2019 Environmental Protection Report

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PUBLIC

2019 ENVIRONMENTAL PROTECTION REPORT

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ABSTRACT OF PRESENT REVISION:

Initial Issue

Executive Summary

Bruce Power's mission is to provide clean, affordable and reliable energy for the province of Ontario, as well as to provide life-saving medical isotopes, while protecting the environment and supporting our communities. Bruce Power has focused on innovation, returning the site to its full operating potential, which contributes to the efforts of the Province to combat the impacts of climate change, by providing clean energy. Bruce Power recognizes the business has direct and indirect interactions with the environment, and we consistently make efforts (i.e. influencing our Supply Chain) to ensure these interactions take place with no significant adverse environmental effects. Ensuring environmental protection has been a focus of the business since Bruce Power was formed in 2001.

The purpose of this report is to fulfill regulatory requirements on environmental protection in accordance with Power Reactor Operating Licence (PROL) for Bruce Nuclear Generating Stations A and B Licence number 18:00/2028 Condition 3.3, and CNSC Regulatory Document REGDOC 3.1.1 Reporting Requirements for Nuclear Power Plants, Section 3.5.

This report describes the effluent and environmental monitoring programs related to Bruce Power's operations, as well as an overview of waste management. These programs are within Bruce Power's environmental management framework. They are developed, implemented, periodically reviewed and enhanced where possible to ensure environmental protection. Monitoring of radiological, non-radiological (conventional and hazardous) substances and assessing the effect on human and non-human biota forms the basis for demonstrating environmental protection at a nuclear facility. The effluent and environmental monitoring programs are important to our facility because at they ensure, through sampling and analysis, that there are no negative effects from our plant operations on the environment and the public.

Bruce Power strives to maintain a positive working relationship with those who have an interest in our business. We are committed to open communications with community members, Indigenous communities and all stakeholders. This includes local residents, government representatives, charities, service clubs, schools and students. This report includes a summary of Bruce Power's key environmental protection and stewardship activities beyond compliance obligations that occur within the local communities.

Site Location

The Site is located on the eastern shore of Lake Huron near Tiverton, Ontario within the traditional lands and treaty territory of the people of the Saugeen Ojibway Nation (SON), which includes the Chippewas of Nawash and Saugeen First Nations. Bruce Power is dedicated to honouring Indigenous history and culture and is committed to moving forward in the spirit of reconciliation and respect with the Saugeen Ojibway Nation (SON), Georgian Bay Métis Nation of Ontario (MNO) and the Historic Saugeen Métis, and to leading by example in this community and industry.

Nuclear power has been safely generated from the Site for the past 52 years, initially through the Douglas Point Nuclear Generating Station (1968-1982) and subsequently through the

Bruce A and B Nuclear Generating Stations which were put into service from 1977 to 1979 and from 1984 to 1987, respectively.

Regulatory Requirements

Bruce Power complies with relevant Federal and Provincial environmental legislation, regulations, and other requirements; specifically with regulations and programs which protect human health and the environment under the Canadian Environmental Protection Act, and the Nuclear Safety and Control Act. As well, Bruce Power complies with the Environmental Compliance Approvals and Permits issued by the Ontario Ministry of Environment Conservation and Parks.

REGDOC 2.9.1

The CNSC Regulatory Document, REGDOC 2.9.1 Environmental Protection Environmental Principles, Assessments and Protection Measures describe CNSC's principles for environmental protection for new and existing nuclear facilities. Bruce Power implements this standard to demonstrate that environmental protection measures are or will be in place. The CNSC has accepted the request from Bruce Power to move to the most recent version of this standard, REGDOC-2.9.1, version 1.1 (2017). Bruce Power implements this standard to demonstrate that environmental protection measures are or will be in place.

ISO 14001

Registration to ISO 14001 Environment Management System is a requirement of REGDOC 2.9.1, version 1.1 (2017). Bruce Power implements ISO 14001:2015 as our environmental framework, and incorporates industry best standards (CSA N288 Series) to conduct our effluent/environmental monitoring programs, achieve performance targets, and drive continual improvement, to ensure continued environmental protection.

ISO 14001:2015 was released by the International Organization for Standardization on September 15, 2015. ISO 14001:2015 focuses on the Environment Management System (EMS) being integrated throughout business processes to aid in the organization's knowledge and understanding of external and internal issues, identification of stakeholders needs and expectations, and identification of risks and opportunities impacting the organization and interested parties. The standard also focuses on leadership's commitment to environmental performance, protection of the environment beyond prevention of pollution, and adoption of a lifecycle approach when considering and evaluating its environmental aspects.

Bruce Power had a successful re-registration audit in 2017 to acquire certification to this enhanced version of the ISO 14001 standard. Bruce Power's ISO 14001:2015 surveillance audits were conducted by the external registrar, SAI Global, in the spring and fall of 2019. The auditor determined that the management system is effectively implemented and meets the requirements of the standard. As such, Bruce Power continues to maintain certification to ISO 14001. There were zero non-conformances, several strengths and a few opportunities for improvement (OFIs) identified which have been implemented.

CSA N288 Series Implementation

The CSA N Series of standards provide an interlinked set of requirements for the management of nuclear facilities and activities. The CSA N288 series of Standards and Guidelines provide overall direction on environmental management for nuclear facilities and several are a requirement of the operating licence for the facility.

Bruce Power has fully implemented the following N288 series of standards; N288.1-2008 Update No. 1 (2011), Guidelines for Calculating Derived Release Limits for Radioactive Material in Airborne and Liquid Effluents for Normal Operation of Nuclear Facilities, N288.4-10, Environmental Monitoring Programs at Nuclear Facilities and Uranium Mines and Mills, N288.5-11, Effluent Monitoring Programs at Nuclear Facilities and Uranium Mines and Mills and N288.6-12, Environmental Risk Assessments at Class I Nuclear Facilities and Uranium Mines and Mills.

Bruce Power continues to progress through its implementation plans for additional standards in the N288 series for environmental management. N288.7-15, Groundwater Protection Programs at Class I Nuclear Facilities and Uranium mines and Mills is progressing to be fully implemented by December 31, 2020 and will enhance and improve the already existing groundwater monitoring program. N288.1-14 Updates No. 1 (May 2017), No. 2 (Nov. 2017), and No.3 (June 2018) Guidelines for Calculating Derived Release Limits for Radioactive Material in Airborne and Liquid Effluents for Normal Operation of Nuclear Facilities is progressing to be fully implemented by June 30, 2021. The updates in the new N288.1-14 version of the standard were the result of significant scientific advances in dosimetry and in the understanding of radionuclide behavior in the environment resulting in the Canadian Nuclear industry consensus that the models and data in N288.1-2008 needed to be updated.

Bruce Power is working toward a voluntary implementation of another N288 standard, N288.8-17, Establishing and Implementing Action Levels for Releases to the Environment from Nuclear Facilities. The revised limits in this standard are more aggressive and will require reporting to the CNSC when releases demonstrate a loss of operational control (e.g. failed filters), even if the releases remain well under levels which pose any threat to public dose limits Bruce Power is progressing to full implementation of this new standard by June 30, 2021.

Fisheries Act Authorization

Bruce Power received a Fisheries Act Authorization from Fisheries and Oceans Canada (DFO) in December 2019. The Authorization requires Bruce Power to quantify fish losses through continued monitoring fish impingement and entrainment, and then to quantify fish gains through monitoring improvements to the Lake Huron watershed. Monitoring of fish losses continued in 2019 and is ongoing.

Bruce Power partnered with the Lake Huron Fishing Club and the Municipality of Brockton to complete a partial removal of the Truax Dam on the Saugeen River in Walkerton Ontario. The dam has long been identified as a major barrier to upstream passage of fish. The dam was removed in August and September 2019, with a partial removal allowing fish passage while maintaining a recreational area for the town. Pre-monitoring of the fish community in the stretch of the Saugeen River near to and upstream of the Truax Dam occurred in 2018 and 2019 and post monitoring will begin in 2020.

In addition to the Truax dam offset project, Bruce Power worked with the Ontario Ministry of Natural Resources and Forestry to support their lake trout stocking program in 2019. Re-establishment of lake trout enriches the deep water food web, resulting in a more stable fish community. Bruce Power also began working with SON on a Coastal Water Monitoring Program, designed as a complementary measure to increase understanding of the aquatic ecosystem. Bruce Power is engaging with Indigenous communities to develop an offsetting plan focused on improving fish and fish habitat in the Lake Huron watershed. A minimum of three cost-effective projects are to be planned for implementation within the duration of the Fisheries Act Authorization.

Thermal Emissions

Bruce Power has been in active dialogue with the Canadian Nuclear Safety Commission (CNSC) and Environment and Climate Change Canada (ECCC) to ensure that fish are being protected from the effects of thermal discharge of water. Quantitative analysis using an alternate methodology was conducted in the update to the ERA and further updated to incorporate regulatory comments. Seventeen fish species representing cold, cool and warm water guilds were assessed against measured temperature values over 3 years. Results using the most thermally sensitive species and life stage by month concluded that thermal effluent causes minimal to negligible risk to fish. Further detailed quantitative analysis was completed for whitefish embryos over winter in the nearshore and concluded a low to moderate risk for cold water species such as round whitefish.

In addition, with respect to the Provincial Environmental Compliance Approval with the Ministry of Environment, Conservation and Parks, Bruce Power has a temporary amendment to the ECA to continue with the Operational Flexibility for thermal effluent in the summer months. The ECA operational flexibility has been evaluated in terms of fish thermal benchmarks, which also resulted in minimal to negligible risk to fish. Discussions on this topic with regulators and Indigenous communities continued in 2019. Monitoring has continued and the potential risk will be reassessed every 5 years in the ERA as part of regular processes at Bruce Power, which will capture evolving conditions and new information. A Thermal Monitoring Plan, developed with local Indigenous groups, was submitted to the Ministry of Environment, Conservation and Parks by May 31 2019.

Effluent Monitoring

Results of the Effluent Monitoring program demonstrate that all conventional and radiological effluents (waterborne and airborne) are, and continue to be, well below regulatory limits.

Radiological Effluent Monitoring

With respect to radiological airborne emissions and liquid releases, derived release limits (DRLs) are in place to ensure release limits to the environment will not exceed the annual regulatory public dose limit of 1 mSv. Furthermore, to ensure that DRLs are never reached, Bruce Power has developed and implemented additional administrative limits well below DRLs, to ensure action is taken well before there is any emission that would significantly contribute to public dose. These lower levels are called Environmental Action Levels (EALs) and Internal Investigation Levels (IILs). Environmental Action Levels are currently set at approximately 10 percent of the DRLs for each radionuclide/radionuclide group. Action levels, if reached, are reportable to the CNSC and require specific actions to be taken to promptly mitigate the release. An Internal Investigation Level is an administrative level set much lower than Environmental Action Levels. It is set at the upper range of normal releases (both airborne and waterborne) for each radionuclide/radionuclide group. If an IIL is exceeded, Bruce Power promptly begins an investigation to determine why it happened and put corrective actions in place to ensure future releases remain within the normal range. Bruce Power strives to maintain emissions as low as reasonably achievable (ALARA).

In 2019, all releases remained well below the derived release limits and action levels. For waterborne emissions, tritium releases from Bruce B increased relative to 2018 due to maintenance activities and delays in de-tritiation processing of heavy water (D_2O) off site. Bruce A waterborne tritium emissions show a long term stable trend. Waterborne ^{14}C emissions have decreased at Bruce A and Bruce B since 2015 due to an increased focus on resin management on reactor purification systems, however Bruce B waterborne ^{14}C emissions increased since 2018 due to ion exchange resin dewatering and replacements in preparation of Major Component Replacement activities. Bruce A waterborne ^{14}C emissions continue to show a long term stable trend. Waterborne gamma emissions have remained stable over the long term at both stations.

For airborne radiological releases, a decrease in tritium was observed in 2019 at Bruce A and Bruce B compared to 2018. Airborne ^{14}C emissions at Bruce B have significantly declined since 2010 and have remained relatively stable since, and Bruce A experienced an overall reduction in ^{14}C emissions since 2015. Improvements realized in ^{14}C emissions can be attributed to an increased focus on resin management and a decrease in moderator cover gas purges. Iodine emissions at Bruce B have been very low and stable over the long term; however, Bruce A experienced elevated iodine emissions in 2019 due to occurrences of failed fuel. An increased focus on the equipment monitoring and reliability of the exhaust stack filters has ensured the minimization of iodine emissions.

The dose to public remains *de minimus* for the 28th consecutive year (since measurement commenced). Bruce Power is always striving to implement industry best practices and frequently requests to adopt new standards. Currently Bruce Power is working towards the implementation of N288.8 which would include the development of more stringent Environmental Actions Levels (approximately 1,000 times lower than current EALs) that are more closely aligned with operational performance.

Conventional Effluent Monitoring

With respect to non-radiological (conventional) emissions, Bruce Power complies with applicable provincial regulations, approvals, and permits. Bruce Power continues to comply with its Environmental Compliance Approvals and regulations under, but not limited to, the

Environmental Protection Act and the Ontario Water Resources Act. For conventional waterborne emissions, there were two moderate infractions in 2019, as discussed in Sections 3.2.3.2 and 3.2.3.3.

In accordance with the ECA (Air), noise complaints received from Inverhuron residents during the spring/summer period of 2019 were reported to the Ministry of the Environment Conservation and Parks (MECP) District Office. Noise monitoring and assessments conducted between 2015 and 2019 demonstrate that Bruce Power's noise level at concerned receptor locations remain in compliance with MECP limits.

As discussed in Section 3.2.2.1 Bruce Power completed a noise mitigation project in 2019 which involved installing silencers on the deaerator vents at Bruce B. The installation of silencers resulted in a 26 to 33 dBA reduction in sound levels from each of the deaerator vents. Furthermore, the distinctive tone from the deaerator vents was no longer audible. During a two week community monitoring campaign conducted after the silencers were installed, the deaerator vents were not audible above background sound levels (i.e. waves, wind, birds, etc.). Bruce Power provided updates to the community as the project progressed, and following its completion, received positive feedback on sound levels from several members of the community.

Greenhouse gas emissions have trended downwards due to the shutdown of the Bruce Steam Plant in 2015 and remain below the federal and provincial greenhouse gas emission thresholds for reporting, as discussed in Section 3.2.2.3.

Waste Management

Bruce Power manages many different forms of waste, including: hazardous waste (oils, chemicals, lighting lamps and ballasts – some of these are recycled), recyclable waste (glass, plastic, metal, cardboard, paper, wood, batteries, and electronics), organic waste (compost), and landfill waste. Bruce Power also manages radioactive waste in partnership with Ontario Power Generation (OPG). Bruce Power complies with all waste regulations and requirements of the relevant Federal, Provincial, and Municipal authorities. Further, Bruce Power has taken an active role for many years to reduce all forms of waste: from an environmental and financial standpoint waste reduction is good for our company and the community in which we reside. Our philosophy employs a whole life-cycle approach in that we reduce waste at the consumer level, generate less waste at the company level, find opportunities to reuse products (on-site, off-site donations, or sell them at auction), and implement recycling programs that are available in the ever-changing recycling market. To minimize the amount of waste sent to landfill each day, Bruce Power has implemented a number of initiatives that apply the principles of reduce, reuse, recycle, and recover. Wherever its fate, each waste stream generated at Bruce Power is processed and disposed of in a safe and environmentally-responsible manner.

Environmental Monitoring

The environmental monitoring program is designed to meet the requirements of CSA N288.4-10. This consists of both radiological environmental monitoring program, which is used to characterize dose-to-public annually, and non-radiological (conventional) environmental monitoring.

The conventional environmental monitoring program monitors for conventional (non-radiological) contaminants, physical stressors, potential biological effects and pathways for both human and non-human biota. The objectives are to: demonstrate compliance with limits on the concentration and/or intensity of conventional contaminants and physical stressors in the environment or their effect on the environment; to check, independently of conventional effluent monitoring, on the effectiveness of contaminant and effluent control; with respect to the ERA – verify predictions, refine models and reduce uncertainty in predictions as needed. In 2019 monitoring included wildlife surveys (amphibians, reptiles, birds, fish), water quality (storm water, thermal effluent) as well as fish impingement and monitoring for the Truax dam offset program. Results are indicative of healthy local populations with no water quality changes as a result of site activities. Phragmites removal continued in Baie du Dore. This type of effort, partnered with community restoration and conservation initiatives, continue to extend our understanding of the local area as well as provide opportunities for sustainable environmental protection. Bruce Power continues to work with industrial and external agencies to enhance environmental understanding (i.e. ECCC, conservation authorities, non-profits, CANDU Owners Group).

During the 2018 licence renewal process, Bruce Power presented their commitment to working with Saugeen Ojibway Nation (SON), Métis Nation of Ontario (MNO) and Historic Saugeen Métis (HSM) in a manner that best suits their communities to enhance involvement in environmental monitoring. Recognizing that every community has a unique set of interests, in 2019 we worked with each community to further these discussions. This included:

- SON's Coastal Waters Monitoring Program development and the execution of year one of a three year monitoring program commitment. Bruce Power was provided the opportunity to provide input into the development of this program, as the program is intended to supplement Bruce Power's existing environmental programs.

- MNO's update to their Valued Components Report, distribution and discussion of next steps during the multi-party Environmental Workshop in October, which includes the MNO, Bruce Power, Ontario Power Generation and Canadian Nuclear Safety Commission.

- HSMs Oral History Project, the project is intended to help inform ongoing Climate Change study as well as other additional processes at the Bruce Power site such as environmental monitoring.

- Involvement in Environmental Monitoring remains a routine and active topic with all three communities moving into 2020.

During the 2018 Licence Renewal process Indigenous Communities that Bruce Power routinely engages with indicated that the dose to public calculation was not relatable of their specific communities, and rather more reflective of communities further north. Over the course of 2019 we continued this dialogue during our routine interactions to understand how we can better refine the relevancy of this calculation. Through this process we:

- Finalized a new version of the diet survey and in the fall of 2019 started to distribute to communities via a process guided by each community.

- For SON this included two community workshops; HSM participation during routine meetings; and MNO plans to host community workshops over four days in 2020.

Following participation from all three communities, survey results will be used to refine the dose to public calculation as it relates to local Indigenous community members and citizens.

A site specific survey is conducted routinely, typically every 5 years, and the most recent survey was conducted in 2016 and included over 260 local respondents. This survey provides important information about the human, social, economic and natural environment surrounding the site. Bruce Power gathers information on meteorology and severe weather, land use, population, water usage, agriculture, recreation, food sources (how much of a person's diet is locally produced), daycares, before/after school programs, long term care homes, school boards and parks within the vicinity of the Bruce site. Bruce Power uses the data to calculate an annual radiation dose to the public, perform periodic Environmental Risk Assessments and calculate Derived Release Limits. This data is also used to inform the environmental monitoring program design, and it is also important for emergency preparedness and response planning.

As part of the Radiological Environmental Monitoring (REM) Program, a variety of environmental media are collected in the local area each year and analyzed for radiological contaminants. This includes air, precipitation, drinking water, surface and well water, milk, fish, fruit and vegetables, deer (when available) and eggs. Media is collected near and far field of the site and the results are compared to Provincial values where possible. The information is used in verifying both the environmental monitoring program design and Environmental Risk Assessment conclusions, and also in calculating the dose to representative persons each year. For 2019, the dose to the most exposed individuals near site remains *de minimus.*

Dose to Public

Each year Bruce Power gathers information in order to calculate the radiological dose to potential representative persons living near the site. This includes meteorological data, analysis results from local environmental media and site radiological emissions that include all utilities near or within the Bruce Power boundary. Following the methodology outlined in CSA N288.1 DRL Guidance and using the environmental transfer model Integrated Model for the Probabilistic Assessment of Contaminant Transport (IMPACT 5.5.2), a dose is calculated for each representative person at three age classes – adult, child and infant. A representative person is determined using the lifestyle characteristics identified n the Site Specific Survey and is defined as an individual who receives a dose that is representative of the most highly exposed individuals in the population. The most limiting result, or highest calculated dose, is used as the annual dose to public and is published annually in this report.

For the 28th consecutive year Bruce Power's calculated dose to a member of the public is less than the 10 μSv/year value that is regarded as the lower threshold for significance (de minimus). The highest dose calculated for year 2019 is 1.5 μSv, representing 0.15% of the regulatory dose limit of 1000 μSv/y. The representative person estimated for year 2019 is an adult at Bruce Farmer 14 location (BF 14 Adult).

<u>2019 Maximum Representative Person's Dose</u>

Representative Person	Committed Effective Dose	Percentage of Legal Limit
BF14 Adult	1.5 μSv/y	0.15%

Groundwater Protection

Bruce Power has had a robust groundwater monitoring program in place at the site since the early 1990's. This program was largely based on historical risks, assessments and events as a result of operations over many decades. Recently, the groundwater monitoring program has evolved to ensure alignment with the new groundwater protection standard, CSA N288.7-15, Groundwater Protection Programs at Class I Nuclear Facilities and Uranium Mines and Mills. Groundwater monitoring onsite is an element of the groundwater protection program in which systems, structures and components, contaminants of potential concern, identified receptors and pathways of migration are evaluated as part of an overall conceptual site model to ensure the protection of groundwater as a resource. Sampling and analysis plans are optimized in order to verify that groundwater results are achieving performance objectives specific to each groundwater monitoring site. Monitoring results are compared against either statistically based or ecologically based evaluation criteria. Criteria, if and when exceeded, are managed through already established corrective action processes in order to ensure timely resolution and follow up investigation if required. Annual assessments are conducted to ensure these monitoring revisions and corrective actions are completed. Currently the Bruce Power groundwater monitoring program includes 16 specific sites with over 120 wells which are maintained and sampled annually.

The groundwater protection program goal is to protect the overall quality and quantity of groundwater by minimizing the interactions with the environment from activities associated with Bruce Power thereby allowing the effective management of groundwater as a resource. Through development of sampling plans, monitoring, sampling and testing, evaluation of results against performance objectives and investigation of exceedances leading to revision of sampling plans Bruce Power ensures that the overall groundwater protection goal is met.

Environmental Sustainability

Created in 2015, the Environment and Sustainability fund, since its inception has seen the distribution of about $2 million dollars into over 98 environmental projects, partnerships and initiatives mainly across Grey, Bruce and Huron counties. This fund focuses on the areas of conservation, restoration and education. Some of the key initiatives in 2019 included:

- Continued protection of the Lake Huron and Georgian Bay Shoreline aquatic habitat via the removal and management of Phragmites in partnership with the Invasive Phragmites Control Centre, and local resident organizations including the Kincardine Residents against Phragmites.

- Improvement of water quality through the continued installation of livestock exclusion fencing. In 2019 exclusion fencing was installed in the Bothwells Creek Subwatershed and the Pine River Watershed in partnership with Grey Sauble Conservation Authority, Saugeen Valley Conservation Authority and Pine River Watershed Group.

- Continued effort in clean air and biodiversity enhancement through the planting of 82,480 trees brining our total effort to at least 150,923 trees since 2012 via many organizations including Pine River Watershed Group, Penetangore Watershed Group, SauGREEN, Huron Stewardship Council and Saugeen Valley Conservation Authority.

- Land Preservation

    - In 2019 we continued our efforts in land preservation adding 5 acres of land locally through our partnership with Ontario Nature and their initiative to expand Petrel Point and Sauble Dunes existing nature reserves. To date our collaborative efforts in land preservation through groups such as but not limited to Bruce Trails Conservancy, Ontario Nature and Nature Conservancy Canada now totals 142 acres of ecologically significant land.

- Education

    - Environmental community education remained a priority in 2019 with the continuation of the Earth Week Eco mentors program. For the fifth year in a row Bruce Power in partnership with the Bruce County Museum and Cultural Centre and the Lake Huron Coastal Centre for conservation delivered three days of programming to over 200 grade six students in the local area. The program focused on Biodiversity, including the impacts of invasive species, plastic pollution and benefits of pollinators, as well as the importance of protecting turtles.

- Bruce Power remains dedicated to promoting environmental stewardship and awareness, both throughout the local communities and in the greater Ontario region. In 2019, Bruce Power has continued to collaborate and realize success in terms of common environmental goals within the community.

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ADCP - Acoustic Doppler Current Profiler
AECL - Atomic Energy Canada Limited
AHJ - Authority Having Jurisdiction
AL - Action Level
ALARA - As Low As Reasonably Achievable
ALc - Combined Dose Action Level
ALI - Acute Lung Injury
AoC - Areas of Concern
BBEG - Bruce B Emergency Power Generator
BBSG - Bruce B Standby Generator
BDF - Bruce Dairy Farm Resident
BEC - Bruce Energy Centre (now known as Bruce Eco-Industrial Park)
BEIR - Biological Effects of Ionizing Radiation
BF - Bruce Farm Resident
BMF - Bruce Mennonite Farmer
BR - Bruce Non-Farm Resident
BSP - Bruce Steam Plant
BTEX - Benzene, Toluene, Ethylbenzene, and Xylenes
CALA - Canadian Association for Laboratory Accreditation
CANDU - Canada Deuterium Uranium
CAP - Corrective Action Program
CCME - Canadian Council of the Ministers of the Environment
CCW - Condenser Cooling Water
CEPA - Canadian Environmental Protection Act
CIE - Chemistry Impact Evaluation
CFC - Chlorofluorocarbon
CMF - Central Maintenance Facility
CMLF - Central Maintenance and Laundry Facility
CNSC - Canadian Nuclear Safety Commission
CO - Carbon Monoxide
COC - Contaminant of Concern
COG - CANDU Owners Group
COPC - Contaminant of Potential Concern
CNSC - Canadian Nuclear Safety Commission
CSA - Canadian Standards Association
CSDV - Surplus Baseload Generation Derate Events
CSR - Corporate Social Responsibility
CT - Computed Tomography
DFO - Fisheries and Oceans Canada
DJF - Double Joint Frequency
DNA - Deoxyribonucleic acid
DO - Dissolved Oxygen
DRL - Derived Release Limit
DPWF - Douglas Point Waste Facility
DSC - Dry Storage Containers

EA	-	Environmental Assessment
EA FUP	-	Environmental Assessment Follow-Up
EAL	-	Environmental Action Level
ECA	-	Environmental Compliance Approval
ECCC	-	Environment and Climate Change Canada
EED	-	Emission Effective Dose
EIW	-	Environmental Impact Worksheets
EM	-	Environmental Monitoring
EMO	-	Emergency Management Ontario
EMP	-	Environmental Monitoring Program
EMS	-	Environmental Management System
ENE	-	East Northeast
EPA	-	Environmental Protection Agency
EPR	-	Environmental Protection Report
ERA	-	Environmental Risk Assessment
ESA	-	Environmental Site Assessment
ESDM	-	Emission Summary and Dispersion Modelling
EWST	-	Emergency Water Storage Tank
FAA	-	Fisheries Act Authorization
FFA	-	Film Forming Amines
FNU	-	Formazin Nephelometric Unit
FPS	-	Fixed Point Surveillance
GB	-	Gross Beta
GHG	-	Greenhouse Gas
GPS	-	Global Positioning Satellite
GS	-	Gross Scan
ha	-	Hectare
HASP	-	High Altitude Student Platform
HCFC	-	Hydrochlorofluorocarbon
HECA	-	High Efficiency Carbon Air
HEPA	-	High Efficiency Particulate Air
HTO	-	Tritium Oxide
HPI	-	Habitat Productivity Index
HPL	-	Health Physics Laboratory
HSM	-	Historic Saugeen Métis
IAEA	-	International Atomic Energy Agency
ICES	-	Institute for Clinical Evaluative Sciences
ICRP	-	International Commission on Radiological Protection
ICU	-	Intensive Care Unit
IEMP	-	Independent Environmental Monitoring Program
IESO	-	Independent Electricity System Operator
IIL	-	Internal Investigation Level
IMPACT	-	Integrated Model for Probabilistic Assessment of Contaminant Transport
IPCC	-	Invasive Phragmites Control Centre
IQR	-	Interquartile Range
ISO	-	International Organization for Standardization
ITRC	-	Interstate Technology and Regulatory Council

KERMA	-	Kinetic Energy Released in Matter
Lc	-	Critical Level
LCH	-	Licence Condition Handbook
Ld	-	Detection Level
LDR	-	Low Dose Radiation
LEC	-	Lens Epithelial Cell
LHFC	-	Lake Huron Fishing Club
L&ILW	-	Low and Intermediate Level Waste
LIMS	-	Laboratory Information Management System
LNAPL	-	Light Non-Aqueous Phase Liquid
LNT	-	Linear No-Threshold
LPS	-	Lipopolysaccharides
MCR	-	Major Component Replacement
MDL	-	Minimum Detectable Level
MECP	-	Ministry of the Environment, Conservation and Parks
MGLC	-	Maximum Ground Level Concentration
MISA	-	Municipal Industrial Strategy for Abatement
MNA	-	Monitored Natural Attenuation
MNO	-	Métis Nation of Ontario
MNRF	-	Ministry of Natural Resources and Forestry
MOHLTC	-	Ministry of Health and Long Term Care
MOL	-	Ministry of Labour
MOU	-	Memorandum of Understanding
mRNA	-	Messenger Ribonucleic Acid
MW	-	Megawatts
NA	-	Natural Attenuation
NaI	-	Sodium Iodide
NASA	-	National Aeronautics and Space Administration
NCRP	-	National Council on Radiation Protection and Measurements
NCs	-	Non-Conformances
NEUDOSE	-	Neutron Dosimetry & Exploration
NII	-	Nuclear Innovation Institute
NOAA	-	National Oceanic and Atmospheric Administration
NOL	-	Normal Operating Level
NOSM	-	Northern Ontario School of Medicine
NOx	-	Nitrogen Oxides
NPP	-	Nuclear Power Plant
NPRI	-	National Pollutant Release Inventory
NSCA	-	Nuclear Safety Control Act
NSERC	-	Natural Sciences and Engineering Research Council of Canada
OBT	-	Organically Bound Tritium
OFI	-	Opportunities for Improvement
OMNRF	-	Ontario Ministry of Natural Resources and Forestry
OPG	-	Ontario Power Generation
ORP	-	Oxidation Reduction Potential
OWRA	-	Ontario Water Resources Act
PAH	-	Polycyclic Aromatic Hydrocarbon

PCB	-	Polychlorinated Biphenyl
PEA	-	Predictive Environmental Assessment
PET	-	Positron Emission Tomography
PHC	-	Petroleum Hydrocarbon
PING	-	Particulate, Iodine, Noble Gas
PM	-	Particulate Matter
PN	-	Pickering Nuclear
POI	-	Point Of Impingement
PROL	-	Power Reactor Operating Licence
PSA	-	Prostate Specific Antigen
P&T	-	Pump-and-Treat
PTTW	-	Permit to Take Water
PWMF		Pickering Waste Management Facility
PWQO	-	Provincial Water Quality Objective
QA	-	Quality Assurance
QC	-	Quality Control
QTR	-	Quarterly Technical Operations Report
REGDOC	-	Regulatory Document
REM	-	Radiological Environmental Monitoring
REMP	-	Radiological Environmental Monitoring Program
REPAIR	-	Researching the Effects of the Presence and Absence of Ionizing Radiation
ROS	-	Reactive Oxygen Species
RPD	-	Relative Percent Difference
RV	-	Relief Valve
SAC	-	Spills Action Centre
SAP	-	Sampling and Analysis Plan
SBG	-	Surplus Base Load Generation
SCO	-	Station Containment Outage
SEA	-	Significant Environmental Aspects
SI	-	International System (Système International d'unités)
SNOLAB	-	Sudbury Neutrino Observatory Laboratory
SNP	-	Single Nucleotide Polymorphism
SON	-	Saugeen Ojibway Nation
SOR	-	Statement of Requirements
SOx	-	Sulphur Oxides
SPP	-	Sewage Processing Plant
SSCs	-	Systems, Structures, Components
SVCA	-	Saugeen Valley Conservation Authority
TDG	-	Transportation of Dangerous Goods
TJF	-	Triple Joint Frequency
TLD	-	Thermoluminescent Dosimeter
TPMB	-	Transportation Package Maintenance Building
TQP	-	Tool Qualification Program
UNSCEAR		United Nations Scientific Committee of the Effects of Atomic Radiation
VBO	-	Vacuum Building Outage
VOC	-	Volatile Organic Compound
WCTF	-	Waste Chemical Transfer Facility

WMU	-	Wildlife ManagementUnit
WNSL	-	Waste Nuclear Substance Licence
WSER	-	Wastewater Systems Effluent Regulations
WSP	-	Water Supply Plant
WVRB	-	Waste Volume Reduction Building
WWMF	-	Western Waste Management Facility
Am-243	-	Americium-243
Ar-41	-	Argon-41
C-14	-	Carbon-14
Cm-244	-	Curium-244
CO2	-	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
Pu-239	-	Plutonium-239
Pu-240	-	Plutonium-240
Rn-222	-	Radon-222
Xe-133	-	Xenon-133
Xe-135	-	Xenon-135
µGy	-	microgray
µSv	-	microsievert
β	-	beta
Bq	-	becquerel
Bq/kg-C	-	becquerels per kilogram carbon
Ci	-	Curie
dBA	-	decibels
Gy	-	Gray
kg	-	kilogram
L	-	Litre
mGy	-	milligray
mSv	-	millisievert
nGy	-	nanogray
ppm	-	parts per million
Sv	-	Sievert
%RSE	-	Percent Relative Standard Error
ΔT	-	Delta temperature

1.0 INTRODUCTION

1.1 Purpose

The purpose of this report is to fulfill regulatory requirements on environmental protection in accordance with Licence Condition 3.3 of the Bruce A and Bruce B Power Reactor Operating Licence (PROL) Bruce Nuclear Generating Stations A and B 18:00/2028 [R-1] [R-3] and the CNSC Regulatory Document REGDOC-3.1.1 Reporting Requirements for Nuclear Power Plants, Section 3.5 [R-2]. This report meets the content, timing and reporting requirements of REGDOC-3.1.1 [R-2].

