ONTARIO POWER GENERATION

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2014 Results Of Environmental Monitoring Programs

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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, soil, 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	2015-04-20	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 station 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.

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 supports the calculation of annual public dose resulting from operation of OPG nuclear facilities, as required by the Canadian Nuclear Safety Commission (CNSC) S-99 standard.

The 2014 program results contained in this report include concentrations of radionuclides in the air, water, milk, soil, sediments, vegetation, animal feed, eggs, poultry, 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 away from the influence of the nuclear stations.

The EMP designs address the monitoring of non-radiological substances through scheduled supplementary studies. The supplementary studies conducted in 2014 include monitoring of morpholine and chlorine in lake water around DN, and monitoring of hydrazine in lake water along the PN discharge channels.

In 2014, OPG operated 10 nuclear reactors that produced 48.2 terawatt hours (TWh) of electricity. The production performance of DN and PN stations was 91.0% and 74.0% of their respective rated capacities. Station radiological emissions remained at a very small fraction of their licensed Derived Release Limits (DRLs).

A total of 958 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, with the exception of DN beach sand due to inaccessibility of two beach sand sampling locations in 2014. The 2014 dose from beach sand in the vicinity of DN was conservatively modelled.

IMPACT 5.4.0 software, which is consistent with the method of dose calculation described in the CSA N288.1-08 standard, was used for the dose calculations.

The 2014 critical group doses resulting from the operation of the OPG Nuclear Generating Stations 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 2014 public doses for the DN and PN sites are similar to those observed in 2013 and are summarized in Table 1:

Table 1-1: OPG Public Dose Estimates - 2014

Facility	Critical Group (Receptor)	Effective Dose (*µ*Sv)	Percentage of Legal Limit (%)	Percentage of Background Radiation around DN and PN (%)
Darlington Nuclear	Farm (Adult)	0.6	0.1	< 0.1
Pickering Nuclear	Urban Resident (Adult)	1.2	0.1	0.1

The results of the 2014 supplementary studies on chlorine and morpholine in lake water around DN and hydrazine in lake water near PN indicate that no human health or ecological effects are expected as a result of station operations.

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 stations 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) standard S-296 [R-1]. Additionally, this program is registered to the International Organization for Standardization (ISO) 14001 Environmental Management Systems standard.

As part of this program, each station has an Environmental Monitoring Program (EMP), which identifies the contaminants and physical stressors to be monitored and conducts monitoring in the environment surrounding the station. The EMP design uses a risk-based approach and relies on the results of station Environmental Risk Assessments (ERAs), as described in Section 3.1.1. Locations considered to be outside the influence of PN and DN station 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, which provides 2014 data, is prepared and submitted to the CNSC in accordance with their S-99 standard [R-3] per the REGDOC 3.1.1 Transition Strategy described in Appendix J. It is also made available to the public.

The emissions and environmental data collected for each site during the 2014 sampling year, their interpretations, and the estimates of radiation doses to the public resulting from the operation of PN and DN stations are provided in this report.

The emissions and environmental data are summarized in Sections 2.0 and 3.0, respectively. The 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 stations, 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 Stations

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. It provides about 20% of Ontario's electricity needs, enough to serve a city of two million people.

DN also operates 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 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 the Used Fuel Dry Storage Facility and the Re-Tube Components Storage Area.

PN has six operating CANDU reactors. This station has a total output of 3,100 MW, enough to serve a city of one and a half million people. 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 2014, OPG operated ten nuclear reactors that produced 48.2 terawatt hours (TWh) of electricity. This production is broken down as follows:

Darlington Nuclear: Net electrical output in 2014 was 28.0 TWh.

Pickering Nuclear: Net electrical output in 2014 was 20.2 TWh.

2.0 EFFLUENT MONITORING PROGRAM

2.1 Radiological Emissions

The radiological emissions from DN and PN in 2014 remain at a very small fraction of the station 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/a) of the most affected critical group. See Section 4.0 for the description of a critical group.

Table 2-1 shows the 2014 total airborne and waterborne emissions for radionuclides measured at the DN and PN sites and the percentage of their respective DRLs.

Table 2-1: OPG Annual Site Radiological Emissions 2014

Site Emissions	DN		PN	
	Bq	% DRL	Bq	% DRL
AIR				
Tritium Oxide	2.7E+14	0.46	5.3E+14	0.36
Elemental Tritium (a)	5.2E+13	0.01	NA	NA
Noble Gas (b)	4.6E+13	0.10	1.2E+14	0.38
I-131	1.6E+08	0.01	1.6E+07	<0.01
Particulate	3.1E+07	<0.01	7.9E+06	<0.01
C-14	1.3E+12	0.37	1.8E+12	0.09
WATER				
Tritium Oxide	1.7E+14	<0.01	3.4E+14	0.06
Gross Beta/Gamma	3.0E+10	0.04	3.2E+10	1.26
C-14	5.5E+09	0.01	1.5E+09	<0.01

NOTES: NA = Not Applicable, Bq = Bequerels

(a) Emissions from Darlington Tritium Removal Facility

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

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 at times 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. In 2014, the HT emissions were 5.2 x 10^{13} becquerels (Bq). The increase in HT emissions observed in 2014 is due to TRF restart activities following outages. The elevated emissions in 2005 were the result of a rupture disk failure at the TRF and had minimal impact on public dose.

PN

PN does not experience routine HT emissions as it does not have a TRF, which is the main producer of HT at DN.

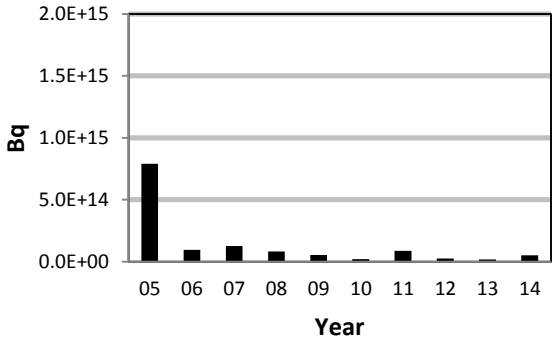

Figure 2-1: Darlington Nuclear Airborne Elemental Tritium Emissions

Tritium Oxide Airborne Emissions

DN – Figure 2-2

The increase in DN tritium oxide (HTO) airborne emissions observed in 2014 is attributed to both dryer performance and TRF restart activities. The 2014 HTO airborne emission was 2.7 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 managing emissions, reliability and operation of vapour recovery dryers, and reduction of HTO source terms. The increase in emissions observed in 2014 is primarily attributed to dryer performance. Airborne HTO emissions in 2014 were 5.3 x 10^{14} Bq.

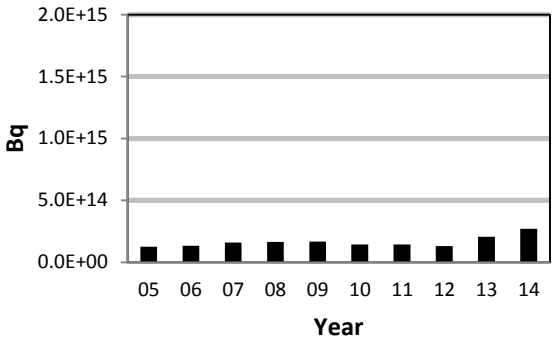

Figure 2-2: Darlington Nuclear Tritium Oxide Air Emissions

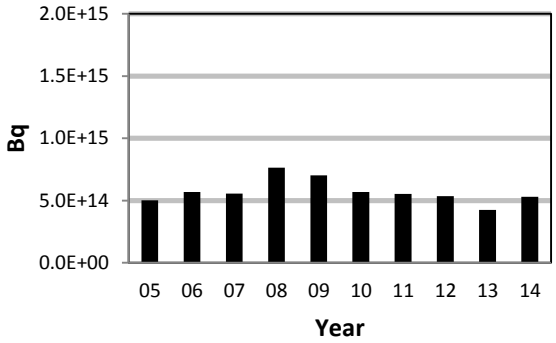

Figure 2-3: Pickering Nuclear Tritium Oxide Air Emissions

Carbon-14 Airborne Emissions

DN – Figure 2-4

DN C-14 airborne emissions remain stable. The 2014 C-14 airborne emissions were 1.3 x 10^{12} Bq.

PN – Figure 2-5

A decrease in PN C-14 airborne emissions has been observed in recent years as compared with 2007. The previous peak in emissions was due to a failed calandria tube on Unit 7, which allowed carbon dioxide (CO_2) from the annulus gas to enter the moderator system. The 2014 C-14 airborne emissions were 1.8 x 10^{12} Bq.

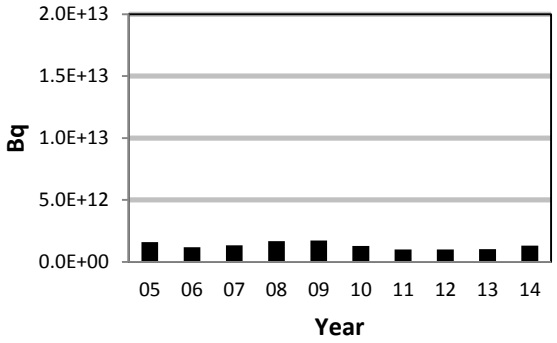

Figure 2-4: Darlington Nuclear C-14 Air Emissions

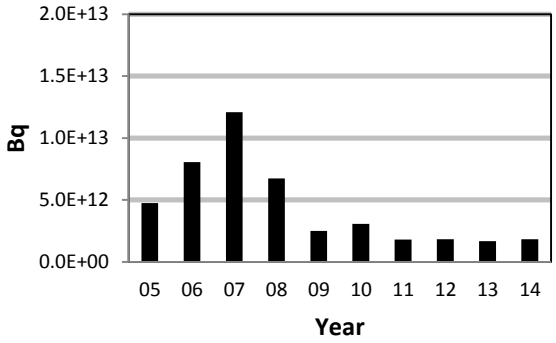

Figure 2-5: Pickering Nuclear C-14 Air Emissions

Tritium Oxide Waterborne Emissions

DN – Figure 2-6

DN HTO to water emissions remain stable. Drainage and discharge activities of the vacuum building dousing water began in 2014 in preparation for the vacuum building outage (VBO) in 2015. This resulted in a slight increase of DN HTO to water emissions observed in 2014. The last DN VBO occurred in 2009 with drainage of the system taking place in 2007 and 2008. However, the significant increase in HTO to water emissions observed during those years was mainly due to apparent contamination from ambient air to the water samples in the auto-sampler, which is not reflective of a true increase in emissions. A VBO is scheduled to occur every 10 years in order to meet licensing requirements. The DN VBO has been moved ahead of schedule in preparation for the DN refurbishment activities The 2014 DN tritium to water emission was 1.7 x 10^{14} Bq.

PN – Figure 2-7

The PN waterborne HTO emissions remain stable. The slightly elevated emissions in 2008 and 2009 were due to a minor heavy water leak from a Unit 1 shutdown cooling heat exchanger and a small Unit 1 boiler tube leak, respectively. The PN tritium to water emission in 2014 was 3.4 x 10^{14} Bq. The slight increase observed in 2014 is primarily attributed to tritiated water processing activities in active liquid waste.

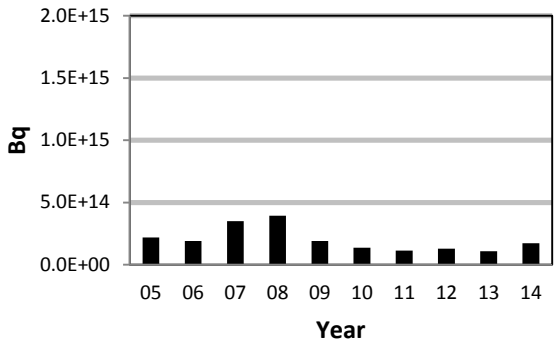

Figure 2-6: Darlington Nuclear Tritium Oxide Water Emissions

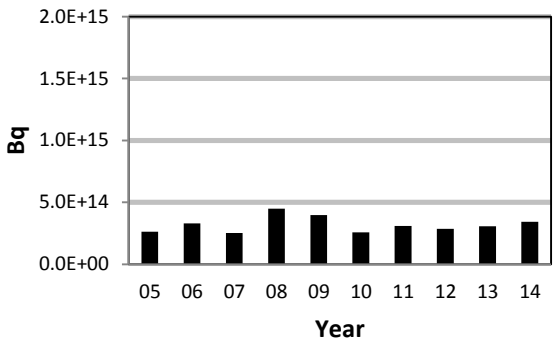

Figure 2-7: Pickering Nuclear Tritium Oxide Water Emissions

Gross Beta-Gamma Waterborne Emissions

DN – Figure 2-8

The DN gross beta-gamma emissions to water remain low as shown in Figure 2-8. The 2014 gross beta-gamma water emission was 3.0 x 10^{10} Bq.

PN – Figure 2-9

The PN gross beta-gamma emissions to water remain low. The increase in 2009 and 2010 was 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 returned to pre-2009 levels, as shown in Figure 2-9. The 2014 gross beta-gamma waterborne emission was 3.2 x 10^{10} Bq.

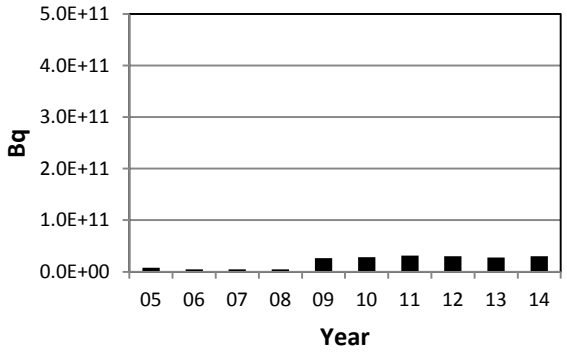

Figure 2-8: Darlington Nuclear Gross Beta-Gamma Water Emissions

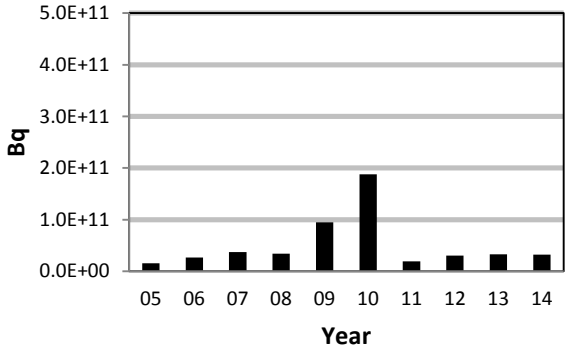

Figure 2-9: Pickering Nuclear Gross Beta-Gamma Water Emissions

2.1.2 OPG Nuclear Carbon-14 Inventory Data

The C-14 inventories within the PN and DN stations are included in this report to fulfill a regulatory commitment to the CNSC [R-5]. The 2014 estimates of C-14 inventory within the PN and DN stations are 8.3 x10^{14} Bq and 5.8 x10^{14} Bq, respectively [R-6].

2.2 Conventional Emissions

OPG monitors conventional substances emitted to air and water as a result of PN and DN 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 required. In addition, emissions of conventional hazardous substances are reported to the CNSC in the station Quarterly Operations Reports (QORs).

The QORs provide the conventional hazardous substance emissions from the previous calendar year. Therefore, the 2014 QORs provide the 2013 hazardous substance emissions, consistent with the reporting requirements of S-99 [R-3]. Table 2-2 summarizes the emissions of conventional hazardous substances released from PN and DN, as reported in the 2014 QORs [R-7] [R-8] [R-9] [R-10] [R-11] [R-12].

Table 2-2: OPG Annual Site Emissions of Conventional Hazardous Substances - 2013

Hazardous Material	DN	PN
	Mg	Mg
AIR		
SO_2 to Air	1.2E-02	1.1E-02
NO_2 to Air	6.3E+00	2.3E+01
CO_2 to Air	1.2E+03	4.1E+03
Ammonia to Air	6.3E+00	6.2E+00
Hydrazine to Air	2.1E-02	6.0E-03
Ozone-Depleting Substances (ODS)	7.6E-02	0.0E-00
WATER		
Ammonia to Water	2.0E+00	9.2E-01
Hydrazine to Water	2.2E-01	3.1E-01
Chlorine to Water	9.6E+00	3.6E+00

NOTES:
Mg = Megagrams

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, which account for sulphur dioxide, nitrogen oxides and carbon dioxide emissions. These generators are routinely tested to ensure their availability. There were no regulatory non-compliances associated with the air emissions from these generators in 2013 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 2013 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 2013 for DN or PN.

Chlorine

Sodium hypochlorite is used as a biocide to control mussel infestations in station water systems that use lake water. There were no regulatory non-compliances associated with chlorine emissions in 2013 for DN or PN.

3.0 ENVIRONMENTAL MONITORING PROGRAM

3.1 Design of EMP

The EMP design was 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 which are present in the environment as a result of station operations. The ERAs help to identify what monitoring to include in the EMPs. A review of the most recent ERAs was conducted for the 2014 EMPs.

The most recent DN ERA and Environmental Assessment (EA) results indicate that DN station operation does not present any radiological, conventional, or physical stressor risks for human or non-human biota [R-13] [R-14]. Therefore, no additional sampling was required for the DN EMP beyond that required to estimate the public dose from radiological emissions.

DN made changes to its chlorination process subsequent to the completion of the most recent EA [R-13]. The change in the process included increasing the chlorination in response to zebra mussel infestations. Chlorination to prevent zebra mussels is followed by dechlorination to limit total residual chlorine (TRC) input to the lake. Additionally, at the time the DN refurbishment ERA [R-14] was performed, morpholine was used as a boiler feed chemical in one DN unit on a trial basis. Morpholine is now used in all units. As a result of these changes a supplementary study was conducted in 2014 to confirm that TRC and morpholine concentrations near the DN discharge remain below their respective Provincial Water Quality Objectives (PWQOs) and toxicity reference values (TRVs) for aquatic life. The results of the study are discussed in Section 3.4.2 of this report.

The PN ERA was updated in 2013 following the requirements of CSA N288.6-12, Environmental Risk Assessments at Class I Nuclear Facilities and Uranium Mines and Mills [R-15]. The results indicate that PN station operation does not present any radiological or physical stressor risks to human or non-human biota, however hydrazine in lake water was identified as a potential human health risk due to uncertainty in the lake water concentrations used in the assessment [R-16]. To clarify this potential risk, a supplementary study was conducted in 2014 to measure the hydrazine concentration in lake water near the PN outfalls. The results of the study are discussed in Section 3.4.1 of this report.

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, 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 interpretation of the data 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 station operations. Samples are collected at station boundary locations as well as at 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 critical group locations, contaminant concentrations for the critical groups 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. Refer to Section 3.2.2 for a discussion of the supplementary studies that took place in 2014.

3.2.1 Radiological Contaminants

Radionuclides that are emitted as a result of PN and DN station operations and monitored in the EMPs are listed below. They are identified through the station pathway analyses and site specific survey reviews as discussed in Section 4.2 of this document. The specific 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 present in the atmosphere primarily as a result of the emissions from the TRF at DN. HT concentration in air is modeled from emissions and not monitored in the environment. However, some 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. A standard method for the measurement of OBT in environmental samples is under development. OBT concentrations are currently modeled from HTO concentrations measured in sample media at each critical group location and in fish. OPG dose calculations incorporate dose from OBT via intake of terrestrial plants and animal products, and from fish.

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 modelled 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 last pathway analyses in the program design reviews. 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 and that of past weapons testing.

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 will be achieved through supplementary studies.

In 2014 the following supplementary studies were conducted to confirm and/or clarify ERA predictions:

- Monitoring of morpholine in lake water around DN.
- Monitoring of chlorine in lake water around DN.
- Monitoring of hydrazine in lake water along the PN discharge channels.

Morpholine- OPG uses morpholine in station water systems to prevent corrosion. This chemical is released when steam is vented to the atmosphere and when water from the boilers is drained to Lake Ontario.

Chlorine- OPG uses sodium hypochlorite as a biocide to control mussel infestations in station water systems that use lake water.

Hydrazine- OPG uses hydrazine in station water systems to prevent corrosion. This chemical is released when steam is vented to the atmosphere and when water from the boilers is drained to Lake Ontario.

A detailed description of each study and the associated analytical results are discussed in Section 3.4 of this report.

Table 3-1: Routine Environmental Samples Used for the Darlington and Pickering EMPs

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

3.3 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 was performed for most historical data, however, it is more meaningful where sampling locations and frequencies remained consistent from year to year such as radionuclides in air monitored at the EMP boundary locations and drinking water samples from local water supply plants.

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 EMP uses a probability of 5%.

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 EMP uses a probability of 5%.

When reporting the analytical data in Appendix D tables, the following conventions were used:

- Where the measured value was lower than the Ld of the analytical method but higher than the Lc, the measured value was reported in bold type.
- Where the measured value was less than the Lc, then “< Lc” was reported without an uncertainty measure.
- Where the actual numerical measurement is censored at the Ld, then an upper limit is reported as “< Ld”, such is the case for gamma spectrometer results, noble gas data, and conventional contaminants.
- Where single values were reported, the associated uncertainty is the laboratory analytical uncertainty for that particular sample.
- Where averages of datasets were reported, the associated uncertainty is two times the standard deviation of the dataset.
- Where averages were performed on datasets containing data censored at the Ld, the statistical mean and standard deviation of the dataset were determined using the Kaplan-Meier methodology.

