10	6.42E-12	0.00E+00	9.68E-05	6.89E-02	1.68E-01	4.83E-01
Child-10y	C-14	uSv/a	2.14E-04	1.73E-07	2.46E-06	3.51E-11	0.00E+00	0.00E+00	5.54E-10	6.42E-12	0.00E+00	5.24E-05	2.00E-02	9.14E-02	1.12E-01
	Co-60	uSv/a	7.46E-06	1.98E-07	0.00E+00	0.00E+00	3.44E-08	2.75E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.33E-05	3.34E-05	2.89E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	0.00E+00	4.07E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.07E-06
	HT	uSv/a	2.35E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.35E-06
	HTO	uSv/a	1.60E-01	0.00E+00	1.91E-02	1.47E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.01E-06	2.30E-02	3.02E-02	2.34E-01
	NobleGases	uSv/a	0.00E+00	7.66E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.66E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.42E-06	4.15E-03	1.04E-02	1.46E-02
	I (mfp)	uSv/a	2.03E-04	6.36E-06	0.00E+00	0.00E+00	4.23E-09	1.98E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.87E-03	1.03E-02	1.34E-02
	Total	uSv/a	1.60E-01	7.66E-02	1.91E-02	1.47E-03	3.86E-08	2.77E-03	5.54E-10	6.42E-12	0.00E+00	5.69E-05	5.02E-02	1.42E-01	4.53E-01
Infant_1y	C-14	uSv/a	1.46E-04	1.73E-07	0.00E+00	1.04E-11	0.00E+00	0.00E+00	1.11E-09	6.42E-12	0.00E+00	3.09E-05	1.65E-02	1.21E-01	1.38E-01
	Co-60	uSv/a	5.47E-06	2.58E-07	0.00E+00	0.00E+00	8.43E-08	3.58E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.03E-05	8.80E-05	3.76E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	HT	uSv/a	1.61E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.61E-06
	HTO	uSv/a	1.10E-01	0.00E+00	0.00E+00	1.63E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.88E-06	1.93E-02	5.73E-02	1.86E-01
	NobleGases	uSv/a	0.00E+00	9.42E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.42E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.60E-07	3.31E-03	1.29E-02	1.62E-02
	I (mfp)	uSv/a	2.37E-04	8.27E-06	0.00E+00	0.00E+00	1.48E-08	2.58E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.96E-03	3.94E-02	4.36E-02
	Total	uSv/a	1.10E-01	9.42E-02	0.00E+00	1.63E-04	9.92E-08	3.60E-03	1.11E-09	6.42E-12	0.00E+00	3.36E-05	4.32E-02	2.31E-01	4.82E-01