Canadian Standards Association (CSA) N288.4-10, Environmental monitoring programs at Class 1 nuclear facilities and uranium mines and mills [R-3] identified in the licence was, published in 2010 and supersedes the first edition published in 1990, titled Guidelines for Radiological Monitoring of the Environment. The first edition of this standard (N288.4-M90) discussed the monitoring of radioactive contaminants in the environment in pathways leading to human exposure. The second edition (2010) of CSA N288.4-10 [R-3] expanded to include protection of the environment in alignment with the Nuclear Safety and Control Act, and includes radiological and conventional contaminants, physical stressors, potential biological effects, and pathways for human and non-human biota. The most recent third edition was issued in 2019 [R-4] was updated to reflect current industry practice and includes new research and analysis methods. Bruce Power is currently reviewing the third edition of N288.4-19 to determine a path forward in the adoption of this new version.

Bruce Power has adopted CSA N288.4-10 [R-3] as a framework for achieving continual improvement. Previous Environmental Monitoring reports are listed in Table 1.

Table 1
Previous Environmental Monitoring Reports

B-REP-07000-00007	2014 Environmental Monitoring Program Report
B-REP-07000-00008	2015 Environmental Monitoring Program Report
B-REP-07000-00009	2016 Environmental Monitoring Program Report
B-REP-07000-00010	2017 Environmental Monitoring Program Report
B-REP-07000-00011	2018 Environmental Monitoring Program Report

1.2 Regulatory Requirements

1.2.1 Licence Requirements

Power Reactor Operating Licence (PROL) Bruce Nuclear Generating Stations A and B 18:00/2028 [R-1] and the associated Licence Condition Handbook [R-9], has Section 3.3 Reporting Requirements that require Bruce Power to notify and report in accordance with CNSC regulatory document REGDOC-3.1.1, version 2 [R-2]. Environmental Protection is one safety control area which covers programs that identify, control, and monitor all releases of radiological, non-radiological and hazardous substances, and monitors the effects on the environment from the operation of facilities or as the result of licensed activities.

The environmental protection report shall be submitted annually and contain the following information as governed by REGDOC-3.1.1, version 2 [R-2]:

- A summary of the results of the environmental protection program and an analysis of its significance, with respect to the health and safety of persons and the protection of the environment.

- The amount of nuclear substances (i.e., activity concentrations, flow rates and loadings), in International System (Système International d'unités [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.

- The amount of nuclear substances measured in the environment, in SI units, as part of the licensee's radiological environmental monitoring program.

- The results and calculations of the annual radiation doses to the representative persons or 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 (NPP), including the dispersion and dosimetric models used.

- 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.

- 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).

- A description of any significant events, findings or results, in respect to the conduct of the environmental monitoring program.

- A summary of any proposed changes to the environmental monitoring program.

1.2.1.1 Guidance

Federal and provincial regulations require licencees to monitor and report on the characteristics of airborne and waterborne effluent. Licencees are required to comply with any statutes, regulations, licences, or permits that govern the operation of the nuclear facility or licenced activity. The release of hazardous substances is regulated by both the Ontario

Ministry of the Environment Conservation and Parks (MECP) and Environment and Climate Change Canada (ECCC) through various acts and regulations, as well as by the CNSC.

If the licencee is required to submit annual reports to other government departments concerning their environmental protection program, including hazardous substances, that show the results of the effluent/emission and environmental monitoring programs, sending a copy of the report to the CNSC is acceptable. This satisfies the CNSC's requirement for oversight of the Bruce Power environmental monitoring program.

1.2.2 Environmental Protection Program

Bruce Power complies with Federal Regulations, programs, and standards which protect human health and the environment under the Nuclear Safety and Control Act. The key elements are listed below:

- The Class 1 Nuclear Facilities Regulations [R-5] set out environmental protection requirements that must be met.
- The General Nuclear Safety and Control Regulations [R-6] require every licensee to take all reasonable precautions to protect the environment and to control release of radioactive nuclear substances or hazardous substances within the site of the licensed activity and into the environment as a result of the licenced activity.
- The Radiation Protection Regulations prescribe radiation dose limits for the general public of 1 mSv (1000 μSv) per calendar year [R-7].
- The CNSC, when considering relicensing, has an obligation through the Nuclear Safety and Control Act to consider whether an applicant will, in carrying on that activity, make adequate provision for the protection of the environment and the health and safety of people. As outlined in REGDOC 2.9.1 Environmental Protection Policies, Programs and Procedures [R-8]. As a result, the CSA N288 standards are implemented through requirements set out in the License Condition Handbook (LCH) [R-9].
- The N288 standards are part of a series of guidelines and standards for environmental protection at Class I nuclear facilities and uranium mines and mills.

CNSC regulatory document REGDOC 2.9.1 Version 1.1 Environmental Protection Environmental Principles, Assessments and Protection Measures [R-8] outlines the requirements needed for an environmental protection program as required by the PROL [R-1]. Bruce Power's environmental governance procedure "Environmental Management BP-PROG-00.02" [R-10] documents and outlines Bruce Power's Environmental Protection Program required by REGDOC 2.9.1 Version 1.1 [R-8].

REGDOC-2.9.1 [R-8] requires Bruce Power to establish, implement and maintain an Environmental Management System (EMS) that meets the requirements set by CAN/CSA ISO 14001, Environmental Management System [R-11]. Bruce Power is currently registered to this standard. The EMS serves as the management tool for integrating all of the applicable environmental protection measures in a documented, managed and auditable process.

The assessment of risks related to non-human biota was discussed in the published Environmental Risk Assessment (ERA) [R-12][R-13] submitted to the CNSC in 2017 with comments incorporated and resubmitted to the CNSC in 2018.

1.2.2.1 Canadian Standards Association (CSA) N288

The CSA N288 standards are part of a series of guidelines and standards on environmental management of nuclear facilities. The CSA standards are developed and revised by technical experts and Subject Matter Experts (SMEs) from around the globe, such that, standards are leading and drive improvement across the industry. Bruce Power will continue to strive to be industry best and implement newer versions of the CSA N288 series of environmental standards as they become available.

The following environmental protection regulatory documents and CSA standards are relevant to the CNSC's regulatory framework for environmental compliance:

- CSA N288.1-14, Guidelines for calculating derived release limits for radioactive material in airborne and liquid effluents for normal operation of nuclear facilities [R-14];
- CSA N288.4-10, Environmental Monitoring Program at Class I nuclear facilities and uranium mines and mills [R-3];
- CSA N288.5-11, Effluent monitoring programs at Class I nuclear facilities and uranium mines and mills [R-15];
- CSA N288.6-12, Environmental Risk Assessments at Class I nuclear facilities and uranium mines and mills [R-16]; and
- CSA N288.7-15, Groundwater Protection Programs at Class I nuclear facilities and uranium mines and mills [R-17].

Bruce Power has implemented N288.1-14, N288.4-10, N288.5-11 and N288.6-12 [R-14][R-3][R-15][R-16]. N288.6-12 outlines the requirements for an environmental risk assessment. The results of the ERA inform the effluent and environmental monitoring programs and changes to these programs are made accordingly. Results from routine effluent and environmental monitoring programs are incorporated into the 5-year ERA cycle and into the annual environmental protection report. The ERA [R-12][R-13] continues to demonstrate that the operation of the Bruce Power Facility and associated life extension activities has not and will not result in significant adverse environmental effects, both for human health of nearby residents or visitors and for ecological receptors as a result of exposure to radiological or non-radiological substances. Bruce Power is working towards the implementation of CSA N288.7-15 - Groundwater Protection Programs at Class 1 Nuclear Facilities and Uranium Mines and Mills [R-17] by December 31, 2020.

Bruce Power is working towards a voluntary implementation of:

- CSA N288.3.4-13, Performance testing of nuclear air-cleaning systems at nuclear facilities [R-18]; and
- CSA N288.8-17, Establishing and implementing action levels for releases to the environment from nuclear facilities [R-19].

1.2.2.2 Environmental Management System (ISO 14001)

ISO 14001 [R-11] specifies the requirements for an environmental management system that an organization can use to enhance its environmental performance. The standard is used to manage its environmental responsibilities in a systematic manner that contributes to environmental sustainability and ensures environmental protection.

In 2019 Bruce Power had a successful surveillance audit confirming Bruce Power's management system is effectively implemented and meets the requirements of the ISO 14001 standard, Environmental Management Systems standard (2015) [R-11] The results of the surveillance audit showed zero non-conformances to the standard, twelve positive comments (strengths) and four opportunities for improvement. The strengths included:

- Communication and engagement with interested parties.
- Improvements in direct inspection of buried piping systems.
- Transformer failures (System Service Transformer 8) Corrective Action Plan (CAP) activity demonstrates well thought causes and action plans.
- Evaluation of new technologies to evaluate feasible options to reduce Impingement and Entrainment (I&E) and to improve underground piping inspection and protection.
- I&E biomass offsetting strategy such as the Truax Dam project.
- Environmental Health Index (EHI) Summary provides a detailed analysis and breakdown of critical areas that drive investigations and actions.
- Application of risk based approach built into Bruce Power's management system.
- Process Interactions – processes are integrated and do not take place in isolation from other departments.
- The organizational structure of Bruce Power was designed ensuring all legal and other requirements are met.
- Internal audits – Provide clear, concise conclusions. Scope and criteria is very well defined. The follow-up from previous non-conformances is well done.

- Environmental Aspects review and considerations based on Environmental Impact Worksheet (EIW) for work performed on-site – EIW optimization project to create efficiencies for assessment of environmental impacts.

- Emergency preparedness and response assets, training, variety of hands on scenarios; high level of detail on after action reviews.

The Bruce Power Environmental Management Program [R-10] oversees the planning, implementation, and operation of activities, with a focus on minimizing the potential adverse impact of Bruce Power operations on the environment and ensures protection of the environment. This includes ensuring the Bruce Power Environmental Safety Program conforms to International Organization for Standardization (ISO) 14001 standard for Environmental Management Systems [R-11], environmental legislation (acts and regulations), and other requirements applicable to the activities at Bruce Power (documented in BP-PROG-00.02, Environmental Management [R-10]). Other requirements are comprised of commitments to interested parties (e.g. regulators, contractual agreements with Ontario Power Generation (OPG) and other community members or interested groups). Currently, other requirements to which Bruce Power subscribes include:

- Agreement For Mutual Exchange Of Environmental Event Reports Related To The Bruce Nuclear Power Development Site [R-20], including providing an annual environmental summary report to OPG with emphasis on contamination of leased grounds and any remediation activities in progress, being considered or having been ordered by a governmental authority.

- Drinking water sampling for radiological analyses at local water supply plant [R-21].

- Commitment to the Ministry of the Environment Conservation and Parks (MECP) and Ministry of Health and Long Term Care (MOHLTC) to maintain the annual average tritium level below ~ 100 Bq/L at treatment plants upstream and downstream of Bruce Power (i.e., the Kincardine and Southampton Water Treatment Plant) [R-22].

- Protocol agreements between Indigenous groups and Bruce Power; SON – Revised Protocol Agreement between Saugeen Ojibway Nations (SON) and Bruce Power L.P [R-23], HSM – The Amended and Restated Participation Agreement [R-24], MNO – The Relationship Agreement [R-25].

- Commitment to update Inverhuron residents on noise attenuation project on Bruce site [R-26].

<u>Environmental Policy</u>

The Environmental Policy establishes guiding principles for environmental management and environmental expectations for employees and those working on behalf of Bruce Power. The Environmental Policy reflects the commitment of Bruce Power to protect the environment. You can count on Bruce Power to:

- Commit to comply with relevant legislation, regulations, and other requirements as a minimum standard;
- Ingrain a sense of environmental responsibility into our nuclear safety culture;
- Hold ourselves accountable to preventing pollution through emissions, spills, and waste, and reducing our impact on the environment;
- Protect, conserve, and restore our resources through energy conservation, reducing water consumption, and by reusing or recycling materials;
- Focus on continuous improvement by adopting applicable industry best practices and requirements of ISO 14001;
- Uphold the trust of the community through open and transparent communication with partners, Indigenous communities, and stakeholders on environmental interests;
- Promote environmental stewardship and awareness at work, in the community, and across Ontario; and
- Ensure our business decisions support the application and practice of sustainability principles.

ISO 14001:2015, Environmental Management Systems [R-11] focuses on integration throughout business processes to aid in the organization's knowledge and understanding of external and internal issues, stakeholder's needs and expectations, and risks and opportunities that impact the organization. Bruce Power was re-registered to the newest version of ISO 14001:2015 standard [R-11], Environmental Management in the fall of 2017 which demonstrates that the environmental management system is sufficiently implemented across Bruce Power.

Bruce Power operates an extensive Environment and Sustainability Program that benefits local communities in various ways. From tree planting, to stream rehabilitation, to butterfly preservation, to educational programs, and outreach to youth, Bruce Power is always interested in collaborating with community groups that are striving to better the local environment for wildlife and residents. Bruce Power also invests in independent, university led research projects and extensive long term monitoring programs that track the state of the regional environment and health of ecosystems.

Every person and every business has an impact on the natural environment in which we live. Wherever feasible Bruce Power develops and delivers or supports offset projects. These projects are designed to offset the impact Bruce Power has on the natural environment to help ensure a sustainable environment for future generations. Some projects are based on regulatory requirements but the vast majority of projects are good stewardship activities. Bruce Power has been working with the CNSC and received a Fisheries Act Authorization [R-102] from Fisheries and Oceans Canada (DFO) in 2019 that is linked to a carefully developed plan to offset fish losses from Bruce Power operations. Work on the main offsetting project (removal of the Truax Dam, Municipality of Brockton) was complete in 2019 and biological monitoring will continue for several years to demonstrate the benefits of removing this large migration barrier on the Saugeen River fishery. Bruce Power is working with local Indigenous communities, the CNSC, and the DFO to define and implement a number of additional fisheries related offsets that will be tied to the authorization, including aquatic habitat restoration projects and a coastal waters monitoring program. Bruce Power has also funded a significant number of other aquatic habitat improvements led by neighboring conservation authorities and environmental groups demonstrating our ongoing commitment to corporate social responsibility.

2.0 BACKGROUND

2.1 Bruce Site

Bruce Power is located on the east shore of Lake Huron, approximately 18 kilometres (km) north of Kincardine and 17 km southwest of Port Elgin. The site occupies an area of 932 hectares (2300 acres) within the Municipality of Kincardine, County of Bruce, and Province of Ontario.

The Site is located within the traditional lands and treaty territory of the people of the Saugeen Ojibway Nation (SON), which includes the Chippewas of Nawash and Saugeen First Nations. Bruce Power is dedicated to honouring Indigenous history and culture and is committed to moving forward in the spirit of reconciliation and respect with the Saugeen Ojibway Nation (SON), Georgian Bay Métis Nation of Ontario (MNO) and the Historic Saugeen Métis and to leading by example in this community and industry.

Nuclear power has been safely generated from the Site for the past 50 years, initially through the Douglas Point Nuclear Generating Station (1968-1982) and subsequently through the Bruce A and B Nuclear Generating Stations which were put into service from 1977 to 1979 and from 1984 to 1987, respectively.

Land use in the immediate vicinity is primarily agricultural, recreational, and rural residential. Surrounding the Bruce Power site is a mixture of rural agricultural land, former gravel pits, fragmented woodlands, streams, and wetlands. Recreational land use includes Inverhuron Park and cottages in the hamlet of Inverhuron (south of Bruce Power) and Baie du Doré/Scott Point area (north of Bruce Power) [R-27].

2.2 On-Site Facilities

Bruce Power utilizes a site specific survey to identify on-site facilities as well as activities and behaviours of neighbouring user groups within the area. Bruce Power updates the facility's site specific survey every five years. The most recent survey took place in 2016 and the updated information is provided in the report entitled "2016 Bruce Power Site Specific Survey Report," B-REP-03443-00015 [R-27]. This 2016 Site Specific Survey information has been integrated into the relevant sections of this report. Multiple companies occupy and operate the lands at the Bruce Site (formally known as the Bruce Nuclear Power Development). The on-site facilities are summarized below.

2.2.1 Bruce Power

Bruce Power operates the Bruce Nuclear Generating Station A (Bruce A) and Bruce Nuclear Generating Station B (Bruce B), which each house four CANDU® reactors. All eight of these units are currently operational with a current production capacity of 6,400 megawatts of electricity for the Ontario grid. Two units at Bruce A restarted in late 2012. Unit 6 is currently in outage for major component replacement (MCR). Several support facilities are located on the site, such as garages, warehouses, workshops, a sewage processing plant, and various administrative buildings (collectively known as Centre of Site) [R-27].

2.2.1.1 Life Extension Program and Major Component Replacement Project 2019 Annual Environmental Review

In December 2015, Bruce Power reached an agreement with the Independent Electricity System Operator (IESO) [R-92] to advance a long-term investment program which would refurbish its nuclear fleet and secure the site's operation until 2064.

The Life-Extension Program started planning activities on January 1, 2016 and involves the gradual replacement of older systems in the company's eight reactor units during regularly scheduled maintenance outages.

As part of the Life-Extension Program, Bruce Power is carrying out its intensive Major Component Replacement (MCR) Project. The MCR Project activities began in January 2020 and focuses on the replacement of key reactor components in Units 3-8, including steam generators, pressure tubes, calandria tubes and feeder tubes.

To support the objectives of MCR, an Environmental team made up of our in-house Environmental Technical Officers was assigned to focus solely on environmental protection during execution of project deliverables; this team provides environmental governance and oversight of the project, through review of designs, work plans and packages, completion of Environmental Impact Worksheets (EIW), ensuring procedural adherence, via observations and oversight. EIW's are Bruce Power's Environmental Management System tool to capture the environmental evaluation of the identified activities within prescribed scopes of work, and outline requirements necessary to ensure the work is carried out in an environmentally protective manner, mitigate risk, and ensure the evolutions remain in compliance with regulatory requirements.

The project itself is managed under already established environmental programs and processes, which have been revisited to ensure they cover MCR activities. As an example, the Effluent Monitoring Program includes a specific section outlining the required effluent monitoring and reporting parameters for a Unit that is currently in an MCR state. In some cases, minor modifications within the limits of operational flexibility, of existing Environmental Compliance Approvals were acquired, however Bruce Power remains within existing environmental limits for effluents and dose to public. Limits and reporting requirements are based on regulatory requirements established in permits and licenses granted to Bruce Power.

Involvement and oversight from the Environment team will continue throughout the duration of MCR, and targets are set for Environmental performance.

2.2.2 Ontario Power Generation

The Western Waste Management Facility (WWMF) is owned and operated by Ontario Power Generation (OPG). It is located on site, defined by the parcel of land designated for the management of OPG's radioactive waste and licenced for such use by the CNSC. This 19 hectare area currently contains the Low and Intermediate Level Waste (L&ILW) storage area and the used fuel dry storage area. This area is situated inside the Bruce Site (formally known as the Bruce Nuclear Power Development).

The objectives of the WWMF are to provide safe material handling (receipt, transfers, and retrieval), treatment, and storage of radioactive materials produced at nuclear generating stations and other facilities currently or previously operated by Ontario Power Generation or its predecessor, Ontario Hydro. This facility also provides safe storage of Bruce Power's used fuel in Dry Storage Containers (DSC) until it can be transported to an alternative long term used fuel storage or disposal facility. The used fuel dry storage area is a security protected area located northeast of the L&ILW storage area, and consists of DSC processing and storage buildings [R-27].

The L&ILW storage area consists of various structures such as the Amenities Building, Waste Volume Reduction Building (WVRB), Transportation Package Maintenance Building (TPMB), above ground low level and intermediate level waste storage buildings, quadricells, inground containers, trenches, and tile holes. These structures are primarily used for storage and processing of the L&ILW from OPG's Pickering and Darlington Nuclear Generating Stations as well as Bruce Power operations.

2.2.3 Canadian Nuclear Laboratories

The Douglas Point Waste Facility (DPWF) is owned by Canadian Nuclear Laboratories (CNL) and is located on the Bruce Site. The facility consists of a permanently shut down, partially decommissioned prototype 200 megawatt CANDU® reactor and associated structures and ancillaries. This facility is presently in the long-term "Storage with Surveillance" phase of a decommissioning program [R-27].

2.2.4 Hydro One

Hydro One owns and operates a number of assets within Bruce Site. These include, but are not limited to office and workshops for maintenance, switchyards at Bruce A and Bruce B, switching stations and transformer stations [R-27].

2.3 Off-Site Facilities

Kinectrics' KI North Facility is located in Tiverton, Ontario, approximately 3 km from the Bruce Site. The site has an approximate footprint of 16.66 hectares and houses one building with an approximate footprint of 3440 m^2. The facility functions as a radioactive work space to decontaminate and refurbish large nuclear reactor tools and equipment used during reactor maintenance outages. Other services provided include general laboratory tests and physical machining processes [R-28].

2.4 Overview of Surrounding Area and Community

The Site is located in the Municipality of Kincardine on the eastern shore of Lake Huron within Bruce County. The Municipality of Kincardine is comprised of the town of Kincardine and several small villages and towns including Inverhuron and Tiverton. The area is a popular tourist destination with many cottages and holiday parks attracting visitors from across Ontario and the United States. The Municipality of Kincardine was created in 1999 following the amalgamation of the Town of Kincardine, the Township of Kincardine and the Township of Bruce. The Municipality of Kincardine is one of eight municipalities in Bruce County. The next closest municipality to the Site is the Town of Saugeen Shores, which is approximately 25km from the Site. The Town of Saugeen Shores includes Southampton and Port Elgin.

Bruce County can be broadly split into three sections: (i) the Bruce Peninsula, part of the Niagara Escarpment, (ii) the Lakeshore that includes a number of sandy beaches and fresh water, and (iii) the Interior Region, also known as the “bread basket” which has a strong history of farming and agriculture. Bruce County has economic strengths in many sectors including tourism, agriculture and energy.

The 2016 Census showed a population of 11,389 people in the Municipality of Kincardine (an increase of 1.9% from 2011) and a population of 13,715 in the Town of Saugeen Shores (an increase of 8.3% from 2011), which includes Southampton and Port Elgin. Both municipalities are in Bruce County, which has a total population of 68,147 (an increase of 3.1% from 2011).

2.4.1 Local Indigenous Communities

The Site lies within the traditional lands and treaty territory of the Saugeen Ojibway Nation. Bruce Power is dedicated to honouring Indigenous history and culture and is committed to moving forward in the spirit of reconciliation and respect with the Saugeen Ojibway Nation (SON), Georgian Bay Métis Nation of Ontario (MNO) and the Historic Saugeen Métis and to leading by example in this community and industry.

2.4.1.1 Saugeen Ojibway Nation

The SON is comprised of the Chippewas of Nawash Unceded First Nation and the Chippewas of Saugeen First Nation. They are Aboriginal peoples of the Grey and Bruce region, which they know as Anishnaabekiing. Their traditional territory includes the lands and waters that surround the Site. The SON has two main on-reserve communities which are located approximately 30 km (Chippewas of Saugeen First Nation Reserve No. 29) and 80 km north of the Site (Cape Croker Reserve No. 27). The SON also has two hunting ground reserves that are located approximately 115 km north of the Site.

The SON’s traditional territory is identified in Figure 1.

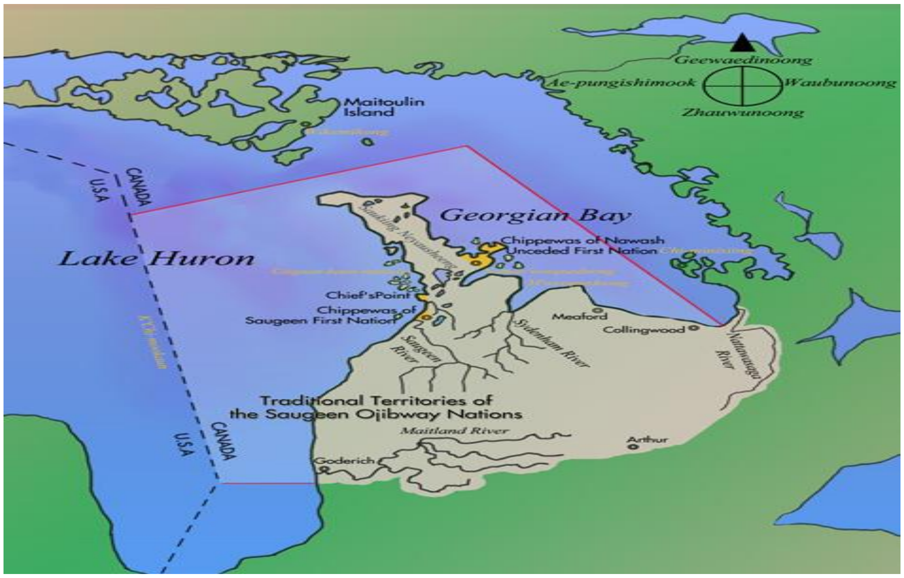


Figure 1
SON Traditional Territory
Source: saugeenobibwaynation.ca

The SON describes their assertedand established Aboriginal andtreaty rights as follows:

“SON has asserted and proven Aboriginal and Treaty rights throughout its Traditional Territory and continues to rely on this Territory for its economic, cultural, and spiritual survival. The SON Territory, includingits large reserves, is also the basis of significantand growing commercial fishingand tourism economies. SON asserts its Aboriginal andTreaty rights entitle its members to be sustained by the lands, waters and resources of their Traditional Territory. SON has the right to protect and preserve its Traditional Territory toensure that it will be able to sustain its futuregenerations. SON asserts that its rights include, butare not limitedto:

- The right to continue to be a distinctpeople living withintheir Traditional Territory;
- The right to maintain their culture, languageand way of life;
- The right to be sustained by the lands, waters and resources of their Traditional Territory;
- The right to the exclusive use and occupation oftheir communal lands;
- The right to continued use of all of their Traditional Territory;
- The right to harvest for sustenance, cultural and livelihood purposes;

- The right to be meaningfully involved in decisions that will affect their Traditional Territory so that they can protect their way of life for many generations to come; and
- The right to be the stewards of their Traditional Territory.

SON has a proven and exclusive Aboriginal and Treaty Right to a commercial fishery in the waters of Georgian Bay and Lake Huron, within SON Territory. Members of SON and their ancestors have been fishing these waters for sustenance and as the basis of trade and commerce for many hundreds of generations, and they continue to do so today. This fact has been recognized by the courts and by the Crown. While Lake Whitefish have significant cultural and economic significance to SON - and have consequently been discussed at length in past proceedings and in these submissions - SON's fishing rights are not species specific and include the right to harvest all species of fish" [R-29][R-30].

2.4.1.2 Historic Saugeen Métis

Métis people living near the Site may be represented by either the HSM or the MNO. The HSM is a self-governing Métis community at the mouth of the Saugeen River in Southampton, Ontario. The HSM are an independent rights bearing community that began with the arrival of trader Pierre Piché in the Saugeen territory in 1818. Its members have historically hunted, fished, traded and lived in the traditional Saugeen territory since the early 1800s and assert harvesting rights based on the R. v. Powley decision of the Supreme Court of Canada. The HSM became independent and self-governing in 2008 (AECOM, 2011), and left the MNO in or around 2009. This Métis community is one of the formally organized Métis communities in Ontario that is not represented by the MNO. Its office is found in Southampton (AECOM, 2011).

According to the HSM website, the HSM [R-31]:

"…are a distinctive Aboriginal community descended from unions between our European traders and Indian women. We are the Lake Huron watershed Métis with a unique Métis history and culture that lived, fished, hunted, trapped, and harvested the lands and waters of the Bruce Peninsula, the Lake Huron proper shoreline and its watersheds, their traditional Métis territory.

The HSM traded in a regional network since the early 1800s as far as the north shore of Lake Huron and have kinship with the Wikwemikong First Nations community and Killarney Métis community. The geographic scope of the contemporary community is described as covering over 275 kms of shoreline from Tobermory and south of Goderich, and includes the counties of Bruce, Grey and Huron. Upon the decline of the fur trade in the early 1820s, Métis families from the Northwest joined these early Métis at Goderich. The community traded in a cohesive regional trading network that extended from the Upper Detroit River system to the northern shoreline of Lake Huron, to the historic Métis community of Killarney, creating kinship along the network from Detroit to Killarney."

2.4.1.3 Métis Nation of Ontario

The MNO was established in 1993 "as a representative organization with the objective to protect, assert, and support the distinct culture, traditions, economic wellbeing, and Métis constitutional rights embodied in the Constitution Act, 1982, Section 35, within the Métis Homelands of Ontario [R-32]. The MNO has 29 community councils across Ontario, which represents regional rights bearing Métis communities. Three of these councils (Moon River Metis Council, Georgian Bay Metis Council, and the Great Lakes Metis Council) represent a regional rights bearing community defined as the Georgian Bay Traditional Harvesting Territory which includes the area surrounding the Site. These three councils (collectively known as "Georgian Bay Regional Consultation Committee") are distinct from the HSM which are no longer part of the MNO.