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 the 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 five site boundary EMP monitoring locations around DN (D1, D2, D5, D9, and D10- note that in previous years D10 was referred to as DF5) 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 was consistently below the active sampler detection limit of 0.2 Bq/m^3.

The 2014 annual average results of airborne HTO at the DN, PN, and background sites are summarized in Appendix D, Table D1. The boundary average values are meant to provide a year-to-year comparison of the HTO in air concentration around the sites. 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 station HTO emissions remain constant.

In light of the EMP designs, the monitoring locations used for the 2014 boundary location averages are different from those used prior to 2013. This should be considered when referring to the data in Table D1.

For the purpose of statistical trend analyses, in Figures 3-1 and 3-2 only boundary locations which have been sampled for the past 10 years were used in order to provide a representative 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 2014 HTO in air annual average concentrations measured at DN boundary locations ranged from 0.3 to 2.0 Bq/m^3. The average boundary concentration was 1.0 Bq/m^3. The increase observed in 2014, as compared with 2013 concentrations, reflects the increase in station HTO emissions from DN. Despite this increase, the 2014 concentrations remain consistent with overall performance observed over the past 10 years. A Mann-Kendall trend analysis at the 95% confidence level does not indicate a statistically significant trend for DN HTO in air over the past 10 years. Refer to Figure 3-1.

PN – Figure 3-2

The 2014 HTO in air annual average concentrations measured at PN boundary locations ranged from 1.1 to 11.5 Bq/m^3. The average boundary concentration was 5.5 Bq/m^3. The increase observed in 2014, as compared with 2013 concentrations, reflects the increase in station HTO emissions from PN. A Mann-Kendall trend analysis at the 95% confidence level indicates a statistically significant decreasing trend in PN HTO in air over the past 10 years. Refer to Figure 3-2.

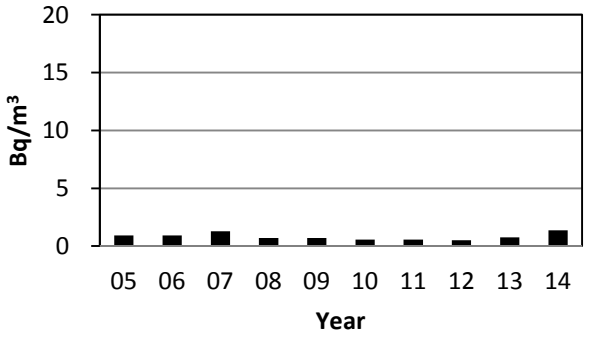

Figure 3-1: Darlington Nuclear Boundary Average HTO in Air

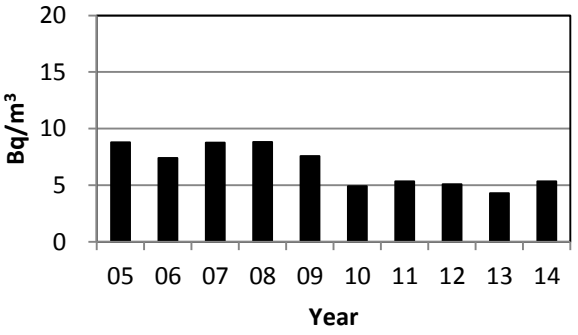

Figure 3-2: Pickering Nuclear Boundary Average HTO in Air

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 1960's. C-14 background concentrations around the world are currently decreasing as weapons test C-14 is removed naturally from the environment over time. Pre-atmospheric weapons test levels were measured at 226 Bq/kg-C [R-17]. The annual average C-14 in air concentration observed at the Nanticoke EMP background location in 2014 was 214 Bq/kg-C.

In the EMP design, C-14 in air is monitored at four boundary locations for DN (D1, D2, D5, and D10- note that in previous years D10 was referred to as DF5) and four

boundary locations for PN (P3, P4, P6, and P10). Appendix D, Table D2, provides the 2014 annual averages of airborne C-14 measured at the DN, PN, and background sampling locations.

For the purpose of statistical trend analyses, in Figures 3-3 and 3-4 only boundary locations which have been sampled for the past 10 years were used in order to provide a representative comparison. For DN this includes locations D1, D2, and D10. For PN this includes locations P6 and P10.

DN – Figure 3-3

The annual average C-14 in air concentrations measured at the four DN boundary locations ranged from 222 to 250 Bq/kg-C. The 2014 C-14 in air boundary average concentration was 235 Bq/kg-C. Using data from the past 10 years, a Mann-Kendall trend analysis at the 95% confidence level indicates that no statistically significant trend is present. Refer to Figure 3-3.

PN – Figure 3-4

The annual average C-14 in air concentrations measured at the four PN boundary locations ranged from 227 to 467 Bq/kg-C. The 2014 C-14 in air boundary average concentration was 336 Bq/kg-C. A Mann-Kendall trend analysis at the 95% confidence level indicates a statistically significant decreasing trend in PN C-14 over the past 10 years. Refer to Figure 3-4. The increase observed in 2007 is in line with the station emissions patterns, as discussed in Section 2.1.1.

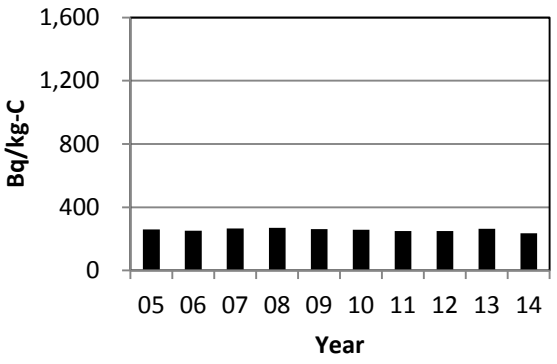

Figure 3-3: Darlington Nuclear Boundary Average C-14 in Air

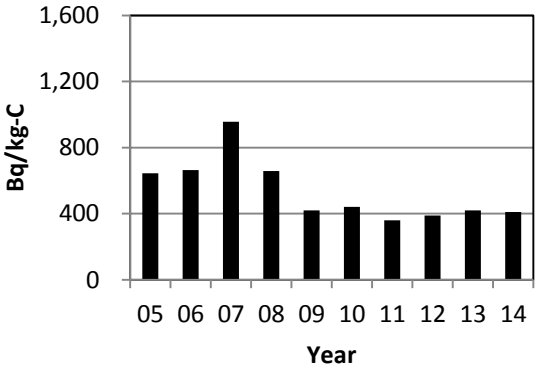

Figure 3-4: Pickering Nuclear Boundary Average C-14 in Air

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-18].

In previous years, 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 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 (note that location DF5 is now referred to as D10) and eight detectors around the PN site. These detectors continuously monitor doses and an annual total is used in the dose calculation. 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 2014 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 emissions of noble gases 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 167 nanogray (nGy)/month in 2014. This is consistent with the dose rate observed in 2013.

Figure 3-5 illustrates the boundary average Ar-41 dose rate for PN from 2006 to 2014, which represents the period of time where all six PN units were operational, in units of nanogray (nGy)/month.

A Mann-Kendall trend analysis at the 95% confidence level using boundary location data from 2006 to 2014 indicates a statistically significant increasing trend is present for PN Ar-41 in air. Ar-41 emissions and measurements in the environment are largely related to the number of operating days of PN Units 1 and 4.The increasing trend is primarily attributed to a higher number of operating days of these two units.

Xe-133 and Xe-135 were also, at times, measured above the detection limit at PN. Measured boundary average values in 2014 were 6 nGy/month for Xe-133 and 4 nGy/month for Xe-135. Dose from Ir-192 was not detected in 2014.

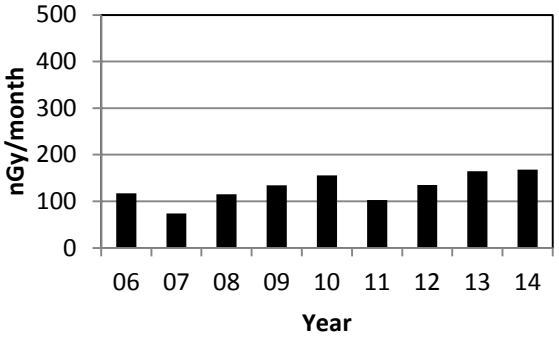

Figure 3-5: Pickering Nuclear Boundary Average Ar-41 Dose Rate in Air

3.3.3 Terrestrial Sampling

Terrestrial biota receives 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 various 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 2014 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 design, fruits and vegetables are sampled three times from each location in order to ensure an accurate representation of the growing season. Each sample is analysed for C-14 and HTO. Sampling locations for 2014 are shown in Appendix C: Maps of Environmental Monitoring and Critical Group Locations.

A total of 10 fruit and vegetable locations were sampled around DN and at total of 8 were sampled around PN. The population around PN is much more urban and, as a result, fewer residents in the surrounding areas grow their own fruits and vegetables. Fruits and vegetables were sampled from five background locations.

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

Tritium Oxide

The average HTO concentrations measured in fruits and vegetables from the provincial-background locations in 2014 were 7.0 Bq/L in fruits and 4.6 Bq/L in vegetables.

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 have changed over the years. These variations should be considered when reviewing the following graphs.

DN – Figure 3-6

Local fruit and vegetables collected around the DN site had HTO concentrations above the background average. The 2014 average concentration of HTO was 27.5 Bq/L in fruits and 33.3 Bq/L in vegetables. Figure 3-6 illustrates the combined DN fruit and vegetable HTO results over the past 10 years. The increase observed in 2014 reflects the increase in HTO emissions from DN. Despite this increase, 2014 concentrations remain consistent overall with the results observed over the past 10 years. A Mann-Kendall trend analysis at the 95% confidence level does not indicate any statistically significant trend is present.

PN – Figure 3-7

Local fruit and vegetables collected around the PN site had HTO concentrations above the background average. The 2014 average concentration of HTO was 98.6 Bq/L in fruits and 75.6 Bq/L in vegetables. Figure 3-7 illustrates the combined PN fruit and vegetable HTO results over the past 10 years. The increase observed in 2014 reflects the increase in HTO emissions from PN. A Mann-Kendall trend analysis at the 95% confidence level does not indicate any statistically significant trend is present.

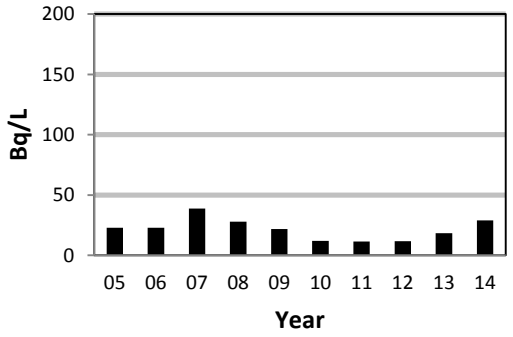

Figure 3-6: Darlington Nuclear HTO in Vegetation

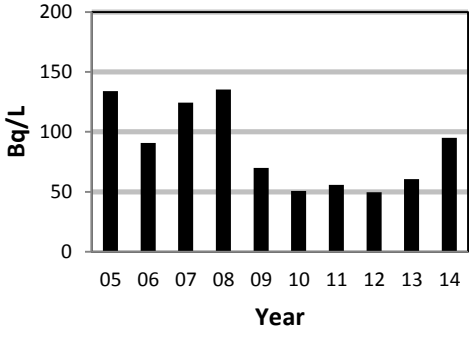

Figure 3-7: Pickering Nuclear HTO in Vegetation

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. The average C-14 concentrations measured in fruits and vegetables from the provincial-background locations in 2014 were 251 Bq/kg-C and 258 Bq/kg-C respectively.

DN – Figure 3-8

The 2014 average concentration of C-14 at DN locations was 268 Bq/kg-C in fruits and 245 Bq/kg-C in vegetables. Figure 3-8 illustrates the combined DN fruit and vegetable C-14 results over the past 10 years. 2014 concentrations remain consistent with past results. A Mann-Kendall trend analysis at the 95% confidence level does not indicate any statistically significant trends for DN C-14 in vegetation over the past 10 years.

PN – Figure 3-9

The 2014 average concentration of C-14 at PN locations was 329 Bq/kg-C in fruits and 286 Bq/kg-C in vegetables. Figure 3-9 illustrates the combined PN fruit and vegetable C-14 results over the past 10 years. A Mann-Kendall trend analysis at the 95% confidence level does not indicate any statistically significant trends for PN C-14 in vegetation over the past 10 years.

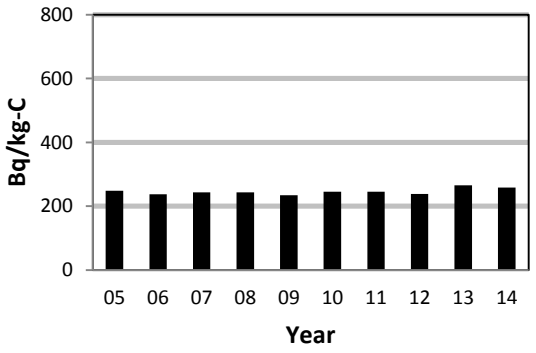

Figure 3-8: Darlington Nuclear C-14 in Vegetation

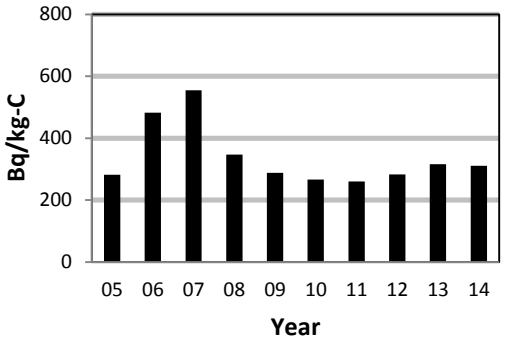

Figure 3-9: Pickering Nuclear C-14 in Vegetation

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 critical group. Milk consumed by other members of the public comes from a commercial dairy whose product consists of a composite from many dairy farms across Ontario. Values in this report are only applicable to residents of the surrounding dairy farms consuming 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 the three dairy farms around DN and two dairy farms located around PN. Darlington dairy farm location DF5 was replaced with DF9 in 2014 as DF5 is no longer a dairy farm producing milk. Quarterly milk samples are collected from one dairy farm in 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. It is collected from one dairy farm around PN twice a year, with four replicates collected per visit, and from one background location twice a year, with four replicates collected per visit. Animal feed is analysed for HTO and C-14.

Annual average values of HTO and C-14 in milk and animal feed are provided in Appendix D, Table D6 and D5, 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. Furthermore, the number and location of dairy farms sampled at both PN and DN have changed over the years, which should be considered when reviewing Figures 3-10 and 3-11.

Tritium Oxide

The background average HTO in milk concentration was below the Lc of 2.3 Bq/L based on sampling at one farm outside the influence of the stations.

As expected, both the DN and PN values of HTO in milk were above the background average concentration.

DN – Figure 3-10

The 2014 average level of HTO in milk was 7.3 Bq/L based on three dairy farms around DN. The slight increase from 2013 is attributed to the increase in DN station emissions. Overall, the 2014 results were in line with levels observed over the past 10 years. Figure 3-10 illustrates DN HTO in milk results over the past 10 years, and a Mann-Kendall trend analysis at the 95% confidence level does not indicate that any statistically significant trend is present.

PN – Figure 3-11

For the PN site, the average concentration of HTO in milk was 14.6 Bq/L in 2014 based on two dairy farms located within 12 km of the site. There was no change to the dairy farm sampling locations for PN in 2014, and the average is in line with that of 2013. 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 statistically significant decreasing trend for PN HTO in milk over the past 10 years.

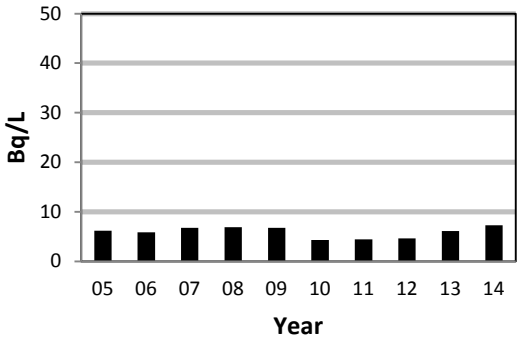

Figure 3-10: Darlington Nuclear HTO in Milk

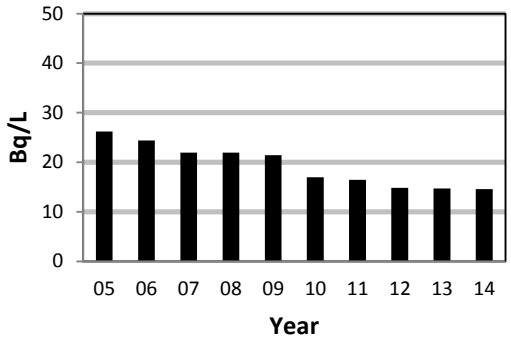

Figure 3-11: Pickering Nuclear HTO in Milk

Carbon-14

The background average C-14 in milk sampled from one dairy farm on a quarterly basis was 236 Bq/kg-C. The 2014 C-14 levels in milk measured at the dairy farms around DN and PN were only slightly above the background level.

The C-14 level in animal feed consumed by the cows is the main contributing factor to the C-14 levels in milk. The 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 local feed sources.

DN – Figure 3-12

The 2014 average concentration of C-14 in milk from dairy farm locations in the vicinity of DN was 240 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 trends for DN C-14 in milk over the past 10 years.

The average C-14 concentration in animal feed was 247 Bq/kg-C for wet feed (forage) and 235 Bq/kg-C for dry feed (grains, hay etc.). No trend analysis was performed on animal feed given that 2013 was the first year that wet feed and dry feed was sampled separately and changes to sampling frequency and replicates were incorporated.

PN – Figure 3-13

The 2014 average concentration of C-14 in milk from dairy farm locations in the vicinity of PN was 242 Bq/kg-C. Figure 3-13 illustrates that C-14 levels in milk around PN 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 trends for PN C-14 in milk over the past 10 years.

The average C-14 concentration in animal feed was 259 Bq/kg-C for both wet feed and dry feed. No trend analysis was performed on animal feed given that 2013 was the first year that wet feed and dry feed were sampled separately and changes to sampling frequency and replicates were incorporated.

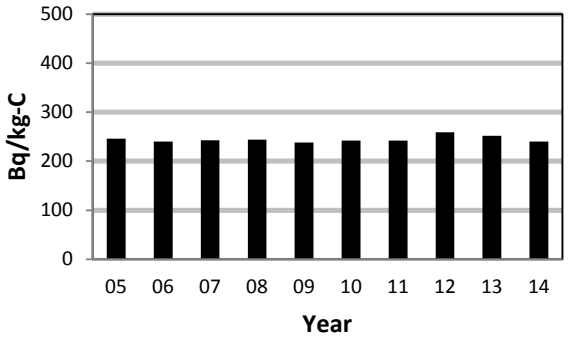

Figure 3-12: Darlington Nuclear C-14 in Milk

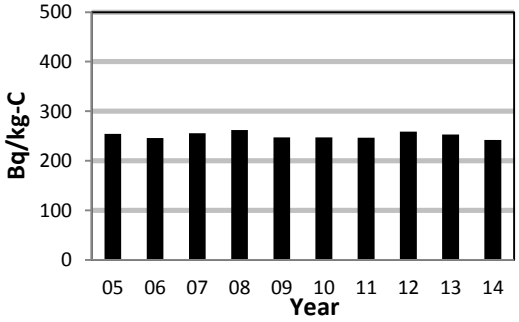

Figure 3-13: Pickering Nuclear C-14 in Milk

3.3.3.3 Eggs and Poultry

Eggs and poultry were added to the EMP sampling program in 2013. 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, formerly known as DF5) and one farm location is sampled for poultry (F16). Sampling from DN location F38 was discontinued in 2014 as the participant has moved. No farm locations selling fresh eggs and poultry could be identified in the PN vicinity, and therefore these pathways continue to be modelled for PN. One background location is sampled for both eggs and poultry at the frequencies specified above.

The background concentration of HTO was 4.2 Bq/L for poultry and 2.6 Bq/L for eggs. The background concentration of C-14 was 244 Bq/kg-C for poultry and 235 Bq/kg-C for eggs.

As expected, the concentrations of HTO and C-14 in eggs and poultry for the DN sampling location were above background. HTO in DN eggs was 3.6 Bq/L and HTO in poultry was 13.2 Bq/L. C-14 in DN eggs was 243 Bq/kg-C and C-14 in poultry was 230 Bq/kg-C. Refer to Table D6 in Appendix D for detailed data. No trend graph is provided in this report for eggs and poultry as there is only one year of historical data for these sample media.