Table G-3: Darlington Nuclear – Rural Resident Doses – 2018

HumanType	Radionuclide	Unit	Air (inhalation)	Air (external)	Water (ingestion)	Water (external)	Soil (ingestion)	Soil (external)	Sediment (ingestion)	Sediment (external)	Aquatic plants	Aquatic animals	Terrestrial plants	Terrestrial animals	Total
Adult	C-14	uSv/a	2.39E-04	2.75E-07	2.64E-06	4.68E-11	2.97E-14	5.53E-13	9.86E-11	6.30E-12	0.00E+00	2.99E-04	2.15E-02	1.02E-02	3.22E-02
	Co-60	uSv/a	6.05E-06	2.30E-07	1.54E-07	1.18E-08	5.45E-09	5.65E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.05E-05	1.09E-06	5.70E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	1.05E-04	4.23E-06	5.51E-09	3.60E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.21E-06	1.65E-07	4.73E-04
	HT	uSv/a	2.28E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.28E-06
	HTO	uSv/a	1.56E-01	0.00E+00	1.18E-01	3.14E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.90E-05	1.24E-02	1.64E-03	2.91E-01
	NobleGases	uSv/a	0.00E+00	4.50E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.50E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.14E-06	1.90E-03	1.03E-03	2.93E-03
	I (mfp)	uSv/a	1.03E-04	7.04E-06	1.07E-06	3.18E-09	5.30E-10	2.34E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.61E-03	1.38E-04	1.88E-03
	Total	uSv/a	1.56E-01	4.50E-02	1.18E-01	3.14E-03	1.15E-08	6.04E-03	9.86E-11	6.30E-12	0.00E+00	3.27E-04	3.75E-02	1.30E-02	3.79E-01
Child-10y	C-14	uSv/a	3.39E-04	2.74E-07	1.89E-06	4.77E-11	1.67E-13	5.64E-13	5.54E-10	6.42E-12	0.00E+00	1.80E-04	1.67E-02	6.51E-03	2.38E-02
	Co-60	uSv/a	8.43E-06	2.24E-07	2.60E-07	1.20E-08	6.89E-08	5.52E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.70E-05	1.78E-06	5.59E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	3.77E-05	4.31E-06	1.73E-08	3.67E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.33E-06	6.04E-08	4.10E-04
	HT	uSv/a	2.65E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.65E-06
	HTO	uSv/a	1.81E-01	0.00E+00	7.67E-02	2.66E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.03E-05	8.48E-03	9.45E-04	2.69E-01
	NobleGases	uSv/a	0.00E+00	4.39E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.39E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.86E-06	1.48E-03	6.36E-04	2.12E-03
	I (mfp)	uSv/a	2.29E-04	6.85E-06	1.32E-06	3.24E-09	4.89E-09	2.29E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.94E-03	2.18E-04	2.41E-03
	Total	uSv/a	1.81E-01	4.39E-02	7.67E-02	2.67E-03	9.10E-08	5.91E-03	5.54E-10	6.42E-12	0.00E+00	1.95E-04	2.87E-02	8.31E-03	3.48E-01
Infant_1y	C-14	uSv/a	2.32E-04	2.74E-07	0.00E+00	1.46E-11	3.34E-13	5.64E-13	1.11E-09	6.42E-12	0.00E+00	1.06E-04	1.39E-02	6.87E-03	2.12E-02
	Co-60	uSv/a	6.18E-06	2.91E-07	0.00E+00	1.56E-08	1.69E-07	7.17E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.54E-05	2.51E-06	7.25E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	0.00E+00	3.11E-07	2.07E-08	4.78E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.96E-07	3.61E-08	4.79E-04
	HT	uSv/a	1.82E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.82E-06
	HTO	uSv/a	1.24E-01	0.00E+00	0.00E+00	8.65E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.45E-06	8.05E-03	1.05E-03	1.34E-01
	NobleGases	uSv/a	0.00E+00	5.40E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.40E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.95E-06	1.29E-03	6.65E-04	1.96E-03
	I (mfp)	uSv/a	2.68E-04	8.90E-06	0.00E+00	4.21E-09	1.71E-08	2.97E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.69E-03	6.25E-04	3.63E-03
	Total	uSv/a	1.24E-01	5.40E-02	0.00E+00	8.65E-04	2.07E-07	7.68E-03	1.11E-09	6.42E-12	0.00E+00	1.16E-04	2.61E-02	9.21E-03	2.22E-01