The MNO and the Georgian Bay Regional Consultation Committee assert that their people exercise Aboriginal rights throughout the territory surrounding the Site. This includes hunting, fishing, trapping, gathering, sugaring, wood harvesting, use of sacred and communal sites, and use of water as described in the MNO's Oral Presentation to the CNSC in the public hearing for Bruce Power's application to renew its operating licence in 2015:

"The MNO and their Regional Consultation Committee assert that their people exercise Aboriginal rights throughout the territory surrounding the Bruce site, including, among other things, hunting, fishing (food and commercial), trapping (food and commercial), gathering, sugaring, wood harvesting, use of sacred and communal sites (i.e., incidental cabins, family group assembly locations etc.) and use of water. These rights are protected under the Constitution Act, 1982, section 35, as existing Aboriginal rights that have not been extinguished by the Crown by way of treaty or other means. Métis peoples live in, harvest throughout and extensively rely on their traditional territories for their individual and community's wellbeing" [R-32]

2.5 Bruce Power's Community Engagement

Bruce Power has a long history of engaging and supporting local communities surrounding the Site. Bruce Power's values guide its conduct, decision-making and relationships both on the Site and in the community. To Bruce Power, living its values means conducting business ethically, respectfully, safely and with professionalism. Bruce Power's Code of Conduct is based upon these corporate values and sets a high standard of personal and professional integrity and behavioural expectations for everyone. It provides detailed information, guidelines, and references to other policies and resources that will help the company's employees make the right choices on a daily basis.

Bruce Power's engagement with local communities and Indigenous groups is supported by its Public Disclosure Protocol, its Indigenous Relations Policy, and its relationship/engagement agreements with the three Indigenous groups.

2.5.1 Bruce Power's Community Involvement and Investment

Corporate Social Responsibility (CSR) has been a core value at Bruce Power. Since 2001, Bruce Power has been making an overall positive contribution to the region. Bruce Power's Community Investment fund has grown over the years and currently results in an annual giving of upwards of $2 million a year, through five funding streams: Community Investment & Sponsorship, Environment & Sustainability, Indigenous Community Investment, Gifts in Kind and Tripartite. Since 2001, Bruce Power has contributed approximately $17 million to the local communities. The following sections detail some of the community-related initiatives that Bruce Power has supported in recent years. The Environment & Sustainability (E&S) Fund for 2019 saw the distribution of around $400 k amongst sponsorship, long term partnerships and events. Established in 2015 the E&S fund focuses allocation of resources to initiatives in the areas of:

- Conservation & Preservation;
- Education, Awareness & Research and;
- Restoration, Remediation & Quality Improvement.

Priority is given to those initiatives within the Grey, Bruce and Huron counties, the local study area of our site environmental interactions. Bruce Power strives for as low as environmental impact as possible, this means that even when we are well within our regulatory limits, we continue to seek ways to drive our impact even lower, all while aligning support with broader provincial, national and global goals of sustainability. Over the years, including in 2019, we have had special opportunities arise which results in funds beyond the Environment & Sustainability fund being allocated. Over the course of 2019, Bruce Power partnered with 20 initiatives to help the continued enhancement of the local environment. Included below in Table 2 is a variety of indicators providing an overview of some of the impact the E&S Fund has had since its inception in 2015. A report providing more detail of our 2019 overall sustainability efforts was published in November of 2019 [R-93]. Over the years, Bruce Power has partnered with many difference organizations that focus on tree planting including Pine River Watershed Group, Penetangore Watershed Group, SauGREEN, Huron Stewardship Council and Saugeen Valley Conservation Authority. In 2018 and 2019 our significant increase in tree planting was realized through our partnership with Saugeen Valley Conservation Authority (SVCA), where we funded the planting of 53,265 and 76,130 seedlings respectively in addition to our other partnerships those years (Table 2 (1)).

Bruce Power provided over 50% of the total cost for the preservation of 142 acres of land via the Bruce Trail Conservancy, the property purchased has an ecological value of over $1.5 million. In 2019, we contributed to the preservation of 5 acres of land locally through our partnership with Ontario Nature and their initiative to expand Petrel Point and Sauble Dunes existing nature reserves (Table 2 (2)).

From 2015 to 2019, Bruce Power and Butterfly Gardens of Saugeen Shores were partners in biodiversity education and habitat creation. Through this four year endeavor Bruce Power was one of the main funders to this organization providing funds towards the initial 13

Monarch waystations created during the BGOSS inaugural year. Following the inaugural year, the funds as well as in-kind resources were used towards additional waystations, maintenance of the stations (pods), caterpillar corner colouring book, speaking engagements, and educational programs. Based on citizen science observations, there has been a noted increase in Monarchs in the Saugeen Shores area since the inception of this program (Table 2 (3)).

Bruce Power has provided financial contributions that attributed to the overall success recorded by the Pine River Watershed Group through 2016, 2017, 2018 and 2019. This number does not represent the total land restored via other watershed groups that receive funding. This value is a cumulative value (Table 2 (4)).

Bruce Power has been helping with the control of Phragmites since 2013 initially in partnership with the Municipality of Kincardine and the Lake Huron Centre for Coastal Conservation. The first few years' involved financial support and in-kind professional services, including field and data collection, and development of a Phragmites Management Plan. In 2017, Bruce Power provided funding to the Invasive Phragmites Control Centre (IPCC) allowing them to purchase the Truxor, an amphibious machine that can operate in any water depth and efficiently cut and remove large, dense Phragmites infestations from coastal areas. In 2019, funding provided continued the ongoing efforts of Phragmites control along the Lake Huron shoreline from Sarnia all the way to Oliphant. We want to continue to acknowledge the efforts many groups have contributed to this effort of the years (Table 2 (5)).

Livestock exclusion fencing has been installed through our partnership between the Pine River Watershed Group from starting in 2016 through to 2019. In 2019, Bruce Power funded additional fencing installation through the Grey Sauble Conservation Authority within the Bothwell's Creek Subwatershed. Livestock exclusion fencing restricts cattle from eroding streambanks and defecating directly into the water. Over time, these types of projects improve water quality, mainly as a result of the decreased sedimentation and erosion, and indirectly improve water quality of Lake Huron as it improves quality of water going into tributaries and streams that feed into the Lake (Table 2 (6)).

Total waste generated per employee is an annual metric that started in 2016; this metric allows Bruce Power another way to evaluate overall efficiency, health and use of our onsite diversion programs. When you look at overall metric since 2016, there is an overall improvement in the use of our diversion programs, meaning less waste is going to landfill per employee. For 2015, it is assumed that there was an average of 4,200 employees working on site as this was a normal operating year (Table 2 (7)).

In 2019, Bruce Power continued to offer 18 additional waste diversion programs beyond those mandated by regulatory guidelines. We have provided examples of diversion programs we have onsite; the battery recycling program being a program we offer beyond conventional waste regulatory requirements, and the mixed stream recycling as well as paper and cardboard being a required regulatory driven program. All three programs we continue to realize enhanced usage. A key objective for Bruce Power is to increase landfill diversion through all of our existing programs onsite. In all three of the above examples, an increase in usage rate corresponds to an increase in diversion rate (meaning less material going to landfill). In 2020, we will continue to enhancecommunication andknowledge of all diversion opportunities that exist atour facility and continue tostrive for improvements (Table 2 [8]).

Table 2
Sustainability

INDICATOR	2015	2016	2017	2018	2019	Total [a]
AIR, LAND & BIODIVERSITY						
Cumulative Trees planted since 2015 [1]	6,291	11,384	13,978	68,443	82,480	150,923
Acres of Land Preserved [2]	No Data Recorded	No Data Recorded	No Data Recorded	142	5	147
Monarch waystation pods [3]	13	2	2	0	5	22
WATER QUALITY						
Hectares of land restored in Pine RiverWatershed [4]	No Data Recorded	2.83	2.02	4.45	2.9	13.2
Phragmites removed along Lake Huron Shoreline and Coastal wetlands [5]	No Data Recorded	No Data Recorded	140	310	385	835
Livestock Exclusion Fencing installed (km) [6]	No Data Recorded	0.8	0.7	1.7	2.2	5.4
WASTE DIVERSION						
Total waste generated per employee (kg/year) [7]	398.7	468	209.1	217	201.4	Not cumulative
Total onsite diversion programs beyond regulatory compliance [8]	13	13	12	13	18	Not cumulative
Battery diversionprogram (tonnes) [8]	Program started mid-year	118.0	87.4	44.1	147.4	Not cumulative
Mixed stream Recycling & Other Plastics (tonnes) [8]	62.3	69.7	165.7	144.0	205.1	Not cumulative
Paper & Cardboard (tonnes) [8]	145.2	161.3	163.4	284.1	317.8	Not cumulative
Other						
Number of environmental organizations benefiting from the fund [9]	16	22	20	20	20	98
Investment into environmental initiatives (millions)	$0.4	$0.4	$0.4	$0.4	$0.4	$2.0

Note that some efforts are cumulative in nature, where this is applicable the cumulative value is shown in the total column. Some efforts are an annual value and a cumulative value is not applicable it is noted as 'not cumulative'. Annual receipt of funding does include organizations that have received funding multiple years in a row, the total overall number does not mean 98 different organizations (Table 2[9]).

3.0 EFFLUENT MONITORING

The effluent monitoring program operated by Bruce Power is described in BP-PROC-00080, Effluent Monitoring Program [R-33]. Bruce Power's effluent monitoring program demonstrates:

- Compliance with authorized release limits
- Effective monitoring of effluent
- Provision of data to assist in modelling refinement
- Meeting stakeholder commitments

BP-PROC-00080, Effluent Monitoring [R-33] encompasses radiological and conventional effluent monitoring, with lower level procedures providing more specific governance for radiological and conventional (non-radiological) effluent monitoring programs:

- BP-PROC-00171, Radiological Emissions [R-34] for radiological effluents
- BP-PROC-00099 Conventional Emissions – Water [R-35] for conventional effluent to water
- BP-PROC-00928 Conventional Emissions – Air [R-36] for conventional emissions to air

3.1 Radiological Effluent Monitoring Programs – Bruce A, Bruce B, CMF, OPG, AECL, KI North Facility

Monitoring of emissions/effluents occur at Bruce A and Bruce B Nuclear Generating Stations and at the Central Maintenance Facility (CMF) in accordance with BP-PROC-00080, Effluent Monitoring [R-33]. Bruce Power fully implemented CSA N288.5 Effluent Monitoring Programs at Class 1 nuclear facilities and uranium mines and mills [R-15] in 2018. BP-PROC-00080, Effluent Monitoring [R-33] encompasses radiological and conventional effluent monitoring, with BP-PROC-00171, Radiological Emissions [R-34] for radiological effluents.

The purpose of Bruce Power's Radiological Effluent Monitoring is to establish the requirements for radiological effluent monitoring and equipment in order to comply with Nuclear Safety Control Act, regulations, and Licences. Radiological Effluent Monitoring describes the Bruce Power framework for control of radioactive emissions from Bruce A, Bruce B and the Central Maintenance Facility (CMF); including the radionuclide effluent monitoring system operating and quality assurance (QA) requirements.

As detailed in the Licence Condition Handbook, to ensure that members of the public and the environment are protected, Bruce Power operates well below Derived Release Limits (DRLs) that are developed (using CSA Standard N288.1) [R-14] based on a public dose limit of 1 mSv per year as mandated by the CNSC (Radiation Protection Regulations, SOR/2000-203) [R-7]. Furthermore, as an added layer of protection, Environmental Action Levels (EALs) are put in place, to provide early warnings of any actual or potential losses of control of the Environmental Protection Program. EALs are precautionary levels that are set far below the actual DRLs to alert the operator before DRLs are reached. Bruce Power strives to control radiological emissions As Low As Reasonably Achievable (ALARA) and to take action to investigate causes and mitigate causes of increased emissions.

To demonstrate due diligence, Radiological Effluent Monitoring feeds into the larger Environmental Protection framework to ensure the public and environment is protected at all times. Radiological Effluent Monitoring Data is reported to the CNSC quarterly and is compared against internal investigative and regulatory levels and limits.

Emissions data from Radiological Effluent Monitoring is also compounded with other radiological and conventional environmental measurements to complete comprehensive Environmental Risk Assessments in accordance with CSA N288.6 [R-16]. This confirms that Bruce Power has sound and robust Environmental Monitoring.

The OPG WWMF monitors emissions in accordance with N-STD-OP-0031 Monitoring of Nuclear and Hazardous Substances in Effluents which establishes minimum standards for monitoring radioactivity in airborne and waterborne effluents. One parameter that is monitored is unavailability (i.e. the fraction of time a sample is not being collected or a stream is not being monitored). Unavailability results from such incidents as component failures, maintenance or inspection outages, and operator action and calibration sequences without backup monitoring. At OPG WWMF, the radioactive waste incinerator stack monitor and the Waste Volume Reduction Building (WVRB), Transportation Package Maintenance Building (TPMB) and Western Used Fuel Dry Storage Facility (WUFDSF) ventilation stack monitors are monitored for unavailability.

CNL Douglas Point monitors for emissions in accordance with 22-00960-SWS-001, Douglas Point Waste Facility Storage with Surveillance Plan.

Kinectrics carries out effluent monitoring activities on both airborne tritium releases through exhaust stacks and on liquid releases to sewer, following Kinectrics' effluent monitoring procedures. Specifically:

- Kinectrics' Waste Nuclear Substance Licence requires releases to air to be monitored for tritium only, since particulates are caught in HEPA filters and pre-filters prior to exhaust. Tritium releases through exhaust stacks are continuously sampled, and analysis of the samples is conducted weekly [R-28].

- Potentially active waste water is temporarily stored in collection tanks, and sampled and analyzed prior to release. If any radiological or chemical contaminant is found to be above administrative control levels, which are set below unconditional clearance levels, then the tank contents are filtered through two charcoal filters and then re-analyzed. All releases are maintained below prescribed unconditional clearance levels [R-28].

A revised PROL for Bruce A and Bruce B was received in Q4 2018 from the CNSC [R-1][R-9] As part of Power Reactor Operating Licence (PROL) renewal in 2018, a review and revision of existing Derived Release Limits (DRLs) and Environmental Action Levels (ALs) took place and was submitted to the CNSC for review. This revision considered updates to:

- Meteorological conditions

- Limiting radionuclides

- Representative persons
- Results from the site specific survey and assumptions
- CSA N288.8 (Establishing and implementing action levels) [R-19]

Bruce A, Bruce B, CMF, CNL, and the OPG WWMF monitor for airborne and waterborne radionuclides. Airborne radionuclides include tritium, noble gases, radioiodine (^{131}I), carbon-14 (^{14}C), alpha, beta, and gamma (emitters on particulate material); the results are presented in Table 6. Airborne radiological emissions are monitored at the Bruce A and Bruce B Nuclear Generating Stations' applicable stacks and on the applicable stacks at the Central Maintenance and Laundry Facility (CMLF). Waterborne radionuclides include tritium, carbon-14 (^{14}C), gross alpha/beta/gamma; these results are presented in Table 7. All airborne and waterborne emissions are well below regulatory limits (DRLs, ALs) and on most occasions below Internal Investigation Levels (IILs).

Table 3 shows the radioactive effluent controls and limits. For further reference, figures showing historical effluent data are also included, and these are also well below regulatory limits and within the normal operation range (see Sections 3.1.1 for airborne emissions and 3.1.2 for waterborne emissions).

Table 3 Framework for Radioactive Effluent Controls and Limits

Basis	Levels/Limits	Unit of Measure	Description/Detail
1000 μSv/y	DRLs	Bq/wk (air) Bq/mo (water)	For each radionuclide release group per facility plus "sum of fractions of DRL" rule over all radionuclides per facility to ensure the total dose remains below the limit.
20 μSv/mo	ALc	EEDs (μSv/mo)	One combined dose Action Level for all radionuclide release groups from all Bruce Power facilities EEDs = Bruce Power emission effective dose.
2 μSv/wk (air) 8 μSv/mo (water)	AL	Bq/wk (air) Bq/mo (water)	For each radionuclide release group per facility. 10% of DRL.
	IIL	Bq/wk (air) Bq/mo (water)	For each radionuclide release group per facility. IIL is at the high end of normal release rates, e.g., at 97.5th percentile. Single Pathway Thresholds are on each release point.
↑ ALARA	↑ Normal Range of Releases	Bq/wk (air) Bq/mo (water)	Normal releases may be characterized by 95% confidence interval and/or mean.

↓		↓
Legend		
DRL	=	Derived Release Limit for individual radionuclide groups, which triggers reporting to CNSC.
AL	=	Action Level for individual radionuclide groups, which triggers reporting to CNSC.
ALc	=	Combined Dose Action Level for all radionuclides, which triggers reporting to CNSC.
IIL	=	Internal Investigation Level, which triggers the internal Bruce Power SCR process.
NOL	=	Normal Operating Level, i.e., mean of historic releases. For longer term trend analysis.

Emissions can change depending on activities occurring in the nuclear facilities, such as planned/unplanned outages, Surplus Base Load Generation (SBG) derates and shutdowns to support dynamic electricity demand, and refurbishment activities. Outages are required to complete maintenance for continued safe and reliable activities involving operation of the site. Maintenance activities may cause periodic elevated emissions during outage activities due to systems that are typically closed being opened up for inspections and maintenance. The Bruce Power outage schedule by unit for the 451 outage days in 2019 has been provided in Table 4. These longer outages were required for appropriate Asset Management to support safe operation for Life Extension and involved significant inspection and maintenance activities across site. Surplus Baseload Generation (SBG) occurrences in 2019 have been provided in Table 5. Potential sources of emissions in 2019 are provided in the Section 3.1.1 and Section 3.1.2.

Table 4
2019 Bruce Power Outage Schedule

Unit	Total Outage Days
1	0
2	51.8
3	132.5
4	22.7
5	107.5
6	23.1
7	113.5
8	0
Total Days	451

Note: Includes planned and unplanned outages.

Table 5
2019 Bruce Power Surplus Baseload Generation

Unit	SBG Derate Events (CSDVs)	SBG Shutdown Events
1	52	0
2	37	0
3	30	0
4	40	1
5	29	1
6	33	0
7	26	0
8	47	0
Total	294	2

3.1.1 Air

3.1.1.1 2019 Radiological Airborne Effluent Results

Through Bruce Power's normal operation, inclusive of outage maintenance activities, airborne radiological emissions are released to the environment. These airborne emissions are primarily monitored through exhaust stacks and are well below regulatory levels as described throughout the remainder of this report. These airborne emissions typically originate within reactor systems including the moderator and heat transport systems as well as their associated systems such as purification. These airborne emissions may fluctuate or elevate during particular planned and unplanned activities. Unplanned events that may cause emission increases can be a result of; equipment deficiencies including stack filter by-pass, resin exhaustion in ion-exchange purification processes, boiler tube leaks causing increased emissions through feedwater venting, and process leaks escaping out of reactor systems or air ingress into reactor systems. Planned activities where emission fluctuations may occur include; scheduled fuel bundle defect removals from the heat transport system, purges from systems including moderator cover gas required to keep key process parameters within specifications, and increased outage days where maintenance work is performed on reactor systems as required to support equipment health and continued safe operation (in outages reactor systems need to be opened up potentially releasing increased airborne emissions).

Where possible Bruce Power has several engineered barriers in place to assist in minimizing radionuclides released to the environment and keeping releases as low as reasonably achievable (ALARA). These barriers include high efficiency particulate air (HEPA) filters and high efficiency carbon air (HECA) filters to minimize the release of radionuclides through the exhaust stacks. Testing of Bruce Power's stack filters are conducted annually by a third party to assess and assure their removal efficiency. Additional barriers include moderator and heat transport purification systems designed to remove radionuclides which minimizes these contaminants from becoming an airborne emission, as well as vault vapour recovery systems which reduce airborne tritium releases through the capture of water vapour within the vault before it reaches the exhaust stack. These barriers in conjunction with performing work activities in accordance with the ALARA principle, systematic monitoring and trending of airborne emissions, and prompting investigations when emissions fluctuate, assists Bruce Power in minimizing emissions and ensuring emissions remain ALARA and well below regulatory limits.

In 2019, Bruce Power's radiological airborne effluent emissions were well below regulatory limits. Bruce Power routinely reports the results of the radiological airborne effluent monitoring in accordance with the licence to the CNSC. The 2019 Radiological Airborne Effluent Results for all utilities onsite are shown in Table 6. In addition to normal operations, maintenance work completed on the heat transport system, moderator, feeders and boilers also contributed to radiological emissions in 2019. The outage activities in 2019 were also focused on fuel channel inspections at both stations.

Table 6
Annual Radiological Airborne (Gaseous) Effluent Results for 2019

Pathway - Radionuclide		Emissions (Bq)/yr					
	Bruce A	Bruce B	CMLF	WWMF (OPG)	CNL	Kinectrics KI**	Total
	Air						
Tritium Oxide	4.63E+14	3.30E+14	2.23E+10	1.03E+13	2.41E+11	1.88E+11	8.03E+14
Noble Gas	7.07E+13	3.39E+13	Not applicable	Not applicable	Not applicable	Not applicable	1.05E+14
Iodine-131	4.17E+07	4.40E+05	2.52E+04	0.00E+00	Not applicable	Not applicable	4.21E+07
Particulate Gamma	1.97E+06	4.76E+06	0.00E+00*	6.52E+02	Not applicable	Not applicable	6.73E+06
Particulate Gross Beta	Not applicable	Not applicable	Not applicable	Not applicable	3.9E+04	Not applicable	3.90E+04
Particulate Gross Alpha	2.43E+04	2.63E+04	0.00E+00*	Not applicable	4.9E+03	Not applicable	5.54E+04
Carbon-14	1.34E+12	1.08E+12	Not applicable	2.62E+09	Not applicable	Not applicable	2.43E+12

Note: * Natural occurring radionuclide material detected in gamma spectrum analysis is not reported.
** This is the net airborne emission from KI North Facility for the period of Dec 27, 2018 to Jan 23, 2020.

3.1.1.2 Historical Radiological Airborne Effluent Results

The figures below provide representations of the cumulative annual releases of radionuclide airborne effluents at Bruce A and Bruce B.

Figure 2 through Figure 4 includes the long term trend, illustrated by the 5 year moving average line. Note that all Bruce A units (1-4) were in lay up from 2001 to 2004, Units 3 and Unit 4 have been in operation from 2004 to present, and Units 1 and Unit 2 have been in operations from late 2012 to present.

Figure 2 provides the historical trend in airborne tritium emissions. Airborne tritium is a principal radiological emission associated with dose to the public. Radiological airborne effluent emissions are managed inline with the concept of As Low As Reasonably Achievable (ALARA). In 2019, airborne tritium emissions have decreased at Bruce A and Bruce B compared to 2018.

Figure 3 details the historical trend in airborne ^{14}C emissions. Airborne ^{14}C is a principal radiological emission contribution to dose to public. ^{14}C emissions at Bruce A show an increase from shutdown/refurbishment years due to return to service in 2012, and have seen a decrease since 2015, which may be attributed to an increased focus on resin management and a heightened awareness and sustained efforts towards minimizing moderator cover gas purging. Bruce B shows low variability in ^{14}C emissions post 2010 due to an increased focus on moderator purification, resin management, and reduction of moderator cover gas purging. In 2019, ^{14}C emissions remained low at Bruce B, with a slight increase at Bruce A compared to the previous year.

The majority of airborne iodine emissions are captured by the high efficiency carbon air (HECA) filters, which are tested on an annual basis to probe filter exhaustion, overall efficiency, and in order to maintain equipment reliability. Most analytical results for iodine as measured in the stacks are less than Limit of Detection (L_d). To prevent producing an over-conservative number, as of 2016 results that were below L_d were stated as such during routine reporting, and results greater than L_d were included in the summation of iodine to provide a more representative value. The majority of iodine emissions at both Bruce A and B were below L_d.

Figure 4 details the historical trend in iodine airborne emissions over the last 10 years. Iodine in air is a radiological emission associated with dose to the public. The noted iodine emissions at Bruce A in 2014 are greater than previous years but remain well below all regulatory limits. The Bruce A 2014 iodine emissions were due to debris in the heat transport system after return to service of Units 1 and 2 which resulted in fuel defects and associated releases of iodine when these fuel defects were removed from the heat transport system. The 2012 iodine emissions are due to iodine not being captured by exhausted HECA filter beds. These HECA filter beds have since been replaced. Following the identification of this deficiency, an increased focus has been placed on filter maintenance and the filter testing program. In 2019, Bruce A experienced failed fuel issues that contributed to the increased iodine emissions in comparison to the previous year. Iodine emissions have been stable at Bruce B over the long term.

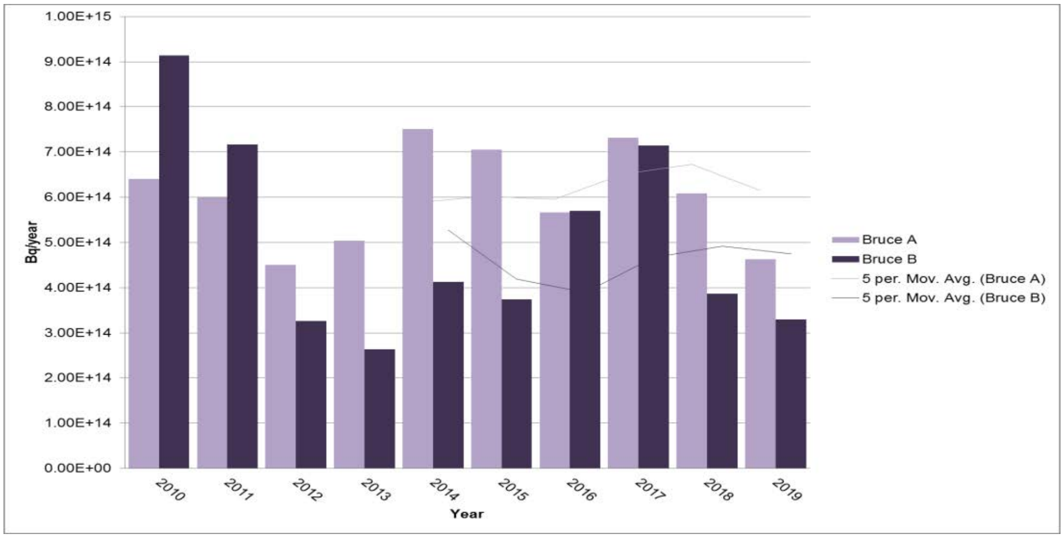


Figure 2
Historical Airborne Tritium Emissions

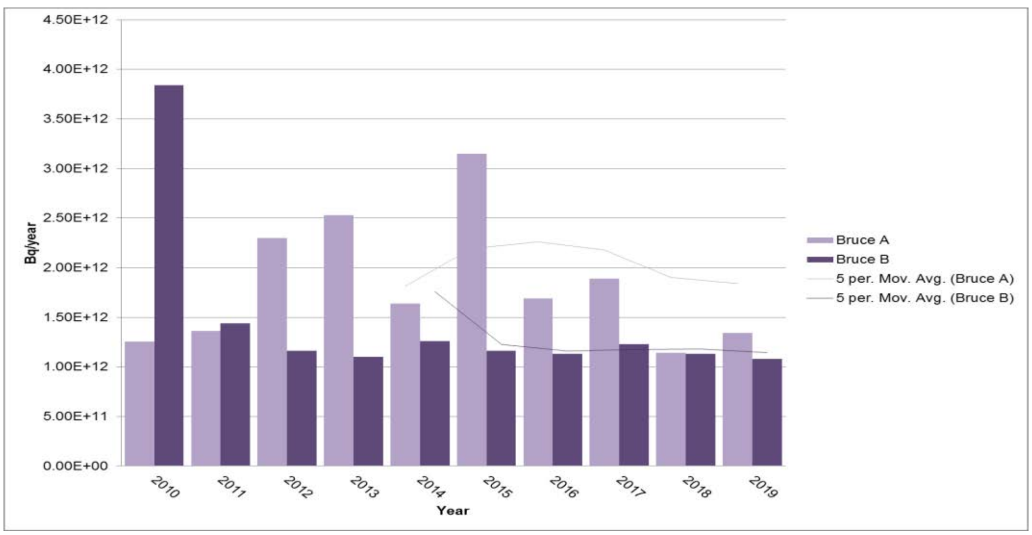


Figure 3
Historical Airborne ^{14}C Emissions

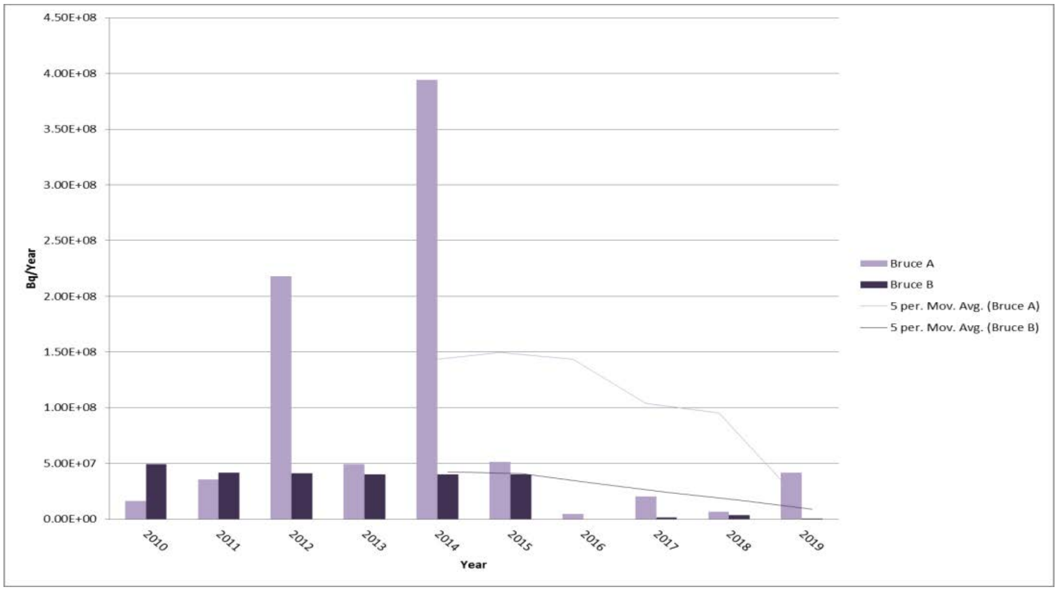


Figure 4
Historical Iodine Emissions in Air

3.1.2 Water

3.1.2.1 2019 Radiological Waterborne Effluent Results

Through Bruce Power's normal operation, inclusive of outage activities, waterborne radiological emissions are released to the environment. These waterborne emissions are well below regulatory limits. Waterborne emissions are monitored through release pathways including active liquid waste, feedwater discharges, a collection of building effluent and foundation drainage in sumps prior to release to the Condenser Cooling Water (CCW) duct. These radiological waterborne emissions typically originate within reactor systems including the moderator and heat transport systems as well as their associated systems such as purification.

A majority of the waterborne radiological emissions produced from the aforementioned systems are captured within the active liquid waste system within the plant where tanks are analyzed to ensure acceptance criteria are met prior to release (batch discharge) to the environment. Waterborne emissions may fluctuate or elevate during particular planned and unplanned activities. Unplanned events that may cause emission increases can be a result of; equipment deficiencies including the moderator or primary heat transport upgraders being out of service for maintenance, external challenges delaying D_2O de-tritiation processing off-site, purification resin exhaustion, boiler tube leaks, controlled discharges from reactor systems routed to collection and recovery processes, air ingress into reactor systems, and fuel defects. Planned activities for which emission fluctuations may occur include; scheduled fuel bundle defect removals from the heat transport system, increased spent resin transfers, and increased outage days where maintenance work is performed on reactor systems as required to support equipment health and continued safe operation (in outages reactor systems need to be opened up potentially leading to increased waterborne emissions).

Where possible, Bruce Power has several barriers in place to assist in minimizing waterborne radionuclides from being released to the environment. These barriers include moderator and heat transport purification to remove waterborne radionuclides from reactor systems, D_2O in H_2O leak detection to provide early indication of a heavy water leak or boiler tube leak, D_2O Supply and Inventory systems to maximize the capture of D_2O for re-use, and the Active Liquid Waste system incorporates decay time as well as a reverse osmosis/conventional filtration for increased particulate removal. It is important to note that the Active Liquid Waste system is also managed via a batch discharge process where contents are sampled and measured against conservative criteria prior to approval for discharge. These barriers in conjunction with performing work activities in accordance with the ALARA principle, monitoring and trending waterborne emissions and initiating investigations when emissions fluctuate, assists Bruce Power in minimizing emissions and ensuring emissions remain ALARA and well below regulatory limits.