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 2012. Therefore, no sampling of soil was conducted in 2014. The 2012 results for soil sampling are provided in the 2012 Results of Radiological Environmental Monitoring Programs report [R-19].

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 D11, 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 were well below the Ontario Drinking Water Quality Standard of 7,000 Bq/L [R-20].

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, included 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 2014 was conservatively estimated to be 1.4 Bq/L, using the Great Lakes Time-Concentration Tritium Model [R-21].

The WSPs annual average concentrations of tritium in drinking water are shown in Figures 3-14 through 3-20. A statistical trend analysis was performed for each WSP over a 10 year period.

DN – Figures 3-14 to 3-16

Annual average HTO concentrations measured at the Bowmanville, Newcastle, and Oshawa WSPs ranged from 4.6 to 5.8 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 at Oshawa WSP. No statistically significant trends were observed for the Bowmanville and Newcastle WSP locations.

PN – Figure 3-17 to 3-20

Annual average HTO concentrations measured at the Ajax, Horgan, Harris, and Whitby WSPs ranged from 4.0 to 5.1 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 at all PN WSP locations.

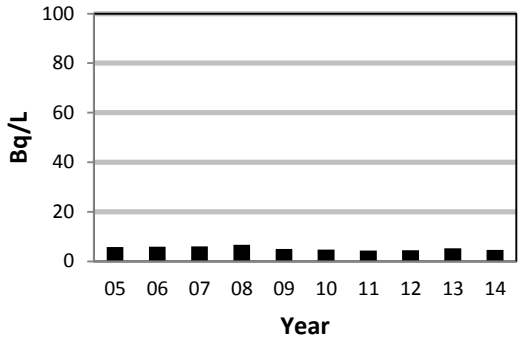

Figure 3-14: Bowmanville WSP – HTO in Water

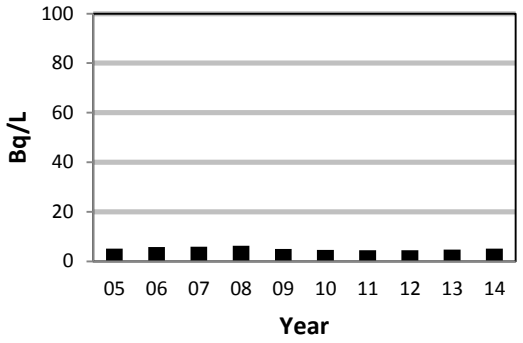

Figure 3-15: Newcastle WSP – HTO in Water

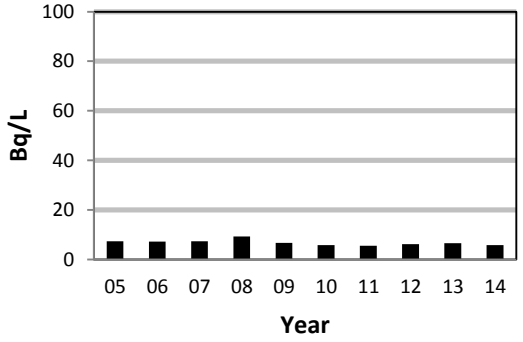

Figure 3-16: Oshawa WSP – HTO in Water

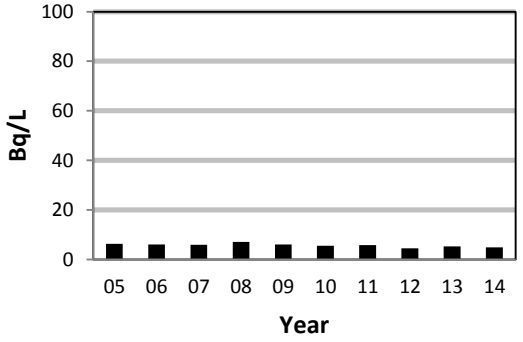

Figure 3-17: Ajax WSP – HTO in Water

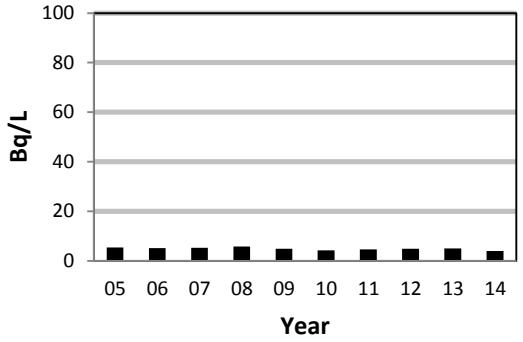

Figure 3-18: Scarborough Horgan WSP – HTO in Water

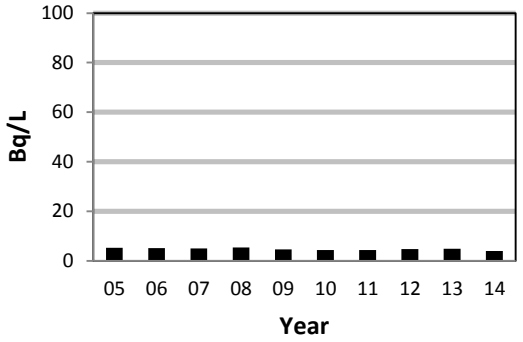

Figure 3-19: Toronto Harris WSP – HTO in Water

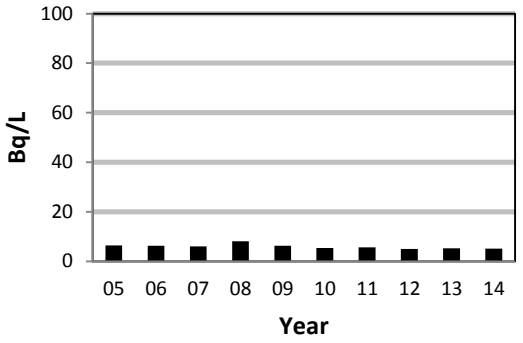

Figure 3-20: Whitby WSP – HTO in Water

Gross Beta

Annual average gross beta activity levels in samples from DN and PN area WSPs were 0.13 Bq/L and 0.14 Bq/L, respectively. These results are well below the gross beta activity screening level of 1 Bq/L, which is both an internal OPG level and a level recommended by Health Canada [R-22].

3.3.4.2 Well Water

Monthly well water samples are collected from three wells around the DN area for public dose purposes. In 2014, samples were also collected from a fourth location, R320, until the participant moved away and was replaced by location R316. Monthly well water samples are collected from two wells around the PN area. The wells sampled represent the critical groups for which the annual public dose is calculated under the new EMP design. Samples are analyzed monthly for HTO at PN and DN locations. 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.

For the purpose of statistical trend analyses, in Figures 3-21 and 3-22 only well water sampling locations which have been sampled for the past 10 years for PN and DN were used in order to provide a representative comparison. For PN this includes locations DF8 and R143, and for DN this includes locations DF12, R2, R316, R320, and R329.

DN – Figure 3-21

The 2014 annual average HTO concentration observed in well water samples collected from the DN area was 10.0 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 3-22

The 2014 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 indicates a decreasing trend for PN HTO in well water.

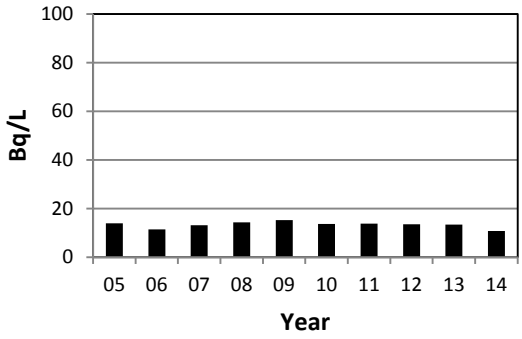

Figure 3-21: Darlington Nuclear HTO in Well Water

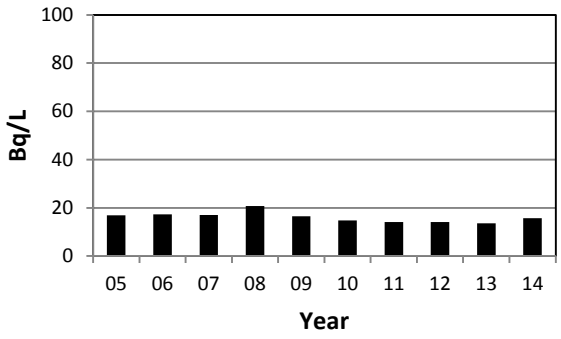

Figure 3-22: Pickering Nuclear HTO in Well Water

3.3.4.3 Lake Water

Lake water (non-drinking water) is sampled from three beaches in the vicinity of PN and three beaches in the vicinity of DN on a monthly basis and analysed for HTO. It is used to assess the water immersion dose exposure pathway from swimming. 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 3-23

The 2014 annual average HTO concentration observed in lake water samples collected from three beaches in the DN area was 17.9 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 3-24

The 2014 annual average HTO concentration observed in lake water samples collected from three beaches in the PN area was 21.2 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 PN HTO in lake water. Figure 3-24 generally aligns with station waterborne HTO emissions as shown in Figure 2-7.

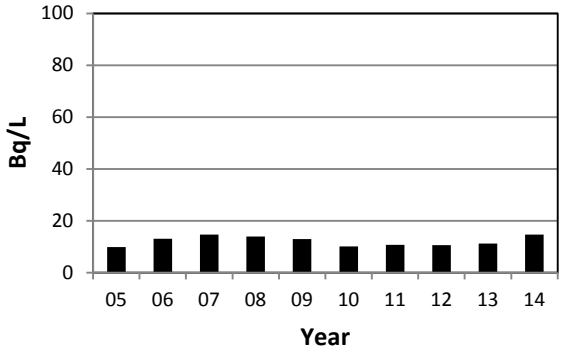

Figure 3-23: Darlington Nuclear HTO in Lake Water

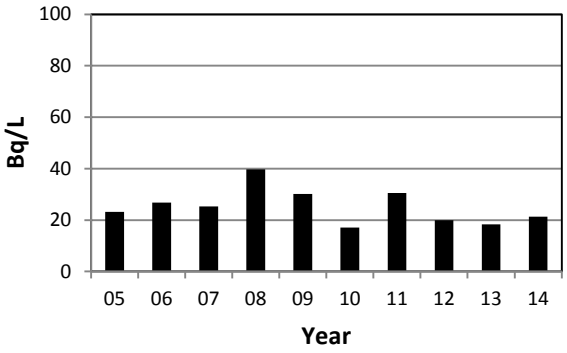

Figure 3-24: Pickering Nuclear HTO in Lake Water

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 were previously taken from the New York side of Lake Ontario. However, due to an unreliable fish supply, the background location was changed in 2011 to the Bay of Quinte area of Lake Ontario, which is a sufficient distance away from the influence of the stations.

- The target fish species to be collected at DN, PN, and at background locations is White Sucker, with Brown Bullhead as the backup species. Lake Ontario whitefish sampling was discontinued in 2012 [R-23] to reduce unnecessary mortality of this 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 station 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 3-25 and 3-26. In 2014, the HTO in Lake Ontario background fish samples averaged 2.1 Bq/L.

DN – Figure 3-25

The HTO levels in the DN outfall fish samples averaged 5.5 Bq/L. This value is similar to the levels observed in previous years. Based on the past 10 years of data, a Mann-Kendall trend analysis at the 95% confidence level does not indicate any statistically significant trends for HTO in DN fish.

PN – Figure 3-26

The HTO concentration in the PN outfall fish samples averaged 5.8 Bq/L. This value is similar to levels observed in previous years. Based on the past 10 years of data, a Mann-Kendall trend analysis at the 95% confidence level does not indicate any statistically significant trends for HTO in PN fish.

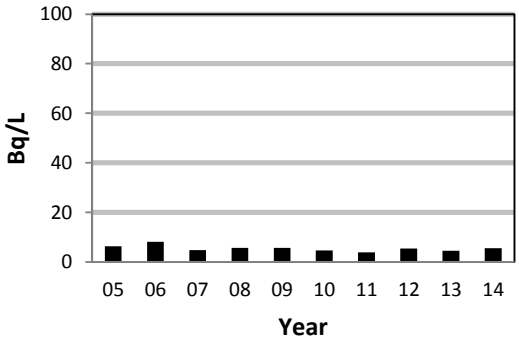

Figure 3-25: Darlington Nuclear HTO in Fish

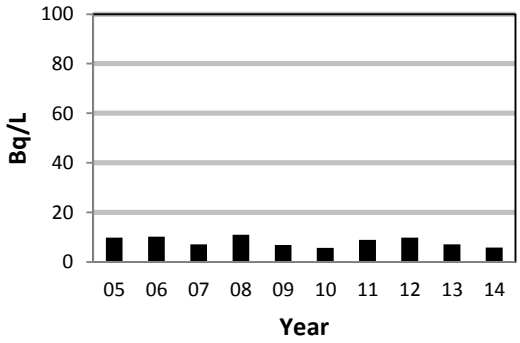

Figure 3-26: Pickering Nuclear HTO in Fish

Carbon-14

The average C-14 level in fish measured at a background Lake Ontario location was 220 Bq/kg-C in 2014.

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 3-27 and 3-28.

DN – Figure 3-27

The 2014 annual average C-14 level in DN fish was 230 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 trends for C-14 in DN fish.

PN – Figure 3-28

The 2014 annual average C-14 level in PN fish was 252 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 trends for C-14 in PN fish.

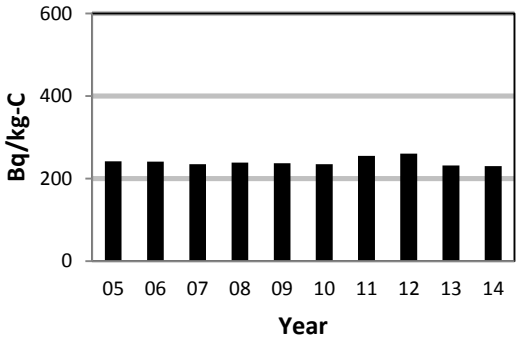

Figure 3-27: Darlington Nuclear C-14 in Fish

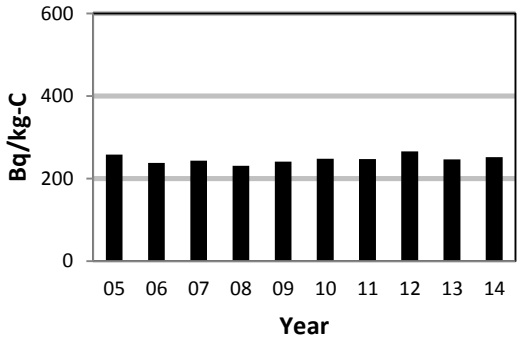

Figure 3-28: Pickering Nuclear C-14 in Fish

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 0.4 Bq/kg.

Figures 3-29 and 3-30 illustrate that the Cs-137 levels in fish around DN and PN in 2014 are consistent with previous years.

DN – Figure 3-29

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 2014.

PN – Figure 3-30

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 2014.

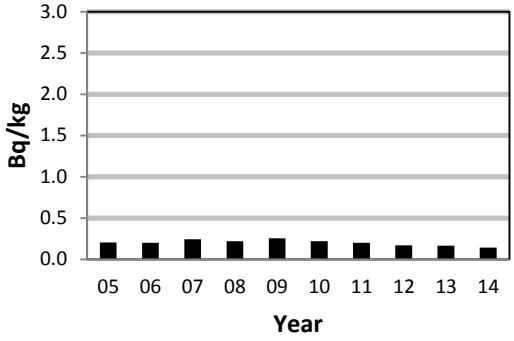

Figure 3-29: Darlington Nuclear Cs-137 in Fish

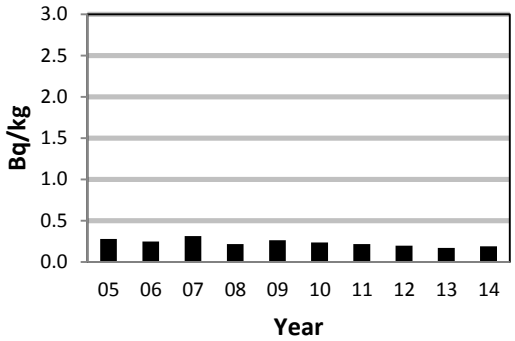

Figure 3-30: Pickering Nuclear Cs-137 in Fish

3.3.4.5 Beach Sand

Sand from three beaches around DN and three beaches around PN is collected annually as it represents 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/silt are provided in Appendix D, Table D10.

Gamma Spectrometry

Background Cs-137 concentrations in beach sand samples measured at Cobourg averaged 0.4 Bq/kg in 2014. These values are consistent with values observed over the past five years.

DN

The average concentration of Cs-137 measured in DN beach sand was 0.1 Bq/kg for the year. Similar to previous years, there was no Co-60 detected in any of the samples and only one sample out of eight where Cs-134 was detected. In 2014, only one out of three DN beach sand sampling locations was sampled due to accessibility issues with the other two locations. This caused the unavailability limit for DN beach sand to be exceeded as discussed in Section 5.5.1 of this report. Dose resulting from exposure to DN beach sand was conservatively modelled from emissions in 2014.

PN

The average concentration of Cs-137 measured at PN area beaches ranged from 0.5 to 0.6 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 close 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

CSA N288.4-10 recommends that monitoring of sediments should be focused on depositional areas where sediment and associated contaminants are expected to accumulate. This will represent the highest potential exposure levels for sediment-associated natural biota. Sampling of very dynamic sediments is problematic and generally not needed. To align the EMP sediment sampling program with the CSA N288.4-10 recommendation, a study was commissioned by the Candu Owners Group (COG) in 2011 to identify the sediment depositional areas near Canadian nuclear facilities [R-24]. Prior to this study the locations of sediment sampling were based on proximity to the effluent discharge and not always located where sediment deposition occurs.

COG study COG-12-3045 identified the nearest sediment depositional area near PN to be inside the mouth of Frenchman's Bay. Extensive sampling and radionuclide analyses were conducted in this location as part of the study in 2011. The results have been summarized in Appendix D Table 11 of this report. The Frenchman's Bay location will be used for future sediment sampling conducted every 5 years based on consideration of the rate of sediment deposition in the Great Lakes. The next PN EMP sediment sampling will take place in 2016.

COG-12-3045 concluded that there were no depositional areas for sediment near DN, and further sampling was not needed as it would not provide information on radionuclide accumulation. Going forward, sediment sampling will no longer be conducted as part of the DN EMP.

In addition, COG-12-3045 recommended that OPG find a more suitable sediment depositional reference area in Lake Ontario to more closely match the characteristics of Frenchman's Bay. The details and results of this study are presented in section 3.5.1 of this report.

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 EMP until the objective of the study has been achieved. At that time, the supplementary study is terminated.

In 2014 OPG conducted two supplementary studies in support of the PN and DN EMPs.

(a) Hydrazine in Lake Water near PN.

(b) Chlorine and Morpholine in Lake Water near DN.

The following sections provide a description and the results of each study.

3.4.1 Pickering EMP Supplementary Study- Hydrazine in Lake Water

The updated 2013 PN ERA [R-16] identified hydrazine in drinking water as a potential environmental and human health risk. However, there was significant uncertainty associated with this risk estimate since all the analyses were censored as being less than the detection limit of 5 ug/L. In 2014, OPG contracted EcoMetrix Inc. to determine if the hydrazine concentrations in Lake Ontario near the PN outfalls and in Frenchman's Bay pose risks to:

(a) Humans (through drinking water and fish consumption); and

(b) Invertebrates and aquatic plants through exposure to lake water.

To address this objective samples were submitted to a laboratory that was capable of obtaining a detection limit of 1 µg/L or less, a substantial reduction compared to the minimum Ld of 5 µg/L used previously.

The following sections outline the sampling plan, selected benchmarks, data analysis, results and conclusions from the PN hydrazine in lake water supplementary study conducted by EcoMetrix Inc. [R-25].

3.4.1.1 Sampling Plan

- Three sampling events (22 July, 15 August and 10 September 2014);
- Three locations at the PN-A and PN-B outfalls (~100 m, 250 m and 500 m from discharge), see Figure H-1 in Appendix H;
- Two downstream locations (500 m and 1000 m downstream of PN according to the plume direction at time of sampling);
- Samples collected at top, middle and bottom of the water column at all locations;

3.4.1.2 Benchmarks - Hydrazine

Hydrazine concentrations were compared to chronic benchmark values for protection of drinking water, fish ingestion, aquatic invertebrates and aquatic plants. These benchmark values were generally consistent with those used in the 2013 PN ERA [R-16] with the exception of the benchmark for the risk to aquatic plants. A value of 1.2 µg/L was used in the ERA, whereas in this document a value of 2.6 µg/L was used for interpretation. This is the concentration recommended by Environment Canada as the Federal Water Quality Guideline for hydrazine to be protective of all aquatic species [R-26]. Table 3-3 summarizes the benchmarks used in the analysis.