Table G-4: Pickering Nuclear – Dairy Farm Doses – 2018

HumanType	Radionuclide	Unit	Air (inhalation)	Air (external)	Water (ingestion)	Water (external)	Soil (ingestion)	Soil (external)	Sediment (ingestion)	Sediment (external)	Aquatic plants	Aquatic animals	Terrestrial plants	Terrestrial animals	Total
Adult	C-14	uSv/a	2.28E-04	2.63E-07	3.47E-06	2.05E-10	0.00E+00	0.00E+00	1.72E-09	1.10E-10	0.00E+00	0.00E+00	3.69E-02	1.19E-01	1.56E-01
	Co-60	uSv/a	3.93E-07	1.49E-08	0.00E+00	1.40E-10	2.15E-10	2.23E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.21E-06	4.68E-07	2.26E-04
	Cs-137+	uSv/a	0.00E+00	0.00E+00	1.71E-04	1.27E-04	0.00E+00	0.00E+00	5.85E-07	2.96E-04	0.00E+00	0.00E+00	0.00E+00	8.04E-07	5.95E-04
	HTO	uSv/a	9.60E-02	0.00E+00	7.31E-02	2.71E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.84E-02	3.18E-02	2.22E-01
	NobleGases	uSv/a	0.00E+00	9.56E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.56E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.00E-03	1.32E-02	1.62E-02
	I (mfp)	uSv/a	1.81E-06	8.95E-08	0.00E+00	1.63E-11	9.15E-12	3.96E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.09E-05	4.24E-05	7.56E-05
	Total	uSv/a	9.62E-02	9.56E-02	7.33E-02	2.83E-03	2.24E-10	2.23E-04	5.87E-07	2.96E-04	0.00E+00	0.00E+00	5.83E-02	1.64E-01	4.91E-01
Child-10y	C-14	uSv/a	3.26E-04	2.63E-07	2.46E-06	2.05E-10	0.00E+00	0.00E+00	9.51E-09	1.10E-10	0.00E+00	0.00E+00	2.82E-02	7.27E-02	1.01E-01
	Co-60	uSv/a	5.61E-07	1.49E-08	0.00E+00	1.40E-10	2.78E-09	2.23E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.56E-06	1.16E-06	2.28E-04
	Cs-137+	uSv/a	0.00E+00	0.00E+00	6.76E-05	1.27E-04	0.00E+00	0.00E+00	1.80E-06	2.96E-04	0.00E+00	0.00E+00	0.00E+00	2.38E-07	4.93E-04
	HTO	uSv/a	1.14E-01	0.00E+00	4.70E-02	2.26E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.23E-02	3.04E-02	2.06E-01
	NobleGases	uSv/a	0.00E+00	9.56E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.56E-02
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.30E-03	9.81E-03	1.21E-02
	I (mfp)	uSv/a	4.12E-06	8.95E-08	0.00E+00	1.63E-11	8.65E-11	3.96E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.63E-05	8.52E-05	1.26E-04
	Total	uSv/a	1.14E-01	9.56E-02	4.71E-02	2.38E-03	2.87E-09	2.23E-04	1.81E-06	2.96E-04	0.00E+00	0.00E+00	4.28E-02	1.13E-01	4.16E-01
Infant_1y	C-14	uSv/a	2.22E-04	2.63E-07	0.00E+00	1.54E-11	0.00E+00	0.00E+00	1.90E-08	1.10E-10	0.00E+00	0.00E+00	2.11E-02	5.67E-02	7.80E-02
	Co-60	uSv/a	4.11E-07	1.94E-08	0.00E+00	1.82E-10	6.83E-09	2.90E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.32E-06	2.66E-06	2.96E-04
	Cs-137+	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.16E-06	3.85E-04	0.00E+00	0.00E+00	0.00E+00	2.13E-07	3.88E-04
	HTO	uSv/a	7.82E-02	0.00E+00	0.00E+00	3.96E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.82E-03	6.06E-02	1.49E-01
	NobleGases	uSv/a	0.00E+00	1.16E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.16E-01
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.77E-03	1.32E-02	1.50E-02
	I (mfp)	uSv/a	4.82E-06	1.16E-07	0.00E+00	2.12E-11	3.03E-10	5.15E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.85E-05	2.99E-04	3.53E-04
	Total	uSv/a	7.85E-02	1.16E-01	0.00E+00	3.96E-04	7.13E-09	2.90E-04	2.18E-06	3.85E-04	0.00E+00	0.00E+00	3.27E-02	1.31E-01	3.59E-01

Table G-5: Pickering Nuclear – Industrial/Commercial Doses – 2018

HumanType	Radionuclide	Unit	Air (inhalation)	Air (external)	Water (ingestion)	Water (external)	Soil (ingestion)	Soil (external)	Sediment (ingestion)	Sediment (external)	Aquatic plants	Aquatic animals	Terrestrial plants	Terrestrial animals	Total
Adult	C-14	uSv/a	8.01E-04	9.21E-07	2.29E-06	1.62E-11	1.29E-13	2.41E-12	1.06E-10	6.79E-12	0.00E+00	3.45E-07	5.37E-04	1.26E-06	1.34E-03
	Co-60	uSv/a	3.02E-06	1.15E-07	4.03E-296	1.41E-11	2.11E-10	2.19E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.45E-07	1.02E-11	2.22E-04
	Cs-137+	uSv/a	0.00E+00	0.00E+00	2.00E-03	1.21E-05	4.36E-08	2.85E-03	3.60E-08	1.83E-05	0.00E+00	0.00E+00	6.53E-06	1.48E-10	4.89E-03
	HTO	uSv/a	7.28E-01	0.00E+00	1.22E-02	1.76E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.59E-09	9.92E-04	2.57E-07	7.41E-01
	NobleGases	uSv/a	0.00E+00	8.14E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.14E-01
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.40E-09	1.56E-04	1.41E-07	1.56E-04
	I (mfp)	uSv/a	1.43E-05	1.00E-06	0.00E+00	9.87E-13	5.31E-12	2.36E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.62E-06	2.66E-09	1.71E-05
	Total	uSv/a	7.29E-01	8.14E-01	1.42E-02	1.88E-04	4.38E-08	3.07E-03	3.61E-08	1.83E-05	0.00E+00	3.53E-07	1.69E-03	1.66E-06	1.56E+00