In 2019, Bruce Power's radiological waterborne effluent emissions were well below regulatory limits. Bruce Power routinely reports the results of the radiological waterborne effluent monitoring in accordance with the CNSC licence. The 2019 waterborne radiological effluent results are shown below in Table 7 (including tritium emissions from foundation drainage sump discharges).

Table 7
Annual Waterborne (Aqueous) Radioactive Effluent Results for 2019

Pathway - Radionuclide	Emissions (Bq)/yr						
	Bruce A	Bruce B	CMLF	WWMF (OPG)	CNL	Kinectrics KI*	Total
Water							
Tritium Oxide	2.12E+14	8.82E+14	Not applicable	1.60E+11	3.73E+10	Not applicable	1.09E+15
Carbon-14	8.17E+08	4.68E+09	Not applicable	Not applicable	Not applicable	Not applicable	5.49E+09
Gross Beta/Gamma	2.13E+09	2.26E+09	Not applicable	Not applicable	Not applicable	Not applicable	4.39E+09
Gross Beta	Not applicable	Not applicable	Not applicable	7.08E+07	4.52E+07	Not applicable	1.16E+08
Gross Alpha	$<L_d$	$<L_d$	Not applicable	Not applicable	6.75E+06	Not applicable	6.75E+06

Note: $<L_d$ = less than limit of detection

*There were no waterborne emissions in 2019 for Kinectrics KI.

3.1.2.2 Historical Radiological Waterborne Effluent Results

The figures below (Figure 5 through Figure 7) provide representations of the cumulative annual releases of radionuclide waterborne effluents at Bruce A and Bruce B. The figures include the long-term trend, illustrated by the 5 year moving average line. Note that all Bruce A units (1-4) were in lay up from 2001 to 2004, Units 3 and 4 have been in operation from 2004 to present, and Units 1 and 2 have been in operations from late 2012 to present.

Figure 5 details the historical trend in tritium waterborne emissions. Tritium in water is a minor radiological emission in terms of dose to the public. Bruce A shows a long term stable trend with regard to tritium waterborne emissions. Bruce B experienced elevated tritium emissions (well within regulatory limits) in 2012 due to a boiler tube leak. These emissions remain well below the Derived Release Limit (DRL) and dose to public values remain *de minimus*. Bruce B waterborne tritium emissions increased in 2019 compared to 2018, and this may be due to delays in de-tritiation processing of D_2O off-site. Since 2017, Unit 5 at Bruce B has been experiencing a minor ongoing boiler tube leak. The leak rate is monitored regularly and has remained controlled within acceptable values so as to continue operation until it can be repaired. The leak was inspected during a planned outage in 2019 and a repair strategy was developed. The repair is scheduled to occur in 2022.

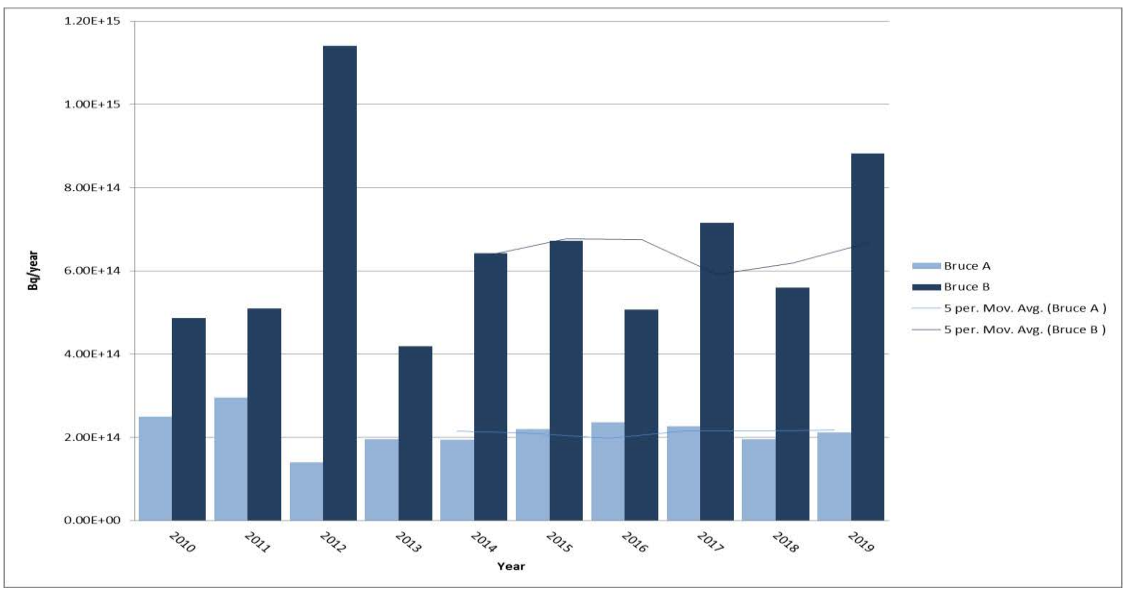


Figure 5
Historical Tritium Waterborne Emissions

Figure 6 details the historical trend in ^{14}C waterborne emissions. ^{14}C in water is a radiological emission associated with dose to the public. ^{14}C emissions are being managed through Bruce Power's Resin Management Program. The increase in ^{14}C emissions in 2014 and 2015 at Bruce B can be attributed to the draining of the Emergency Water Storage Tank (EWST) in preparation for the Vacuum Building Outage (VBO). These emissions remain well below the Derived Release Limit (DRL) and dose to public remains *de minimus*. In 2016 and 2017, a reduction at Bruce A and B returned emissions to more consistent levels. This may be attributed to an increased focus on resin management and the return of routine outage activities (no draining activities from VBO). In 2019 waterborne ^{14}C emissions were higher at Bruce B than the previous year due to ion exchange resin dewatering and replacements in preparation of Major Component Replacement activities.

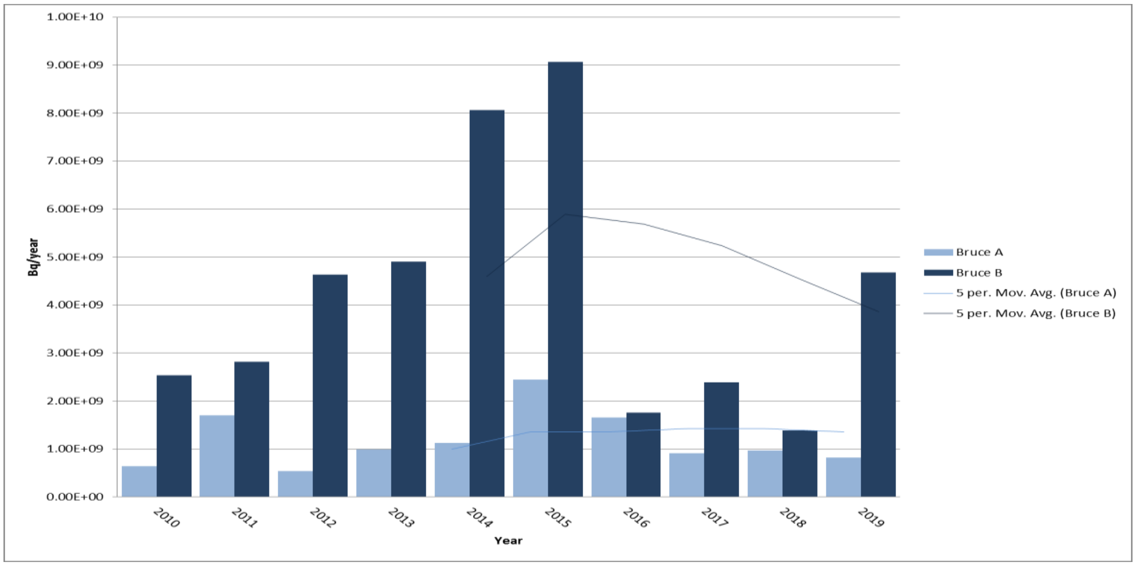


Figure 6
Historical ^{14}C Waterborne Emissions

Historical waterborne gamma emissions are shown in Figure 7. It should be noted that the methodology employed for reporting Minimum Detection Levels (MDLs) was not consistent from year to year. Bruce A gamma emissions have been consistently low since 2011 however there was a small increase in 2019 due to an increase in loading of low reactivity water to the Active Liquid Waste System and the cumulative impact of setting values that are less than background to equal the background value. This results in over-conservative reporting. There were no events to contribute to this slight increase and emissions are well below the regulatory limits. Bruce B experienced elevated gamma emissions in 2012 associated with a boiler tube leak; these emissions remain well below the Derived Release Limit (DRL) and dose to public values remain *de minimus*. Since 2017, Unit 5 at Bruce B has been experiencing a minor ongoing boiler tube leak, releases from which are included in the overall waterborne gamma emissions for 2019.

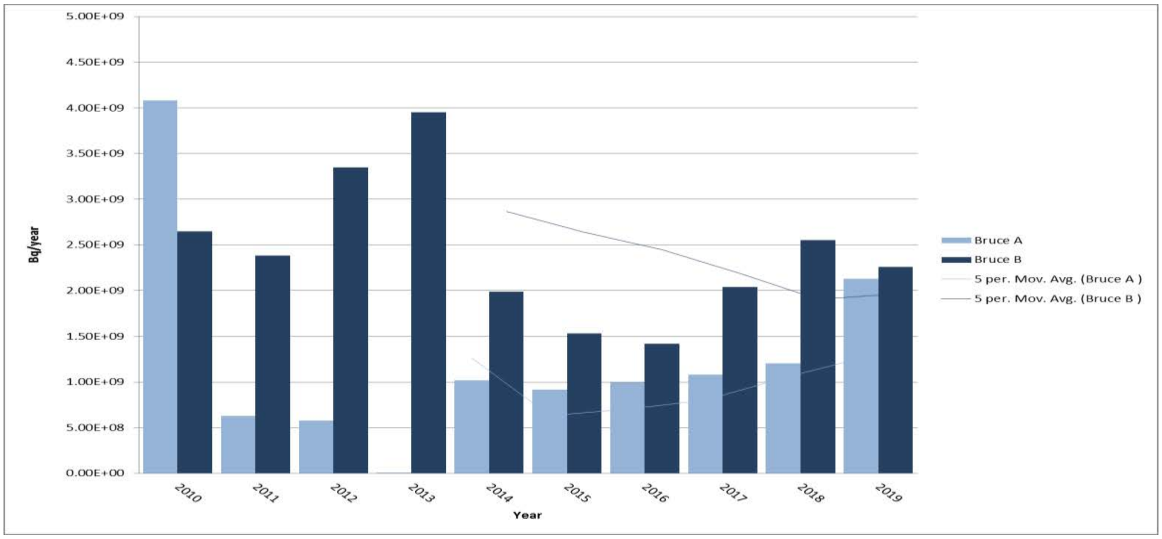


Figure 7
Historical γ Emissions in Water

3.1.2.3 Foundation Drainage Waterborne Effluent Results

Bruce A and Bruce B have a foundation drainage system that maintains a water level of 577 ft (176 m) or less, and therefore creates a local hydraulic sink around the powerhouses. The foundation drainage system is designed to collect groundwater seepage; this water is monitored and discharged to Lake Huron through the CCW duct.

Bruce Power monitors the foundation drainage system on a monthly basis and the tritium concentrations are used to estimate tritium loading (concentrations x volume) and are included in the total station waterborne effluent results that are routinely reported in accordance with the CNSC licence. All waterborne tritium results are well below any regulatory limits. Foundation drainage contributes to only a very minor fraction of the annual total. In relation to the 2019 total station tritium waterborne emissions foundation drainage contributed 4.4% at Bruce A and 0.24% at Bruce B.

Tritium trends in the foundation sumps are monitored and actions taken to narrow down the possible reasons why concentration trends may be fluctuating in some cases. Variability may be attributed to atmospheric tritium in the powerhouse which accumulates in low lying areas and concentrates in collection sumps over time (this effect is particularly elevated during outage maintenance activities when systems are opened up and there are periods of elevated tritium in the station) It is evident from the trends that the potential implications and impacts on the environment are low, as indicated by monitoring on two fronts: (1) CCW tritium measurements remain very low, and (2) multi-level groundwater wells situated near the perimeter of the powerhouse continue to show no evidence of contamination of concern with respect to tritium measurements.

Multi-level groundwater wells show tritium concentrations that are well below the drinking water guideline of 7,000 Bq/L, which is used as a reference point (note that this value is a guideline for potable water). There is no regulatory criterion for tritium in non-potable water. Foundation drainage acts as a hydraulic sink and pulls groundwater towards the station and discharges out via a monitored pathway to the lake. From the monitoring data, it can be concluded that the potential impacts on the environment as a result of tritium concentration in foundation drainage are low.

Foundation Drainage Bruce A

The Bruce A 2019 foundation drainage waterborne tritium effluent results are included in the water effluent results in Table 7 and presented with further detail in Table 8. Routine monitoring on a monthly basis continues. There are periods when tritium levels are elevated; however, there are no adverse effects on the environment or impact on groundwater quality as confirmed by the concentrations of tritium measured in the multi-level groundwater wells. Historical Bruce A foundation drainage waterborne effluent results for the past 10 years are presented in Figure 8. It should be noted that the measured tritium concentrations improved (lower) in 2019 compared to historical values.

Due to the slight increase in tritium concentrations in 2018 at Units 3 and 4 in comparison to Units 1 and 2 and also Units 5-8, an investigation into the potential sources or causes was initiated in 2019. This investigation is ongoing, but includes exploratory work into the substructure and sump liners of the Bruce A station and also a supplementary study with increased sampling of the U4 foundation drainage sump.

Table 8
2019 Bruce A Foundation Drainage

Month	Concentration of Tritium (Bq/L)			
	Unit 1	Unit 2	Unit 3	Unit 4
January	1,036	4,810	9,398	77,182
February	2,775	24,864	5,735	50,394
March	1,850	32,745	10,027	106,116
April	2,627	13,764	4,329	7,659
May	925	27,935	6,549	12,950
June	925	13,542	34,114	105,043
July	2,294	2,072	56,092	52,059
August	1,295	1,332	7,955	72,039
September	1,443	3,663	15,170	242,461
October	1,702	40,293	18,167	53,391
November	2,035	42,957	19,980	69,523
December	1,961	16,391	15,725	190,106
Average	1,739	18,697	16,937	86,577

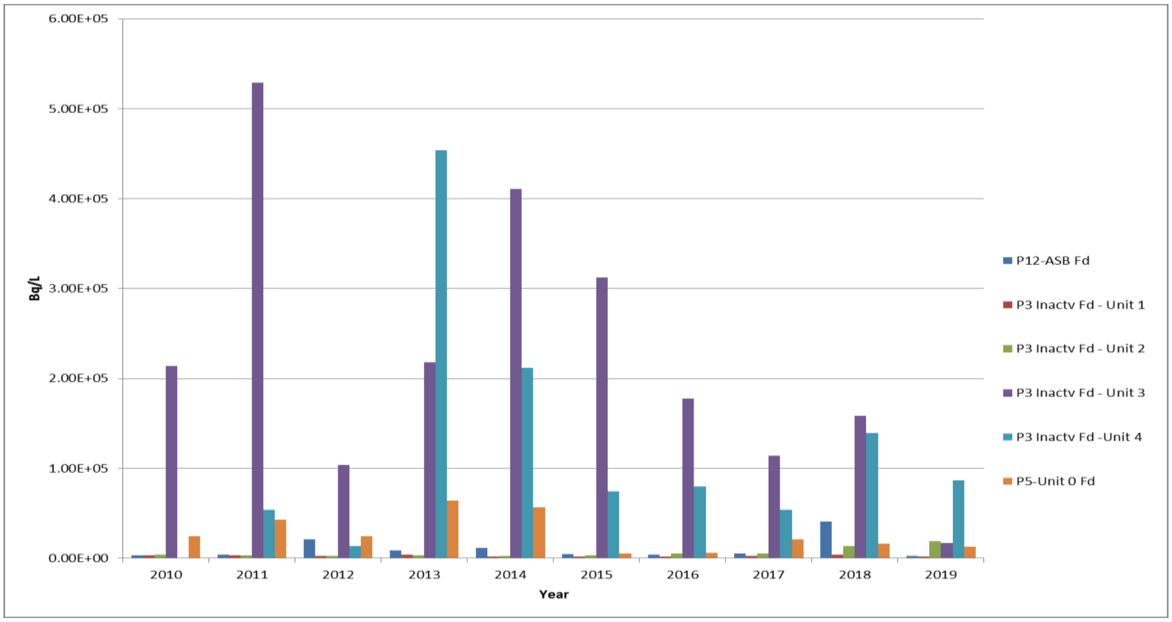


Figure 8
Bruce A Historical Foundation Drainage

Foundation Drainage Bruce B

The Bruce B 2019 foundation drainage waterborne Tritium results are included in the overall station waterborne effluent results in Table 7 and presented with further detail in Table 9. As stated previously, in 2019, Bruce Power's radiological waterborne effluent emissions (including foundation drainage discharges) were well below regulatory limits. Historical Bruce B foundation drainage waterborne Tritium results since 2010 are presented in Figure 9. In general, tritium in foundation drainage discharges has had low variability, with the exception of 2012.

Table 9
2019 Bruce B Foundation Drainage

Month	Concentration of Tritium (Bq/L)			
	Unit 5	Unit 6	Unit 7	Unit 8
January	29,515	4,033	3,552	19,329
February	25,900	2,960	3,330	37,370
March	20,350	2,960	5,920	38,850
April	1,480	2,590	15,170	38,480
May	1,850	1,850	23,310	25,160
June	18,500	3,700	21,460	31,450

July	36,612	4,377	10,556	23,706
August	13,690	4,070	11,100	57,350
September	718	3,918	73,197	80,164
October	1,661	4,621	105,350	14,038
November	233	3,589	51,356	24,383
December	2,142	6,601	74,241	20,261
Average	12,721	3,772	33,212	34,212

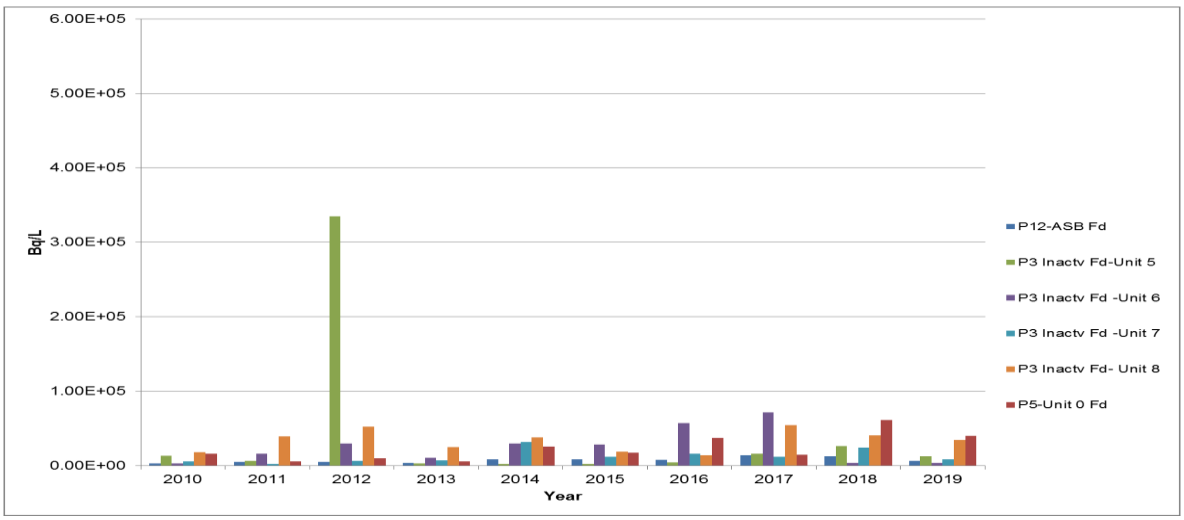


Figure 9
Bruce B Historical Foundation Drainage

Wastewater Treatment (Sewage Processing Plant) Wastewater is collected from all facilities at the Bruce Power site including Bruce A and Bruce B, CMLF, CNL (Douglas Point), OPG (WWMF) and Centre of Site buildings, and is treated onsite at the Bruce Power Sewage Processing Plant (SPP). The sanitary sewage collection system is a network of 3 km of gravity sewers and 7 km of force mains. The Bruce Power site decreased the number of pumping stations from 26 to 19 in 2018. This decrease has occurred by combining and/or decommissioning pumping stations with efforts to replace obsolete equipment and simplify the site sanitary system [R-37].

The sewage processing plant has an average design flow capacity of 1,590 m^3/day and a maximum design flow capacity of 4,700 m^3/day. The plant consists of an inlet chamber, aerated equalization tank, screening and grinding equipment, liquid chemical injection, and two parallel biological treatment trains consisting of aeration tanks, settling tanks, and aerobic sludge digesters, followed by ultraviolet disinfection (UV), and two onsite lagoons for sludge storage. Final effluent from the plant is discharged to Lake Huron via a gravity pipe to the Lake Huron outfall located near Douglas Point.

Sewage processing plant effluent monitoring data was previously reported to the CNSC in the quarterly technical report. This included radiological analytical results from the treated liquid effluent routed to the lake and the sludge digester tanks routed to onsite lagoons. In 2017, Bruce Power requested to have the Waste Nuclear Substance Licence (WNSL) for the CMLF revoked and consolidated into the Bruce A and Bruce B PROL since the activities were already described in the Bruce Power PROL. The consolidation occurred July 1, 2017 and now requires the sewage effluent to be reported in this Environmental Protection report. In 2019, the average daily effluent flow was 930m^3/day, a minor decrease from 961m^3/day in 2018 [R-37]. Table 10 shows radiological sewage analysis for 2019.

Quarterly averages for radiological parameters in sludge and sewage effluent in 2019 were well below internal acceptance criteria limits and the annual average is well below the Provincial Water Quality objective annual average limit for tritium (7,000 Bq/L). The quarterly average tritium concentrations in sludge were within the same range as previous years, although the annual average is higher. The average value in 2018 was 2.79E+01 Bq/L. A low concentration of gamma was identified in one digester tank in the second quarter of 2019, identified as Molebdium-99, a short half-life species. Tritium concentrations in sewage effluent in 2019 were similar to quarterly values in 2018, with the exception of the third quarter results. In August 2019, an elevated tritium concentration was identified in the SPP effluent and digester sludge tank which launched an investigation into the cause. The source was identified as an unmonitored sewage sump at Bruce B. From this event, Bruce Power has posted signage on all sewage sumps across site, increased awareness to all employees, and initiated a monitoring program for the unmonitored sewage sumps at both stations for 2020. Bruce Power continues to sample sewage at the primary Bruce A and Bruce B powerhouse sumps including the Unit 0 and Unit 1-8 sumps.

Table 10
2019 Sewage Processing Plant Monitoring

Sample Source	Tritium Bq/L	Beta Bq/L	Gamma Bq/L
Sewage Digester Sludge			
Q1	2.67E+02	Not Applicable	None detected
Q2	2.59E+02	Not Applicable	5.64E-02
Q3	8.54E+02	Not Applicable	None detected
Q4	3.22E+02	Not Applicable	None detected
Average	**4.25E+02**	Not Applicable	**1.41E-02**
Effluent			
Q1	3.08E+02	4.01E-01	**
Q2	2.32E+02	3.54E-01	**
Q3	5.33E+03	5.91E-01	**

Q4	3.00E+02	5.43E-01	**
Average	**1.54E+03**	**4.72E-01**	Not Applicable

Note: * Analyses are not done on sludge samples due to sample β-self absorption.
**Gamma analyses are not done on effluent samples since β is the most sensitive analysis for liquids.

3.2 Conventional (Non-Radiological) Effluent Monitoring Program

Bruce Power monitors the effluent emission streams for a variety of conventional parameters including hazardous substances. This monitoring is performed to meet the regulatory obligations of several Federal and Provincial regulatory agencies, including the CNSC. The results for these monitoring events are submitted to the lead environmental agencies at various times throughout the year. Table 11 provides a summary of the monitoring reports that Bruce Power submits throughout the year as well as identifies the time of submission and the lead regulatory agency. The reports provide details and information necessary to meet regulatory report requirements. The following sections describe some of the regulatory context for each report.

3.2.1 Conventional (Non-Radiological) Effluent Monitoring Program

The conventional monitoring program operated by Bruce Power is described in:

- BP-PROC-00080, Effluent Monitoring Program [R-33]
- BP-PROC-00099, Conventional Emissions Water [R-35]
- BP-PROC-00928, Conventional Emissions-Air [R-36]

The aforementioned procedures provide requirements for effluent sampling, monitoring and compliance with limits set forth in the following:

- Ontario Regulation 215/95: Effluent Monitoring and Effluent Limits - Electrical Power Generation Sector [R-38]
- Ontario Regulation 419/05: Air Pollution - Local Air Quality [R-39]
- Ontario Water Resources Act (R.S.O. 1990, c.O.40) [R-40]
- ECAs issued by the Ministry of the Environment Conservation and Parks (MECP) [R-41] [R-42][R-43][R-44]
- Permits to Take Water (PTTW) [R-45][R-46][R-47] issued by MECP and with Internal Administrative Limits
- Ontario Regulation 389/18: Quantification, Reporting and Verification of Greenhouse Gas Emissions [R-48]

- Federal Halocarbon Regulations, 2003, SOR 2003-289 [R-49]
- Wastewater Systems Effluent Regulations, 2003, SOR 2003-289 [R-50]
- Notice to Report: Under the authority of Section 46 of the Canadian Environmental Protection Act (CEPA), operators of facilities thatmeet the criteria specifiedin the annual notice with respect to reporting of greenhouse gases (GHGs), published inthe *Canada Gazette*, are required to report facility GHG emissions toEnvironment and Climate Change Canada by the annual June 1st reporting deadline[R-51][R-51]
- Notice to Report: Under the authority of the Canadian Environmental Protection Act, 1999 (CEPA 1999), owners or operators of facilities thatmeet published reporting requirements are required to report to the NPRI[R-52]
- Ontario Regulation 463/10: Ozone Depleting Substances and other Halocarbons[R-53]
- Ozone-Depleting Substances Regulations, 1998, SOR/99-7[R-53]

Table 11
2019 Bruce Power Regulator Reporting for Conventional Parameters

Hazardous Substance (Section Reference)	Report Title (Document Control Number)	Regulatory Agency	Submission Date (Frequency)
Air - ECA)	Written Summary for Reporting Year 2019 Environmental Compliance Approval-Air 7477-8PGMTZ (B-CORR-00541-00010)	Ministry of Environment, Conservation and Parks	15JUN2020 (Annual)
Air - Halocarbon	Halocarbon Release Report Pursuant to the Federal Halocarbon Regulations (SOR 2003-289) Section 33 January to June 2019 (B-CORR-00521-00171)	Environment Climate Change Canada	31JUL2019 (Semi-annual)
	Halocarbon Release Report Pursuant To The Federal Halocarbon Regulations (SOR/2003-289), Section 33, July to December 2019 (B-CORR-00521-00002)	Environment Climate Change Canada	31JAN2020 (Semi-annual)
Air - Greenhouse Gas	Not required to report 2019 Federal Greenhouse Gas Reporting	Internal Report	Quantify by GHG emissions by 01JUN2020 (Annual) Not required to report

Hazardous Substance (Section Reference)	Report Title (Document Control Number)	Regulatory Agency	Submission Date (Frequency)
	Not required to report 2019 Provincial Greenhouse Gas	Internal Report	Quantify by GHG emissions by 01JUN2020 (Annual) Not required to report
Air - NPRI	2019 National Pollutant Release Inventory for Bruce Power NPRI ID #7041 (B-CORR-00521-00003)	Environment Climate Change Canada	01JUN2020 (Annual)
Water - EMEL	2019 Annual Effluent Monitoring Effluent Limit (EMEL) Report (BP-CORR-00541-00019)	Ministry of Environment, Conservation and Parks	01JUN2020 (Annual)
Water - EMEL/ECA	Bruce Power EMEL and Environmental Compliance Approval Submission- First Quarter 2019 (B-CORR-00541-00332)	Ministry of Environment, Conservation and Parks	14MAY2019 (Quarterly)
	Q2 2019 Effluent Monitoring Effluent Limit– Quarterly (B-CORR-00541-00333)	Ministry of Environment, Conservation and Parks	14AUG2019 (Quarterly)
	Bruce Power EMEL and Environmental Compliance Approval Submission Third Quarter (B-CORR-00541-00334)	Ministry of Environment, Conservation and Parks	14NOV2019 (Quarterly)
	Bruce Power EMEL and Environmental Compliance Approval Submission Fourth Quarter (B-CORR-00541-00011)	Ministry of Environment, Conservation and Parks	14FEB2020 (Quarterly)
Water - ECA	2019 Environmental Compliance Approval (Water) Annual Compliance Report for Bruce A (BP-CORR-00541-00020)	Ministry of Environment, Conservation and Parks	01JUN2020 (Annual)

Hazardous Substance (Section Reference)	Report Title (Document Control Number)	Regulatory Agency	Submission Date (Frequency)
	2019 Environmental ComplianceApproval (Water) Annual Compliance Report for Bruce B (BP-CORR-00541-00021)	Ministry of Environment, Conservation and Parks	01JUN2020 (Annual)
	2019 Environmental ComplianceApproval (Water) Annual Compliance Report for Centre of Site (BP-CORR-00541-00013)	Ministry of Environment, Conservation and Parks	01MAR2020 (Annual)
Water - PTTW	2019 Water Taking Data - Permit To Take Water 1813-8MLLHG Bruce A (BP-CORR-00541-00023)	Ministry of Environment, Conservation and Parks	31MAR2020 (Annual)
	2019 Water Taking Data - Permit To Take Water 2233-8MLN8J Bruce B (BP-CORR-00541-00024)	Ministry of Environment, Conservation and Parks	31MAR2020 (Annual)
	2019 Water Taking Data - Permit To Take Water 1152-8MLPCR Centre of Site (BP-CORR-00541-00025)	Ministry of Environment, Conservation and Parks	31MAR2020 (Annual)
Water - WSER	2019 Q1 Wastewater System Effluent Regulation (WSER) Report (BP-CORR-00521-00008)	Environment Climate Change Canada	14MAY2019 (Quarterly)
	2019 Q2 Wastewater System Effluent Regulation Report (NK37-CORR-00521-00043)	Environment Climate Change Canada	14AUG2019 (Quarterly)
	2019 Q3 Wastewater System Effluent Regulation Report (NK37-CORR-00521-00045)	Environment Climate Change Canada	14NOV2019 (Quarterly)
	2019 Q4 Wastewater System Effluent Regulation Report (BP-CORR-00521-00006)	Environment Climate Change Canada	14FEB2020 (Quarterly)

3.2.2 Air - Effluent

3.2.2.1 Environmental Compliance Approval

Site conventional air emissions are controlled to meet regulatory requirements and to minimize environmental impacts to protect the environment.

Conventional air emissions are held to performance standards stipulated in the Environmental Compliance Approval (ECA) (7477-8PGMTZ) [R-41] which incorporates all non-radiological air emission sources on site. The ECA allows flexibility to release contaminants up to a maximum Point of Impingent (POI) concentration limit at its property boundary. These limits are typically MECP limits (as per O.Reg. 419/05) [R-39], and for cases where there is no pre-defined MECP POI level, Bruce Power is bound by a Maximum Ground Level Concentration (MGLC) accepted by the MECP upon its ECA application submission.