Table 3-3: Selected Benchmarks for Hydrazine

Receptor	Toxicity Reference Value/ Cancer Risk Value	Remarks
Drinking Water	0.36 ug/L	10^{-5} cancer risk (Health Canada)
	0.036 ug/L	10^{-6} cancer risk (CSA, EPA, MOECC)
Fish Ingestion	1.5 ug/L	10^{-5} cancer risk (Health Canada)
Risk to Aquatic Invertebrates	4 ug/L	Fisher et al., 1999* [R-27]
Risk to Aquatic Plants	2.6 ug/L	Environment Canada, 2013 [R-26]

*LC50 (48 hour) converted to chronic

3.4.1.3 Results

Hydrazine concentrations in Lake Ontario near PNGS during the sampling program ranged from < 0.05 to 0.25 ug/L, with 50% or more of the results during each sampling event being less than the detection limit. Table 3-4 provides a summary of the 95th percentile concentrations and detailed results are provided in Appendix H. The 95th percentile concentrations were used to represent the exposure concentrations due to the large number of non-detects in the data set.

Table 3-4: Hydrazine Concentration in Lake Ontario near PNGS

Sampling Period	95th percentile hydrazine concentration (ug/L)	
	All data points	PN-A and PN-B outfall only
July	0.14	0.16
August	0.068	0.066
September	< 0.05	< 0.05

3.4.1.4 Comparison to Benchmarks

The exposure concentrations were compared to their respective benchmark values identified in Section 3.4.1.2 above. A summary of these results is provided in Table 3-5.

Table 3-5: Exposure Concentrations Comparison to Selected Benchmarks for Hydrazine

Receptor	Toxicity Reference Value/ Cancer Risk Value	Exposure Concentration (ug/L)	
		July	August
Drinking Water	0.36 ug/L	0.015	0.006
	0.036 ug/L		
Fish Ingestion	1.5 ug/L	0.140	0.0684
Risk to Aquatic Invertebrates	4 ug/L	0.140	0.0684
Risk to Aquatic Plants	2.6 ug/L	0.052	0.022

Note: Exposure concentrations from September are not presented since all the measurements were below the detection limit.

The 95th percentile concentrations of hydrazine from the PN-A and PN-B outfalls were used to calculate concentrations for the Ajax WSP intake and aquatic plants within Frenchman's Bay.

- For Ajax WSP drinking water, the degradation half-life of 1.3 days was used to determine the decayed concentration prior to applying the estimated dilution factor of 8 to obtain the exposure concentration for the Ajax WSP. Ajax WSP is located 6.5 km east of PNGS.

- For aquatic plants, a dilution factor of 3, based on the PN ERA [R-16] was used to obtain the exposure concentration for Frenchman's Bay water. Frenchman's Bay is located 1.5 km west of PN.

The 95th percentile of concentration of hydrazine in the 1 km^2 area in the vicinity of PN was used as the exposure concentration for fish and aquatic invertebrate. Using all the data for a 1 km^2 area is considered appropriate because exposed fish are mobile and do not always remain in the area of the highest concentration. Similarly, planktonic invertebrates drift over a chronic exposure period.

All the calculated exposure concentrations were less than their lowest chronic exposure benchmark values, as demonstrated in Table 3-5.

3.4.1.5 Conclusions and Recommendations

The results of the supplementary study on hydrazine concentrations in Lake Ontario water near the PN facility indicate that no human health or ecological effects are expected. The concentrations of hydrazine were below all benchmarks for the various receptors identified in the PN ERA. The objective of the supplementary study has been achieved and as such, this study and all associated sampling can be removed from the EMP.

3.4.2 Darlington EMP Supplementary Study – Chlorine and Morpholine in Lake Water

Chlorine

The DN facility made changes to its chlorination process subsequent to the completion of the most recent EA [R-13]. The change in the process included increasing the chlorination in response to zebra mussel infestations. Chlorination to prevent zebra mussels is followed by dechlorination to limit TRC input to the lake.

Morpholine

At the time that the DN refurbishment ERA was conducted [R-14], morpholine was used as a boiler feed chemical in one of the DN units on a trial basis. Morpholine is now used in all units.

In 2014 OPG contracted EcoMetrix Inc. to conduct lake water sampling for TRC and morpholine near the DNGS discharge to determine if:

(a) TRC concentrations remain below the PWQO of 2 µg/L, and less than the toxicity reference values for aquatic life.

(b) Morpholine concentrations are less that the interim PWQO of 4 µg/L and the toxicity reference values for aquatic life.

The following sections outline the sampling plan, selected benchmarks, data analysis, results and conclusions from the DN morpholine and chlorine in lake water supplementary study conducted by EcoMetrix Inc. [R-28].

3.4.2.1 Sampling Plan

- Three sampling events (26 June, 14 August and 9 September 2014);
- Three locations along the diffuser near shore, mid-point, and far end), see Figure I-1 in Appendix I;
- Two downstream locations (500 m and 1000 m downstream of the diffuser according to the plume direction at time of sampling);
- Samples collected at top, middle and bottom of the water column at all locations.

3.4.2.2 Benchmarks – Chlorine and Morpholine

Morpholine and TRC data were compared to their respective PWQO and the toxicity reference values identified in the PN ERA [R-16]. Table 3-6 summarizes the benchmarks used in the analysis.

Table 3-6: Selected Benchmarks for Morpholine and Chlorine

Parameter	Benchmark Type	Value	Remarks
Morpholine	Interim PWQO (1) Toxicity reference values for chronic exposure	4 ug/L 2,800 ug/L 10,000 ug/L 18,000 ug/L	MOEE, 1994 [R-29] Aquatic Plant [R-30] Aquatic Invertebrate [R-30] Fish and Frog [R-30]
TRC	PWQO Toxicity reference values for chronic exposure	2 ug/L 5ug/L 3.2 ug/L 5.9 ug/L	MOEE, 1994 [R-29] Aquatic Plants [R-31] Aquatic Invertebrate [R-27] Fish and Frog [R-27]

(1) The interim PWQO for morpholine was set for emergency purposes using readily available data and a large application factor. The MOECC advises caution when applying such values. They are conservative screening values, not closely tied to toxicological data.

3.4.2.3 Results and Comparison to Benchmarks

All samples of morpholine and TRC collected in all three sampling events were less than their method detection limits of 1 ug/L and 1.2 ug/L, respectively. Detailed results are provided in Appendix I.

Consequently the exposure point concentration for morpholine is < 1 µg/L, and < 1.2 ug/L for TRC, both of which are less than the lowest benchmark value presented in Table 3-6.

3.4.2.4 Conclusions and Recommendations

The results of the supplementary study on chlorine and morpholine indicate that there is no risk of ecological effects from these chemicals in Lake Ontario near the Darlington Nuclear facility. The objective of the supplementary study has been achieved and as such, this study and all associated sampling can be removed from the EMP.

3.5 Other Studies

3.5.1 Lake Ontario Reference Location for Sediment

COG study COG-12-3045 was conducted in 2011 to identify the sediment depositional areas near Canadian nuclear facilities. As part of this study, Picton Bay was chosen as the reference location for PN. Subsequent analysis of the sediments from Picton Bay indicated levels of radionuclides, particularly Cs-137, that were higher than anticipated for a reference location. These levels, at least partly related to high total organic carbon (TOC) in Picton Bay, were not observed in sediments from Frenchman's Bay near PN. It was recommended that a more suitable reference area be established in Lake Ontario to more closely match the characteristics of Frenchman's Bay. In 2014, EcoMetrix Inc. was engaged by OPG to conduct additional sediment investigations in Lake Ontario to locate an appropriate reference location for use in the EMP program.

Candidate sampling areas were selected based on habitat similarity to Frenchman's Bay. Three areas were selected in eastern Lake Ontario (i.e., West Lake, Wellers Bay and Presqu'ile Bay) and one area was selected in western Lake Ontario (i.e., Jordan Harbour). The surficial 5 cm were collected at ten locations in each area. Samples were analysed for particle size, TOC and radionuclides Cs-137, C-14 and K-40.

The criteria used for selection of a reference location were:

1) Uninfluenced by station;

2) Matching physical nature and habitat of the area;

3) Matching TOC concentrations; and,

4) Matching particle size distribution

Comparison to a reference area with sediments of similar particle size and TOC to Frenchman's Bay is the best way to determine if there is an impact in Frenchman's Bay from the facilities. Previous research indicates that sediment organic content and grain size are more important in determining Cs-137 concentrations in sediment than proximity to the nuclear facilities. This is supported by the 2014 Ecometrix Inc. study and the findings from COG-12-3045.

The TOC and particle size of sediment from Presqu'ile Bay was found to be very similar to that of Frenchman's Bay. The Cs-137 concentrations were found to be slightly lower with similar variability when plotted against TOC. Therefore, the conclusion of the study was that the most appropriate area for future reference area sampling is Presqu'ile Bay. The full study is documented in Ecometrix Inc. report, Lake Ontario Sediment Reference Location for Radionuclide Concentrations – 2014 [R-32].

3.5.2 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-33] default cesium bioaccumulation factor (Cs BAF) for fish of 3,500, which is used for the calculation of station 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-34]. This study is conducted once every three years [R-35]. The next potassium in lake water measurements will take place in 2016.

3.6 Areas of Regulatory Interest and Other Monitoring Programs

While the primary focus of this report is the results of 2014 monitoring conducted in support of the annual public dose calculation, the overall EMP encompasses 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 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 system has potential to impact the spawning success and larvae development of round whitefish. Whitefish spawn in Lake Ontario in the late fall on coarse substrates (gravel or cobble) between the depths of 3 to 12 m. Their eggs develop over the winter and larvae emerge in early spring.

In 2008, the CNSC requested PN to undertake studies to determine the impact of the thermal plume. A three year thermal monitoring program was completed and an overall summary of the program submitted to CNSC in 2013 [R-36]. Plume temperatures were monitored at 16 locations between the PN discharge and Duffins Creek. Lake background (reference) temperatures were monitored at 7 locations near Thickson Point and Bonnie Brae Point. The impacts were assessed using the survival model developed by Environment Canada. The conclusion of the study was that the thermal plume represents minimal risk to the round whitefish spawning in the area.

For DN, a thermal monitoring program was initiated in January 2011 and concluded in May 2012 to support the DN Refurbishment and Continued Operation Environmental Assessment. The study concluded that the effects of temperature increases from DN CCW diffuser discharge on the local round whitefish population, even under unusually warm winter conditions of 2011/12, are minor and limited to a small area around the offshore end of the diffuser. The study confirmed that the current performance of the diffuser is consistent with the original design expectation and is effective in protecting round whitefish populations [R-37].

In 2014, COG study COG-13-3025 -Effects of Fixed and Fluctuating Temperatures on Mortality and Hatch of Round Whitefish and Lake Whitefish Eggs, was issued [R-38]. 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.

3.6.2 Impingement and Entrainment Monitoring Program

In October of 2008 the CNSC issued a directive to OPG to reduce impingement of all species of fish at PN by 80%. To meet this requirement, PN installed a barrier net (or Fish Diversion System (FDS)) covering the entire intake channel in 2009. Based on monitoring results in 2010 and 2011, the CNSC has accepted the FDS as meeting the reduction target. Annual reporting of fish impingement is required by the CNSC to ensure ongoing compliance with reduction targets. Results of the 2013 monitoring program are presented in Pickering Nuclear Generating Station 2013 Impingement Monitoring Report [R-39]. The biomass impinged in 2013 was estimated to be 2,926 kg, or 0.6 kg/million m^3 of station flow. This met the reduction target for the FDS. In addition, a project was initiated in 2014 to improve approximately 3 ha of wetland habitat at Duffins Creek to offset residual impingement. Entrainment cannot be practically reduced, but equivalent ecological benefit was realized by undertaking a fish stocking program [R-40].

The DN intake is different in design to the intake at PN as it incorporates features to prevent entrapment of large schools of fish by being located off-shore (10 to 12 m depth) and ensuring flow velocities do not exceed the swimming capacities of prevalent schooling species. Since the DN intake was designed with fish protection issues in mind, the operation of DN has resulted in relatively low estimated losses of fish from impingement and entrainment.

3.6.3 Groundwater Monitoring Program

In 2013, PN and DN completed annual groundwater monitoring programs to evaluate groundwater quality across the sites and to detect any emergent issues.

Both groundwater monitoring programs occurred from January 1 to December 31 2013, with 237 groundwater monitoring wells sampled in total for tritium, the key contaminant of concern. Within certain areas, samples were also analyzed for select hazardous substances, such as petroleum hydrocarbons (PHCs), volatile organic compounds (VOCs), metals, and chloride due to historical impact.

As expected, the 2013 groundwater monitoring results did not differ appreciably from the results of previous years. In general, tritium trends over time show levels which have remained nearly constant or have decreased, indicating stable or improved environmental performance. However, there are isolated cases where tritium concentrations have shown increases. Where unexpected tritium concentrations were identified, investigations were completed to determine the root cause and 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 Nuclear Generating Stations. The effective dose limit for members of the public as set out in the Radiation Protection Regulations [R-41] is 1,000 uSv/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 stations, and to demonstrate that these doses remain below the regulatory limit.

The doses are based, as much as possible, on environmental concentrations of radionuclides measured at the potential critical group locations and surrounding environment. For the radionuclides and pathways where environmental measurements were not available, dose was 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-42]. Assumptions, modeling parameters, and mean intake rates were used in accordance with CSA N288.1-08 [R-33]. Annual average meteorological data were used along with local intake fractions and representative locations for critical groups identified in the site-specific survey reviews [R-43] [R-44], incorporating any recent changes. Appendix F provides details on how the data were used.

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

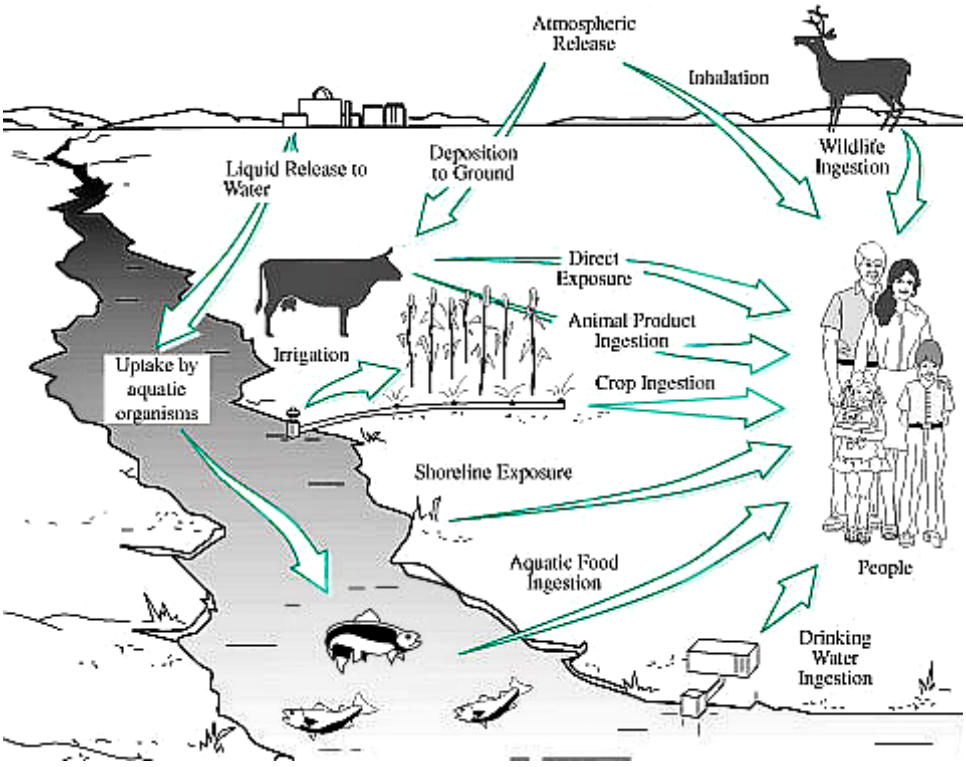

Figure 4-1: Model of Exposure Pathways from Station Emissions

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

4.1 Atmospheric Modelling

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

The IMPACT version 5.4.0 program was used to calculate doses to the critical groups using 2014 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-33].

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 station 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 station 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 station 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 – 2014

INDICATOR SITES	Measured Average Airborne Tritium Concentration (Bq/m^3)	Measured Ka (s/m^3)
D1 – Southeast Fence	2.02	2.3E-07
D2 – East Fence	1.56	1.8E-07
D5 – Knight Road	0.49	5.8E-08
D9- Courtice WPCP	0.61	7.10E-08
DF5 – Holt Road	0.34	3.95E-08
Average		**1.2E-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 – 2014

INDICATOR SITES	Measured Average Airborne Tritium Concentration (Bq/m^3)	Measured Ka (s/m^3)
P2 – Montgomery Park Rd.	11.46	6.8E-07
P3 – Sandy Beach Rd.	2.73	1.6E-07
P4 – Liverpool Rd.	1.08	6.4E-08
P6 – East Boundary	5.89	3.5E-07
P10 – Central Maintenance –East	8.66	5.1E-07
P11 – Alex Robertson Park	2.20	1.3E-07
Average		**3.2E-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 2014 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 critical group locations where measured data is not available (such as pathways for I(mfp), Co-60, Cs-137+ and HT). In 2014, the wind sector from which the wind predominantly blew towards the land was the SSW for both DN and PN. Table 4-3 indicates the wind frequencies blowing from each direction.

An issue with the DN meteorological tower cable connector, which has since been resolved, caused the 10m wind monitor to read incorrectly from June to November. Data from the PN meteorological tower was used to represent DN for this time period.

Table 4-3: Darlington and Pickering Nuclear – 2014 Annual Average Wind Frequency by Direction (at 10 m height)

Direction Wind Blowing From	Darlington Nuclear Wind Frequency (%)	Pickering Nuclear Wind Frequency (%)
N	9.55	8.08
NNE	6.36	4.22
NE	3.29	2.33
ENE	2.40	3.23
E	5.75	8.61
ESE	7.04	4.77
SE	5.66	3.02
SSE	2.66	1.64
S	2.49	2.81
SSW	**7.25**	**10.78**
SW	5.96	8.46
WSW	5.43	8.72
W	8.33	7.08
WNW	11.01	8.72
NW	8.83	8.99
NNW	7.99	8.51
Total	100.00	100.00

Note: Shaded fields indicate landward wind sectors.
Bolded values indicate wind sectors with the highest wind frequency for the year.

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-43] [R-44] [R-45] [R-46]. The site specific surveys identify the potential critical groups for PN and DN as discussed in Appendix E. 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 updated in 2012 and pathway analyses were updated in 2014, however these did not identify any significant changes with the potential to substantially alter the predictions of the ERAs or the implementation of the EMP. 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 will be incorporated during the next EMP revisions.

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-33]. 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 critical groups at DN and PN, i.e. the three critical groups for each site which yield the highest dose estimates based on the last pathway analyses. For DN these are the dairy farm, the farm, and the rural resident. For PN these are the industrial/commercial worker, the urban resident, and the occupants of a correctional institute. Additionally, the annual public dose is also calculated for the PN dairy farm critical group, as this group is exposed to the most media types/pathways. Including this 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. The EMP sampling plan is designed to monitor for these potential critical groups.

For groups that occupy a relatively small geographic location, radionuclide measurements taken at that location were 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 were determined for a single conservative representative location, and group average values were used for terrestrial samples and water sources.

A small fraction of the adult residents living near PN or DN 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 critical group workers live near PN or DN station and continue to receive a dose while at home. As a result, the dose estimates for these 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 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 modeling from emissions.

4.2.2 Age Classes

In accordance with CSA N-288.1-08 [R-33], 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-47].

4.2.3 Basis of Dose Calculation

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

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

- Doses from HTO and noble gases in air were estimated based on measurements at the fence line boundary and applying a calculated air dispersion ratio for the critical group location.

- Doses from the remaining radionuclide pathways for I(mfp), Co-60, and HT, were modeled from emissions applying the Ka dispersion factor as well as the calculated air dispersion ratio for the critical group location (see Section F.2.1)

4.2.4 Uncertainty in Dose Calculation

As described previously, the public dose estimates use a combination of measured environmental concentrations and modelled environmental concentrations of radionuclides released. A study was completed through CANDU Owners Group Inc. (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-48].

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 critical groups and their representative locations are primarily based on the DN site-specific survey review [R-43] and modified, if required, when significant changes are identified prior to the next site-specific survey review.

4.3.2 Dose Calculation Results

For 2014, the limiting critical group at DN was the Farm Adult, with a dose of 0.6 µSv/a, 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 2014 DN public dose calculation are presented in Table 4-4.

Table 4-4: 2014 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	0.3	0.3	0.4
Farm Residents	**0.6**	0.5	0.4
Rural Residents	0.3	0.2	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 almost 90% of the total dose.

Table 4-5: 2014 Darlington Nuclear Public Does (Farm Adult)

Radionuclide	Dose (µSv/a)	% Dose Contribution
C-14	7.0E-02	12%
Co-60	7.1E-03	1%
Cs-137+	1.6E-03	0%
HT	2.3E-06	0%
HTO	3.6E-01	60%
Noble Gases	1.3E-01	21%
OBT	2.9E-02	5%
I (mfp)	4.3E-03	1%
Total	6.0E-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 increase in the noble gas dose contribution as compared with previous years is reflective of a more conservative approach to noble gas data treatment, and does not indicate an increase in noble gas emissions from DN. As discussed in Section 3.3.2.3 of this report, starting in 2014 OPG used noble gas data generated by Health Canada for its public dose. Health Canada uses a higher limit of detection and censors results at the Ld. 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.