Table G-6: Pickering Nuclear – Correctional Institute (C2) Doses – 2018

HumanType	Radionuclide	Unit	Air (inhalation)	Air (external)	Water (ingestion)	Water (external)	Soil (ingestion)	Soil (external)	Sediment (ingestion)	Sediment (external)	Aquatic plants	Aquatic animals	Terrestrial plants	Terrestrial animals	Total
Adult	C-14	uSv/a	1.58E-03	1.82E-06	8.12E-06	2.44E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.59E-03
	Co-60	uSv/a	2.72E-06	1.03E-07	0.00E+00	0.00E+00	1.44E-09	1.49E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.49E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	7.12E-03	1.84E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.14E-03
	HTO	uSv/a	6.65E-01	0.00E+00	4.29E-02	2.70E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.08E-01
	NobleGases	uSv/a	0.00E+00	6.65E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.65E-01
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	I (mfp)	uSv/a	1.27E-05	8.29E-07	0.00E+00	0.00E+00	6.35E-11	2.85E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.64E-05
	Total	uSv/a	6.66E-01	6.65E-01	5.01E-02	2.89E-04	1.50E-09	1.49E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.38E+00
Child-10y	C-14	uSv/a	2.26E-03	1.82E-06	5.76E-06	2.44E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.27E-03
	Co-60	uSv/a	3.89E-06	1.03E-07	0.00E+00	0.00E+00	1.86E-08	1.49E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.49E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	2.82E-03	1.84E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.84E-03
	HTO	uSv/a	7.90E-01	0.00E+00	2.76E-02	2.25E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.18E-01
	NobleGases	uSv/a	0.00E+00	6.65E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.65E-01
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	I (mfp)	uSv/a	2.89E-05	8.29E-07	0.00E+00	0.00E+00	6.00E-10	2.85E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.26E-05
	Total	uSv/a	7.93E-01	6.65E-01	3.04E-02	2.44E-04	1.92E-08	1.49E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.49E+00

Table G-7: Pickering Nuclear – Urban Resident Doses – 2018

HumanType	Radionuclide	Unit	Air (inhalation)	Air (external)	Water (ingestion)	Water (external)	Soil (ingestion)	Soil (external)	Sediment (ingestion)	Sediment (external)	Aquatic plants	Aquatic animals	Terrestrial plants	Terrestrial animals	Total
Adult	C-14	uSv/a	8.87E-04	1.02E-06	6.93E-06	2.53E-10	2.02E-12	3.77E-11	1.66E-09	1.06E-10	0.00E+00	5.40E-06	8.39E-03	1.98E-05	9.31E-03
	Co-60	uSv/a	3.83E-06	1.45E-07	6.30E-295	2.20E-10	3.31E-09	3.43E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.26E-06	1.60E-10	3.43E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	5.95E-03	1.90E-04	6.82E-07	4.45E-02	5.63E-07	2.85E-04	0.00E+00	0.00E+00	1.02E-04	2.32E-09	5.11E-02
	HTO	uSv/a	9.08E-01	0.00E+00	3.75E-02	2.75E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.75E-08	1.55E-02	4.02E-06	9.64E-01
	NobleGases	uSv/a	0.00E+00	1.11E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.11E+00
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.76E-08	2.44E-03	2.20E-06	2.44E-03
	I (mfp)	uSv/a	1.83E-05	1.32E-06	0.00E+00	1.54E-11	8.30E-11	3.68E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.54E-05	4.16E-08	4.87E-05
	Total	uSv/a	9.09E-01	1.11E+00	4.35E-02	2.94E-03	6.85E-07	4.80E-02	5.65E-07	2.85E-04	0.00E+00	5.52E-06	2.65E-02	2.60E-05	2.14E+00
Child-10y	C-14	uSv/a	1.14E-03	9.16E-07	4.89E-06	2.63E-10	1.16E-11	3.92E-11	9.51E-09	1.10E-10	0.00E+00	3.31E-06	6.44E-03	2.01E-05	7.60E-03
	Co-60	uSv/a	5.00E-06	1.33E-07	1.09E-294	2.29E-10	4.44E-08	3.56E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.80E-06	4.83E-10	3.57E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	2.34E-03	1.97E-04	2.18E-06	4.62E-02	1.80E-06	2.96E-04	0.00E+00	0.00E+00	4.28E-05	8.94E-10	4.91E-02
	HTO	uSv/a	9.88E-01	0.00E+00	2.40E-02	2.38E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.86E-08	1.07E-02	3.03E-06	1.02E+00
	NobleGases	uSv/a	0.00E+00	1.03E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.03E+00
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.29E-08	1.93E-03	1.60E-06	1.93E-03
	I (mfp)	uSv/a	3.81E-05	1.22E-06	0.00E+00	1.60E-11	8.14E-10	3.82E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.09E-05	9.28E-08	7.41E-05
	Total	uSv/a	9.89E-01	1.03E+00	2.63E-02	2.57E-03	2.22E-06	4.98E-02	1.81E-06	2.96E-04	0.00E+00	3.38E-06	1.92E-02	2.49E-05	2.12E+00
Infant_1y	C-14	uSv/a	7.76E-04	9.16E-07	0.00E+00	2.51E-11	2.32E-11	3.92E-11	1.90E-08	1.10E-10	0.00E+00	1.95E-06	5.58E-03	3.68E-05	6.40E-03
	Co-60	uSv/a	3.67E-06	1.73E-07	0.00E+00	2.97E-10	1.09E-07	4.62E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.59E-06	1.25E-09	4.63E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	0.00E+00	2.34E-05	2.61E-06	6.02E-02	2.16E-06	3.85E-04	0.00E+00	0.00E+00	2.10E-05	6.35E-10	6.07E-02
	HTO	uSv/a	6.77E-01	0.00E+00	0.00E+00	3.99E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.03E-08	9.28E-03	4.87E-06	6.87E-01
	NobleGases	uSv/a	0.00E+00	1.26E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.26E+00
	OBT	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.39E-08	1.57E-03	2.13E-06	1.57E-03
	I (mfp)	uSv/a	4.45E-05	1.58E-06	0.00E+00	2.08E-11	2.85E-09	4.97E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.20E-05	3.44E-07	9.34E-05
	Total	uSv/a	6.78E-01	1.26E+00	0.00E+00	4.22E-04	2.72E-06	6.49E-02	2.18E-06	3.85E-04	0.00E+00	1.99E-06	1.65E-02	4.42E-05	2.02E+00