Air contaminants of concern are modelled for all non-negligible sources in worst-case scenarios. Estimated emission rates are then analyzed to ensure regulatory limits at the POI are met. While Bruce Power is bound by ECA performance limits, the company has operational flexibility (e.g. location of emission sources for temporary generator units) once it can be demonstrated that it will remain within these limits.

Specific contaminants emitted from every air emission source on site are identified in the Emission Summary and Dispersion Modelling (ESDM) Report that reflects the actual operation of the facility [R-39]. Bruce Power maintains up to date ESDM report that reflects current operations. Upon making any modifications, the modification log and ESDM report are updated to document that the facility is in compliance. The ESDM Report shows that:

- The nature of the operations of the facility continues to be consistent with the description section of the ECA;
- The production at the facility continues to be below the facility production limit specified on the ECA; and
- The performance limits are met.

During 2019, four modifications were made. Three of the modifications were for the installation of silencers on the deaerator vents for Unit 5, Unit 6 and Unit 7 resulting in a decrease in noise levels. The fourth modification was for the injection of film forming amines (FFA) in the Unit 6 (MCR) feedwater and main steam systems resulting in the release of a new amine contaminant. All of the modifications demonstrated compliance with the POI limits (as per O. Reg 419/05) and the conditions of Bruce Power's ECA. As per the conditions of the ECA, the MECP District Office was notified of each modification.

<u>Noise</u>

The Environmental Compliance Approval (ECA) [R-41][R-39] for air requires that Bruce Power is within the noise limits of NPC-232 Sound Level Limits for Stationary Sources in Class 3 Areas (Rural).

Noise complaints and reports were received from various Inverhuron residents between May 24, 2019 and October 20, 2019. In accordance with the conditions of Bruce Power's ECA, the MECP District Office was notified of the complaints in writing following each complaint.

<u>2015-2018 Noise Monitoring and Noise Control Investigations</u>

Noise investigations conducted in the summer 2015, 2016 and winter 2017 demonstrated that the sound levels at the concerned receptors (Lake Street) complied with the quantitative limits stipulated by the MECP. There was no direct correlation between the noise logs provided by the residents at Lake Street and operational events at Bruce Power. The study revealed that meteorological conditions influence the propagation of sound from the stations (i.e., Bruce Power is slightly audible during periods of low background noise).

A Noise Control Investigation for the four rooftop deaerator vents at Bruce B was conducted using sound level measurements and source measurements collected during the 2015 and 2016 Noise Monitoring Programs. The sound power emission measurements collected from each of the four deaerator vents at Bruce B in 2015 were input to an acoustical model of the Bruce Power site and surrounding area to determine predicted sound levels at locations within the surrounding community. With a worst-case predicted sound level of 33 dBA at Lake Street, the facility is well below the applicable criteria.

In order to mitigate the sound level concerns from neighbours, a project was initiated in 2018 to install silencers on the four deaerator vents at Bruce B affording a minimum of 30 dBA of attenuation. A silencer was installed on the Unit 8 deaerator vent in October 2018.

<u>2019 Noise Monitoring and Noise Control Investigations</u>

A sound level measurement was collected from the Unit 8 deaerator vent following the installation of the vent silencer and compared to measurements collected in 2015. The sound level measurement confirmed that an overall reduction of 31dBA was achieved relative to the unsilenced vent (4 by-pass valves open). In addition, the sound from the Unit 8 deaerator vent is no longer tonal (high frequency hum/whistle). The reduction exceeded the target of 30dBA as recommended by the Noise Control Investigation.

Silencers were installed on the Unit 7 deaerator vent in March; the Unit 6 deaerator vent in May; and the Unit 5 deaerator vent in October. A two week noise monitoring campaign was completed in August to assess the change in sound levels following the installation of Unit 6, Unit 7 and Unit 8 deaerator vent silencers. Unit 5 was in outage at the time of the campaign which implies there were no dearator venting or associated noise emissions from Unit 5. Results indicated that the sounds of nature and resident activities were dominant at Lake Street and within Inverhuron Provincial Park. The distinct tone that was audible from all four deaerator vents prior to installation of the silencers was completely inaudible, which is an indication ofthe effectiveness ofthe silencers. Bruce Power provided updates to the community as the project progressed, and following its completion, received positive feedback on sound levels from several members of the community.

3.2.2.2 Halocarbons

In Canada, the federal, provincial and territorial governments have legislation inplace for the protection of the ozone layer and management of ozone-depleting substances and their halocarbon alternatives. The use and handling of these substances are regulated by the provinces and territories intheir respectivejurisdictions, and throughthe Federal Halocarbon Regulations, 2003 [R-49] for refrigeration, air-conditioning, fire extinguishing, and solvent systems under federal jurisdiction. Bruce Power is governed by both the provincial and federal regulations.

Figure 10 below provides a summary of all the halocarbon releases across site for the 2019 calendar year. These leaks (releases) are broken down by magnitude; releases between 10 kg and 100 kg are reportable in semi-annual reports, and releases greater than 100 kg are immediately reportable to ECCC andMECP. There were no releases greater than 100 kg in 2019, and 8 releases on Site that were between 10-100 kg.

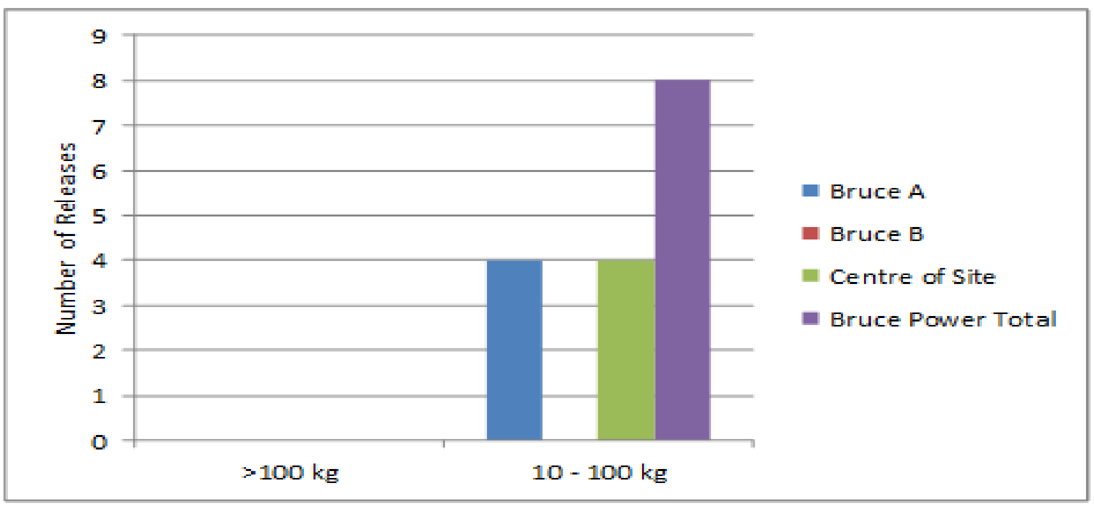


Figure 10
2019 Bruce Power Halocarbon Release Occurrences

<u>Historical Conventional Halocarbons Air Monitoring</u>

The environmental impactof these halocarbon discharges is reducedas a result of the older ozone depleting refrigerants (chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) being replaced by Hydrofluorocarbons (HFCs) with negligible impact on the ozone layer (e.g., R134a and R410). HFCs however have high global warming potential and pose a threat as a greenhouse gas[R-49]. Figure 11 below provides the historical trendof the total number of halocarbon releases reported to ECCC since 2008. The number of events has remained stable with a slight decrease in 2011 and 2017.

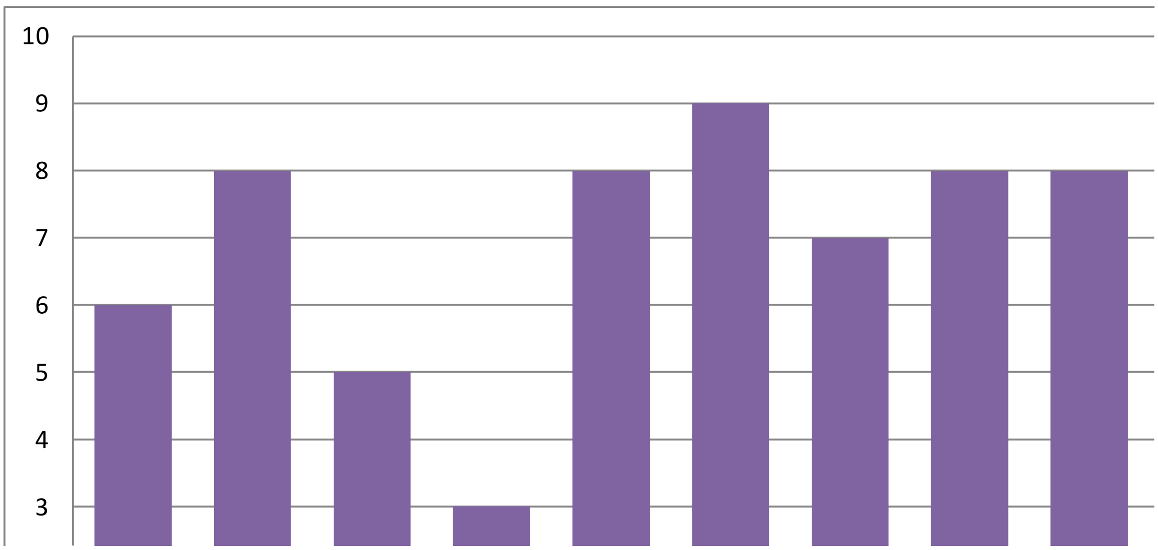


Figure 11
Historical Bruce Power Halocarbon Releases (> 10 kg)

Releases > 100 kg are immediately reportable to the Spills Action Centre (SAC).

3.2.2.3 Greenhouse Gas

In 2018, the province ordered a wind down of the cap and trade program and filed a new greenhouse gas reporting regulation, O. Reg 390/18 Greenhouse Gas Emissions: Quantification, Reporting and Verification [R-55]. O. Reg. 390/18 has taken the place of O. Reg. 143/16 which was issued in 2016 to support the implementation of the Provincial Cap and Trade Program.

The Provincial threshold for reporting GHG emissions dropped from 25,000 tonnes CO_2e to 10,000 tonnes CO_2e in 2015. Bruce Power was below the 25,000 tonnes CO_2e threshold in 2013 and 2014 and below the 10,000 tonnes CO_2e threshold in 2015 to 2018. In order to cease reporting, there must be three consecutive years reported under the threshold. Therefore, 2015 was the last year of reporting GHG emissions

Emissions will continue to be calculated in 2019 and onwards to confirm they are below threshold values.

<u>Historical Greenhouse Gas (GHG)</u>

GHG releases on site have trended downwards due to the Bruce Steam Plant (BSP) shut down strategy. The Steam Plant operated in 2015 to supplement the Vacuum Building

Outage at Bruce B and was shut down in December of 2015 when the stack was removed. Calculations for 2019 will be completed by June 1, 2020 and will be reported in the 2020 EPR.

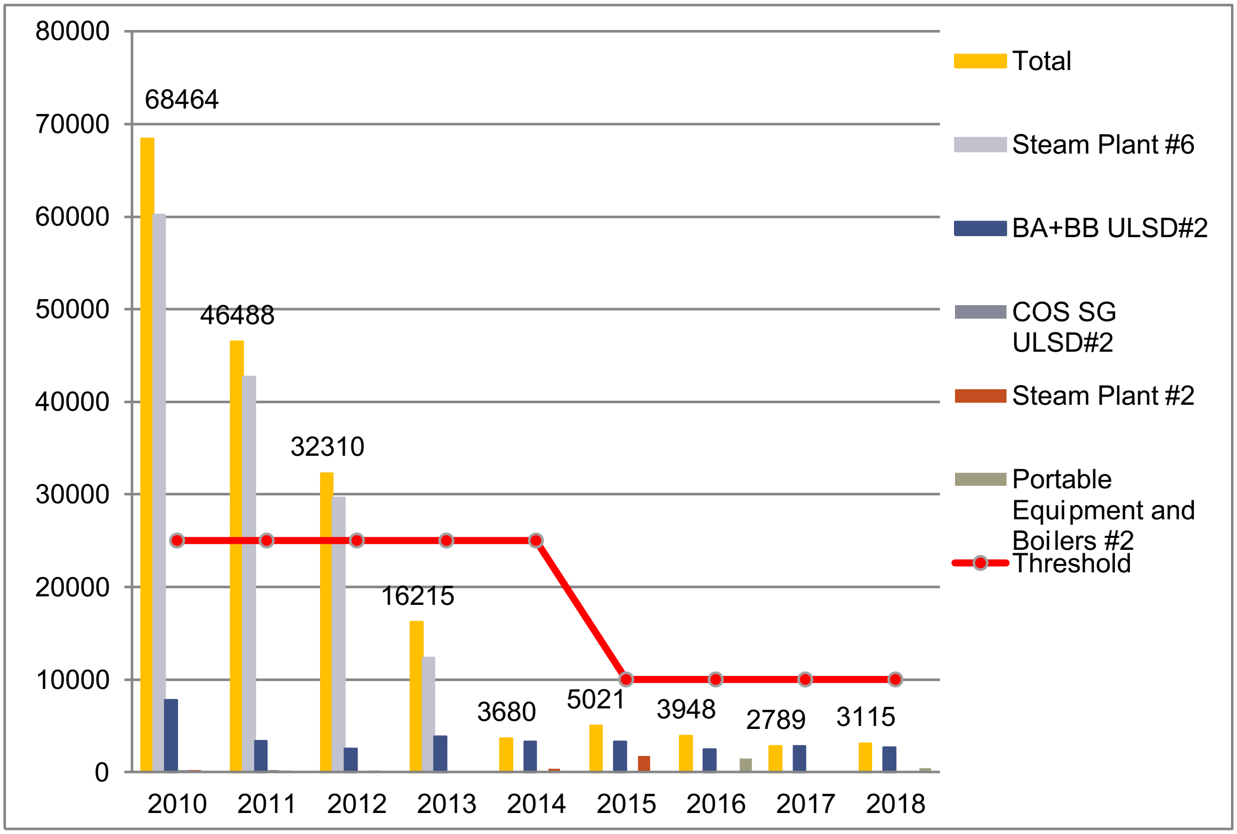


Figure 12
Provincial Greenhouse Gas Reporting Tonnes CO_2 Equivalent - Conventional Air

3.2.2.4 National Pollutant Release Inventory

The National Pollutant Release Inventory (NPRI) is Canada's legislated, publicly accessible inventory of pollutant releases, disposals and recycling.NPRI information is a major starting point for identifying andmonitoring sources ofpollution in Canada, and in developing indicators for thequality of air, land, and water. The NPRI provides Canadians withannual information onindustrial,institutional,commercial, andother releases and transfers in Canadian communities[R-52]. Bruce Power complies withreporting requirements and regulatory limits, as shownin Sections 0 and 3.2.3. Bruce Power's NPRI contaminants reported for the 2018 calendar year are presented in Table 12. 2019 calculations will be available in the 2020 EPR. A graphical comparisonof NPRI contaminant change over time is shown in Figure 13, including thosethat fell below the threshold to report in 2018. There was an incorrect formula in 2013 and 2014 calculations resultingin over reporting of Sulphur dioxide,VOCs, particulate matter and carbon monoxide for those years. This was identified during the 2016 calculations which resultedin a decrease for these contaminants. There was a slight increase in ammonia and volatile organic compound releases in 2017 due to refinements to the calculations for air emissions from the Bruce B deaerator vents. Releases of nitrogen oxides decreased due to a decrease in Bruce B standby generator test runs.

Calculations and reporting for the 2019 calendar year will be completed by June 1, 2020 and will be reported in the 2020 EPR.

Table 12
NPRI Contaminants Reported for 2018

Contaminant	Total kgs
Ammonia (total)	15,323
Hydrazine	1,596
Lead[22, 23]	172
Nitrogen Oxides (expressed as NO_2)	72,465
PM10[26]	3,922
PM2.5[25]	14,466
Sulphuric acid	0.05
Volatile organic compounds[28]	18,789

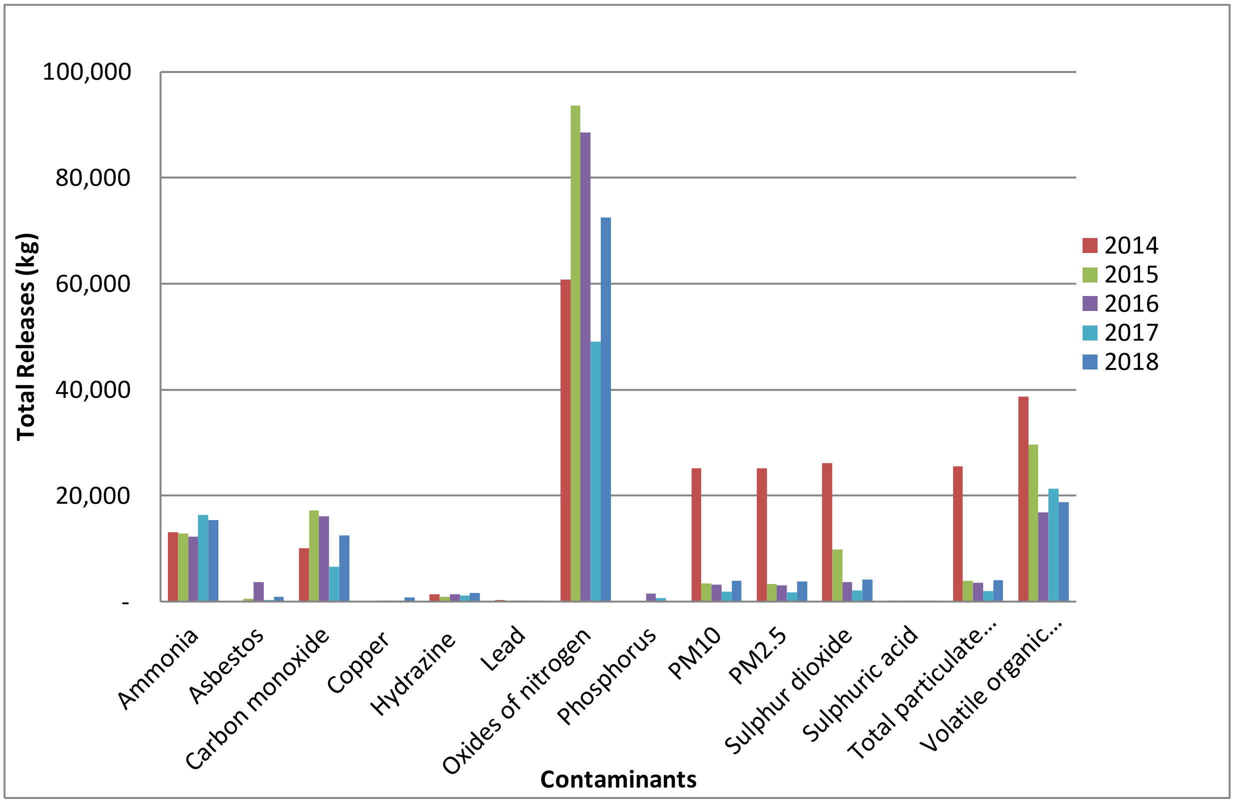


Figure 13
2014 to 2018 Contaminant Total Releases to Air, Water and Land

3.2.2.5 Chemical Management Plan

Environment and Climate Change Canada routinely collects information from industry to assist in managing toxic and priority substances identified under the Canadian Environmental Protection Act, 1999 (CEPA) Part 5 [R-56] in order to protect the environment and human health. Bruce Power participates in the information collects. ECCC did not request any mandatory surveys under the Chemical Management Plan in 2019.

3.2.2.6 Pollution Prevention

Under Part 4 of CEPA [R-57], Environment and Climate Change Canada has the authority to require preparation and implementation of pollution prevention plans for toxic substances. Pollution prevention planning is a method of identifying and implementing pollution prevention options to minimize or avoid the creation of pollutants or waste. ECCC issued a pollution prevention planning notice for any person who operated a facility in the electricity sector that has a concentration of hydrazine that is higher than the specified target levels under normal operating conditions and at any final discharge point. Bruce Power reviewed the notice and determined that the notice does not apply. As such, Bruce Power will be submitting a Notification of Non-Engagement in 2020.

The Notification of Non-Engagement is a voluntary form submitted to ECCC acknowledging that Bruce Power does not meet the description of a facility required to prepare and implement a plan as specified in the Notice.

3.2.2.7 Climate Change

In 2018, Bruce Power announced its intent to partner with the Council of the Great Lakes Region to conduct a lake level (Lake Huron) report focusing on Climate Change. This report would describe the impacts that the Lake Huron area could experience based on a variety of climate change predictions. An official Memorandum of Understanding was reached in early 2019. A literature review and preliminary research was completed from spring to fall 2019. Following the literature review, a scope was formed that will result in a land based model being developed. The intent of the land based model is to complement the existing Lake Huron climate model that Bruce Power has already developed. This portion of the project is taking place over the course of 2020 with the intent of having a first draft of the report prepared this year.

In 2019, Bruce Power continued to work with Golder Associates on hydrothermal dynamics in Lake Huron with a focus on consideration of three future scenarios (average, extreme warm and extreme cold conditions). Future climate is expected to affect lake conditions, specifically water temperature which is expected to increase as a result of warmer air temperatures and increased extreme events. The validated MIKE3 FM hydrothermal model configuration was used to carry out climate change simulations. The meteorological, hydrological and operational inputs used by the model to drive the lake-wide processes were updated to develop combinations of future climate conditions. Average annual water temperatures are expected to increase by approximately 1.5-2.0°C with higher spring water temperatures compared to baseline. Summer water temperatures are predicted to increase 2 to 4°C and winter water temperatures increase up to 2°C under extreme warm conditions. Operations versus no operations scenarios were compared and resulted in little change to lake temperatures in the vicinity of the Site (0.3°C in July and 1°C in December).

3.2.2.8 Carbon Footprint

The operation of the Bruce Power site has had a steadily declining production of GHG emissions and a related reduction in Carbon Footprint since the 2014 closure of the onsite Steam Plant.

Since 2012, Bruce Power has been steadily increasing support for tree planting efforts in our neighbouring communities, based on the assumption that one tree has the capability to offset 1 ton of carbon in its lifetime. Bruce Power has generated a total of 67,078 tons of CO2 and we have planted 150,923 trees from 2012 to 2019. These 150,923 trees have a projected offset capability of 2x the value of our GHG emissions generated over the past seven years (Table 13). Our focus in 2020 will be to increase out GHG offsets further by planting additional trees.

Table 13
Bruce Power Tree Planting Efforts

	2012	2013	2014	2015	2016	2017	2018	2019	Total
Total Trees Planted (Cumulative)	147	1544	4142	6291	11,384	13,978	68,443	82,480	150,923
Total GHG Emissions On-Site	32,310	16,215	3680	5021	3948	2789	3115	3231	67,078
Total GHG Emissions Off-Site (assuming trees live to 40 years) (1 ton per tree)	147	1544	4142	6291	11,384	13,978	68,443	82,480	150,923

3.2.3 Water - Effluent

Site conventional water effluents are controlled to meet regulatory requirements, prevent pollution, reduce emissions, and minimize environmental impacts in an effort to protect the environment. Conventional water emissions at Bruce Power are discharged according to specific licenses, permits, and regulations under (but not limited to) the Environmental Protection Act (EPA) [R-58] and the Ontario Water Resources Act (OWRA) [R-59].

The EPA contains regulations which prescribe limits on discharge streams across nine different industrial sectors that discharge more than 50,000 litres of water a day. The electric power generating sector is regulated under O. Reg. 215/95 - Effluent Monitoring Effluent Limits (EMEL) [R-38]. This regulation defines a daily limit and a monthly average limit for each regulated parameter. It also requires that the discharge is not toxic to fish. Monitoring and reporting requirements are also defined within the regulation. Non-compliances to O. Reg. 215/95 [R-38] are reportable to the MECP and are subject to Environmental Penalties under O. Reg. 222/07 [R-60].

In addition to EMEL, and as per OWRA, no person shall use, operate, establish, alter, extend, or replace new or existing sewage works except under, and in accordance with, an Environmental Compliance Approval (ECA). Bruce Power operates according to three ECAs regulating conventional water emissions across site; Bruce A, Bruce B, and Centre of Site. The ECAs impose site-specific effluent limits, monitoring and reporting requirements for the operation of the facility. As mentioned, these site-specific limits are in addition to limits imposed by EMEL. Non-compliances to ECA limits are subject to Environmental Penalties under O. Reg. 223/07 [R-61]. In 2016, Bruce Power obtained a Temporary Amendment to Bruce A thermal limits ECA 6383-5FDRFJ, with respect to an extension to thermal limits and was valid until May 2018. On 20JUL2018, Bruce A received a revised Environmental Compliance Approval, 0732-B2MKLY, which granted Bruce A thermal flexibility for five years (6 summer seasons), expiring following the summer season of 2023. This flexibility requires the development of a thermal monitoring plan in collaboration with local Indigenous communities. This plan has been developed in collaboration as required and successfully implemented in 2019.

3.2.3.1 Permit to Take Water

In Ontario, anyone who takes more than 50,000 litres of water per day from a lake, river, stream, or groundwater source must obtain a Permit to Take Water (PTTW) from the MECP [R-35] (with a few exceptions). These permits help to ensure the conservation, protection, management, and sustainable use of Ontario's water. Ontario's Water Taking Regulation (O. Reg. 387/04) [R-40] helps to ensure fair sharing of water resources and prevent interferences among water users. Permits are not issued to assign rights to water or to establish priorities on water use. O. Reg. 387/04 [R-40] sets out criteria that the Ministry must consider when assessing an application for a PTTW. A permit will not be issued if the Ministry determines that the proposed water taking will adversely impact existing users or the environment [R-40].

Bruce Power has a separate PTTW for each Bruce A (1813-8MLLHG) [R-45], Bruce B (2233-8MLN8J) [R-46], and Centre of Site (COS) (1152-8MLPCR) [R-47]. Bruce Power remained in compliance with all PTTW requirements in 2019.

3.2.3.2 Effluent Monitoring Effluent Limits and Wastewater Systems Effluent Regulations (SPP only)

The Effluent Monitoring and Effluent Limits (EMEL) program (previously referenced as Municipal Industrial Strategy for Abatement (MISA) [R-38]) is the Ontario provincial response for addressing levels of persistent toxic substances in industry directly discharging into Ontario's waterways. The EMEL program covers nine industrial sectors. The nine sectors are petroleum, pulp and paper, metal mining, industrial minerals, metal casting, organic chemical manufacturing, inorganic chemical, iron and steel, and electric power generation. The industrial sectoral regulations were promulgated between 1993 and 1995.

The main features of the EMEL Industrial Regulations include monitoring and reporting requirements [R-35]. Bruce Power's EMEL reporting is in line with provincial requirements as laid out in O. Reg. 215/95 [R-38]. Table 14 summarizes the EMEL events reported in 2018. Bruce Power met the reporting requirements in its commitment to protect the public and the environment.

Table 14
2019 Bruce Power EMEL Events/WSER Events

Facility	Event Description
Bruce A	None
Bruce B	None
Centre of Site	SPP un-ionized ammonia WSER exceedance

SPP WSER Un-ionized Ammonia Exceedance (SCR 28732596: Elevated SPP Effluent Discharge Parameters)

On February 13, 2019, monthly samples were collected under the WSER regulations [R-50] for the Sewage Processing Plant (SPP) effluent. Due diligence analysis was also performed for un-ionized ammonia on this monthly sample, although no longer required by the WSER regulation post July 2014. Analysis for the required parameters determined the compliance limits were met. However, the analysis for un-ionized ammonia, although no longer required to be measured according to the regulation, was above the concentration for which the WSER regulations authorize in Section 6(1) [R-50].

The elevated un-ionized ammonia is attributed to a mechanical failure at the SPP and the associated repair work that occurred in early February whereby the West Plant was removed from service. With only the East Plant in service during the repairs and low ambient temperatures, the ability of the SPP to manage ammonia was negatively impacted. The efficiency of the SPP returned to normal over subsequent weeks.

The March 2019 WSER sample was also analyzed for un-ionized ammonia; the results were well within compliance to the WSER authorized deposits following this noted plant upset, confirming and demonstrating satisfactory plant performance.

3.2.3.3 Environmental Compliance Approvals

Table 15 summarizes the ECA events reported in 2019.

Table 15
2019 Bruce Power ECA Events

Facility	Event Description
Bruce A	U3 Boiler Blowdown/ Feedwater ECA Morpholine Exceedance
Bruce B	None
Centre of Site	None

U3 Boiler Blowdown/Feedwater ECA morpholine exceedance

On April 11, 2019, Bruce A Chemistry conducted routine feedwater sampling in the Unit 3 steam drums; Unit 3 was in outage at this time. Analysis identified a morpholine concentration of 69 mg/L, which is above the outage Environmental Compliance Approval limit of 50 mg/L. No discharges were occurring at that time and appropriate steps were taken to prevent any discharges from occurring while Chemistry and Operations initiated an investigation and returned the morpholine concentration to compliant levels prior to any further discharges.

It was determined that during execution of a Chemistry Control Action Request (CCAR), morpholine was unintentionally added instead of hydrazine as intended, due to a human performance error, resulting in the elevated morpholine concentration (above compliance limits). It was determined that two batch discharges occurred: one on April 6, 2019 and the second on April 8, 2019, totaling approximately 21,000L. Note that feedwater is approved for discharge under the Environmental Compliance Approval once the parameter limits are met.

For the April 6, 2019 and April 8, 2019 batch discharges, there was a failure to execute the procedural requirement to sample and analyze to confirm compliance to parameter limits, and therefore the elevated concentration was not identified prior to discharge.

The Bruce Power corrective action program was initiated, requiring further investigations and corrective measures for this event. Corrective action plans with the highest level of oversight were developed to prevent reoccurrence of these human performance errors; actions included organizational effectiveness investigations and information rollouts to Operations and Chemistry staff as well as enhancements to procedures and other administrative barriers.

3.3 Quality Assurance

3.3.1 Effluent Monitoring

A revised Quality Control/ Quality Assurance (QA/QC) manual for chemistry laboratories (Bruce A, Bruce B and Centre of Site) was issued in Q2 2016. The manual was developed to ensure that Bruce Power chemistry laboratories practices are aligned with CSA N286-12, Management System Requirements for Nuclear Facilities [R-63]. ISO/IEC 17025, General Requirements for the Competence of Calibrating and Testing Laboratories [R-64], was used as a guideline in developing the revised QA/QC Manual. The following improvement initiatives have been applied since the implementation of the new QA/QC manual:

- Calculated analytical uncertainties associated with Environmental Regulatory Parameters reported by the Chemistry Laboratories.
- Initiated a Quarterly Chemistry QA/QC Working Group to monitor the QA/QC program.
- Held the Annual Management Review Meeting to review the compliance of the QA/QC program.
- Issued a Chemistry Impact Evaluation (CIE) to institute proper QC check compliance.
- Initiated definition of Corrective Actions to be followed upon QC failure of Protocol for the Sampling and Analysis of Industrial/Municipal Wastewater [R-65].
- Initiated QA/QC Monthly Peer Metrics.

In 2019, the focus was on the following activities:

- Deriving Valid Requirements (i.e., total uncertainty) associated with all Control & Regulatory Parameters reported by the Chemistry Laboratories.
- Deriving significant digits required when reporting Control & Regulatory Parameters reported by the Chemistry Laboratories.
- Deriving analytical uncertainties associated with Regulatory and Control Parameters reported by the Chemistry Laboratories.

- Continuing the definition of Corrective Actions to be followed upon QC failure of Protocol for the Sampling and Analysis of Industrial/Municipal Wastewater [R-65].

Bruce Power has purchased a new Laboratory Information Management System (LIMS) product called NuclearIQ from GCR Inc., and has implemented the new system across all on-site laboratories. As part of the implementation naming convention of samples for both effluent and environmental monitoring may have changed slightly and are reflected in this annual report. Additionally, Bruce Power is moving towards using critical levels in lieu of detection levels.