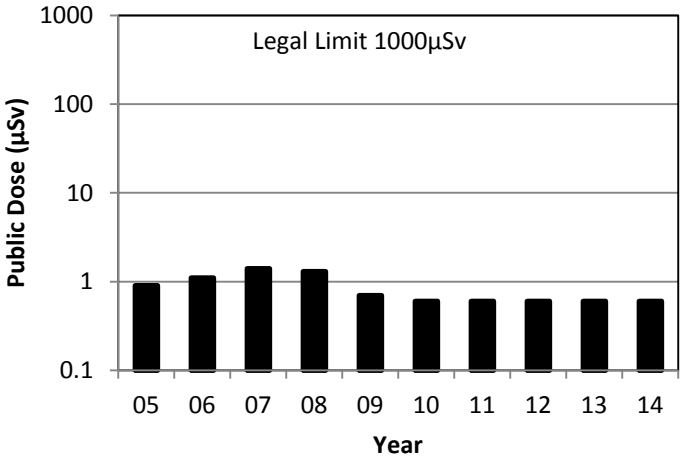

Figure 4-2: Darlington Nuclear Public Dose Trend

4.3.3 Discussion of Results

The 2014 DN site public dose of 0.6 µSv, as represented by the Farm adult, is about 0.1% of the 1000 µSv/a legal limit for a member of the public. The DN dose for 2014 is the same in both value and critical group as the 2013 site public dose for DN.

The DN dose for 2014 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/a (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.

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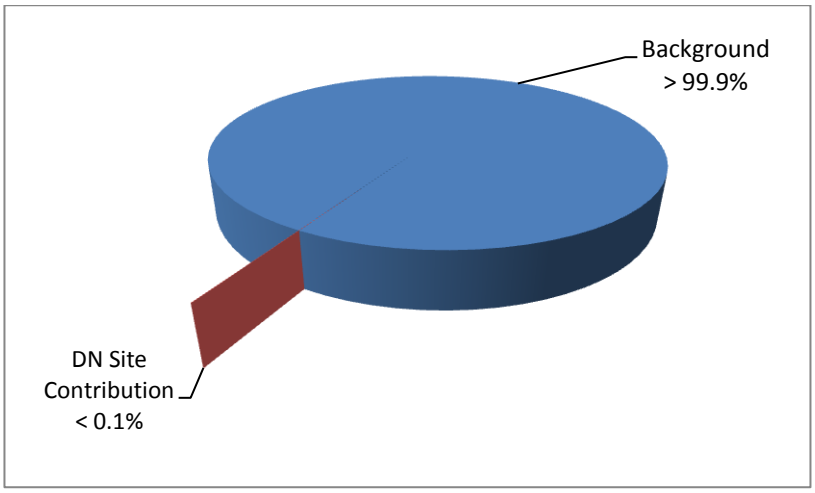

Figure 4-3: Comparison of Darlington Nuclear Public Dose to Background Dose

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-44] and modified, if required, when significant changes are identified prior to the next site-specific review cycle.

4.4.2 Dose Calculation Results

For 2014, the limiting critical group at PN was the Urban Resident adult, with a dose of 1.2 µSv/a, 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 2014 PN public dose calculation are presented in Table 4-6.

Table 4-6: 2014 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	0.3
Urban Residents	1.2	1.1	1.1
C2 Correctional Institution	0.9	1.0	
Industrial Workers	1.0		

Table 4-7 illustrates the dose from each radionuclide and percent contribution to the total dose. HTO and noble gases contribute more than 90% of the total dose.

Table 4-7: 2014 Pickering Nuclear Public Dose

Radionuclide	Dose (µSv/a)	% Dose Contribution
C-14	1.1E-02	1%
Co-60	1.9E-03	0%
Cs-137+	3.8E-02	3%
HTO	4.9E-01	41%
Noble Gases	6.4E-01	54%
OBT	2.3E-03	0%
I (mfp)	3.9E-05	0%
Total	1.2E+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.

The reduction in dose from 2005 to 2006 is due to the closure of the correctional institution (C1) and the expropriation of the Squires Beach community for the expansion of the municipal WPCP. These two former potential critical groups were located close to the station and often had the highest doses around the PN site. The reduction in dose from 2008 to 2009 is attributed to changes in methodology and transfer parameters specified by CSA N288.1-08 [R-49].

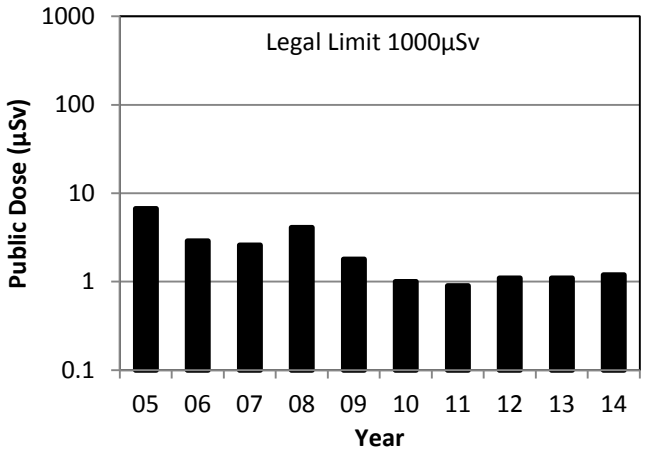

Figure 4-4: Pickering Nuclear Public Dose Trend

4.4.3 Discussion of Results

The 2014 PN site public dose of 1.2 µSv, as represented by the Urban Resident adult, is 0.1% of the 1000 µSv/a legal limit for a member of the public. The PN dose for 2014 is essentially unchanged from the 2013 site dose of 1.1 µSv.

The PN dose for 2014 was equivalent to 0.1% of the estimated background dose around PN of 1,400 µSv/a, 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.

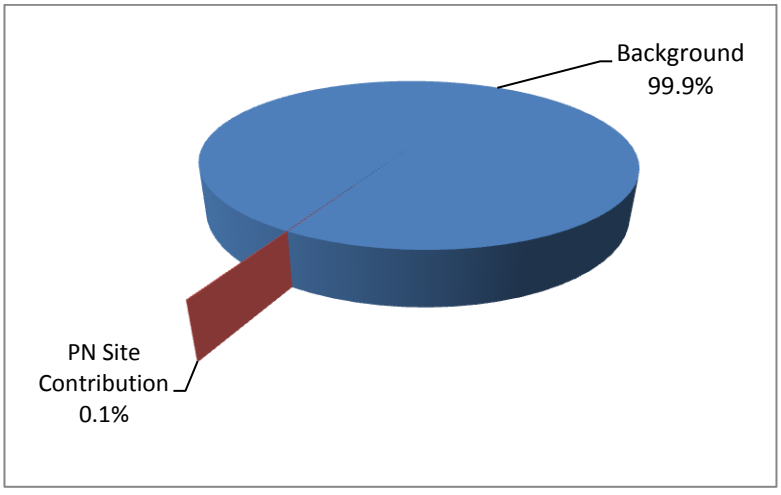

Figure 4-5: Comparison of Pickering Nuclear Public Dose to Background Dose

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-50]	4
Chest X-Ray (single film) [R-51]	10
Airplane Travel (two hour flight) [R-52]	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-53] [R-54]. 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/a 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/a. The average Canadian dose from medical sources averages 1,100 µSv/a 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-55].

5.0 QUALITY ASSURANCE AND PERFORMANCE

The Quality Assurance (QA) program for the EMPs encompasses all activities in field sample collection, laboratory analysis, laboratory quality control, and external laboratory comparison. 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 Environment and Climate Change. HPL performs laboratory activities in accordance with the OPG Dosimetry and Radiological Environmental Quality Assurance Program [R-56].

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 EMP:

(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) to be included for final analysis. The analysis of the environmental sample is considered valid when the results of the accompanying QC samples are within $\pm$ 10-20% of the known/expected values, depending on the analysis type.

For 2014, 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 to 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.

In 2014, OPG Nuclear participated in a laboratory performance testing program where Eckert and Ziegler Analytics Inc supplied the test samples [R-57]:

This program involved the measurement of tritium in water, gross beta in water, and gamma in water/drinking water.

QA test samples are supplied on a quarterly basis by Eckert and Ziegler Analytics Inc. Results of analyses are reported back to Eckert and Ziegler Analytics who then provide performance reports for each of the analytical types. The performance test limits are 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-58].

All QA performance test results in 2014 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 – 2014

Sample Types	Relative Difference (%)		Relative Precision (%)	
	High	Low	High	Low
Tritium in Water	0	-2	2	2
Gross Beta in Water	+1	-11	9	9
Gamma in Water	+29	-10	25	2

5.2 Equipment Calibrations/Maintenance

Equipment calibrations and maintenance are conducted in accordance with the Environmental Monitoring Program Equipment Maintenance Manual [R-59].

In addition, annual sensitivity checks are performed on the noble gas detectors to quantify the deterioration of the sensitivity on the sodium iodide crystal in each detector. The 2014 results indicate that detectors are functioning at acceptable levels of sensitivity [R-60].

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]. A performance based assessment was conducted from October 27th to November 7th 2014 by OPG's Nuclear Oversight department. The assessment confirmed that the EMPs are being effectively managed and are in compliance with OPG and regulatory requirements.

Minor issues identified pertaining to documentation and oversight of the EMPs did not impact overall program performance. A review of the use of organization tools, including action tracking for improvement initiatives and station condition records to identify deficiencies in overall management/operations, concluded that the tools are being applied effectively. The assessment concluded that the OPG personnel supporting the EMPs are qualified in accordance with training requirements.

A report was issued summarizing the results of the audit [R-61]. All findings were minor in nature and are being tracked though OPG's internal Action Tracking system.

5.3.2 Self-Assessments

In 2014, Environment Operations Support (EOS) performed two self-assessments on different elements of the EMPs.

(a) Program Documentation and Implementation of CSA N288.4-10

The focus of the first self-assessment was to review the PN and DN EMP documentation to verify that the requirements of CSA N288.4-10 were implemented in full. The expectation was that all "shall" clauses from CSA N288.4-10 would be implemented into the PN and DN EMPs. The majority of requirements were found to be effectively implemented. Areas for improvement identified through the self-assessment are documented in the OPG Self-Assessment Database under plan number COE14-001247 and via OPG's Action Tracking system.

(b) Preparation of Monthly Samples

Self-assessment COE14-001366 was completed on the subject of monthly sample preparation in accordance with approved laboratory procedures. Overall, the monthly sample preparation process was found to be effective and procedures adequately followed. Minor suggestions for procedural improvement were identified and have since been addressed.

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 Enviro Health Physics Consulting 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 958 laboratory analyses were performed for the 2014 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 47% and 17% 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 field 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 analyses 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-62], 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 3%, 6% and 0%, respectively. For 2014, all unavailability limits were met for individual analyses used in dose calculations with the exception of DN beach sand.

Beach sand samples were not collected from two of the three DN beach locations in 2014. West-East Beach was inaccessible due to construction fencing blocking off access to the beach, and the vegetation at McLaughlin Bay was overgrown preventing access to the shoreline. While samples from the third beach location were successfully obtained, the missing samples resulted in the 2014 unavailability limit for beach sand being exceeded. As such, DN dose from exposure to local beach sand was conservatively modelled in IMPACT for the 2014 dose calculation.

While not exceeded, the unavailability limit of 20% for PN fruits was reached in 2014. This was due to unavailability of the fruit trees from location F10, resulting in three missed fruit samples for the year. Results from F10 are used to represent the PN dairy farm critical group dose from local fruit consumption. For 2014 dose, fruit results from location DF3 were used for this purpose.

While not exceeded, the unavailability limit of 25% for DN lake water was nearly reached in 2014, with an overall unavailability of 24%. This was due to West/East Beach being inaccessible for several months of the year due to construction. The DN immersion dose from local swimming was primarily based on results from Courtice Road Beach and McLaughlin Bay in 2014.

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
		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	69	4%	5	60	57	5%	1	12	12	0%	10%
Water Supply Plants	Weekly Composite	1	48	48	0%	2	95	95	0%					15%
Residential Wells	Monthly	2	24	24	0%	3	36	34	6%					15%
Milk	Monthly	2	24	24	0%	3	34	34	0%					25%
Milk	Quarterly									1	12	12	0%	25%
Lake Water	Monthly [a]	3	24	23	4%	3	21	16	24%					25%
Fruits	Annual	5	15	12	20%	7	21	18	14%	5	10	10	0%	20%
Vegetables	Annual	5	15	15	0%	8	18	18	0%	5	10	10	0%	20%
Animal Feed	Annual	1	4	4	0%	4	8	8	0%	1	2	2	0%	25%
Poultry	Annual					1	8	8	0%	1	8	8	0%	20%
Eggs	Quarterly					1	12	12	0%	1	12	12	0%	25%
Fish	Annual	1	8	8	0%	8	8	8	0%					25%
Carbon-14														
Carbon-14 in Air	Quarterly	4	16	16	0%	4	16	16	0%	1	12	12	0%	25%
Milk	Monthly	2	24	24	0%	3	34	34	0%					10%
Milk	Quarterly									1	12	12	0%	10%
Fruits	Annual	5	15	12	20%	7	21	18	14%	5	10	10	0%	20%
Vegetables	Annual	5	15	15	0%	8	18	18	0%	5	10	10	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%	20%
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	0%					25%
Gamma														
Fish	Annual	1	8	8	0%	8	8	8	0%	1	8	8	0%	25%
Beach Sand	Annual	3	24	24	0%	3	24	8	67%	1	8	8	0%	25%
Overall dose sample Unavailability [c]			352	342	**3%**		486	454	**6%**		162	162	**0%**	

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.

5.6 Annual Assessment of the EMP

The annual assessment of OPG's 2014 EMPs is summarized as follows:

- Overall, the EMPs met their objectives in collecting environmental data for the PN and DN site public dose estimations, for supporting the DRL model and assumptions, and for confirming station emission control.

- There were no significant deficiencies in sample collection and sample analyses this year. A total of 958 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 3%, 6%, and 0% for the PN, DN, and provincial-background EMPs, respectively.

- Supplementary studies on the topics of hydrazine in lake water at PN and morpholine and chlorine in lake water at DN were conducted in order to refine the results of the most recent ERAs. These studies concluded that there is no human health risk or ecological risk from station emissions of these conventional contaminants.

- An independent audit of the EMPs was conducted by OPG's Nuclear Oversight department in 2014 with no major findings [R-61].

- Two self assessments were completed this year for the EMPs. No significant findings were identified. Minor improvements were recommended for the EMP database and monthly sampling procedures.

- An independent third-party verification of the annual dose calculations and this report was carried out by Enviro Health Physics Consulting Incorporated.

5.6.1 Summary of Darlington Results

- The main dose contributing station emissions, which include HTO, C-14, and HT emissions to air and HTO emissions to water, remained at very small fractions of their respective DRLs in 2014. Boundary noble gas detector dose rates remained below detection limits.

- 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 10.0 Bq/L.

- Concentrations of HTO in air, vegetation, milk, and fish were in line with results seen over the last ten years, and generally consistent with the minor increase in station airborne HTO emissions observed for 2014. Concentrations of C-14 in air, vegetation, milk, and fish, and Cs-137 in fish were in line with results seen over the last ten years. Eggs and poultry sampling resulted in annual averages of 3.6 Bq/L and 13.2 Bq/L respectively for HTO, and 230 Bq/kg-C and 243 Bq/kg-C

respectively for C-14. These were comparable to or lower than levels in milk and vegetation

- The 2014 public dose for the DN site was 0.6 µSv and was represented by the adult of the Farm critical group. The site public dose remains unchanged from 2013.

5.6.2 Summary of Pickering Results

- The main dose contributing station emissions, which include HTO emissions to air and water, C-14 emissions to air, and gross beta-gamma emissions to water, remained at a very small fraction of their respective DRLs in 2014.

- The average dose measured by environmental noble gas monitors at the boundary locations was in line with 2013 measurements.

- 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 results seen over the last ten years.

- The 2014 public dose for the PN site was 1.2 µSv and was represented by the adult of the Urban Resident group. The 2014 site public dose is essentially unchanged from the 2013 site public dose of 1.1 µSv .

6.0 OUTLOOK FOR 2015

Program design reviews on the PN and DN EMPs were completed in 2014 and will be finalized and issued in 2015. The design reviews incorporate the most recent ERA results, updated pathway analyses, and incorporation of the results of the latest site specific surveys. However these reviews did not identify any significant change with the potential to substantially alter the predictions of the ERAs or the implementation of the EMP. Therefore, in accordance with N288.4-10 Clause 5.3, no immediate action or change is required to the EMP designs. Recommendations from these studies will be incorporated into the EMPs following the revision of the station DRLs.

In 2015, a supplementary study will be conducted to monitor particulate and I-131 in air around PN and DN boundaries to support the EMP objective of confirming the effectiveness of effluent control and effluent monitoring. The results of this study will be presented in the 2015 annual EMP report.

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Appendix A: Radiological Units and Conversions

Absorbed Dose

1 gray (Gy) = 1 joule/kg

Effective Dose

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

Quantity of Radionuclide

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

Appendix B: Glossary of Acronyms and Symbols

Radionuclides and Units of Measure

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

BAF	Bioaccumulation Factor
CALA	Canadian Association for Laboratory Accreditation
CANDU	Canada Deuterium Uranium
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
EMP	Environmental Monitoring Program
ENE	East North East wind sector
EOS	Environment Operations Support

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)
Lc	Critical Level
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
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
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
TRF	Tritium Removal Facility
TRS	Technical Report Series
TRV	Toxicity Reference Value
TWh	Terawatt Hour
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

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Figure C1 Darlington Nuclear Site Critical Groups and Environmental Monitoring Locations

LEGEND Data as of February, 2015

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, 4, and 8 contain only a Noble Gas monitor
2) Soil sampling performed every five years.

DF12 (15 km NW of DN site)

10.0 km

5.0 km

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

DN

DF1 DF2 DF3 DF7 DF9

RURAL RESIDENT

NON-DAIRY FARM

DAIRY FARM

Oshawa WSP

Bowmanville WSP

Newcastle WSP (13 km ENE of DN site)

DF9(13 km ENE of DN site)

Figure C2 Pickering Nuclear Site Critical Groups and Environmental Monitoring Locations

LEGEND Data as of February, 2015

0 1 2 3 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
- LAKE SEDIMENT
- 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.