Appendix I: Compliance with Regulatory Document REGDOC-3.1.1

The OPG annual EMP report was structured to comply with CNSC regulatory document S-99 *Reporting Requirements for Operating Nuclear Power Plants*. In May 2014, CNSC Regulatory Document REGDOC-3.1.1 *Reporting Requirements for Nuclear Power Plants* was published to replace S-99 [R-3]. It provides revised requirements for an annual report on environmental protection. OPG is required to comply with REGDOC-3.1.1 as of the 2015 reporting year and has modified the annual EMP report such that the requirements in section 3.5 of REGDOC-3.1.1 are met. Corresponding sections are summarized in the table below.

Table I-1: OPG EMP Report Compliance with Regulatory Document-3.1.1, Reporting Requirements for Nuclear Power Plants

REGDOC-3.1.1, Section 3.5 Requirement	Corresponding Section in OPG's Annual EMP Report
1. A summary of the results of the environmental protection program and an analysis of the significance with respect to health and safety or persons and the protection of the environment, of the results of the environmental protection program	Executive Summary
2. The amount of nuclear substances (i.e. activity concentrations, flow rates and loadings) in SI units, released to the environment and monitored as part of the licensee's effluent/emission monitoring program, presented on an appropriate basis (weekly or monthly), along with a comparison to regulatory release limits for the nuclear substance	Section 2.1
3. The amount of nuclear substances measured in the environment, in SI units, as part of the licensee's radiological environmental monitoring program	Section 3.3 Section 3.4 (if any conducted within that year)
4. The results and calculations of the annual radiation doses to the representative persons and/or critical groups in comparison to the regulatory public dose limit with a description of the environmental transfer/exposure pathways associated with the operation of the nuclear power plant including the dispersion and dosimetric models used	Section 4.0
5. The amount of hazardous substances (i.e. concentrations, flow rates and loadings), in SI units released to the environment and monitored as part of the licensee's effluent/emission monitoring program, and measured in the environment as part of the licensee's environmental monitoring program	Section 2.2 Section 3.4 (if any conducted within that year)
6. For each parameter reported as part of the effluent/emission monitoring and environmental monitoring program, a description of the characteristics of the monitoring results, including but not limited to the sample frequency (e.g. daily, monthly, semi-annually), sample type (e.g. grab, composite, activity counts over time), statistical quantity reported (e.g. weekly/ monthly mean, annual average, annual total)	Section 3.0 Appendix D Section 2.0
7. A description of any significant events, findings or results in respect to the conduct of the environmental monitoring program	Section 5.0
8. A summary of any proposed changes to the environmental monitoring program	Section 6.0