3.3.2 OPG WWMF

A review of the effluent monitoring program at the WWMF is in progress. The review was divided into three phases and includes all potential radiological emission sources and pathways including stormwater and subsurface drainage, the incinerator, building ventilation as well as fugitive emissions from waste storage. The review is being completed in consideration of site expansion, historic performance, industry best practice, and updated standards. The results of the review will be used to update the effluent monitoring program at the WWMF. This expected to be complete in the 2nd quarter of 2020. The findings and recommendations of the review will be used to update the effluent monitoring program at the OPG WWMF [R-66].

4.0 GROUNDWATER PROTECTION AND GROUNDWATER MONITORING

Groundwater protection activities effectively interface with other Bruce Power programs as seen below. Environmental protection is achieved through identification of emissions of concern in the Environmental Risk Assessment (ERA) [R-12][R-13] and adequate assessment through environmental monitoring, effluent monitoring and groundwater monitoring. With a focus on this monitoring array, groundwater protection will be achieved.

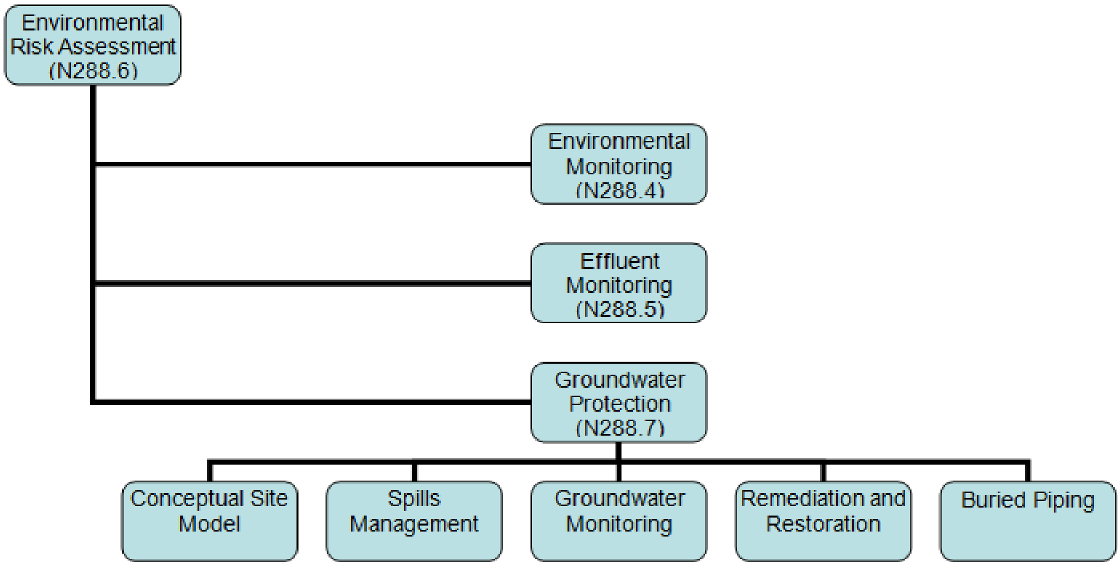


Figure 14
CSA N288.7-15 Interface

The overall goal of groundwater protection at Bruce Power is:

To protect the quality and quantity of groundwater by minimizing interactions with the environment from the activities associated with the site, allowing for effective management of the groundwater resource.

General groundwater protection goals are to:

- Demonstrate compliance to regulators in alignment with the Bruce Power environmental policy;
- Ensure there are control measures to prevent or minimize the release of nuclear and/or hazardous substances directly or indirectly to groundwater by design and operation of structures, systems and components (SSCs);
- Have in place groundwater monitoring to provide timely data confirming that uncontrolled releases are not occurring and, if uncontrolled releases do occur, to identify when and where; and
- Protect the identified groundwater end-use that is potentially affected by releases to groundwater.

Groundwater monitoring at Bruce Power considers the following objectives for determination of applicability. All objectives listed here shall be evaluated but may not be applicable on a site-specific basis. Detailed design plans list applicable groundwater monitoring objectives based on evaluations carried out and in alignment with groundwater protection goals associated with that site. Ultimately, the objectives of groundwater monitoring will be used to measure the level of success in supporting groundwater protection.

General groundwater monitoring objectives are:

- Demonstrate compliance with requirements and conditions of the Authority Having Jurisdiction (AHJ) concerning the release of nuclear and hazardous substances from the source;
- Provide data to verify predictions made and models used in the Environmental Assessment (EA) or Environmental Risk Assessment (ERA), or reduce the uncertainty in predictions;
- Characterize groundwater flow and baseline groundwater quality conditions at a site;
- Characterize groundwater flow and baseline groundwater quality during other phases of a sites lifecycle;
- Provide information to assess risks from site-affected groundwater to human health and the environment;
- Evaluate monitoring data against groundwater evaluation criteria related to nuclear and hazardous substances in groundwater;
- Provide an indication of unusual or unforeseen conditions that might require corrective action or additional monitoring;
- To the extent possible, monitor for releases from high risk SSCs associated with a given facility; and
- Other objectives identified by a facility operator.

Objectives for the groundwater monitoring program will be dependent on the site specific groundwater protection goals. While the overall groundwater protection goal would apply to all groundwater monitoring activities, groundwater monitoring objectives may vary based on intended activity at the site or operational history.

As part of the groundwater protection program design, conceptual site models exist for each specific groundwater monitoring site. The conceptual site models evaluate the following elements specific to the sites:

- Site aerial view identifying spatial boundaries and geological cross sections;
- Climatology and surface water hydrology;

- Determination of potential contamination sources and Contaminant of Potential Concerns (COPCs);
- Identification of contamination risks and high priority SSCs;
- Characterization of the groundwater flow system and COPC migration;
- Identification of groundwater end-use and groundwater vulnerability; and
- Identification of potential receptors that could be affected by groundwater contamination.

4.1 2019 Non-Potable Groundwater Monitoring - Radiological

Monitoring the groundwater around the Bruce A and Bruce B generating stations was initiated as a result of the Reconnaissance Level Groundwater Quality Monitoring Program Study, Bruce Nuclear Power Development Generating Stations, Units 1 to 4, and Units 5 to 8 [R-67]. The purpose of the study was to assess the influence of the operations of the stations on groundwater tritium with subsurface pathways that may discharge to off-site receptors. The study concluded that the groundwater flow system in the vicinity of Bruce A and Bruce B is hydraulically isolated from properties east of the Bruce Power site boundary. Evidence presented in the report strongly suggests that the tritium found in the groundwater around the station is the consequence of the station's airborne emissions and tritiated precipitation infiltrating into the carbonate aquifer.

Bruce Power compares results to the Ontario Drinking Water Standard. In addition, a statistical approach is used to understand any deviation from normal. When observed, further investigation or other actions are undertaken as needed. This last occurred in 2013 with the monitoring results below the Ontario Drinking Water Standard (7,000 Bq/L for tritium) [R-68]. As such, Bruce Power's actions are in line with CNSC policies to take all reasonable precautions to control the releases of radioactive nuclear substances, and to take reasonable precautions to control pollution. The Generic Screening Criterion is used as a reference point, as a comparison of relative risk, not as a trigger for further investigation. Further investigations are conducted at much lower levels.

Groundwater samples from ten multi-level wells installed into the bedrock around the Bruce A and Bruce B stations are collected for semiannual sampling. The 2019 sampling results for each well and zone level are provided in Table 16. A map of the locations as well as the screening depths and stratigraphy type for the ten multi-level wells can be found in Appendix E.

There are 5 groundwater monitoring wells located at each station, between the powerhouse and Lake Huron. These wells are sampled for tritium on a semiannual basis. The 2019 groundwater results at Bruce A and Bruce B multi-level wells remain well below the Generic Guidelines for non-potable water and below the Provincial Water Quality Objective (PWQO) of 7,000 Bq/L.

Table 16
2019 Semi-Annual Groundwater in Multi-Level Wells Installed in the Bedrock around Bruce A and Bruce B

Station	Well Number - Level	Elevation to Top of Zone	Semi-Annual S1 (Spring)		Semi-Annual S2 (Fall)	
		ft. (above sea level)	Tritium (Bq/L)	±2σ	Tritium (Bq/L)	±2σ
Bruce A	1-1	548	15.5	3.4	13.6	3.2
	1-2	559	53.7	4.8	32.7	4.0
	2-1	536	-2.2	2.2	-2.0	2.1
	2-2	551	101	6.1	1.8	2.1
	2-3	566	765	15	389	11
	3-1	536	-0.5	2.2	-1.1	2.1
	3-2	551	-1.5	2.2	-0.2	2.1
	3-3	560	447	12	288	10
	4-1	553	-0.5	2.2	0.5	2.1
	4-2	567	1,610	22	1,020	18
	5-1	536	1.2	2.2	1.8	2.1
	5-2	549	-0.8	2.2	0.5	2.1
Bruce B	1-1	539	11.5	3.3	16.0	3.3
	1-2	553	49.1	4.7	32.4	4.0
	1-3	570	542	13	658	14
	2-1	552	37.3	4.3	40.1	4.3
	2-2	572	904	17	965	17
	3-1	536	5.3	2.7	2.8	2.9
	3-2	553	103.0	6.2	6.2	2.9
	3-3	573	359	11	11	3.0
	4-1	540	28.2	3.9	26.7	3.8
	4-2	558	209	8	320	10
	4-3	573	1,730	23	1,570	22
	5-1	536	397	11	12	3
	5-2	553	428	12	11	3
	5-3	573	513	13	12	3

Note: L_C for S1 = 3.2 Bq/L
L_C for S2 = 3.0 Bq/L

4.1.1 Historical Non-Potable Groundwater –Radiological

4.1.1.1 Bruce A

The average tritium concentrations in multi-level wells near Bruce A from 2010 to 2019 are shown in Figure 15. Generally the average tritium concentrations near Bruce A have remained steady over the years and/or are decreasing over time. The elevated concentration at well 4-2 in 2012 is attributed to the Moderator heavy water spill near the Ancillary Services Building. The tritium concentration at this location has steadily decreased over time.

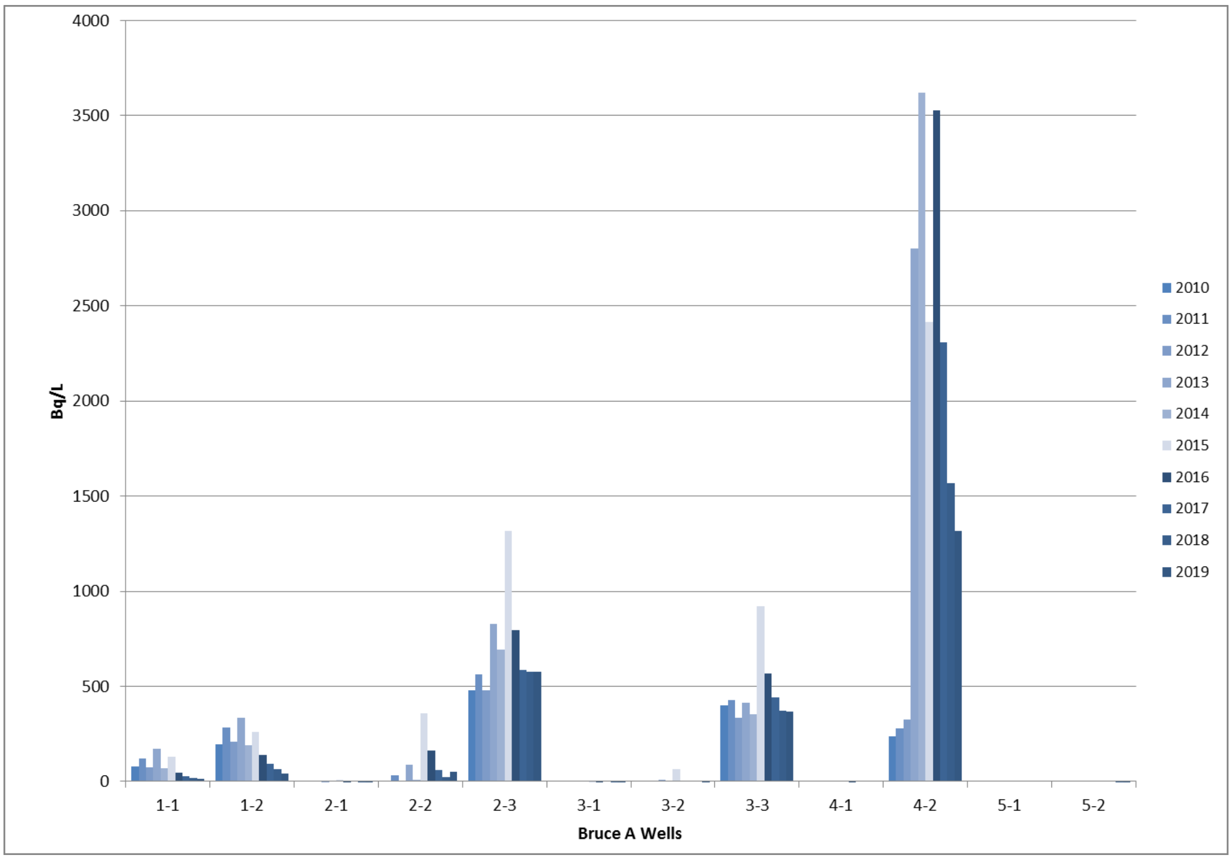


Figure 15
Average Tritium Concentrations in Multi-Level Wells Installed in the Bedrock around the Bruce A Station, 2010-2019

4.1.1.2 Bruce B

The average tritium concentrations in multi-level wells near Bruce B from 2010 to 2019 are shown in Figure 16. In most cases, the tritium concentration decreased in 2019 at all wells and zones, with the exception of well 1-3 and 2-2 that showed minor increases.

The elevated concentration observed at Bruce B well 4-3 is attributed to a historical Ontario Hydro spill [R-69] in the 1990s due to a spill of heavy water from a tanker in the Ancillary Service Building. The trend for tritium levels in well 4-3 has shown a steady decline over the last ten years.

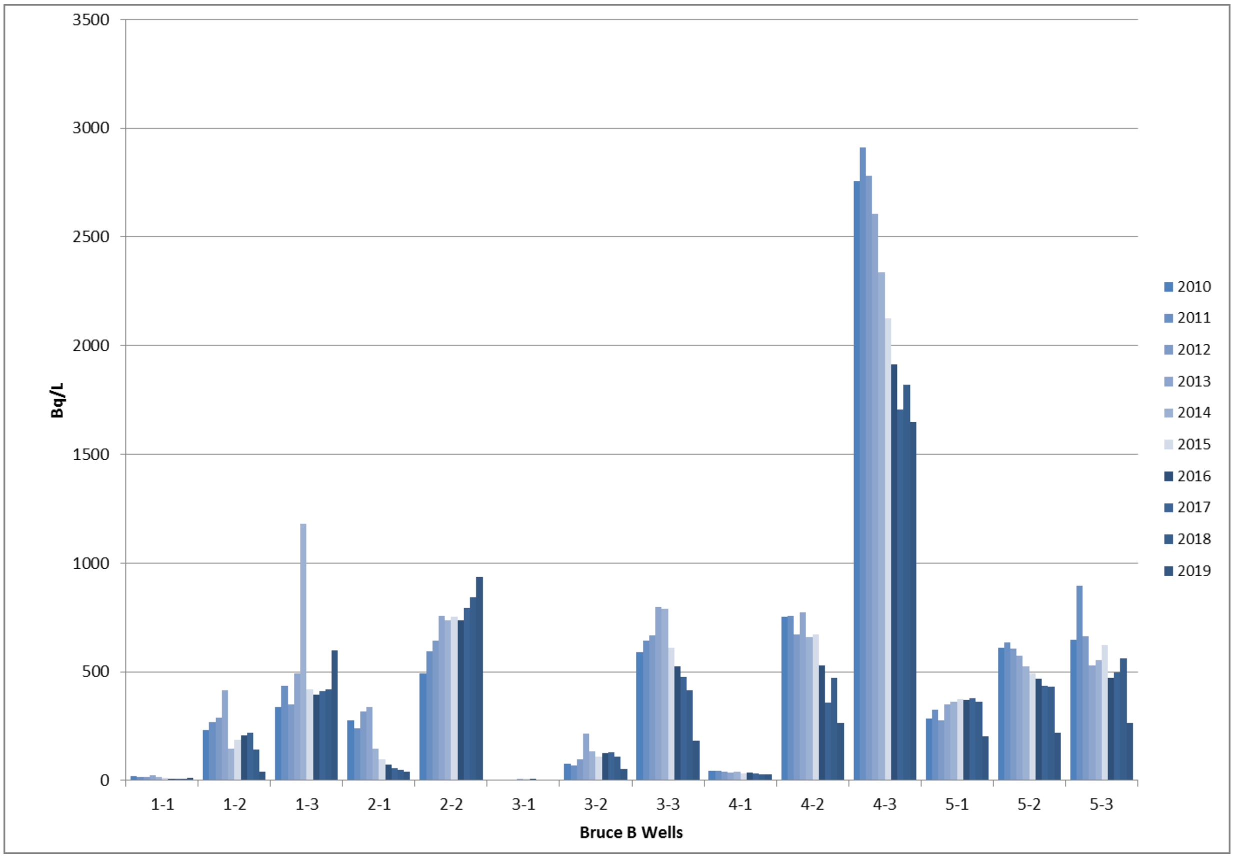


Figure 16
Average Tritium Concentrations in Multi-Level Wells Installed in the Bedrock around the Bruce B Station, 2010-2019

4.2 Non-Potable Groundwater – Conventional

Bruce Power has been carrying out annual groundwater monitoring on the site since 2005 to evaluate impact on the environment. The groundwater monitoring was designed to include 14 subject locations around the site. These locations were determined to be significant based on earlier environmental site assessment (ESA) work that was undertaken by Ontario Hydro. Many of these sites have had historical events which led to groundwater contamination. The annual groundwater monitoring is in place to ensure that any existing contaminant plumes do not migrate such that off-site impact occurs.

The existing groundwater monitoring at Bruce Power will be incorporated in order to align with CSA N288.7 [R-17] so that Bruce Power will ensure an industry best program which is managed and is continuously evaluated and improved to adapt to changing environments on the Bruce Power site.

Detailed design plans for groundwater monitoring sites at Bruce Power are required to provide information necessary to meet the goals established for Bruce Power Groundwater Protection. Due to the size and complexity of the Bruce Power site as well as the varying phases of operation and operational activities, use of chemicals or contaminants of potential concern, proximity to receptors, differing geological and hydrogeological conditions and historical contamination, it is necessary to customize groundwater monitoring on a site by site basis. Detailed design plans for various areas across site may have differing objectives and goals for site specific groundwater monitoring. The site specific plans are created to ensure that the elements of Canadian Standards Association (CSA) N288.7-15[R-17] are considered on a specific basis in order to cumulatively contribute to the achievement of the overall groundwater protection goals of Bruce Power.

Groundwater monitoring and sampling at Bruce Power was completed between September 23 and October 8, 2019. Currently there are 15 groundwater monitoring sites at Bruce Power. This does not include the non-potable groundwater monitoring sites sampled semi-annually for tritium as part of the radiological environmental monitoring program. An additional site was added in 2019 in order to provide groundwater monitoring around the underground fuel dispensing system located at the Central Maintenance Facility. Two groundwater monitoring sites noted below (Bruce B Standby Generator, North Site and Bruce B Emergency Power Generator Site) are undergoing long term Monitored Natural Attenuation Programs in relation to fuel oil releases in 2012 and 2011 respectively. Table 17 lists the groundwater monitoring sites as well as the current evaluated status with respect to comparison against evaluation criteria, MECP Site Condition Standards and overall trends associated with the site. A small statement provides detail on the current status.

Table 17
Groundwater Monitoring Sites and Status

Site Description	2019 Status	Comment
Bruce A Storage Compound.	⇨	Not sampled in 2019 due to non-detections in previous years.
Bruce A Standby Generator Area	⬇	Exceedance of statistically based evaluation criteria at indicator well.
Bunker C Oil Above Ground Storage Tanks	⇧	No issues identified during 2019 sampling
Bunker C Oil and Ignition Day Tanks.	⇧	Decreasing concentration trend in selected substances monitored
BCO Acid Wash Pond	⬇	Exceedance of statistically based evaluation criteria at indicator well.
Former Sewage Lagoons.	⇧	Decreasing concentration trend in selected substances monitored.

Site Description	**2019 Status**	**Comment**
Fire Training Facility	⇧	Decreasing concentration trend in selected substances monitored.
Former Construction Landfill #4	⇨	Similar levels as previous years
Bruce Nuclear Standby Generators	⇧	No issues identified during 2019 sampling.
Bruce B Standby Generators -South	⇨	Similar levels as previous years
Bruce B Standby Generators -North	⇨	Not sampled. Subject to long term MNA program.
Bruce B Emergency Power Generators	⇨	Not sampled. Subject to long term MNA program.
Bruce A Transformer Area	⇩	Exceedance of statistically based evaluation criteria at indicator well.
Bruce B Transformer Area	⇧	Decreasing concentration trend in selected substances monitored.
Distribution Station #1	⇨	Not sampled in 2019 due to non-detections in previous years.
Former Bruce Heavy Water Plant	⇩	Exceedance of ecologically based evaluation criteria at indicator well.
Central Maintenance Facility	⇧	Initial sampling. No issues identified with soil or groundwater.

Results from the 2019 groundwater monitoring and sampling campaign may be used to support achievement of the groundwater monitoring program performance objectives. Performance objectives are documented in site specific detailed design plans.

4.2.1 Bruce B Long Term MNA Remediation Program

Several subsurface investigations have been completed including many remedial activities, to assess and characterize the subsurface impacts associated with the fuel oil leaks that occurred in May 2011 and December 2012. This included the installation and operation of mobile pump-and-treat (P&T) systems to recover free-phase product and impacted groundwater near the source, in an effort to control the migration of groundwater contamination. Between April 2013 and November 2018, the mobile P&T systems typically operated from spring to fall of each year, followed by a shutdown period during the winter, with the intent to monitor the potential “rebound” of free-phase product and associated groundwater contamination. In September 2018, an in-depth evaluation of P&T systems was completed and concluded the further operation of the P&T systems was no longer efficient nor beneficial to control, contain,or recover free-phase product, or to remediate dissolved-phase petroleum hydrocarbon (PHC) -impacted groundwater. After an assessment of remedial options availableas broadly defined by the Interstate Technology & Regulatory Council (ITRC) and based on the site conditions, Bruce Power elected to implement an MNA program.

The primary objective of the full-scale MNA program is to monitor and evaluate the residual Light Non-aqueous Phase Liquid (LNAPL) and the PHC-impacted dissolved-phase groundwater, to prevent these contaminants (to the extent practical) from migrating further, which may adversely affect the natural environment. The specific objectives of the approach are to:

- Prevent LNAPL migration and expansion.
- Prevent expansion of dissolved phase plume and mitigate adverse effects to the natural environment to the extent practicable.
- Conduct performance monitoring to make recommendations for remediation enhancement, as applicable.
- If deemed warranted, implement future recommended remediation enhancement, as applicable.

The MNA sampling program is summarized as follows. The primary contaminants of concern (COCs) include petroleum hydrocarbon (PHC) fractions F1 through F4; benzene, toluene, ethylbenzene, and total xylenes (BTEX); and natural attenuation (NA) parameters nitrate/nitrite, sulphate/sulphide, total and dissolved iron, alkalinity, and methane.

The following are a preliminary high-level summary of key observations from the MNA monitoring data through 2019 for Bruce B Emergency Generator (BBEG) and Bruce B Standby Generator (BBSG). In terms of evidence; indicators of biological activity related to MNA is occurring and was observed in 2019:

- Methane is present in many wells within the plume with methane lower at the edges of, or upgradient of the dissolved plume footprint (suggesting methanogenesis, the anaerobic respiration that generates methane as the final product of metabolism);
- Although sulphate is higher in some of these “background wells” and lower in some impacted it may suggest that sulphate reduction may be a less dominant process at the BBEG than at BBSG;
- Denitrification seems to be a slightly more apparent in the BBEG;
- Iron reduction also seems to be present with higher dissolved iron indicated within the dissolved plume (BBEG-33, BBEG-37, BBEG-54);
- Alkalinity is notably higher in some of the impacted wells (as compared to “background” wells) suggesting biological activity;

- Based on field Dissolved Oxygen (DO) measurements anaerobic conditions have been present in impacted wells; note that DO measurements have a low reliability unless low flow sampling and flow-through cell are used; and

- Oxidation Reduction Potential (ORP) field measurements have indicated that reducing conditions are present.

Bruce Power will continue the quarterly MNA program throughout 2020 that incorporates the current hydrogeological conditions, potential receptors, and suggested action levels/trigger levels while meeting the objectives set out by Bruce Power, as follows:

- Monitoring – Quarterly water-level and free-phase (i.e., non-aqueous) product thickness monitoring (March, June, September, and December) in 2020. The quarterly monitoring should include readily accessible monitoring wells, as well as selected other existing monitoring wells at each site. During the quarterly monitoring events, if free-phase is present, bail it manually.

- Groundwater Sampling – Complete a quarterly groundwater sampling event, consisting of the 47 monitoring well locations stated in the Sampling and Analysis Plan (SAP). COCs include PHCs, BTEX, nitrate/nitrite, sulphate/sulphide, total iron, alkalinity, and methane analysis. Groundwater quality parameters, including temperature, pH, electrical/specific conductivity, ORP and DO should be monitored in the field with a multi-parameter water quality meter. The usage of low-flow sampling techniques should be considered to provide improved reproducibility (i.e. Relative Percent Difference (RPD) of field duplicates) due to the presence of trace free product in select locations and improve the stability of collected MNA field parameters.

- Surface Water Monitoring and Sampling – Continue to complete walkdowns of the Outfall Channel, Eastern Drainage Ditch and Construction North Yard Drainage structures to note the presence or absence of petroleum-related sheen, as well as any construction or environmental changes which may impact the movement of water within the watercourse.

The observed LNAPL extent since 2015 suggests the LNAPL at the Site is not presently migrating and is decreasing, although fluctuations in the water table have caused intermittent reappearances of LNAPL. The overall decrease of the LNAPL extent is considered a combined result of the remedial activities (groundwater remediation) to date (such as manual recovery and operation of the mobile P&T system) and natural attenuation occurring in the subsurface.

4.2.1.1 Bruce B Standby Generator MNA Program

Four quarterly groundwater and free-phase product monitoring events were conducted between January 1 and December 31, 2019, as follows:

- Quarter 1 – March 27th, 2019 to April 2nd, 2019

- Quarter 2 – June 17th, 2019 to June 21st, 2019
- Quarter 3 – September 10th, 2019 to September 18th, 2019
- Quarter 4 – December 10th, 2019 to December 13th, 2019

Approximately 1,014.5 litres (L) of free-phase product were recovered between May 7, 2013 and November 7, 2018 by the Pump and Treat (P&T) system. Approximately 0.95 L of product was manually bailed in 2019. Approximately 50.95 L of free-phase product has been manually bailed from various wells at the BBSG Site between December 2012 and December 31, 2019. The total free-phase product that has been bailed or recovered by the P&T system from various wells at the BBSG Site between December 2012 and December 31, 2019 is approximately 1,065.45 L.

4.2.1.2 Bruce B Emergency Power Generator MNA Program

Four quarterly groundwater and free-phase product monitoring events were conducted during 2019, January 1 to December 31, 2019, are as follows:

- Quarter 1 – March 27th, 2019 to April 8th, 2019
- Quarter 2 – June 17th, 2019 to June 21st, 2019
- Quarter 3 – September 10th, 2019 to September 30th, 2019 (Wells BBEG-33 and BBEG-53 were inaccessible during the original mobilization, we returned to the site September 30th to collect)
- Quarter 4 – December 9th, 2019 to December 11th, 2019

Approximately 52 litres (L) of product was recovered by the Pump and Treat (P&T) system to the end of 2018. Approximately 0.025 L of product were manually bailed or purged from BBEG-33 in 2019. The total free-phase product that has been bailed from various wells at the BBEG Site between December 2011 and December 31, 2019 is approximately 11.5 L. The combined total of free product recovered is approximately 63.5L.

5.0 ENVIRONMENTAL MONITORING

Environmental monitoring is established to monitor the effects of radiological contaminants, hazardous substances and physical stressors of concern in the environment. This demonstrates due diligence by quantitatively affirming the protection of humans and the environment during nuclear power plant operations on the Bruce Site and complies with CSA N288.4-10 [R-3].

For hazardous substances and physical stressors, environmental monitoring concentration data are used to calculate dose and risk to humans and non-human biota at locations where contaminants of potential concern exposure is expected to occur. Environmental monitoring programs are developed by Bruce Power and monitoring is performed to quantify risk as described above. In addition, several other agencies and regulatory bodies also perform independent monitoring for verification purposes and these are summarized below.

5.1 Canadian Nuclear Safety Commission

The Canadian Nuclear Safety Commission (CNSC) has implemented its Independent Environmental Monitoring Program (IEMP) to verify the safety of the public and the environment around licensed nuclear facilities [R-70]. It is separate from, but complementary to, the CNSC's ongoing compliance verification program. The IEMP involves taking samples from public areas around the facilities, and measuring and analyzing the amount of radiological (nuclear) and hazardous substances in those samples. CNSC staff collects the samples and sends them to the CNSC's state-of-the-art laboratory for testing and analysis [R-70].

The IEMP is being implemented for facilities in all segments of the nuclear fuel cycle--uranium mines and mills, uranium and nuclear processing facilities, nuclear power plants, research and medical isotope production facilities, and waste management facilities. The CNSC's program aligns with those of other national and international regulatory bodies and complements the CNSC's ongoing environmental protection activities [R-70].

A screening level for a particular radionuclide in a particular environmental medium represents the activity or mass concentration in that medium which, if consumed as part of a typical Canadian diet all year long, would result in 10% of the public dose limit of 1 millisievert (1 mSv/year) or 1000µSv per year. CNSC staff compares the measured contaminant levels to relevant guidelines and CNSC screening levels to determine if the results are safe for human health and the environment. The CNSC developed screening levels for radionuclides where no environmental standards, guidelines or criteria existed for human and environmental health. Screening levels are not regulatory limits. They were developed to provide a benchmark to compare measured IEMP results and information about risk. The IEMP results provide a snapshot in time of the contaminants in the environment surrounding the facility. If IEMP results are below screening levels, this confirms that there are no expected health impacts and that the public and the environment in the vicinity of a nuclear facility have been protected from releases from that facility [R-70].

5.1.1 Historical IEMP Results

In 2016, 2015 and 2013, the IEMP sampling plan for the Bruce Power site focused on nuclear contaminants. Samples were collected in publicly accessible areas outside the Bruce Power site perimeter. A site specific sampling plan was developed based on CSA Group standards, Bruce Power's environmental monitoring program, and the CNSC's regulatory experience with the Bruce Power site. Samples included air, lake water, soil and sediment, vegetation, and food, such as fish, meat, and produce from local farms [R-70].

The radioactivity measured in air, water, sediment, soil, and vegetation samples, as well as samples of meat and produce, were below available guidelines and CNSC reference levels. CNSC reference levels are based on conservative assumptions about the exposure that would result in a dose of 1000 microsieverts (µSv) per year or 1 millisievert (mSv) per year). No health impacts are expected at this dose level [R-70].

5.2 Health Canada

The Fixed Point Surveillance (FPS) network is the result of a project to build a real time radiation detection system across Canada. This network monitors public doses from radioactive materials in the air and assists Canada in becoming better prepared in case of nuclear or radiological incidents [R-71].