DF3 (18 km NW of PN site)

DAIRY FARM

URBAN RESIDENT

INDUSTRIAL COMMERCIAL

CORRECTIONAL INSTITUTION 2

PN

10 km

5.0 km

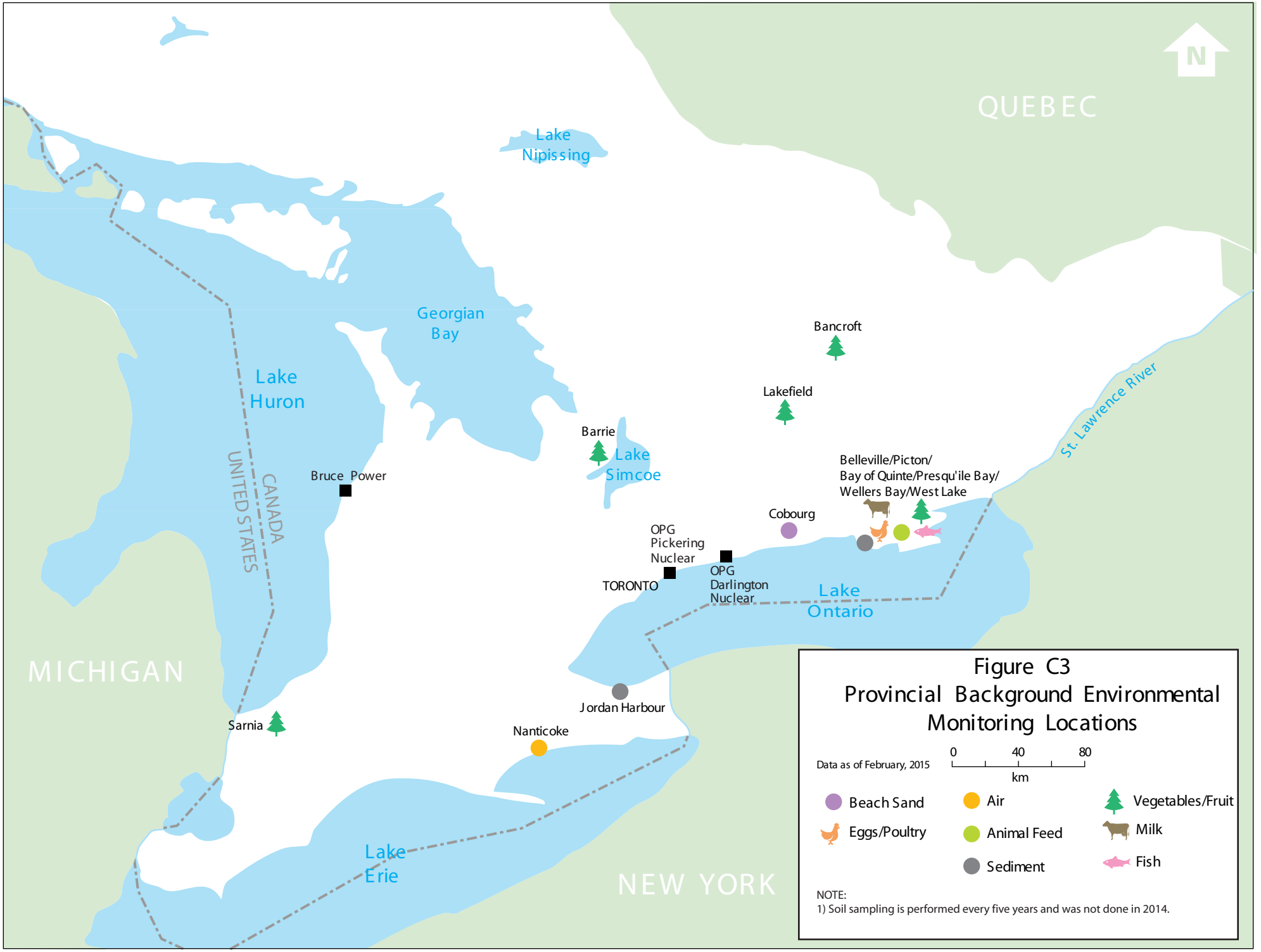
NW NNW N NNE NE ENE E ESE SE SSE S SSW SW WSW W WNW

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
Barrie
Lake Simcoe
Bancroft
Lakefield
St. Lawrence River
Belleville/Picton/
Bay of Quinte/Presqu'ile Bay/
Wellers Bay/West Lake
Cobourg
OPG
Pickering
Nuclear
TORONTO
OPG
Darlington
Nuclear
Lake Ontario
Jordan Harbour
Sarnia
Nanticoke
Lake Erie
NEW YORK
Figure C3
Provincial Background Environmental Monitoring Locations
Data as of February, 2015
0 40 80
km
Beach Sand
Air
Vegetables/Fruit
Eggs/Poultry
Animal Feed
Milk
Sediment
Fish
NOTE:
1) Soil sampling is performed every five years and was not done in 2014.

Appendix D: Environmental Monitoring Data

Table D-1: Annual Average Concentrations of Tritium-in-Air – 2014

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]
D1	12	2.0	5.1	P10	12	8.7	9.1	Nanticoke	12	< 0.1
D2	10	1.6	2.6	P11	11	2.2	2.3			
D5	12	0.5	0.7	P2	12	11.5	11.5			
D9	12	0.6	0.9	P3	11	2.7	2.6			
D10[c]	12	0.3	0.3	P4	11	1.1	0.8			
				P6	12	5.9	5.0			
Boundary Location Annual Average	58	1.0	2.9	Boundary Location Annual Average	69	5.5	9.9	Annual Average	12	< 0.1

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 two times the standard deviation of the dataset.

(c) Formerly DF5

Table D-2: Annual Average Concentrations of Carbon-14 in Air – 2014

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	232	79	P10	4	467	308	Nanticoke	4	214	34
D2	4	250	21	P3	4	297	108				
D5	4	236	41	P4	4	227	69				
D10[c]	4	222	31	P6	4	354	122				
Boundary Location Annual Average	16	235	48	Boundary Location Annual Average	16	336	242	Average	4	214	34

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 two times the standard deviation of the dataset.

(c) Formerly DF5

Table D-3: Annual Average Dose Rates of Noble Gases and Ir-192 Skyshine in Air – 2014

DN EMP	N	Air Kerma Rates							
		Ar-41[c]		Ir-192		Xe-133[c]		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	8*	14	< 5	NA	< 3	NA	< 3	NA
D2	12	< 6	NA	< 5	NA	< 3	NA	< 3	NA
D3	12	< 6	NA	< 5	NA	< 3	NA	< 3	NA
D4	12	< 6	NA	< 5	NA	< 3	NA	< 3	NA
D5	12	< 6	NA	< 5	NA	< 3	NA	< 3	NA
D8	12	< 6	NA	< 5	NA	< 3	NA	< 3	NA
D9	12	< 6	NA	< 5	NA	< 3	NA	< 3	NA
D10	12	< 6	NA	< 5	NA	3*	1	< 3	NA
Boundary Average[b][c]	96	6	5	< 5	NA	3	0.3	< 3	NA
PN EMP	**N**	**Ar-41[c]**		**Ir-192**		**Xe-133[c]**		**Xe-135[c]**	
		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	11	254	336	< 5	NA	9*	12	8*	11
P3	12	132*	277	< 5	NA	4*	5	3*	1
P4	12	75*	104	< 5	NA	4*	2	4*	2
P6	12	123	111	< 5	NA	5*	4	7*	11
P7	12	241	472	< 5	NA	9*	13	3*	2
P8	12	62*	94	< 5	NA	3*	1	3*	0.3
P10	12	358	616	< 5	NA	12*	18	4*	3
P11	12	98*	209	< 5	NA	4*	4	3*	0.3
Boundary Average[b][c]	95	167	375	< 5	NA	6	11	4	7

NOTES:
Refer to Section 3.3.1 for complete list of reporting conventions.
N = number of samples.
"<" indicates less than Ld. NA= Not Applicable.
* indicates that dataset contains both detect and non-detect values

(a) Averages of datasets are reported. 2σ denotes two times the standard deviation of the dataset.
(b) Boundary 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.
(d) Dose from I-131 is modeled from emissions per Section 3.2.1. External gamma dose from I-131 measured at OPG's noble gas detectors will no longer be reported.

Table D-4: Fruits and Vegetables – 2014

Darlington EMP						
Location	Sample Type	N	HTO (Bq/L)[a]		C-14 (Bq/kg-C)[a]	
			Location Average	Uncertainty (±2σ)[c]	Location Average	Uncertainty (±2σ)[c]
DF12	Fruit	3	11.6	2.2	257	34
DF9	Fruit	3	11.9	2.8	267	14
F18	Fruit	3	18.1	3.5	254	40
R19	Fruit	3	41.8	7.0	240	119
R27	Fruit	3	42.1	6.3	299	17
R335	Fruit	3	39.4	9.8	288	21
Annual Average[b]		18	27.5	28.9	268	62
DF2	Vegetables	3	12.9	3.9	226	24
F16	Vegetables	3	25.0	1.3	236	16
R19	Vegetables	3	30.9	2.4	246	35
R2	Vegetables	3	65.3	33.5	240	24
R275	Vegetables	3	48.1	22.9	267	32
R335	Vegetables	3	17.8	4.0	256	23
Annual Average[b]		18	33.3	39.9	245	35

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.

Table D-4: Fruits and Vegetables – 2014 (Continued)

Pickering EMP						
Location	Sample Type	N	HTO (Bq/L)[a]		C-14 (Bq/kg-C)[a]	
			Location Average	Uncertainty (±2σ)[c]	Result	Uncertainty (±2σ)[c]
DF3	Fruit	3	13.2	2.4	264	22
LOC10	Fruit	3	114.7	8.1	359	23
LOC35	Fruit	3	163.2	18.7	339	32
LOC7	Fruit	3	103.5	3.0	353	32
Annual Average[b]		12	98.6	113.5	329	83
DF1	Vegetables	3	16.6	4.5	249	20
DF3	Vegetables	3	9.1	3.4	254	10
P11	Vegetables	3	134.7	7.8	377	35
P9	Vegetables	3	66.5	24.4	263	23
R144	Vegetables	3	151.1	80.2	288	40
Annual Average[b]		15	75.6	125.5	286	101

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.

Table D-4: Fruits and Vegetables – 2014 (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	8.6	2.5	252	21	NR	NR
F1 | Bancroft- Sample B	Fruit	1	6.6	2.4	244	21		
F2 | Lakefield- Sample A	Fruit	1	12.1	2.7	263	22		
F2 | Lakefield- Sample B	Fruit	1	8.2	2.5	247	21		
F3 | Picton- Sample A	Fruit	1	**4.3**	2.3	252	22		
F3 | Picton- Sample B	Fruit	1	< 2.3	NA	263	23		
F4 | Sarnia- Sample A	Fruit	1	4.6	2.4	240	21		
F4 | Sarnia- Sample B	Fruit	1	< 2.3	NA	239	21		
F5 | Barrie- Sample A	Fruit	1	5.9	2.4	252	21		
F5 | Barrie- Sample B	Fruit	1	5.5	2.4	254	22		
Annual Average[c]		10	6.0	6.2	251	17		
F1 | Bancroft- Sample A	Vegetables	1	5.1	2.3	258	22	18.3	2.7
F1 | Bancroft- Sample B	Vegetables	1	5.7	2.3	237	21	NR	NR
F2 | Lakefield- Sample A	Vegetables	1	5.2	2.3	229	20	18.7	2.7
F2 | Lakefield- Sample B	Vegetables	1	**3.0**	2.2	266	22	NR	NR
F3 | Picton- Sample A	Vegetables	1	5.3	2.3	247	22	20.3	2.7
F3 | Picton- Sample B	Vegetables	1	5.7	2.3	254	22	NR	NR
F4 | Sarnia- Sample A	Vegetables	1	**3.4**	2.2	272	22	13.4	2.6
F4 | Sarnia- Sample B	Vegetables	1	**4.1**	2.3	282	23	NR	NR
F5 | Barrie- Sample A	Vegetables	1	**4.2**	2.3	264	22	19.3	2.7
F5 | Barrie- Sample B	Vegetables	1	4.5	2.3	269	22	NR	NR
Annual Average[c]		10	4.6	1.9	258	33	18.0	5.4

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) 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 – 2014

Location	Sample Type	N	Animal Feed[b] HTO (Bq/L)[a] Location Average	HTO (Bq/L)[a] Uncertainty (±2σ)[d]	N	C-14 (Bq/kg-C)[a] Location Average	C-14 (Bq/kg-C)[a] Uncertainty (±2σ)[d]
Darlington EMP							
DF12	Generic Feed	2	18.9	3.2	4	242	28
DF7	Generic Feed	2	8.3	0.7	4	231	48
DF8	Generic Feed	2	16.4	1.5	4	233	26
Annual Average[c]		6	14.5	10.0	12	235	33
DF9	Forage	2	11.5	6.5	4	247	16
Pickering EMP							
DF8	Generic Feed	4	53.8	11.3	8	259	23
Background Locations							
Belleville	Generic Feed	2	7.1	1.6	8	231	58

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.

Table D-6: Annual Average Concentrations in Milk – 2014

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							
DF12	12	7.8*	7.9	243	27	NR	NR
DF9	10	7.1*	12.0	239	32		
DF8	12	6.9*	8.0	239	25		
Annual Average[c]	34	7.3	9.0	240	27		
PN EMP							
DF1	12	12.2	5.2	242	27	NR	NR
DF8	12	17.0	11.2	243	44	29.1	14.4
Annual Average[c]	24	14.6	9.8	242	36		
Background Locations							
Belleville	12	< 2.3	NA	236	33	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.

* indicates that dataset contains both detect and non-detect values

(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 – 2014

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	13.2	3.3	243	15
D10	Eggs	12	**3.6***	2.9	230	38
Background						
Picton	Poultry	8	**4.2***	3.6	244	11
Picton	Eggs	12	**2.6***	2.4	235	26

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.

* indicates that dataset contains both detect and non-detect values

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 – 2014

DN EMP							PN EMP						
Location	Gross Beta Activity Concentration			Tritium Concentration			Location	Gross Beta Activity Concentration			Tritium Concentration		
	N	Location Average (Bq/L)[a]	Uncertainty (±2σ)[c]	N	Location Average (Bq/L)[b]	Uncertainty (±2σ)[c]		N	Location Average (Bq/L)[a]	Uncertainty (±2σ)[c]	N	Location Average (Bq/L)[b]	Uncertainty (±2σ)[c]
WSP							**WSP**						
Bowmanville WSP	12	0.11	0.02	48	4.6*	3.2	Ajax WSP	12	0.12	0.07	48	4.8*	3.3
Newcastle WSP	12	0.17	0.12	48	5.2*	4.4	F. J. Horgan WSP	12	0.11	0.04	48	4.0*	2.5
Oshawa WSP	12	0.12	0.04	47	5.8*	4.2	R.C. Harris WSP	12	0.12	0.04	48	4.0*	2.6
							Whitby WSP	12	0.18	0.16	48	5.1*	4.1
Annual Average[d]	36	0.13	0.09	143	5.2	4.0	Annual Average[d]	48	0.14	0.10	192	4.5	3.3
Well Water							**Well Water**						
DF12	NR		NR	12	4.4*	2.4	DF8	NR		NR	12	12.3	2.5
R2				10	18.5	11.7	R143				12	19.0	6.3
R316				4	8.7	2.1							
R320				3	8.3	7.3							
R329				12	9.4	5.2							
Annual Average[d]	NR		NR	41	10.0	12.4	Annual Average[d]	NR		NR	24	15.7	8.3
Lake Water[e]							**Lake Water[e]**						
Courtice Road Beach	NR		NR	8	7.8*	8.6	Beachfront Park	NR		NR	8	28.2	18.1
McLaughlin Bay				7	31.4	7.3	Frenchman's Bay				7	25.6	10.6
West/East Beach[e]				1	4.7	2.1	Squires Beach				8	10.3	12.0
Annual Average[d]	NR		NR	16	17.9	25.7	Annual Average[d]	NR		NR	23	21.2	21.2

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.

* indicates that dataset contains both detect and non-detect values

(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 two times the standard deviation of the dataset.

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

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

(f) Samples are not required during the winter months.

Table D-9: Lake Fish – 2014

Lake Fish	Sample Type	N	HTO		C-14		Co-60	Cs-134	Cs-137		K-40		OBT composite	
			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)[e]
DN EMP - Locations														
Darlington Diffuser	White sucker	8	5.5	1.7	230	44	< 0.1	< 0.1	0.1*	0.1	133.4	10.0	13.0	2.5
PN EMP - Locations														
Pickering 5-8 Outfall	White sucker	8	5.8	2.0	252	19	< 0.1	< 0.1	0.2	0.2	151.3	142.6	12.2	2.5
Background Locations														
Lake Ontario (USA) Far Field	White sucker	8	2.1	0.8	220	18	< 0.1	< 0.1	0.4	0.2	132.1	7.0	12.4	2.5

NOTES:

Refer to Section 3.3.1 for complete list of reporting conventions.

N = number of samples

* indicates that dataset contains both detect and non-detect values

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.

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

Table D-10: Beach Sand – 2014

Beach Sand	N	Gamma Analysis (Bq/kg dw)[a]						
		Co-60 Result	Cs-134[c]		Cs-137[c]		K-40	
			Result	Uncertainty (±2σ)[b]	Result	Uncertainty (±2σ)[b]	Result	Uncertainty (±2σ)[b]
DN EMP - Locations								
Courtice Road Beach	8	< 0.1	0.2*	0.2	0.1*	0.1	400.8	31.0
McLaughlin Bay	0	NA	NA	NA	NA	NA	NA	NA
West/East Beach	0	NA	NA	NA	NA	NA	NA	NA
PN EMP - Locations								
Beachfront Park	8	< 0.1	< 0.1	NA	0.6	0.3	385.7	57.6
Beachpoint Promenade	8	< 0.1	< 0.2	NA	0.6	0.1	436.7	38.3
Squire Beach	8	< 0.1	< 0.2	NA	0.5	0.1	419.3	48.4
Background Locations								
Cobourg	8	< 0.1	< 0.1	NA	0.4*	0.2	375.3	121.5

Notes: West East beach sand - Unavailable as beach was inaccessible due to construction.

McLaughlin Bay sand - Unavailable as vegetation was found to be severely overgrown, preventing sample collection.

Refer to Section 3.3.1 for complete list of reporting conventions.

* indicates that dataset contains both detect and non-detect values

(a) For gamma analysis "<" indicates less than Ld.
(b) Averages of datasets are reported. 2σ denotes two times the standard deviation of the 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-11: Sediment – 2011

Pickering EMP - Sediment							
Sample Number	Location	C-14 (Bq/kg-C)	Co-60 (Bq/kg)[(a)]	Cs-134 (Bq/kg)[(a)]	Cs-137 (Bq/kg)[(a)]	K-40 (Bq/kg)	TOC (kg-C/kg)
PN-1-1	Frenchman's Bay	251	1	< 0.2	8	510	0.02
PN-2-1	Frenchman's Bay	235	6	< 3	< 3	800	0.06
PN-3-1	Frenchman's Bay	239	< 0.4	1	12	480	0.04
PN-4-1	Frenchman's Bay	236	< 1	< 2	22	710	0.06
PN-5-1	Frenchman's Bay	244	< 2	< 2	22	700	0.05
PN-6-1	Frenchman's Bay	234	< 3	< 2	16	680	0.06
PN-7-1	Frenchman's Bay	247	< 1	< 0.4	8	500	0.03
PN-8-1	Frenchman's Bay	254	< 1	< 1	8	520	0.02
PN-9-1	Frenchman's Bay	223	1	< 1	10	510	0.04
PN-10-1	Frenchman's Bay	218	< 1	< 1	8	500	0.05
Annual Average		238	1	0.3	12	591	0.04
Uncertainty (±2σ)		23	3	0.3	12	235	0.03

NOTES:

Sediment samples are analyzed and reported in dry weight.

Data source is COG-12-3045 [R-24]

COG-12-3045 concluded that there are no depositional areas for sediment near Darlington Nuclear.

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

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 may change based on the updated assessment in the next DN EMP design review. 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 critical group, consume some locally caught fish near the DN diffuser. All potential critical groups with the exception of the Sport Fisher and Industrial/Commercial critical 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-43], 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 critical group resides close to DN. Therefore, the average Adult dose for the Rural Resident 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:

(a) 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.

(b) 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.

(c) 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.

(d) 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.

(e) 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.

(f) 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.

(g) 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.

(h) 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.

(i) 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 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 may change based on the updated assessment in the next PN EMP design review. 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-44], 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.

(a) 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 produced fruits or vegetables. The C2 resident is conservatively assumed to be at this location 100 percent of the time over at least one year.

(b) 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.

(c) 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).

(d) 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).

(e) 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).

(f) 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-03481.21-10000, Methodology for Data Analysis and Public Dose Determination for the Radiological Environmental Monitoring Program [R-42]. Deviations from this methodology are listed below. However, the methodology used is consistent with CSA N288.1-08 [R-33] and software used for dose calculation, IMPACT 5.4.0, is also compliant with CSA N288.1-08.

- 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 cows consuming dry feed. Given that use of the existing parameters produces a conservative dose estimate, this change has not yet been applied and will be incorporated for future dose assessments.

- OBT doses from terrestrial animals and terrestrial plants were modeled using HTO concentrations measured in terrestrial samples at the 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 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 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 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 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 is as follows:

- An arithmetic mean is used for the dose calculation a) when the dataset is comprised entirely of detected values, b) when the dataset is comprised entirely of non-detect values and the non-detect values are not censored as <Ld, and c) when a dataset is comprised of both detect and non-detect values, and the non-detect values are not censored as <Ld.

- If the arithmetic mean is less than 0.5Ld, 0 is used for the dose calculation in order to be conservative, i.e. no background dose is subtracted from the dose resulting from PN and DN operations.

- When a dataset is comprised of both detected and non-detect values, and the non-detect values are censored as <Ld, the Kaplan-Meier mean is used instead of the arithmetic mean.

- If the Kaplan-Meier mean is less than 0.5Ld, 0 is used for the dose calculation in order to be conservative, i.e. no background dose is subtracted from the dose resulting from PN and DN operations.

- If there are not enough samples collected in a given year to accurately reflect the background dose in a particular sample media, 0 is used for HTO and gamma in order to be conservative, i.e. no background dose is subtracted from the dose resulting from PN and DN operations. Previous sampling years are consulted to arrive at an estimate of C-14 in the affected media as it is not expected to vary significantly in background from year to year.

F.3.0 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 critical group dose calculation is presented in Table F1. DRL Guidance document [R-63] provides a description of each pathway.

Table F-1: Darlington Nuclear – Farm Critical Group Doses – 2014

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	✓	
	I(mfp)	✓	
	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)	✓	
	Cs-137+, Co-60	✓	✓ (sand)
Water Ingestion (WSPs, Wells)	HTO		✓
	C-14	✓	
	I(mfp)	✓	
	Cs-137+	✓	

"+" indicates that contributions from progeny are included.

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

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

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

(d) 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 critical group location using the ratio of modeled atmospheric dispersion factors for the boundary monitor location and the critical group location (except for the Fisher critical group where it is modeled from emissions).