Health Canada, as part of routine operations, continuously monitors radiation levels across Canada through a network of stationary monitors that measure radioactivity in air, water, and other environmental samples. The network is primarily used to monitor the total external gamma dose rate from all sources, measured as Air KERMA (Kinetic Energy Released in Matter) as well as the external gamma dose rates from three radioactive gases which escape into the atmosphere during normal operation of nuclear facilities. These three gases are Argon-41, Xenon-133 and Xenon-135. In addition, the system is calibrated for external gamma dose rate from airborne Iodine-131 [R-71]

5.3 Ontario Ministry of Labour

In addition to environmental monitoring performed by Bruce Power, the Ontario Ministry of Labour, Radiation Protection Service [R-72] establishes, maintains, and operates an environmental radiological monitoring network. This network assess radiation exposure around designated nuclear installations, and provides measurement data, expertise and services to Emergency Management Ontario (EMO), the Ministry of the Environment Conservation and Parks, and other agencies to provide early warning of any potential radiation hazards that may affect workers and the public. The Radiation Protection Service [R-72] provides radioanalytical and technical support to other provincial agencies involved in radiation surveillance programs and health studies related to the exposure of workers or the public to radiation.

The Radiation Protection Field Service [R-72] inspects, evaluates, and enforces radiation control measures and safe practices in Ontario workplaces. It reviews and approves the registration of employers in possession and installation of x-ray sources (other than those used for human diagnosis or therapy, which are under the jurisdiction of the Ministry of Health and Long-Term Care), and provides radiation safety services and advice to workplace parties, agencies, and the public. The Field Service also provides assistance and advice on exposure of the public to radiation in the environment to other ministries and agencies, and co-operates with the CNSC, Labour Canada, and Health Canada on investigations of radiation exposure in Ontario workplaces under federal jurisdiction and is responsible for the interpretation and application of the Regulation Respecting X-ray Safety [R-71] [R-72].

Completed annual environmental monitoring reports are available upon request from:

Ontario Ministry of Labour
400 University Avenue

14th Floor
Toronto, ON M7A 1T7

5.4 Bruce Power's Radiological Environmental Monitoring

The assessment of radiological dose to members of the public living near the Bruce Power site is based upon measured levels of radioactivity in the environment where available and detectable, and where measurements are not available these levels of radioactivity are calculated from reported emissions using containment transport modelling (simulates the movement of contaminants at a specific time and location).

Dose estimates are used when direct measurements of low radiation doses to a member of the public from all of Bruce Power's site operations are below detection limits [R-73].

The radiological environmental monitoring (REM) program conducted by Bruce Power is in accordance with CSA N288.4-10 [R-3] and the approach to public dose calculations in which REM data are used directly to quantify levels of exposure of representative members of the public to key radionuclides. The data gathered from the monitoring program is summarized in this report along with site emissions data on a calendar year basis. OPG operates background radiological monitoring and provides this data to Bruce Power [R-73].

REM provides measured activity levels of radionuclides in various media. The REM data implicitly reflect the influence of releases from all Bruce Power facilities as well as facilities within/adjacent to the Bruce Power site that are owned by other parties. This includes the Western Waste Management Facility (WWMF), owned and operated by Ontario Power Generation (OPG), Douglas Point Waste Management Facility (DPWMF) which is owned by Canadian Nuclear Laboratories (CNL), and KI North which is owned by Kinectrics. For use in public dose calculations, the measured radionuclide activities are appropriately adjusted to account for background levels of those same radionuclides, where appropriate. In this approach, the resulting levels of exposure and dose are representative exclusively of Bruce Power site releases.

The human receptors considered in Bruce Power's Dose Methodology consist of representative persons, who are defined as an individual who receives a dose that is representative of the most highly exposed individuals in the population [R-14]. The representative persons considered in the calculation of public doses are consistent with the representative persons considered in past iterations of public dose calculations, in the most recent determination of derived release limits (DRLs), and in the completion of the Environmental Risk Assessment (ERA) [R-12][R-13].

Overall, Bruce Power's Dose Methodology is considered to provide the most reliable and complete assessment of radiological dose to maximally exposed members of the public in the vicinity of Bruce Power nuclear facilities.

The dose calculations presented and discussed herein have been conducted using the 2019 REM results and/or 2019 emissions data and conservative model estimates, following the established methodology set forth in the BP-PROC-00076 [R-76] procedure based on the requirements of CSA N288.4-10 [R-3].

The following sections detail the results of the radiological environmental monitoring for both the Bruce Site and provincial monitoring. This section conveys the methods and findings of calculations of radiological doses to members of the public near the Bruce Power nuclear facilities. Maps of sampling site locations are located in sampling site locations in 12.0Appendix D:.

Bruce Power radiological environmental monitoring carries out sampling and analysis of the following media and relevant radionuclides:

- Media:
    - Air
    - Water
    - Precipitation
    - Aquatic Samples (including fish, sediment, and sand)
    - Terrestrial Samples (including animal feed, eggs, fish, beef, pork, poultry, deer, fruit and berries, milk, root vegetables, non-root vegetables, honey, grain, soil)
- Radionuclides:
    - Tritium
    - Carbon-14 (C-14)
    - Iodine-131 (I-131)
    - Beta
    - Gamma

The external gamma dose rates and the provincial monitoring program samples are measured by the OPG Whitby Health Physics Laboratory [R-73].

Bruce Power has three types of monitoring locations:

- **Indicator** locations are used to assess the potential dose to the public. These locations are on or outside the facility perimeter and represent the most significant risk of public exposure (B02, B03, B04 on the Site-Specific Map in Appendix D). Considerations when deciding where to locate an indicator location are: locations of representative persons, locations of representative persons' food for consumption and prevailing wind directions. Indicator locations should be within 20 km of the facility.

- **Area Near** locations are used in conjunction with indicator locations to provide confirmation of the validity of the computing models used to assign dose to the public. Area Near location data is used to estimate atmospheric dispersion and doses to people in local population centers located further away from the site than the indicator locations, but less than 20 km from the facility. Data from the area location can be used to calculate the average dilution available as a function of distance for a given monitoring period.

- **Area Far** locations are located further away but potentially still under the influence of Bruce Power (B06, B08, B09 on the map in Appendix D).

- **Provincial Background -** Ontario Power Generation (OPG) [1] annually supplies Bruce Power with data on the background radiological levels in the environment which is used to estimate the background radiation levels and is located away from the influence of Bruce Power. The control locations are documented in OPG document B-REP-03481-00002, The Provincial Radiological Environmental Monitoring Program.

For media contributing >10% to the total dose of any human receptor, Bruce Power attempts to obtain sampling media to be monitored at a minimum of one location per 22.5° wind sector over land. For other media, a total of three locations over land within the REM boundary are required.

For aquatic media, monitoring locations must be downstream of the site, at locations where radionuclides are expected to accumulate, and at municipal supply plants that provide drinking water to the local population.

Municipal drinking water is sampled from two Water Supply Plants (WSP) near the Bruce Power Site:

- Southampton Water Supply Plant, 22 km NE of Bruce A.

- Kincardine Water Supply Plant, 15 km SSW of Bruce B.

Additionally, municipal wells at Tiverton, Scott Point, and Underwood are sampled and monitored.

Water is sampled at residential shallow and deep wells, as well as Lake Huron and streams in the vicinity of Bruce Power.

Fish are monitored at downstream locations where radionuclides may accumulate. Monitoring locations include Baie du Doré, a Bruce Power area near site, and area far locations in Lake Huron.

[1] Some of the background data may be from out of the province.

Sediment is monitored at the Bruce A and Bruce B discharge locations, at nearby locations (Baie du Doré, Scott Point, and Inverhuron), at far field locations (Sauble Beach, Southampton), and at provincial background locations.

For terrestrial foodstuffs (milk, meat, fruit, vegetables, grains, eggs, honey), sampling is performed at nearby areas or at local farms and residences, as applicable. Therefore, monitoring locations are based on practical considerations, including the availability of samples and participation of local residents and farmers. Wild animals are sampled only when available (subject to vehicle collisions or samples provided by local hunters). Milk is monitored from three local dairy farms.

Soil is sampled from various locations near the Bruce Power site, far field locations, and provincial background locations.

Ten air monitoring stations are located in the vicinity of Bruce Power, at varying distances and in locations covering all landward wind directions.

The media contributing greater than 10% to receptor dose are air, milk, meat, and terrestrial plants (grain, fruit, and vegetables).

5.4.1 Site Specific Survey

The Site Specific Survey Report is used to support a number of site programs, such as calculation of Derived Released Limits (DRL), Emergency Preparedness, Radiological Environmental Monitoring (REM) program, Safety Reports and license renewal. The Site Specific Survey Report is updated typically every five years to reflect recent changes to the area surrounding the Bruce Site.

The survey encompasses information on meteorology, land usage, population distribution, water usage, agriculture, recreation and food sources in the area surrounding the Bruce Site. In addition, daycare centers, before and after school programs, long-term care homes, school boards, and recreational parks located within 20 km of the Bruce Site were contacted to obtain the number of visitors or residents/students/children and staff at each location.

Multiple surveys were generated as part of this Site Specific Survey process to determine the percentage of locally consumed food and water. Results are used as input parameters for the calculation of annual radiation dose to the public and DRLs, which are updated every five years.

A key aspect of the population characterization is the local food consumption, which is the fraction of an individual's diet that is locally produced. In order to obtain this information from local residents, a **Local Food Production Survey** was conducted in December 2015 to first determine what types of foodstuff are grown by farmers in the region, and where farmers distribute their foodstuffs for purchase and ultimate consumption.

The information obtained from the local farming community was then incorporated into an **Online Meal and Activity Survey** that was completed by a select group of 15 households comprised of residents and farmers. This survey was conducted from March 2016 to September 2016, and collected weekly information pertaining to the amount of local food consumed and the amount of time spent outdoors.

Guided by the results of the Local Food Production Survey and the preliminary results of the Online Survey Meal and Activity Survey, a **Local Population Survey** was prepared and disseminated to approximately 1500 residents within 10 km of the Bruce Site. Approximately 260 residents completed and returned the survey.

Although the data collected in this survey did not identify a commercial dairy farm within 10 km around the Bruce Site, it was noted that 7 households reported consuming some amount of home-produced dairy. In 2017, additional milk sampling locations were added to the REM program. Changes associated with the findings of the latest Site-Specific Survey, were incorporated into the Radiological Environmental Monitoring procedure and used to ensure the most effective monitoring program based on the indicated habits of the local populations.

5.4.1.1 Representative Person Discussion

The 2016 site survey conducted in the area surrounding the Bruce Power site gathered information regarding land usage, population distribution, meteorology, hydrology, water sources, water uses and food sources. The following categories of representative persons were identified as a result of the site survey, based on distinct lifestyle and proximity to the Site:

- Non-farm resident;
- Farm resident;
- Subsistence farm resident;
- Dairy farm resident;
- Bruce Eco Industrial park worker; and
- Hunter/Fisherman (addition beyond survey results)

As stated in the Site Specific Survey, the subsistence farm resident is defined as an individual for whom over half of their diet is self-produced. Therefore, this group is representative of residents who depend on locally grown foodstuff.

In addition to the above groups, a generic hunter/fisherman resident was considered. The hunter/fisherman resident is defined as an individual who catches and consumes wild game and fish in significantly greater quantities than other residents. In this context, the hunter/fisherman is representative of Indigenous populations. Health Canada [R-75] recommends the incorporation of specific ingestion rates for fish and wild game for Indigenous populations; the ingestion rates for all other foodstuff may be assumed to be equivalent to those for the Canadian general population.

In 2019 Bruce Power began working closely with local First Nations and Metis communities to develop and carry out a diet survey in order to further refine the hunter/fisherman receptor characteristics. The completion of these diet surveys is ongoing and the results are not available for inclusion in the 2019 dose to public calculation.

A total of 18 representative persons were selected, each comprised of an adult (16 to 70 years old), child (6 to 15 years old), and infant (0 to 5 years old), except for the Bruce Eco Industrial park worker, who is assumed to be an adult. All representative persons were chosen based on proximity to the Site (i.e., all locations are within 15 km from the Site), with the exception of the hunter/fisherman, who is located approximately 20 km north of the site. The list of representative persons is consistent with the environmental risk assessment for Bruce Power, with an addition of five dairy farm residents who were added as participants to the Bruce Power Environmental Monitoring program in 2016, and the addition of a hunter/fisherman.

Receptor Descriptions

Receptor Descriptions were updated to align with the 2016 Site Specific Survey.

The non-farm resident is considered the typical, full time resident in the area surrounding the Site. They get a large portion of their food from grocery stores.

The farm resident is more likely to consume their own crop or livestock, but still use grocery stores for a portion of their food intake.

The subsistence farm resident gets a larger portion of their food, milk and water from local sources.

The hunter/fisherman shares similar dietary characteristics as the subsistence farm resident. For both groups, the local food fractions for wild game, fish and most other foodstuff are assumed to be 100%.

The only difference between the subsistence farm resident and the hunter/fisherman resident is that the hunter/fisherman consumes a greater amount of wild game and fish each year. The wild game and fish intake rates for the hunter/fisherman were based on mean intake values of Indigenous peoples from the First Nations Food, Nutrition, and Environmental Study reported in 2014 [R-75]. This study provides a detailed report of the diet of First Nations people based on surveying of adults on reserve at 18 different communities throughout Ontario. Since only adults were surveyed, intake rates for infants and children were calculated by scaling the intake rates of adults by the average caloric intake of each age group, as identified in N288.1-14 Update No. 3 [R-14].

The dairy-farm resident is assumed to consume some fresh milk from their own farm, and a slightly higher fraction of locally grown produce and livestock.

For consistency with previous studies related to Site environmental risk assessment, the Bruce Eco Industrial park worker will be hereafter referred to as a BEC worker, which corresponds to the former name of the facility, the Bruce Energy Centre. The assessment for a BEC worker represents occupational exposures at a location near the facility. It is assumed that the BEC worker does not also live at one of the other selected receptor locations, i.e., the BEC dose is independent of the other representative person doses.

A summary of the receptor description and locations is provided below in Table 18 and Figure 17 respectively.

Table 18
Identification of Representative Person

Group Name	General Characteristics and Location of Group
BR1	Non-farm resident, lakeshore at Scott Point (Located to the northeast of Bruce A at a distance of approximately 2 km and northeast of Bruce B at a distance of approximately 5 km)
BR17	Non-farm resident, inland (Located to the southeast of Bruce A at a distance of approximately 4 km and east of Bruce B at a distance of approximately 5 km)
BR25	Non-farm resident, inland (Located to the south of Bruce A at a distance of approximately 5 km and to the southeast of Bruce B at a distance of approximately 4 km)
BR27	Non-farm resident, inland, trailer park (Located to the south of Bruce A at a distance of approximately 5 km and to the southeast of Bruce B at a distance of approximately 3 km)
BR32	Non-farm resident, lakeshore (Located to the south of Bruce A in Inverhuron at a distance of approximately 6 km and to the south of Bruce B in Inverhuron at a distance of approximately 3 km)
BR48	Non-farm resident, inland (Located to the southeast of Bruce A near Baie du Doré at a distance of approximately 2 km and to the east of Bruce B near Baie du Doré at a distance of approximately 3 km)
BF8	Agricultural, farm resident (Located to the south of Bruce A at a distance of approximately 8 km and to the southeast of Bruce B at a distance of approximately 7 km)
BF14	Agricultural, farm resident (Located to the south of Bruce A at a distance of approximately 5 km and to the southeast of Bruce B at a distance of approximately 3 km)
BF16	Agricultural, farm resident (Located to the southeast of Bruce A at a distance of approximately 7 km and to the east of Bruce B at a distance of approximately 8 km)
BSF2	Agricultural, subsistence farm resident (Located to the southeast of Bruce A at a distance of approximately 9 km and to the southeast of Bruce B at a distance of approximately 9 km)
BSF3	Agricultural, subsistence farm resident (Located to the southeast of Bruce A at a distance of approximately 8 km and to the southeast of Bruce B at a distance of approximately 8 km)
BHF1	Generic hunter/fisherman resident (Located approximately 20 km north of the Site in Southampton)

Group Name	General Characteristics and Location of Group
BDF1	Agricultural, dairy farm resident(Located to the northeast of Bruce A at a distance of approximately 11 km and to the northeast of Bruce B at a distance of approximately 14 km)
BDF9	Agricultural, dairy farm resident(Located to the southeast of Bruce A at a distance of approximately 13 km and to the southeast of Bruce B at a distance of approximately 12 km)
BDF12	Agricultural, dairy farm resident(Located to the east of Bruce A at a distance of approximately 13 km and to the northeast of Bruce B at a distance of approximately 15 km)
BDF13	Agricultural, dairy farm resident (Located to the southeast of Bruce A at a distance of approximately 13 km and to the southeast of Bruce B at a distance of approximately 12 km)
BDF14	Agricultural, dairy farm resident(Located to the southeast of Bruce A at a distance of approximately 14 km and to the southeast of Bruce B at a distance of approximately 13 km)
BDF15	Agricultural, dairy farm resident(Located to the southeast of Bruce A at a distance of approximately 13 km and to the southeast of Bruce B at a distance of approximately 12 km)
BEC	Worker in Bruce Energy Centre (Located to the southeast of Bruce A at a distance of approximately 4 km and to the east of Bruce B at a distance of approximately 4 km)

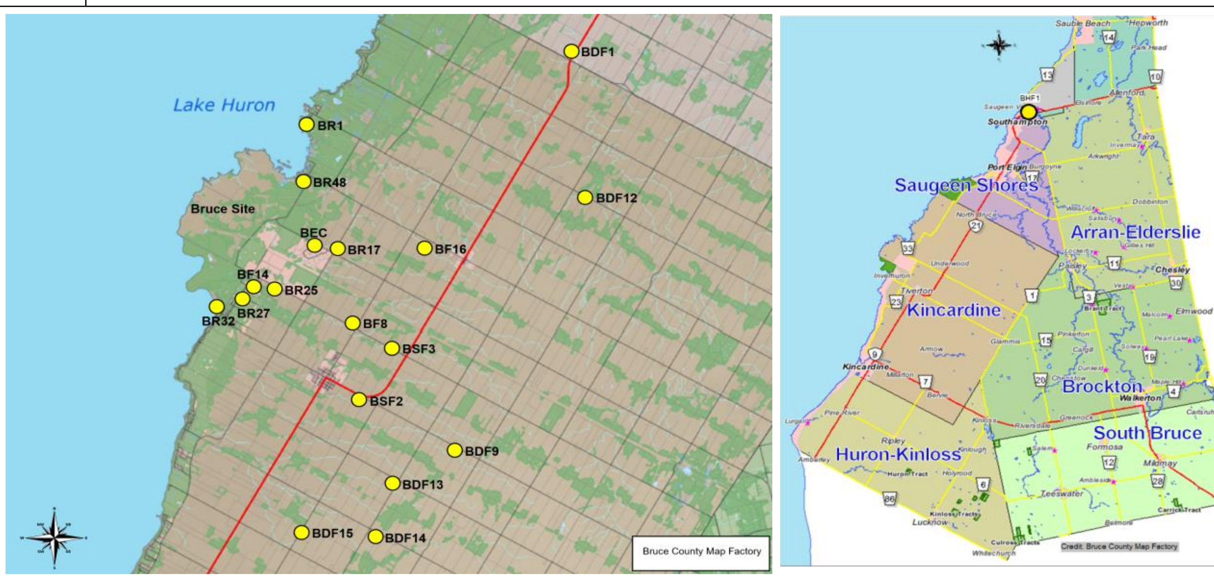


Figure 17
Human Receptor Locations
Left – local receptors, Right – fare field receptors
(Source Base Map from Bruce County Map Factory)

5.4.2 Environmental Monitoring and Emission Data

All emissions/effluentand monitoringdata used as inputfor the 2019 dose calculation process where provided to the contractor by Bruce Power. The environmental monitoringdata used to specify radionuclide concentrations at each location of interest were initially reviewed for QA/QC purposes. The data were then processed (e.g., adjusted for background, converted to required units of input for IMPACT) for the specific purpose of dose calculations.

For some radionuclide/media combinations, technological limitations may inhibit the ability to collect the desired radionuclide measurements. In cases where monitoring data were not available for a particular exposure media, environmental monitoring data were used to explicitly define radionuclide concentrations in the intermediate media as far along the exposure pathway as possible. In some cases, the availability of reliable data in 2019 was such that concentrations of a specific radionuclide could not be defined for any media along a specified exposure pathway. In such cases, transport modelling and emissions data for the specified facility release (either atmospheric or aqueous) were used to define radionuclide concentrations in exposure media at the Bruce Power site [R-73]

The environmental transport models in IMPACT are active for all exposure pathways for which the concentration of any radionuclide or radionuclide group has not been explicitly defined based on direct measures in the exposure medium (i.e., the medium of direct exposure to receptors). The transport models are functional from the point furthest along each exposure pathway for which direct measures (i.e., monitoring data) are available. In some cases, transport modelling may calculate radionuclide concentrations in exposure media based on defined concentrations in other contributing media, or they may calculate concentrations in each medium along the entire pathway on the basis of defined rates of emission from the source [R-73].

For 2019 public dose calculations, the basic set-up of the IMPACT model, in terms of transfer parameters and environmental variables, is identical to that used in the most recent ERA [R-12][R-13] pathways analysis and DRL updates. The transport models in the current version of IMPACT (Version 5.5.2) are taken from CSA N288.1 DRL Guidance [R-14]. As noted, these models are only activated in cases where environmental monitoring data for a given radionuclide in the exposure media are not available. Where such data are available, the calculation of exposure and subsequent dose to human receptors are not based on model results [R-73].

Bruce Power conducts routine monitoring of major radionuclides in both atmospheric emissions and liquid effluent releases from the Bruce Power site. Every operational facility present at each site is monitored for emissions if there is significant spatial separation between those facilities. This approach provides distinct measures of radionuclides from each source (e.g. Bruce A versus Bruce B) [R-73].

5.4.3 Radionuclide and Exposure Pathways

The following radionuclide groups contribute more than 1% to the total dose of a human receptor of interest, and must therefore be monitored in the environment as part of REM program:

- Tritium (HTO)

- Organically Bound Tritium (OBT)
- Carbon-14
- Radioiodines
- Noble gases
- Airborne gross beta/gamma
- Waterborne gross beta/gamma

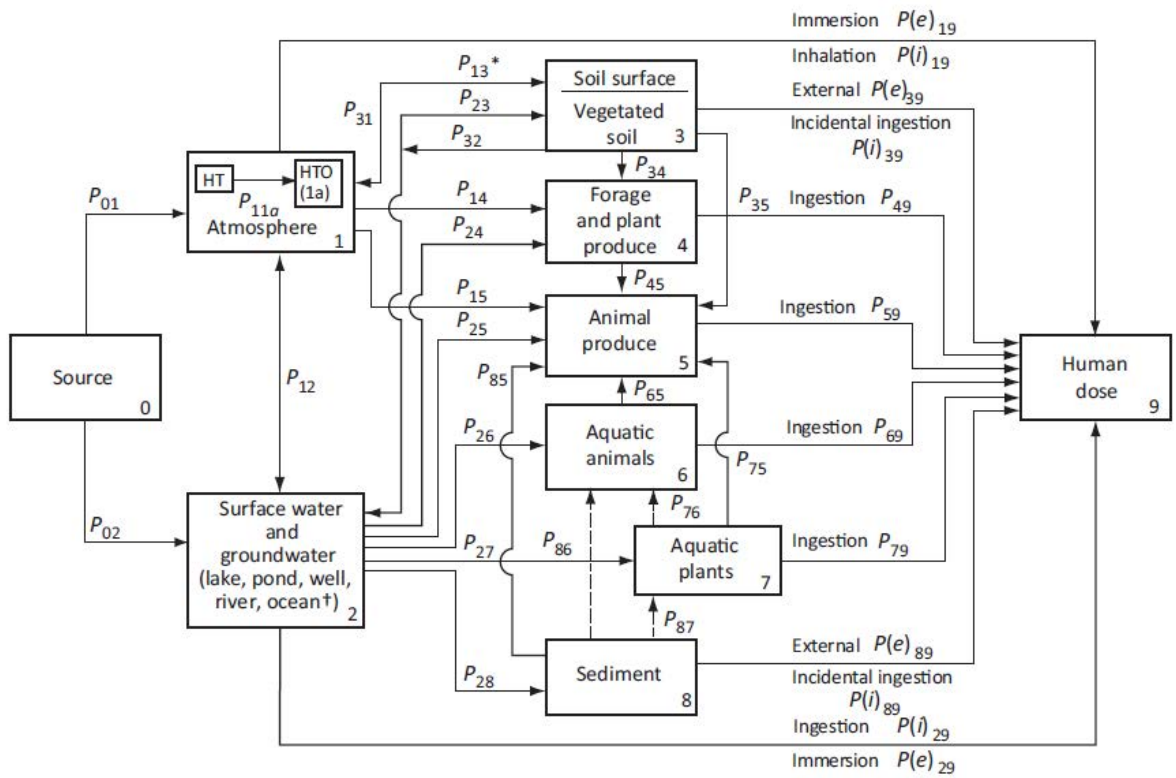
All human receptors in the ERA are considered in the design of REM program, based on the IMPACT environmental transfer model.

Doses are calculated for each of the representative persons according to the exposures to each of the following radionuclides via the pathways listed in Table 19 and represented graphically in Figure 18. The results are then summed to produce the total dose.

Table 19
Radionuclides Measured as Part of Radiological Environmental Monitoring

Radionuclide	Sample Medium	Exposure Pathway
Tritium	Air	Inhalation (includes skin absorption)
	Water (drinking water, surface water, well water)	Ingestion
	Water (precipitation, groundwater)	Ingestion
	Plants (fruits, vegetables, grains)	Ingestion
	Animals (meat, milk, honey)	Ingestion
	Fish	Ingestion
C-14	Air	Inhalation, External
	Plants (fruits, vegetables, grains)	Ingestion
	Animals (meat, milk, honey, eggs)	Ingestion
	Fish	Ingestion
Gamma (e.g., Cs-137)	Air	Inhalation, External
	Water (surface water)	Ingestion
	Animals (meat, honey)	Ingestion

Radionuclide	Sample Medium	Exposure Pathway
	Fish	Ingestion
	Sediment	External
	Soil	External
Gross Beta	Water (drinking water,surface water, well water, precipitation)	Ingestion
I-131	Site emissions	Air inhalation, Air external Terrestrial animals (ingestion)
	Milk	Ingestion
Noble Gases ($t_{½}$~days)	Air	Air External
Organic Bound Tritium (OBT)	Fish	Ingestion



**Includes transfer factors P_{13area}, P_{13mass}, and P_{13spw}.*
†For ocean water, pathways P_{23}, P_{24}, P_{25}, and $P(i)_{29}$ are not used.

Notes:

(1) *The broken lines represent pathways that are not explicitly considered in the model or are considered only in special circumstances.*

(2) *Factors include multiple transfers where appropriate.*

Figure 18
Environmental Transfer Model
Extracted from CSA N288.1-14

5.4.4 2019 Dose Calculations

5.4.4.1 Dose Calculations Methods

The Bruce Power Public Dose Calculations 2019 Report provides the following information regarding the dose to public calculation and outcomes [R-73].

The public dose calculation process considers and discriminates between all significant pathways of exposure. The process also discriminates between the various radionuclides (or radionuclide groups) that have been identified as important or potentially important with respect to public dose implications at Bruce Power and other CANDU facilities.

The calculation of the 2019 public doses has followed this general approach, and the specific routines are documented [R-76]. The procedure employed for the 2019 dose calculations is generally consistent with the procedure employed by Bruce Power since 2001, in the following respects:

- Doses have been calculated for a series of representative persons (formerly termed "critical group members"), identified and characterized based on the most current Site-Specific Survey. For the 2019 public dose calculations, the representative persons are based on the findings of the 2016 Site-Specific Survey [R-27]., and are consistent with those considered in the recent Environmental Risk Assessment (ERA) [R-12][R-13], and also in the most recent Derived Release Limit (DRL).

- Doses have been calculated for those radionuclides or radionuclide groups that have the potential to contribute measurably to the total public dose, as determined during the preparation of the ERA and based on overall experience with CANDU® facilities.

- Exposure of representative persons has been selected based on direct measurements of key radionuclides in the environment (i.e., REM data). For exposure pathways where REM data are not available or do not apply, measures of emissions have been entered into the environmental transport models of IMPACT to conservatively estimate environmental activity levels of radionuclides at locations of public exposure.

- The calculations have been completed using IMPACT software package.

The various general steps in the dose calculation process have been completed in overall keeping with Bruce Power's established procedure.

For public dose calculations for 2019, the basic set-up of the IMPACT model, in terms of transfer parameters and environmental variables, is identical to that used in the most recent ERA and DRL updates. For 2019, the IMPACT application for public dose calculation was not subject to any changes relative to 2018.

As in previous years, characteristics of representative persons in 2019 were based in large part on the latest Site Specific Survey [R-27]. The generic intake rates of air, water and various foods have been revised to be consistent with updated central values reported in the DRL Guidance. For the purpose of public dose calculations, the values adopted for the various intake parameters are mean values reported in the DRL Guidance or other select sources, rather than the more conservative 90 to 95th percentile values that are recommended for DRL calculation purposes.

The detailed characteristics of the representative persons are summarized Table 20 and Table 21. The general physiological characteristics of these representative persons (e.g., inhalation rates, water ingestion rates, food intake rates) are taken from the DRL Guidance [R-14]. For the "hunter/fisherman" group (HF1), rates of intake of fish and game animals have been adjusted slightly from the DRL Guidance values to reflect conservative wild game intake rates of Indigenous communities from the First Nations Food, Nutrition, and Environmental Study (FNFES) [R-75]. For fish intake by the Hunter/Fisherman group, central intake rates taken from the DRL Guidance [R-14] are used. A recent study has indicated that the DRL central intakes are more representative of fish ingestion rates of communities near Bruce Power [R-78].

The fractions of ingested foodstuffs that originate from local sources (backyard gardens or local farm markets) are based in part on the results of the most recent Site Specific Survey [R-27]. The net percentage contribution of each specific food type (e.g., fruits or beef) to each major category of consumption (i.e., total plant product or animal product) is based on both the local fraction and the generic intake rates. The local intake fractions of all representative persons have been recalculated to reflect new values for the generic intake rates.