Concentrations of radionuclides in air that are not monitored at boundary sites or critical groups are obtained for the 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 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 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-21]. For wells, the average concentration found at each 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-21], 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 local farms are sampled on an annual basis. The annual average is used for the dose calculation, with background values subtracted. Since the farms where poultry is sampled are located in close proximity to the dairy farms, it is assumed that there is not a large difference in radionuclide concentrations in poultry obtained from the local farms vs. the local dairy farms. Therefore, the poultry samples taken are applied to both the Farm and Dairy Farm critical groups.

- **Eggs** – Eggs from local farms are sampled on a quarterly basis. The annual average is used for the dose calculation, with background values subtracted. Since the farms where eggs are sampled are located in close proximity to the dairy

farms, it is assumed that there is not a large difference in radionuclide concentrations in eggs obtained from the local farms vs. the local dairy farms. Therefore, the egg samples taken are applied to both the Farm and Dairy Farm critical groups.

- **Fruits and Vegetables** – Fruit and vegetable tritium concentrations are measured at each critical group location and the background tritium concentration is subtracted. The average concentration from all samples measured for each 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-21].

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 only monitored at boundary locations in high frequency 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 critical group location. If more than one sample location is used to represent one 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 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 critical group, minus the average C-14 concentration measured in background media.

(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-64] and standard occupancy and shielding factors for air immersion dose as described in CSA N288.1-08 [R-33].

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

The air kerma rate from the PWMF at the PN site was measured in September 2000 over water on Lake Ontario [R-65]. The results showed a rapid drop in the measured air kerma rate with distance, such that it is below the detection limit (0.13 nGy/h) at a distance of 500 m from these storage areas. At 1 km distance, the air kerma rate is estimated to be negligible assuming an inverse square relation with distance as well as a further reduction of a factor of 1,000 due to scattering in air (effective half distance of 56 m for skyshine radiation at 300 keV [R-66]). The skyshine dose from this source is, therefore, not significant for critical groups outside the 1 km boundary, which are all the 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 critical groups. Skyshine doses from the DWMF are negligible as all 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 critical group noble gas doses. Skyshine doses are found to be negligible for all 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, therefore radioiodine concentrations at critical group locations are obtained as described in Section F.2.1. Where no empirical Ka values are available, air concentrations are directly modeled from emissions.

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 latest program reviews [R-67][R-68], 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-69].

For airborne particulates, concentrations in air are modeled using emissions, the empirical Ka at each critical group location and modeled atmospheric dispersion factors, as described in Section F.2.1, and concentrations in terrestrial media are subsequently modeled from the airborne concentrations. These concentrations are used to calculate doses to critical group individuals.

For waterborne gross-beta gamma, 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 critical group location and modeled atmospheric dispersion factors, as described in Section F.2.1. 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 Critical Groups

Table G-2: Darlington Nuclear – Farm Critical Group Doses – 2014

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	3.06E-04	3.51E-07	4.96E-06	9.64E-11	0.00E+00	0.00E+00	4.61E-10	2.95E-11	0.00E+00	1.80E-04	0.00E+00	6.92E-02	6.97E-02
	Co-60	uSv/a	6.94E-06	2.63E-07	1.51E-07	2.04E-08	6.72E-09	6.97E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.82E-05	3.27E-06	7.06E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	3.21E-05	4.70E-06	0.00E+00	0.00E+00	3.03E-06	1.54E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.58E-03
	HT	uSv/a	2.31E-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	2.31E-06
	HTO	uSv/a	1.80E-01	0.00E+00	9.29E-02	3.26E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.49E-05	5.67E-02	2.87E-02	3.61E-01
	NobleGases	uSv/a	0.00E+00	1.29E-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	1.29E-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	6.39E-06	8.71E-03	1.99E-02	2.87E-02
	I (mfp)	uSv/a	1.11E-04	9.25E-06	9.17E-07	4.81E-09	5.71E-10	2.52E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.86E-03	1.30E-03	4.31E-03
	Total	uSv/a	1.80E-01	1.29E-01	9.29E-02	3.27E-03	7.29E-09	6.99E-03	3.03E-06	1.54E-03	0.00E+00	2.01E-04	6.84E-02	1.19E-01	6.02E-01
Child-10y	C-14	uSv/a	4.36E-04	3.51E-07	3.52E-06	9.64E-11	0.00E+00	0.00E+00	2.55E-09	2.95E-11	0.00E+00	1.06E-04	0.00E+00	4.47E-02	4.53E-02
	Co-60	uSv/a	9.90E-06	2.63E-07	2.51E-07	2.04E-08	8.70E-08	6.97E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.27E-04	6.17E-06	7.11E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	1.27E-05	4.70E-06	0.00E+00	0.00E+00	9.32E-06	1.54E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.56E-03
	HT	uSv/a	2.75E-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	2.75E-06
	HTO	uSv/a	2.14E-01	0.00E+00	5.97E-02	2.72E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.97E-06	3.80E-02	1.61E-02	3.30E-01
	NobleGases	uSv/a	0.00E+00	1.29E-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	1.29E-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	3.75E-06	6.65E-03	1.20E-02	1.86E-02
	I (mfp)	uSv/a	2.52E-04	9.25E-06	1.11E-06	4.81E-09	5.39E-09	2.52E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.38E-03	2.17E-03	5.83E-03
	Total	uSv/a	2.15E-01	1.29E-01	5.97E-02	2.72E-03	9.24E-08	6.99E-03	9.33E-06	1.54E-03	0.00E+00	1.18E-04	4.82E-02	7.50E-02	5.38E-01
Infant_1y	C-14	uSv/a	2.98E-04	3.51E-07	0.00E+00	2.14E-11	0.00E+00	0.00E+00	5.09E-09	2.95E-11	0.00E+00	6.25E-05	0.00E+00	3.86E-02	3.89E-02
	Co-60	uSv/a	7.26E-06	3.42E-07	0.00E+00	2.65E-08	2.14E-07	9.06E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.23E-04	9.97E-06	9.20E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.12E-05	2.00E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.01E-03
	HT	uSv/a	1.88E-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	1.88E-06
	HTO	uSv/a	1.47E-01	0.00E+00	0.00E+00	1.23E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.97E-06	3.56E-02	1.33E-02	1.97E-01
	NobleGases	uSv/a	0.00E+00	1.58E-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	1.58E-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	2.28E-06	5.76E-03	8.98E-03	1.47E-02
	I (mfp)	uSv/a	2.94E-04	1.20E-05	0.00E+00	6.26E-09	1.89E-08	3.28E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.69E-03	6.16E-03	1.12E-02
	Total	uSv/a	1.47E-01	1.58E-01	0.00E+00	1.23E-03	2.32E-07	9.09E-03	1.12E-05	2.00E-03	0.00E+00	6.97E-05	4.61E-02	6.71E-02	4.31E-01

Table G-3: Darlington Nuclear – Dairy Farm Critical Group Doses – 2014

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	1.08E-04	1.24E-07	2.50E-06	6.32E-11	0.00E+00	0.00E+00	4.61E-10	2.95E-11	0.00E+00	3.57E-05	5.90E-04	6.02E-02	6.09E-02
	Co-60	uSv/a	2.63E-06	9.99E-08	0.00E+00	0.00E+00	1.34E-09	1.39E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.15E-05	6.27E-06	1.43E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	0.00E+00	4.70E-06	0.00E+00	0.00E+00	3.03E-06	1.54E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.54E-03
	HT	uSv/a	8.77E-07	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	8.77E-07
	HTO	uSv/a	6.83E-02	0.00E+00	4.49E-02	1.42E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.96E-06	2.24E-02	2.55E-02	1.63E-01
	NobleGases	uSv/a	0.00E+00	7.21E-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	7.21E-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	1.27E-06	3.46E-03	6.02E-03	9.48E-03
	I (mfp)	uSv/a	4.22E-05	3.36E-06	0.00E+00	0.00E+00	2.11E-10	9.34E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.24E-03	2.71E-03	4.00E-03
	Total	uSv/a	6.85E-02	7.21E-02	4.49E-02	1.43E-03	1.55E-09	1.40E-03	3.03E-06	1.54E-03	0.00E+00	4.00E-05	2.77E-02	9.44E-02	3.12E-01
Child-10y	C-14	uSv/a	1.54E-04	1.24E-07	1.77E-06	6.32E-11	0.00E+00	0.00E+00	2.55E-09	2.95E-11	0.00E+00	2.11E-05	4.42E-04	6.71E-02	6.77E-02
	Co-60	uSv/a	3.76E-06	9.99E-08	0.00E+00	0.00E+00	1.73E-08	1.39E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.10E-05	1.94E-05	1.46E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	0.00E+00	4.70E-06	0.00E+00	0.00E+00	9.32E-06	1.54E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.55E-03
	HT	uSv/a	1.04E-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	1.04E-06
	HTO	uSv/a	8.12E-02	0.00E+00	2.89E-02	1.18E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.58E-06	1.50E-02	3.27E-02	1.59E-01
	NobleGases	uSv/a	0.00E+00	7.21E-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	7.21E-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	7.45E-07	2.64E-03	6.48E-03	9.12E-03
	I (mfp)	uSv/a	9.57E-05	3.36E-06	0.00E+00	0.00E+00	2.00E-09	9.34E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.46E-03	6.35E-03	7.91E-03
	Total	uSv/a	8.15E-02	7.21E-02	2.89E-02	1.19E-03	1.93E-08	1.40E-03	9.33E-06	1.54E-03	0.00E+00	2.34E-05	1.96E-02	1.13E-01	3.19E-01
Infant_1y	C-14	uSv/a	1.05E-04	1.24E-07	0.00E+00	7.50E-12	0.00E+00	0.00E+00	5.09E-09	2.95E-11	0.00E+00	1.24E-05	6.20E-04	1.25E-01	1.26E-01
	Co-60	uSv/a	2.75E-06	1.30E-07	0.00E+00	0.00E+00	4.25E-08	1.80E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.93E-05	4.88E-05	1.90E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.12E-05	2.00E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.01E-03
	HT	uSv/a	7.15E-07	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	7.15E-07
	HTO	uSv/a	5.57E-02	0.00E+00	0.00E+00	2.46E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.89E-07	1.38E-02	7.72E-02	1.47E-01
	NobleGases	uSv/a	0.00E+00	8.86E-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	8.86E-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	4.53E-07	2.26E-03	1.26E-02	1.48E-02
	I (mfp)	uSv/a	1.12E-04	4.36E-06	0.00E+00	0.00E+00	6.99E-09	1.21E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.01E-03	2.22E-02	2.44E-02
	Total	uSv/a	5.59E-02	8.86E-02	0.00E+00	2.46E-04	4.95E-08	1.81E-03	1.12E-05	2.00E-03	0.00E+00	1.39E-05	1.87E-02	2.37E-01	4.05E-01

Table G-4: Darlington Nuclear – Rural Resident Critical Group Doses – 2014

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	1.47E-04	1.69E-07	2.46E-06	6.89E-11	1.36E-13	2.54E-12	4.53E-10	2.89E-11	0.00E+00	1.21E-04	2.47E-03	6.89E-03	9.63E-03
	Co-60	uSv/a	2.96E-06	1.12E-07	7.51E-08	5.75E-09	2.67E-09	2.77E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.17E-05	6.95E-07	2.79E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	1.21E-04	4.88E-06	6.36E-09	4.16E-04	2.97E-06	1.51E-03	0.00E+00	0.00E+00	3.71E-06	1.91E-07	2.06E-03
	HT	uSv/a	9.87E-07	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	9.87E-07
	HTO	uSv/a	7.68E-02	0.00E+00	8.75E-02	1.73E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.98E-06	2.43E-02	1.76E-03	1.92E-01
	NobleGases	uSv/a	0.00E+00	4.47E-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	4.47E-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	4.29E-06	3.72E-03	1.07E-03	4.79E-03
	I (mfp)	uSv/a	4.74E-05	3.59E-06	4.89E-07	1.45E-09	2.43E-10	1.07E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.05E-04	1.78E-04	1.05E-03
	Total	uSv/a	7.70E-02	4.47E-02	8.76E-02	1.73E-03	9.28E-09	3.19E-03	2.98E-06	1.51E-03	0.00E+00	1.35E-04	3.13E-02	9.90E-03	2.57E-01
Child-10y	C-14	uSv/a	2.05E-04	1.65E-07	1.70E-06	7.02E-11	7.66E-13	2.59E-12	2.55E-09	2.95E-11	0.00E+00	7.25E-05	1.88E-03	5.04E-03	7.20E-03
	Co-60	uSv/a	4.12E-06	1.10E-07	1.27E-07	5.86E-09	3.37E-08	2.70E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.60E-05	1.32E-06	2.74E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	4.36E-05	4.98E-06	2.00E-08	4.24E-04	9.32E-06	1.54E-03	0.00E+00	0.00E+00	1.54E-06	6.97E-08	2.02E-03
	HT	uSv/a	1.14E-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	1.14E-06
	HTO	uSv/a	8.91E-02	0.00E+00	5.69E-02	1.47E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.44E-06	1.66E-02	1.08E-03	1.65E-01
	NobleGases	uSv/a	0.00E+00	4.35E-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	4.35E-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	2.56E-06	2.90E-03	6.87E-04	3.59E-03
	I (mfp)	uSv/a	1.05E-04	3.49E-06	6.06E-07	1.48E-09	2.24E-09	1.04E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.68E-04	3.50E-04	1.44E-03
	Total	uSv/a	8.94E-02	4.35E-02	5.69E-02	1.47E-03	5.59E-08	3.13E-03	9.33E-06	1.54E-03	0.00E+00	8.05E-05	2.24E-02	7.16E-03	2.26E-01
Infant_1y	C-14	uSv/a	1.40E-04	1.65E-07	0.00E+00	1.11E-11	1.53E-12	2.59E-12	5.09E-09	2.95E-11	0.00E+00	4.27E-05	2.64E-03	5.75E-03	8.57E-03
	Co-60	uSv/a	3.02E-06	1.42E-07	0.00E+00	7.61E-09	8.27E-08	3.51E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.51E-05	2.39E-06	3.55E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	0.00E+00	3.59E-07	2.39E-08	5.52E-04	1.12E-05	2.00E-03	0.00E+00	0.00E+00	8.03E-07	4.17E-08	2.56E-03
	HT	uSv/a	7.84E-07	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	7.84E-07
	HTO	uSv/a	6.11E-02	0.00E+00	0.00E+00	4.38E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.40E-06	1.57E-02	1.19E-03	7.84E-02
	NobleGases	uSv/a	0.00E+00	5.35E-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	5.35E-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	1.56E-06	2.53E-03	6.73E-04	3.20E-03
	I (mfp)	uSv/a	1.23E-04	4.54E-06	0.00E+00	1.92E-09	7.83E-09	1.36E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.35E-03	1.21E-03	2.70E-03
	Total	uSv/a	6.13E-02	5.35E-02	0.00E+00	4.39E-04	1.14E-07	4.07E-03	1.12E-05	2.00E-03	0.00E+00	4.77E-05	2.22E-02	8.82E-03	1.52E-01

Table G-5: Pickering Nuclear – Dairy Farm Critical Group Doses – 2014

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	1.03E-04	1.18E-07	1.73E-06	2.38E-10	0.00E+00	0.00E+00	2.27E-09	1.45E-10	0.00E+00	0.00E+00	1.65E-04	2.09E-01	2.09E-01
	Co-60	uSv/a	3.72E-07	1.41E-08	0.00E+00	1.33E-10	2.04E-10	2.11E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.09E-06	4.43E-07	2.14E-04
	Cs-137+	uSv/a	0.00E+00	0.00E+00	1.26E-04	9.35E-05	0.00E+00	0.00E+00	1.15E-06	5.82E-04	0.00E+00	0.00E+00	0.00E+00	5.93E-07	8.03E-04
	HTO	uSv/a	7.57E-02	0.00E+00	8.27E-02	1.96E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.81E-03	2.33E-02	1.92E-01
	NobleGases	uSv/a	0.00E+00	6.52E-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	6.52E-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	1.44E-03	9.09E-03	1.05E-02
	I (mfp)	uSv/a	2.25E-06	1.13E-07	0.00E+00	2.02E-11	1.14E-11	4.92E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.85E-05	5.29E-05	9.42E-05
	Total	uSv/a	7.58E-02	6.52E-02	8.29E-02	2.05E-03	2.15E-10	2.12E-04	1.15E-06	5.82E-04	0.00E+00	0.00E+00	1.05E-02	2.42E-01	4.79E-01
Child-10y	C-14	uSv/a	1.47E-04	1.18E-07	1.23E-06	2.38E-10	0.00E+00	0.00E+00	1.25E-08	1.45E-10	0.00E+00	0.00E+00	1.19E-04	1.38E-01	1.38E-01
	Co-60	uSv/a	5.32E-07	1.41E-08	0.00E+00	1.33E-10	2.64E-09	2.11E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.38E-06	1.10E-06	2.16E-04
	Cs-137+	uSv/a	0.00E+00	0.00E+00	4.99E-05	9.35E-05	0.00E+00	0.00E+00	3.53E-06	5.82E-04	0.00E+00	0.00E+00	0.00E+00	1.76E-07	7.29E-04
	HTO	uSv/a	9.00E-02	0.00E+00	5.32E-02	1.63E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.87E-03	2.32E-02	1.74E-01
	NobleGases	uSv/a	0.00E+00	6.52E-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	6.52E-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	1.10E-03	6.98E-03	8.08E-03
	I (mfp)	uSv/a	5.12E-06	1.13E-07	0.00E+00	2.02E-11	1.08E-10	4.92E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.52E-05	1.06E-04	1.57E-04
	Total	uSv/a	9.01E-02	6.52E-02	5.32E-02	1.73E-03	2.74E-09	2.12E-04	3.55E-06	5.82E-04	0.00E+00	0.00E+00	7.14E-03	1.68E-01	3.86E-01
Infant_1y	C-14	uSv/a	1.00E-04	1.18E-07	0.00E+00	6.94E-12	0.00E+00	0.00E+00	2.50E-08	1.45E-10	0.00E+00	0.00E+00	1.70E-04	1.31E-01	1.31E-01
	Co-60	uSv/a	3.90E-07	1.84E-08	0.00E+00	1.73E-10	6.47E-09	2.74E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.15E-06	2.52E-06	2.81E-04
	Cs-137+	uSv/a	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.24E-06	7.56E-04	0.00E+00	0.00E+00	0.00E+00	1.57E-07	7.61E-04
	HTO	uSv/a	6.17E-02	0.00E+00	0.00E+00	3.12E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.69E-03	4.81E-02	1.15E-01
	NobleGases	uSv/a	0.00E+00	7.93E-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	7.93E-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	8.47E-04	1.00E-02	1.08E-02
	I (mfp)	uSv/a	5.99E-06	1.47E-07	0.00E+00	2.63E-11	3.77E-10	6.39E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.04E-05	3.72E-04	4.39E-04
	Total	uSv/a	6.18E-02	7.93E-02	0.00E+00	3.12E-04	6.85E-09	2.75E-04	4.27E-06	7.56E-04	0.00E+00	0.00E+00	5.77E-03	1.89E-01	3.38E-01

Table G-6: Pickering Nuclear – Industrial/Commercial Critical Group Doses – 2014

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	9.04E-04	1.04E-06	3.02E-06	2.13E-11	1.70E-13	3.17E-12	1.40E-10	8.93E-12	0.00E+00	4.49E-07	6.04E-04	5.49E-07	1.51E-03
	Co-60	uSv/a	2.46E-06	9.34E-08	2.21E-296	7.71E-12	1.16E-10	1.20E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.25E-08	9.87E-12	1.23E-04
	Cs-137+	uSv/a	0.00E+00	0.00E+00	1.48E-03	8.96E-06	3.22E-08	2.10E-03	7.08E-08	3.58E-05	0.00E+00	0.00E+00	4.82E-06	1.09E-10	3.63E-03
	HTO	uSv/a	4.94E-01	0.00E+00	1.01E-02	1.26E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.32E-08	9.75E-04	2.41E-07	5.05E-01
	NobleGases	uSv/a	0.00E+00	4.98E-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	4.98E-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	5.66E-09	1.50E-04	1.36E-07	1.50E-04
	I (mfp)	uSv/a	1.57E-05	1.11E-06	0.00E+00	7.46E-13	4.01E-12	1.78E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.29E-06	3.61E-09	1.83E-05
	Total	uSv/a	4.95E-01	4.98E-01	1.15E-02	1.35E-04	3.23E-08	2.22E-03	7.09E-08	3.58E-05	0.00E+00	4.68E-07	1.74E-03	9.30E-07	1.01E+00

Table G-7: Pickering Nuclear – Correctional Institute (C2) Critical Group Doses – 2014

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	6.39E-04	7.34E-07	1.07E-05	3.21E-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	6.50E-04
	Co-60	uSv/a	2.31E-06	8.77E-08	0.00E+00	0.00E+00	1.22E-09	1.26E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.27E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	5.26E-03	1.36E-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	5.27E-03
	HTO	uSv/a	4.70E-01	0.00E+00	3.55E-02	2.23E-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	5.06E-01
	NobleGases	uSv/a	0.00E+00	4.00E-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	4.00E-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	1.42E-05	9.38E-07	0.00E+00	0.00E+00	7.06E-11	3.17E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.83E-05
	Total	uSv/a	4.71E-01	4.00E-01	4.07E-02	2.37E-04	1.29E-09	1.27E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.13E-01
Child-10y	C-14	uSv/a	9.11E-04	7.34E-07	7.57E-06	3.21E-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	9.19E-04
	Co-60	uSv/a	3.30E-06	8.77E-08	0.00E+00	0.00E+00	1.58E-08	1.26E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.27E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	2.08E-03	1.36E-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	2.09E-03
	HTO	uSv/a	5.59E-01	0.00E+00	2.28E-02	1.86E-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	5.82E-01
	NobleGases	uSv/a	0.00E+00	4.00E-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	4.00E-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	3.22E-05	9.38E-07	0.00E+00	0.00E+00	6.67E-10	3.17E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.63E-05
	Total	uSv/a	5.60E-01	4.00E-01	2.49E-02	2.00E-04	1.65E-08	1.27E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.86E-01

Table G-8: Pickering Nuclear – Urban Resident Critical Group Doses – 2014

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	1.27E-03	1.46E-06	9.14E-06	3.33E-10	2.66E-12	4.96E-11	2.18E-09	1.40E-10	0.00E+00	7.02E-06	9.45E-03	8.59E-06	1.08E-02
	Co-60	uSv/a	2.23E-06	8.47E-08	3.45E-295	1.20E-10	1.81E-09	1.88E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.29E-06	1.54E-10	1.88E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	4.39E-03	1.40E-04	5.03E-07	3.29E-02	1.11E-06	5.61E-04	0.00E+00	0.00E+00	7.53E-05	1.71E-09	3.80E-02
	HTO	uSv/a	4.45E-01	0.00E+00	3.11E-02	1.97E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.06E-07	1.52E-02	3.77E-06	4.93E-01
	NobleGases	uSv/a	0.00E+00	6.44E-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	6.44E-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	8.85E-08	2.34E-03	2.13E-06	2.35E-03
	I (mfp)	uSv/a	1.46E-05	1.10E-06	0.00E+00	1.17E-11	6.27E-11	2.78E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.02E-05	5.64E-08	3.88E-05
	Total	uSv/a	4.46E-01	6.44E-01	3.55E-02	2.11E-03	5.05E-07	3.47E-02	1.11E-06	5.61E-04	0.00E+00	7.31E-06	2.71E-02	1.45E-05	1.19E+00
Child-10y	C-14	uSv/a	1.69E-03	1.36E-06	6.45E-06	3.46E-10	1.52E-11	5.15E-11	1.25E-08	1.45E-10	0.00E+00	4.30E-06	7.23E-03	8.75E-06	8.94E-03
	Co-60	uSv/a	2.76E-06	7.32E-08	5.96E-295	1.25E-10	2.43E-08	1.95E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.16E-06	4.66E-10	1.95E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	1.73E-03	1.46E-04	1.61E-06	3.41E-02	3.53E-06	5.82E-04	0.00E+00	0.00E+00	3.16E-05	6.60E-10	3.66E-02
	HTO	uSv/a	4.56E-01	0.00E+00	1.99E-02	1.70E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.15E-07	1.05E-02	2.75E-06	4.88E-01
	NobleGases	uSv/a	0.00E+00	5.92E-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	5.92E-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	5.39E-08	1.85E-03	1.52E-06	1.85E-03
	I (mfp)	uSv/a	2.88E-05	9.65E-07	0.00E+00	1.21E-11	6.15E-10	2.89E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-05	1.26E-07	5.74E-05
	Total	uSv/a	4.58E-01	5.92E-01	2.16E-02	1.85E-03	1.63E-06	3.61E-02	3.55E-06	5.82E-04	0.00E+00	4.47E-06	1.97E-02	1.32E-05	1.13E+00
Infant_1y	C-14	uSv/a	1.15E-03	1.36E-06	0.00E+00	3.33E-11	3.05E-11	5.15E-11	2.50E-08	1.45E-10	0.00E+00	2.53E-06	6.18E-03	1.60E-05	7.35E-03
	Co-60	uSv/a	2.02E-06	9.52E-08	0.00E+00	1.63E-10	5.97E-08	2.53E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.05E-06	1.21E-09	2.54E-03
	Cs-137+	uSv/a	0.00E+00	0.00E+00	0.00E+00	1.73E-05	1.93E-06	4.45E-02	4.24E-06	7.56E-04	0.00E+00	0.00E+00	1.55E-05	4.69E-10	4.53E-02
	HTO	uSv/a	3.12E-01	0.00E+00	0.00E+00	2.68E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.15E-08	9.64E-03	4.28E-06	3.22E-01
	NobleGases	uSv/a	0.00E+00	7.20E-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	7.20E-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	3.27E-08	1.57E-03	1.97E-06	1.57E-03
	I (mfp)	uSv/a	3.37E-05	1.25E-06	0.00E+00	1.57E-11	2.15E-09	3.76E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.35E-05	4.67E-07	7.27E-05
	Total	uSv/a	3.14E-01	7.20E-01	0.00E+00	2.85E-04	1.99E-06	4.70E-02	4.27E-06	7.56E-04	0.00E+00	2.64E-06	1.74E-02	2.27E-05	1.10E+00

Appendix H: PN EMP Supplementary Study Hydrazine Data

Figure H-1: Locations of the Hydrazine Sample Collections near the Pickering Nuclear Generating Station (22 July, 15 August and 10 September)

Table H-1: Hydrazine Sampling Results near the Pickering Nuclear Facility – 22 July 2014

			1,1-Dimethylhydrazine (µg/L)	Hydrazine (µg/L)	Methylhydrazine (µg/L)
		Method Detection Limit	0.25	0.05	0.25
		Limit of Quantitation	0.5	0.1	0.5
Station ID	**Location (WG84)**	**Depth (m)**			
PNGSA NEAR 1	17 T 655084 4852645	0.5	<0.25	**0.08**	<0.25
PNGSA NEAR 2	17 T 655084 4852645	2.0	<0.25	<0.05	<0.25
PNGSA NEAR 3	17 T 655084 4852645	4.5	<0.25	<0.05	<0.25
PNGSA MID 1	17 T 654991 4852511	0.5	<0.25	<0.05	<0.25
PNGSA MID 1 - DUP	17 T 654991 4852511	0.5	<0.25	<0.05	<0.25
PNGSA MID 2	17 T 654991 4852511	1.5	<0.25	<0.05	<0.25
PNGSA MID 3	17 T 654991 4852511	3.0	<0.25	<0.05	<0.25
PNGSA FAR 1	17 T 654867 4852287	0.5	<0.25	<0.05	<0.25
PNGSA FAR 2	17 T 654867 4852287	2.0	<0.25	<0.05	<0.25
PNGSA FAR 3	17 T 654867 4852287	4.0	<0.25	<0.05	<0.25
PNGSB NEAR 1	17 T 655998 4852404	0.5	<0.25	0.13	<0.25
PNGSB NEAR 2	17 T 655998 4852404	1.5	<0.25	0.14	<0.25
PNGSB NEAR 3	17 T 655998 4852404	3.0	<0.25	0.25	<0.25
PNGSB MID 1	17 T 656048 4852234	0.1	<0.25	0.1	<0.25
PNGSB MID 2	17 T 656048 4852234	1.0	<0.25	0.14	<0.25
PNGSB MID 3	17 T 656048 4852234	2.0	<0.25	0.12	<0.25
PNGSB FAR 1	17 T 656127 4852015	0.5	<0.25	0.10	<0.25
PNGSB FAR 2	17 T 656127 4852015	2.5	<0.25	0.11	<0.25
PNGSB FAR 3	17 T 656127 4852015	5.0	<0.25	<0.05	<0.25
PNGS 500 1	17 T 654463 4852585	0.5	<0.25	<0.05	<0.25
PNGS 500 2	17 T 654463 4852585	2.0	<0.25	**0.08**	<0.25
PNGS 500 3	17 T 654463 4852585	4.0	<0.25	<0.05	<0.25
PNGS 1000 1	17 T 653842 4852616	0.1	<0.25	<0.05	<0.25
PNGS 1000 2	17 T 653842 4852616	1.5	<0.25	<0.05	<0.25
PNGS 1000 3	17 T 653842 4852616	3.0	<0.25	<0.05	<0.25
FIELD BLANK	-	-	<0.25	<0.05	<0.25
Trip Blank	-	-	<0.25	<0.05	<0.25

Bolded values - estimated value - The result is ≥ the Method Detection Limit (MDL) and < the Limit of Quantitation (LOQ)

Table H-2: Hydrazine Sampling Results near the Pickering Nuclear Facility – 15 August 2014

			1,1-Dimethylhydrazine (µg/L)	Hydrazine (µg/L)	Methylhydrazine (µg/L)
		Method Detection Limit	0.25	0.05	0.25
		Limit of Quantitation	0.5	0.1	0.5
Station ID	Location (WG84)	Depth (m)			
PNGSA NEAR 1	17 T 655084 485264	0.5	<0.25	<0.050	<0.25
PNGSA NEAR 2	17 T 655084 485264	1.5	<0.25	<0.050	<0.25
PNGSA NEAR 3	17 T 655084 485264	3.5	<0.25	<0.050	<0.25
PNGSA MID 1	17 T 654991 485251	0.5	<0.25	<0.050	<0.25
PNGSA MID 2	17 T 654991 485251	1.0	<0.25	<0.050	<0.25
PNGSA MID 3	17 T 654991 485251	2.0	<0.25	<0.050	<0.25
PNGSA FAR 1	17 T 654867 485228	0.3	<0.25	<0.050	<0.25
PNGSA FAR 2	17 T 654867 485228	2.5	<0.25	<0.050	<0.25
PNGSA FAR 3	17 T 654867 485228	5.5	<0.25	<0.050	<0.25
PNGSB NEAR 1	17 T 655998 485240	0.5	<0.25	<0.050	<0.25
PNGSB NEAR 2	17 T 655998 485240	2.0	<0.25	<0.050	<0.25
PNGSB NEAR 22-Dup	17 T 655998 485240	2.0	<0.25	**0.065**	<0.25
PNGSB NEAR 3	17 T 655998 485240	4.0	<0.25	**0.064**	<0.25
PNGSB MID 1	17 T 656048 485223	0.5	<0.25	**0.069**	<0.25
PNGSB MID 2	17 T 656048 485223	1.5	<0.25	<0.050	<0.25
PNGSB MID 3	17 T 656048 485223	3.5	<0.25	<0.050	<0.25
PNGSB FAR 1	17 T 656127 485201	0.5	<0.25	<0.050	<0.25
PNGSB FAR 2	17 T 656127 485201	2.0	<0.25	**0.065**	<0.25
PNGSB FAR 3	17 T 656127 485201	4.0	<0.25	<0.050	<0.25
PNGS 500A 1	17 T 656521 485235	0.5	<0.25	**0.069**	<0.25
PNGS 500A 2	17 T 656521 485235	1.0	<0.25	<0.050	<0.25
PNGS 500A 3	17 T 656521 485235	2.0	<0.25	<0.050	<0.25
PNGS 1000A 1	17 T 656921 485272	0.5	<0.25	<0.050	<0.25
PNGS 1000A 2	17 T 656921 485272	1.5	<0.25	<0.050	<0.25
PNGS 1000A 3	17 T 656921 485272	3.0	<0.25	<0.050	<0.25
FIELD BLANK	-	-	<0.25	<0.050	<0.25
Trip Blank	-	-	<0.25	<0.050	<0.25

Bolded values - estimated value - The result is ≥ the Method Detection Limit (MDL) and < the Limit of Quantitation (LOQ)

Table H-3: Hydrazine Sampling Results near the Pickering Nuclear Facility – 10 September 2014

			1,1-Dimethylhydrazine (µg/L)	Hydrazine (µg/L)	Methylhydrazine (µg/L)
		Method Detection Limit	0.25	0.05	0.25
		Limit of Quantitation	0.5	0.1	0.5
Station ID	Location (WG84)	Depth (m)			
PNGSA NEAR 1	17 T 655084 4852645	0.5	<0.25	<0.050	<0.25
PNGSA NEAR 2	17 T 655084 4852645	1.5	<0.25	<0.050	<0.25
PNGSA NEAR 3	17 T 655084 4852645	3.0	<0.25	<0.050	<0.25
PNGSA MID 1	17 T 654991 4852511	0.5	<0.25	<0.050	<0.25
PNGSA MID 2	17 T 654991 4852511	1.0	<0.25	<0.050	<0.25
PNGSA MID 3	17 T 654991 4852511	2.5	<0.25	<0.050	<0.25
PNGSA FAR 1	17 T 654867 4852287	0.5	<0.25	<0.050	<0.25
PNGSA FAR 2	17 T 654867 4852287	2.5	<0.25	<0.050	<0.25
PNGSA FAR 3	17 T 654867 4852287	5.0	<0.25	<0.050	<0.25
PNGSB NEAR 1	17 T 655998 4852404	0.5	<0.25	<0.050	<0.25
PNGSB NEAR 2	17 T 655998 4852404	1.5	<0.25	<0.050	<0.25
PNGSB NEAR 3	17 T 655998 4852404	3.5	<0.25	<0.050	<0.25
PNGSB MID 1	17 T 656048 4852234	0.5	<0.25	<0.050	<0.25
PNGSB MID 2	17 T 656048 4852234	1.5	<0.25	<0.050	<0.25
PNGSB MID 22 (duplicate)	17 T 656048 4852234	1.5	<0.25	<0.050	<0.25
PNGSB MID 3	17 T 656048 4852234	3.0	<0.25	<0.050	<0.25
PNGSB FAR 1	17 T 656127 4852015	0.5	<0.25	<0.050	<0.25
PNGSB FAR 2	17 T 656127 4852015	3.0	<0.25	<0.050	<0.25
PNGSB FAR 3	17 T 656127 4852015	6.0	<0.25	<0.050	<0.25
PNGS 500 1	17 T 654463 4852585	0.5	<0.25	<0.050	<0.25
PNGS 500 2	17 T 654463 4852585	1.5	<0.25	<0.050	<0.25
PNGS 500 3	17 T 654463 4852585	3.5	<0.25	<0.050	<0.25
PNGS 1000 1	17 T 653842 4852616	0.5	<0.25	<0.050	<0.25
PNGS 1000 2	17 T 653842 4852616	1.5	<0.25	<0.050	<0.25
PNGS 1000 3	17 T 653842 4852616	3.5	<0.25	<0.050	<0.25
FIELD BLANK	-	-	<0.25	<0.050	<0.25
Trip Blank	-	-	<0.25	<0.050	<0.25

Appendix I: Darlington EMP Supplementary Study Chlorine and Morpholine Data

Figure I-1: Locations of the Morpholine and Total Residual Chlorine Collections near the Darlington Nuclear Generating Station (26 June, 14 August, 09 September)

Table I-1: Darlington Nuclear Generating Station Water Collection Results – 26 June 2014

Station ID	Location (WG84)	Depth (m)	Chlorine (mg/L)	Morpholine (µg/L)
DN-GS-NEAR-1	17 T 682064 4859621	0.5	<0.0012	<1.0
DN-GS-NEAR-2	17 T 682064 4859621	3.0	<0.0012	<1.0
DN-GS-NEAR-3	17 T 682064 4859621	6.0	<0.0012	<1.0
DN-GS-MID-1	17 T 681796 4859141	0.5	<0.0012	<1.0
DN-GS-MID-2	17 T 681796 4859141	5.0	<0.0012	<1.0
DN-GS-MID-3	17 T 681796 4859141	10.0	<0.0012	<1.0
DN-GS-FAR-1	17 T 681597 4858398	0.5	<0.0012	<1.0
DN-GS-FAR-2	17 T 681597 4858398	6.0	<0.0012	<1.0
DN-GS-FAR-3	17 T 681597 4858398	12.0	<0.0012	<1.0
DN-GS-500-1	17 T 681548 4859607	0.5	<0.0012	<1.0
DN-GS-500-2	17 T 681548 4859607	2.0	<0.0012	<1.0
DN-GS-500-3	17 T 681548 4859607	4.0	<0.0012	<1.0
DN-GS-1000-1	17 T 681054 4859466	0.5	<0.0012	<1.0
DN-GS-1000-2	17 T 681054 4859466	2.0	<0.0012	<1.0
DN-GS-1000-3	17 T 681054 4859466	4.0	<0.0012	<1.0
DN-GS-FIELD BLANK	-	-	<0.0012	<1.0
TRAVEL BLANK	-	-	<0.0012	<1.0

Table I-2: Darlington Nuclear Generating Station Water Collection Results – 14 August 2014

Station ID	Location (WG84)	Depth (m)	Chlorine (mg/L)	Morpholine (µg/L)
DNGS-NEAR-1	17 T 682064 4859621	0.1	<0.0012	<1.0
DNGS-NEAR-2	17 T 682064 4859621	3.0	<0.0012	<1.0
DNGS-NEAR-3	17 T 682064 4859621	6.0	<0.0012	<1.0
DNGS-MID-1	17 T 681796 4859141	0.1	<0.0012	<1.0
DNGS-MID-2	17 T 681796 4859141	5.0	<0.0012	<1.0
DNGS-MID-3	17 T 681796 4859141	10.0	<0.0012	<1.0
DNGS-FAR-1	17 T 681597 4858398	0.1	<0.0012	<1.0
DN-GS-FAR-2	17 T 681597 4858398	6.0	<0.0012	<1.0
DN-GS-FAR-3	17 T 681597 4858398	12.0	<0.0012	<1.0
DNGS-500A-1	17 T 682405 4859459	0.1	<0.0012	<1.0
DNGS-500A-11	17 T 682405 4859459	0.1	<0.0012	<1.0
DNGS-500A-2	17 T 682405 4859459	4.0	<0.0012	<1.0
DNGS-500A-3	17 T 682405 4859459	7.0	<0.0012	<1.0
DNGS-1000A-1	17 T 682921 4859400	0.1	<0.0012	<1.0
DNGS-1000A-2	17 T 682921 4859400	2.5	<0.0012	<1.0
DNGS-1000A-3	17 T 682921 4859400	5.0	<0.0012	<1.0
DNGS-FIELD BLANK	-	-	<0.0012	<1.0
DNGS-TRAVEL BLANK	-	-	<0.0012	<1.0

Table I-3: Darlington Nuclear Generating Station Water Collection Results – 09 September 2014

Station ID	Location (WG84)	Depth (m)	Chlorine (mg/L)	Morpholine (µg/L)
DNGS-NEAR-1	17 T 682064 4859621	0.5	<0.0012	<1.0
DNGS-NEAR-2	17 T 682064 4859621	3.0	<0.0012	<1.0
DNGS-NEAR-3	17 T 682064 4859621	6.5	<0.0012	<1.0
DNGS-MID-1	17 T 681796 4859141	0.5	<0.0012	<1.0
DNGS-MID-2	17 T 681796 4859141	5.5	<0.0012	<1.0
DNGS-MID-3	17 T 681796 4859141	11.0	<0.0012	<1.0
DNGS-FAR-1	17 T 681597 4858398	0.5	<0.0012	<1.0
DN-GS-FAR-2	17 T 681597 4858398	5.0	<0.0012	<1.0
DN-GS-FAR-3	17 T 681597 4858398	10.0	<0.0012	<1.0
DNGS-500-1	17 T 681548 4859607	0.5	<0.0012	<1.0
DNGS-500-2	17 T 681548 4859607	1.5	<0.0012	<1.0
DNGS-500-3	17 T 681548 4859607	3.0	<0.0012	<1.0
DNGS-1000-1	17 T 681054 4859466	0.5	<0.0012	<1.0
DNGS-1000-2	17 T 681054 4859466	1.5	<0.0012	<1.0
DNGS-1000-3	17 T 681054 4859466	3.0	<0.0012	<1.0
DNGS-FIELD BLANK	-	-	<0.0012	<1.0
DNGS-TRAVEL BLANK	-	-	<0.0012	<1.0

Appendix J: Compliance with Regulatory Document-3.1.1

The OPG annual EMP report is presently structured to comply with CNSC regulatory document S-99-Reporting Requirements for Operating Nuclear Power Plants [R-3]. In May 2014, CNSC Regulatory Document 3.1.1- Reporting Requirements for Nuclear Power Plants was published to replace S-99 [R-70]. It provides the revised requirements for an annual report on environmental protection. OPG is required to comply with REGDOC 3.1.1 for the 2015 reporting year and is in the process of modifying the annual EMP report such that the requirements in section 3.5 of REGDOC-3.1.1 will be met. The requirements which have been implemented to date are summarized in the table below. The 2015 annual EMP report, available May 2016, will be fully compliant with REGDOC-3.1.1.

Table J-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 3.3.2 to 3.3.4.6
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
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)	Not yet implemented.
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