Table 20
Local Percentage of Food Intake Obtained by Local Sources

Food Type	**Infant (1-yr old)**	**Child (10-yr old)**	**Adult**
Non-Farm Residential			
Milk and dairy	23.09%	19.89%	12.06%
Beef	0.72%	1.95%	6.95%
Pork	0.39%	1.07%	2.23%
Poultry	0.85%	2.07%	4.06%
Egg	0.29%	1.00%	2.62%
Deer	0.10%	0.29%	1.11%
Honey	0.08%	0.20%	0.27%
Total Animal Products	***25.5%***	***26.5%***	***29.3%***
Grain	3.44%	3.84%	3.35%
Fruit and Berries	10.41%	7.40%	6.23%
Vegetables (above-ground)	4.26%	5.02%	6.95%
Root Vegetables	1.57%	2.44%	2.85%
Total plant Products	**19.68%**	**18.70%**	**19.38%**
Fish	23.00%	23.00%	23.00%
Non-Dairy Farms			
Milk and dairy	12.47%	10.74%	6.51%
Beef	1.04%	2.80%	9.97%
Pork	0.58%	1.59%	3.33%
Poultry	1.41%	3.42%	6.70%
Egg	0.56%	1.94%	5.10%

Food Type	Infant (1-yr old)	Child (10-yr old)	Adult
Deer	0.20%	0.57%	2.22%
Honey	0.10%	0.26%	0.34%
Total Animal Products	***16.4%***	***21.3%***	***34.2%***
Grain	4.25%	4.73%	4.13%
Fruit and Berries	21.09%	14.99%	12.62%
Vegetables (above-ground)	10.12%	11.95%	16.52%
Root Vegetables	3.60%	5.62%	6.56%
Total Plant Products	**39.07%**	**37.29%**	**39.83%**
Fish	22.30%	22.30%	22.30%
Dairy Farms			
Milk and dairy	61.98%	53.38%	32.37%
Beef	1.04%	2.82%	10.05%
Pork	0.67%	1.82%	3.81%
Poultry	1.88%	4.57%	8.96%
Egg	0.66%	2.31%	6.07%
Deer	0.20%	0.57%	2.22%
Honey	0.12%	0.30%	0.40%
Total Animal Products	***66.60%***	***65.80%***	***63.90%***
Grain	7.92%	8.82%	7.71%
Fruit and Berries	13.78%	9.79%	8.25%
Vegetables (above-ground)	10.28%	12.14%	16.79%
Root Vegetables	3.51%	5.48%	6.39%
Total Plant Products	**35.50%**	**36.24%**	**39.13%**
Fish	25.00%	25.00%	25.00%
Subsistence Farms			
Milk and dairy	73.90%	63.64%	38.59%
Beef	1.97%	5.33%	19.00%
Pork	1.33%	3.64%	7.61%
Poultry	3.14%	7.62%	14.93%
Egg	0.81%	2.81%	7.39%

Food Type	Infant (1-yr old)	Child (10-yr old)	Adult
Deer	0.20%	0.57%	2.22%
Honey	0.18%	0.47%	0.62%
Total Animal Products	***81.50%***	***84.10%***	***90.40%***
Grain	18.67%	20.80%	18.18%
Fruit and Berries	28.40%	20.18%	16.99%
Vegetables (above-ground)	17.06%	20.14%	27.85%
Root Vegetables	5.80%	9.04%	10.54%
Total Plant Products	**69.93%**	**70.16%**	**73.56%**
Fish	100.00%	100.00%	100.00%
Hunter-Fisher			
Milk and dairy	72.87%	62.10%	37.82%
Beef	1.95%	5.20%	18.62%
Pork	1.32%	3.55%	7.46%
Poultry	3.10%	7.44%	14.63%
Egg	0.79%	2.74%	7.24%
Deer	1.58%	2.98%	4.17%
Honey	0.18%	0.46%	0.60%
Total Animal Products	***81.80%***	***84.50%***	***90.50%***
Grain	18.67%	20.80%	18.18%
Fruit and Berries	28.40%	20.18%	16.99%
Vegetables (above-ground)	17.06%	20.14%	27.85%
Root Vegetables	5.80%	9.04%	10.54%
Total Plant Products	**100.00%**	**100.00%**	**100.00%**
Fish	100.00%	100.00%	100.00%

Table 21
Generic Rates of Intake of Air, Water and Various Foods

Parameter	Units	Infant (1-yr old)[1]	Child (10-yr old)	Adult (male)
Inhalation Rate	m^3/yr	1830	5660	5950
Water Ingestion Rate	L/yr	0	151.1	379.6

Parameter	Units	Infant (1-yr old)[1]	Child (10-yr old)	Adult (male)
Grain Intake	kg/yr	55.2	140.7	163.5
Fruit & Berry Intake	kg/yr	54.6	88.8	99.4
Vegetable Intake	kg/yr	25.8	69.7	128.1
Mushrooms Intake	kg/yr	0.3	1.0	1.2
Potato Intake	kg/yr	8.7	30.9	47.9
Total Plant Product Ingestion Rate	*kg/yr*	*144.5*	*331.1*	*440.0*
Beef Intake	kg/yr	4.4	13.1	45.8
Pork Intake	kg/yr	3.5	10.4	19.8
Lamb Intake	kg/yr	0.0	1.0	0.6
Poultry Intake	kg/yr	8.2	21.9	38.9
Egg Intake	kg/yr	2.1	8.1	19.2
Deer Intake	kg/yr	0.0/4.21	0.0/8.75	0.1/11.08
Milk Intake	kg/yr	242.7	228.1	125.6
Total Animal Product Ingestion Rate	*kg/yr*	*261.0/264.2*	*282.6/291.4*	*250.0/261.0*
Total Fish Ingestion Rate	*kg/yr*	*1.8*	*5.4*	*8.2*

1. The 1-year old infant is assumed to ingest cow's milk, which accounts for all fluid needs. Water (or formula made from water) is not ingested.
2. All values are mean or central values from DRL Guidance (CSA N288.1-14), with the exception of Hunter/Fisherman Group Deer intake, which is based on the FNFES [R-75].

5.4.4.2 Radiological Dose to the Public

Canadians are exposed to natural background radiation in their homes, at work and in their everyday lives. Exposure to naturally-occurring radiation occurs from rocks, soil, and space [R-79]. We breathe radon gas which is produced by the earth's crust and the food we eat contains many natural sources of radiation (e.g., potatoes, carrots, bananas, milk, red meats) [R-80]. Consumer products, medical or clinical devices such as X-ray machines and CT scanners [R-79] also provide exposure to Canadians [R-80]. Natural background dose is estimated at 2,400 μSv/year. The operation of medical equipment (600 μSv/year), medical isotope production (10 μSv/year), a cross-country flight (30 μSv), diagnostic procedure such as a dental X-ray (10 μSv) and CT scans may deliver approximately 5,000-30,000 μSv [R-79].

The doses are calculated using data obtained from Bruce Power's REM program, which is designed to meet the radiological monitoring requirements of CSA N288.4-10 [R-3].

For the 28th consecutive year, Bruce Power's calculated dose to a member of the public is less than the 10 µSv/year value that is regarded as the lower threshold for significance (the *de minimus*) [R-81]. The representative person's dose associated with Bruce Power operations in 2019 who is calculated to have the maximum is the BF14 Adult who received 1.5 µSv/a. All other representative persons have a lower dose (see Appendix C).

This maximum dose is a small fraction of a percent of the legal limit (i.e., 1,000 µSv/a) and of the background dose (i.e., ~ 3,100 µSv/a) (see Table 22, Table 23 and Figure 19,). It is also well below the *de minimus* threshold of 10 µSv/a [R-81]. Consistent with previous years, most of the radiological dose is from two radionuclides (^{14}C ~ 46%, tritium oxide~ 40%). Pathways are predominantly via inhalation (for tritium) and ingestion of local food sources (for tritium and ^{14}C).

Table 22
2019 Maximum Representative Person's Dose

Maximum Representative Person	Committed Effective Dose	Percentage of Legal Limit
BF14 Adult	1.5 µSv/a	0.15%

Table 23
2019 Radiological Dose by Contaminant for Representative Persons Group BF14 Adult

	C-14	Co-60	Cs-134	Cs-137	HTO[1]	I (mfp)	Noble Gases	Total
Dose (µSv/a)	6.98E-01	1.14E-02	2.59E-03	2.71E-03	5.93E-01	1.90E-04	1.97E-01	1.50E+00
Percentage	46%	0.8%	0.2%	0.2%	40%	0.0%	13%	100%

[1] Includes dose incurred via ingestion of Organically Bound Tritium (OBT) in fish, plant produce, and animal products.

OBT - tritium is bound to organic matter, resulting from tritium being incorporated in various organic compounds during the synthesis process of living matter.

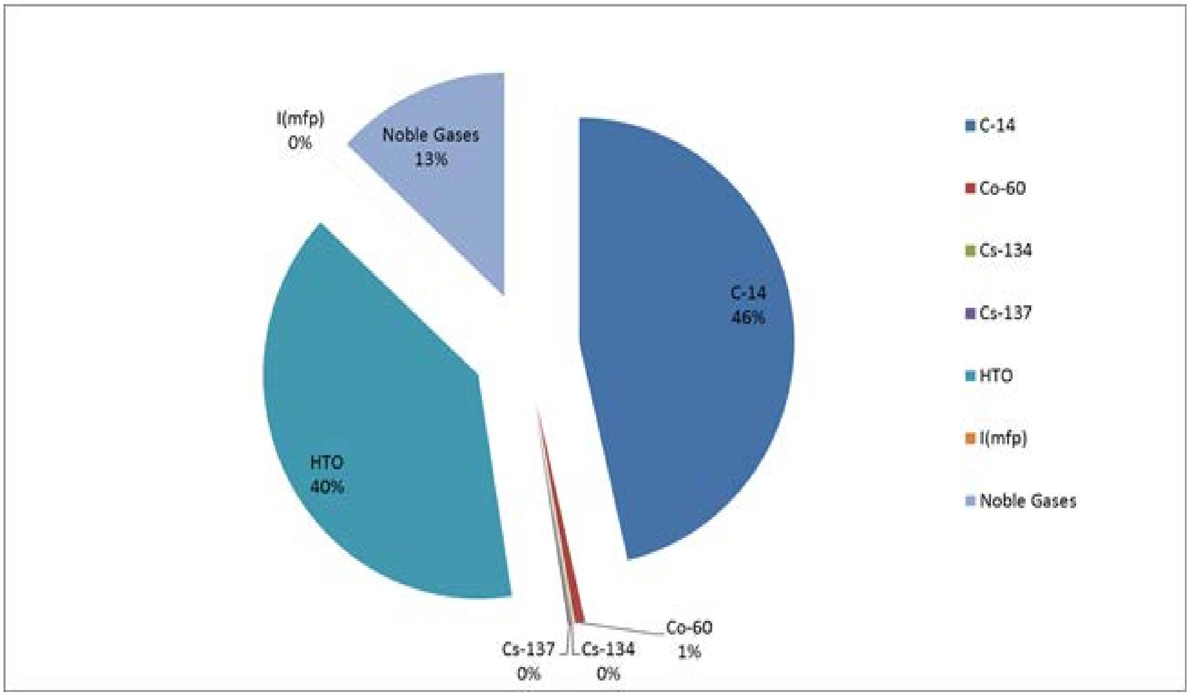


Figure 19
2019 Radiological Dose by Contaminant for Representative Persons Group BF14 Adult

5.4.4.3 Dose Results and Interpretation

The routine monitoring ofradionuclides in atmospheric releases from the Bruce Power site includes tritium oxide(HTO), carbon-14 (C-14), noble gases, iodine(I-131), and combined beta/gamma-emittingparticulates (includes Cs-134,Cs-137, Co-60). Combined alpha-emittingparticulates (e.g. Pu-239, Pu-240, Am-243, and Cm-244) have been monitored since 2012. Routine monitoringof liquideffluent releases from the Bruce Power site encompasses HTO, C-14 and gross beta/gamma emitters and alpha emitters (since2012). For Bruce A and B liquideffluents, beta/gamma emitter isotopes aremeasured. The emissions thatare directly considered in the dose calculation process include HTO, C-14, noble gases, and radio-iodines. For the purpose of public dose calculations, it is assumed that iodineemissions are in the form of mixed fissionproducts (mfp), assumed to be present in ratio associated with a state of secular equilibrium. The dose calculation process assumes that all iodine is I-131 for longer duration pathways (i.e.,anything related to sedimentor soil partitioning, or bio-uptake), but for shorter duration pathways (i.e.air inhalationor immersion, lake water immersionor ingestion) thefull release is equivalentto I(mfp). In modeling the environmental transportand partitioningof radio-iodines,there is assumed to be no isotopic discrimination, and that I(mfp) behaves the same as I-131.

Beta/gamma-emitters are also considered inBruce Power's emissions monitoringand in the dose calculation process, assumingthe full complement of the combined measure consists of a single radionuclide with a high dose implication. It is conservatively assumed that all reported beta/gamma emissions were Co-60. This approach is consistent with the ERA [R-12] and is very likely over-stating the actual dose associated with emissions. Doses for Cs-134 and Cs-137 are still calculated where direct environmental measures of those radionuclides are available through the REM program.

For alpha emitters, the ERA [R-12] and past analysis determined that the dose associated with all alpha emitters is negligible. For this reason, alpha emissions are not included in the dose calculation process.

Both atmospheric and liquid effluent releases are frequently sampled and analyzed for radionuclide content (weekly for atmospheric releases and monthly for liquid effluent releases). The emissions data which are used for public dose calculations consist of the annual total values of each radionuclide at each release source in the most recent year. The use of annual values for public dose calculations is appropriate in that the established dose limits are themselves established on an annual basis.

In essence, the site-specific REM program includes the collection of representative samples of exposure media and subsequent analysis of these samples for the presence of key radionuclides or radionuclide groups. The design of the monitoring program focuses on the collection of samples near the identified representative persons (i.e., at indicator locations) near the Bruce Power site. This approach provides samples, and ultimately measures of radionuclides, which are representative of the exposure media encountered at the location of residence of representative persons. Accordingly, monitoring data of this nature are appropriate for calculating radiological doses to members of the public.

The specific radionuclides which are included in the Bruce Power REM program are based on the radionuclides and the specific pathways of exposure which have been identified as significant, typically through a site-specific Pathways Analysis. The inclusion of the significant radionuclides and specific pathways is also dependent on the availability of reliable sampling and analytical techniques. Despite the incorporation of best available practices, not all radionuclides can be reliably monitored in all media. For example, exposure to tritium is based on average measures of atmospheric HTO taken directly at indicator locations; whereas exposure levels of other radionuclides in air at given locations have typically been based on measured facility emissions of those radionuclides and the application of atmospheric dispersions models.

It is important to note that, unlike emissions data, the radiological data obtained through the REM program are not necessarily reflective of radionuclides which originate exclusively from Bruce Power facilities. Levels of radionuclides measured in environmental media may also be reflective of other sources, such as long distance transport of radionuclides from nuclear weapons testing or acute reactor events (e.g., Fukushima, Chernobyl), and also naturally occurring radionuclides. Radionuclides from sources other than the Bruce facilities are referred to in the current context as background. In order to account for the presence of background levels of radionuclides in the context of REM data, Bruce Power has also established site specific control locations for radiological monitoring for each nuclear facility specifically to provide a quantitative measure of background concentrations of key radionuclides in certain media (e.g. fish). Bruce Power has also undertaken or supported several monitoring efforts which serve to identify the background levels of various radionuclides in various media throughout the province.

In order to be able to calculate doses associated specifically with any nuclear facility, it is necessary to be able to distinguish between radionuclides in the environment which originate from that facility and radionuclides which have originated from other sources. In dose calculations where transport models are used to define environmental concentrations of radionuclides based on emissions data alone, the resulting doses are associated only with the nuclear facility(ies) from which the emissions data were obtained. In those cases where environmental monitoring data for various media serve as the basis for dose calculation, those doses may represent sources of radionuclides other than nuclear facilities. In order for dose calculations based on such data to be relevant to a specified facility or facilities, it is necessary to adjust those data for the presence of background concentrations of the radionuclides of concern. In cases where monitoring data have been employed in the Bruce Power public dose calculations, the concentrations of radionuclides in various media have been adjusted by subtracting the background values, where available. In doing so, the radiological doses are related exclusively to routine releases from Bruce Power site facilities.

The approach taken in selecting representative values from the monitoring data available for 2019 is as consistent as possible with the approach taken in previous calculations of public dose at the Bruce Power site. For radionuclides in air and water, the levels of activity for each radionuclide at each location of representative person exposure are average values of all measures recorded in 2019 at those locations, or at the nearest monitoring station during 2019. For animal and plant produce, the maximum radionuclide level from all available samples from the closest sampling location(s) is conservatively adopted as representative of that location. For those exposure media not specific to any one location of residence of any representative person (e.g., beach sands, fish flesh, lake water), the values selected are averages of all measures taken in the Bruce Power receiving environment in 2019.

In 2019, the approach taken when REM data included values that were less than the associated detection limit (Ld) or critical level (Lc), those values were taken as reported. For example, in the calculation of local or background averages where some measured values were reported as less than Lc or Ld, the uncensored analytical results were used in the calculation. In previous years dose calculations, values <Ld or <Lc were assumed to be half of the respective limit for background samples, and equivalent to the limit for local samples. This change in procedure, initiated for the 2018 dose calculations, is intended to achieve consistency in reporting of REM data and also to achieve consistency with other procedures where those data are also used (e.g. ERA). The implications of this change to the reported doses are very minor. In most cases, the resulting doses are slightly higher in following the new approach.

The critical level or decision threshold, Lc, is the calculated value based on background measurements, below which the net counts measured from the sample are indistinguishable from the background at the 95% probability level. The detection limit, Ld, is the calculated value based on the decision threshold and the measurement system parameters (e.g. count time) above which the net counts measured from the sample are expected to exceed the decision threshold at the 95% confidence level. These definitions of Lc and Ld are consistent with CSA N288.4-10 Annex D [R-3].

In 2019, there were a few additional instances in which the application of the REM data was not as specified in Bruce Power's procedure [R-76] [R-67], however the measures taken were largely conservative and the associated dose is minor in terms of the total calculated public dose. This includes the following:

- The reported levels of HTO activity in Provincial Background fish samples collected in 2019 were higher than expected, exceeding HTO activity in local fish samples caught in close proximity to the Bruce Power site (i.e. in Baie du Doré). As a conservative alternative, the background HTO activity level in waters of the Great Lakes (taken from the Klukas model), was used as representative of the background HTO activity level in fish. The dose associated with the ingestion of HTO in fish accounts for less than 1% of the total dose.

- In 2019, no milk sample was available for location DF14. The average results for the milk samples collected from the nearest dairy farm that is closer to the sources of emissions (i.e., DF13) was applied for location DF14.

- For deep residential wells, the activity level of HTO in all samples collected in 2019 was reported to be less than the critical level. In this specific case, the critical level itself was assigned, with adjustment for background, as the representative value for HTO in all deep residential wells. The public dose associated with HTO in deep residential wells is in the order of 0.01 µSv/a or less.

- The activity level of C-14 in local samples of grain and deer collected in 2019 was lower than the C-14 activity in corresponding background samples. To estimate the C-14 activity in these media, the environmental transport models in IMPACT were invoked.

The dose calculation results for 2019 for the 19 distinct groups of representative persons are provided in Appendix C, which includes a breakdown of doses by both radionuclide and pathway of exposure.

The maximum dose to the public in 2019 was 1.5 µSv/a, representing a decrease of about 10% compared to the maximum dose calculated in 2018 (i.e., 1.67 µSv/a). The maximum dose was calculated for the "Adult" age class of the Farmer (F) group BF14. Within the BF14 group, the higher meat ingestion rate for the “Adult” compared to the “Infant” and “Child” age groups resulted in the “Adult” having the higher dose. The Farmer group as the maximum dose group is a slight departure compared to the past few years, when the highest dose was received by the Subsistence Farmer (SF) group. In 2019, the doses calculated for the SF group at both locations (BSF2 and BSF3) are just slightly less than the BF14 group, in the range of 1.2 to 1.4 µSv/a. Doses to the various representative locations and age classes of the Dairy Farm (DF) group, and also farm groups other than BF14, range from 0.7 to 1 µSv/a. The doses calculated for the non-farming Resident (R) group at various locations in close proximity to Bruce Power are of similar magnitude, ranging from 0.7 to 1.2 µSv/a. The dose calculated for members of the Hunter-Fisher (HF) group near Southampton are between 0.4 and 0.5 µSv/a.

About 60% of the total dose to the BF14 group is from food ingestion, which simply reflects the relatively high rate of local food consumption by members of this farm-based group. For the various other farm-based groups (DF, F, SF), food ingestion similarly accounted for the majority (~60 to 80%) of total dose. For non-farm residential group, the proportion of total dose associated with food ingestion was slightly less but still significant (i.e., about 40% to 50%). Direct exposure to radionuclides in air via inhalation and immersion was the only other significant contributor to total dose, accounting for about 20% to 30% of dose for farm-based groups (DF, F, SF) and 40% to 60% for residential (R) groups. These general patterns are consistent with the patterns observed for the past decade.

The main contributing radionuclides to the limiting dose (BF14 Adult) are C-14 (~46 % of total dose) and HTO (~40% of total dose). Overall, C-14 and HTO (including OBT) combined account for an average of about 84% of the total dose for all groups of representative persons that have been considered in 2019. This dominance of C-14 and HTO as contributors to total dose in 2019 is consistent with the findings of public dose calculations over the past decade. Noble gases were the only other radionuclide group to contribute more than 1% of public dose, accounting for an average of about 15% of total dose for all groups considered.

The decrease in public dose in 2019 relative to 2018 is related primarily to trends in facility emissions. In 2019, total HTO emissions to air from all BP facilities combined decreased by about 20% relative to 2018. This was due to the difference in outage activities at Bruce A and Bruce B that occurred in 2019 compared to 2018. Levels of HTO in various environmental media (air, shallow wells, and various plant and animal products) also exhibited general declines of similar magnitude in 2019. The dose attributable to HTO, which accounts for an average of almost 40% of total dose, declined by about 22% on average for all groups considered. The dose associated with noble gases also declined by about 30% on average, primarily as a result of a decline in total emissions of about 20%.

For C-14, the trend in dose did not fully reflect the trend in emissions. Total atmospheric emissions of C-14 were only slightly (~7%) higher in 2019 than they were in 2018. On average, the public dose attributable to C-14 increased by an average of almost 120% for all the groups considered. This relatively large dose increase is attributable in large part to very large C-14 dose increases to the members of the BF14 group. For the adult member of this group, exhibiting the maximum public dose in 2019, the increase in the C-14 dose was about 35-fold compared to 2018. For the 1-yr old and 10-yr old members of the group, the C-14 dose increased 6-fold and 15-fold, respectively. When excluding the members of the BF14 group, the average C-14 dose to the public in 2019 was about 13% higher than it was in 2018, which is comparable to the slight increase in total C-14 emissions to air. For the BF14 group, the large increase in C-14 dose is attributable to a few main factors, including

- the activation of conservative models when background values exceed local measures, including fruit and vegetable samples in 2018 and grain samples in 2019, and

- a 10% decline in Provincial background measures of C-14 in air in 2019 compared to 2018, resulting in relatively high adjusted measures of C-14 in air at various locations, particularly at BF14, and subsequently high model-based estimates of C-14 in various food sources.

Except for the notable exception of the BF14 group, and also a minor exception of the BR1 group, each of the groups of representative persons experienced a drop in total dose from 2018 to 2019, with an overall average decrease of about 13%. This is driven by decreases in emissions of the radionuclides that contribute meaningfully to public dose, particularly HTO emissions.

5.4.4.4 Historical Dose to Public

The calculation of public dose demonstrates that the emissions from Bruce Power facilities have an extremely small public dose impact. The maximum public dose associated with Bruce Power operations in 2019 (i.e., 1.5 μSv/a for the BF14 Adult) is still only a fraction of a percent of the legal limit (i.e., 1,000 μSv/a) and of the background dose (i.e., ~ 3,100 μSv/a). The dose to public has been well below the *de minimus* threshold of 10 μSv/a for 28 consecutive years.

The historical dose to public trend is shown in **Figure 20**. The data point for 2015 shows a slight increase due to tritium and ^{14}C emissions from vacuum building/unit outages occurring at the same time as the annual media sampling.

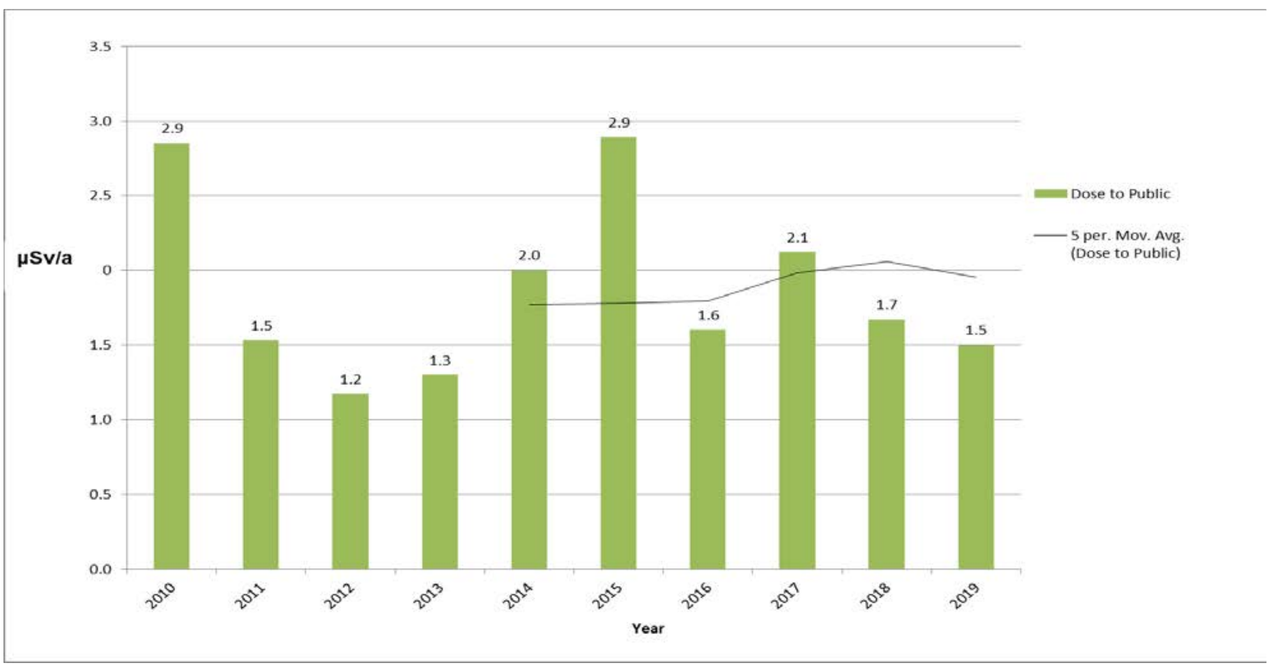


Figure 20
Historical Dose to Public Trend

5.4.4.5 Integrated Model for the Probabilistic Assessment of Contaminant Transport (IMPACT)

For radiological contaminants, environmental monitoring data is used in the IMPACT (Integrated Model for the Probabilistic Assessment of Contaminant Transport) calculation of dose to humans and non-human biota by replacing modeled concentrations with actual measured concentrations. IMPACT is a customizable tool that allows the user to assess the transport and fate of contaminant through a user-specified environment. It also enables the quantification of human exposure to those environmental contaminants and the calculation of DRLs for nuclear facilities (power generating stations, research reactors, waste management (facilities). It covers all of the potential exposure and release scenarios, including atmospheric and aquatic pathways that are in CSA N288.1-14 Update No. 3. IMPACT Version 5.5.2 was released in April 2018 and is the latest version of the code. This version fully implements the models of N288.1-14 and its recommended parameter values, including corrections to parameter values as per CSA N288.1-14 Updates 1, 2 and 3. The code was developed by EcoMetreix Inc., under contract to CANDU Owners Group (COG). The development of IMPACT 5.5.2 has been guided by, and subject to, an overall Tool Qualification Program (TQP), which follows the CSA N286.7-99 [R-126]. Code verification and validation were documented in the Tool Qualification Report. A user manual and theory manual are also available for the version [R-82].

5.4.5 Meteorological Data

This section is extracted from the 2019 Meteorological Data Analysis report [R-77].

There are two meteorological towers on the Bruce Power site, one 50 m on-site tower and one 10 m off-site tower. These towers were installed in 1990, at specific locations to ensure that the meteorological measurements are representative of local atmospheric conditions experienced, and to better account for how emissions are conveyed inland. The 50 m on-site tower measures wind speed and direction at the 10 m and 50 m elevations, as well as temperature at the 10 m elevation. The 10 m off-site tower measures wind speed and direction at the 10 m elevation [R-76].

Meteorological data (12.0Appendix F:) are required in order to calculate doses to the public resulting from the operation of nuclear facilities on the Bruce Power site. Specifically, the processed meteorological data in the format of Triple Joint Frequency (TJF) are required as inputs to the computer code Integrated Model for Probabilistic Assessment of Contaminated Transport (IMPACT) for public dose calculations as part of Bruce Power's annual Environmental Protection Report (EPR) and Derived Release Limits report (five-year cycle).

The data gaps in the 2019 raw meteorological data provided by Bruce Power [R-84][R-84] are significant, which does not meet the requirement of Canadian Standards Association (CSA) N288.2-14 [R-85] to have ninety percent complete data for processing (before substitution) . An explanation for this significant loss of data is discussed in the next section. Therefore, the five-year datasets (from 2011 – 2016) have been analyzed to derive meteorological datasets that will represent the Double Joint Frequency (DJF) and TJF for Bruce Power site in 2019. The calculation of joint frequency data meets the requirements described in Section 6.1.4 of CSA N288.1-14 Update 3 [R-14].

5.4.5.1 Data Availability

For year 2019, raw meteorological data were missing for the following periods of time:

- 50 m on site tower: Data are unavailable for the following period, March 05 to July 16, August 24 to Aug 30. In addition, there are multiple cases where there are two datasets reported for one time slot.
- 10 m off site tower: Data are unavailable from January 01 to July 12.

The meteorological data available for 2019 does not satisfy the 90% criterion for overall valid data collection; as such the data cannot be used.

Table 24
Summary of Missing Records for 2019

Data Source	Available Records	Total Records Planned	Records Missing (%)
10 m Meteorological Tower	4145	8760	53
50 m Meteorological Tower	5419	8760	38

In 2019, the Meteorological Tower data collection process has faced multi-faceted recurring issues. The process of dialing into the tower modems to collect data appears to be failing on a regular basis. The vendor reports that the phone modems appear to pick up but cannot complete a handshake to exchange data. This aligns with reports from Bruce Power IT Analysts that see the PC209W v2.2 software that indicate both the 10Meter and 50Meter are failing to communicate, transfer data, or pass basic data checksums on a regular basis. This indicates that the modems are likely defective, showing high error rates in the few communications that are getting through.

To complicate the data communications issues, the data logger devices (Model: Campbell Scientific 21X) are of a vintage that they do not have any non-volatile memory or battery backup.

Finally, the devices in question are all of a vintage where they are no longer supported.

Taken together, this means that dial-in processes were not downloading data correctly, the data loggers were capturing data into volatile storage, and there is no support contract to understand the resulting data corruption issues.

In previous years, data gaps have been reported in the meteorological data due to ongoing data storage issues. However, with the exception of 2014, the period of data loss was insignificant and data analysis was performed "omitting" the missing data without the need for interpolation, while still meeting the requirements described in Section 4.3.2.6 of CSA N288.2-14, Guidelines for Calculating the Radiological Consequences to the Public of a Release of

Airborne Radioactive Material for Nuclear Reactor Accidents, which states that "…ninety percent of the data must be available before substitution" [R-85].

However, the data gaps in 2017-2019 raw meteorological data are significant, with less than 90% of the data available. Therefore, omitting these data is not an option for processing and analysis. For this reason, the five-year average dataset from the years 2011, 2012, 2013, 2015, and 2016 were utilized as a surrogate to calculate TJF and DJF for 2019. Data from 2014, 2017 and 2018 cannot be used for the same reason as described above for the 2019 data.

The surrogate datasets were collected from the same meteorological towers as previously described, and provide better representation of the 2019 meteorological conditions compared to an alternative off-site location. Although radionuclide transport and dispersion models are sensitive to wind conditions, using this "five-year average" approach will have very low impact on annual doses to representative persons reported in the Environmental Protection Report because these are largely based on measured environmental concentrations.

5.4.5.2 Meteorological Data Analysis Methodology

Meteorological Data Analysis Methodology

The 2019 surrogate DJF and TJF for Bruce Power site were calculated as follows:

1. The raw meteorological data for each year from 2011 to 2016 (excluding 2014) provided by Bruce Power were sorted to select hourly data only.

2. For the 10 m off-site tower, DJF was calculated based on the hourly data from step one. For the 50 m on-site tower, DJF was calculated for both heights and TJF was calculated only for the 10 m height, based on the hourly data from step one. The wind speed bins, wind direction sectors and stability class were determined as follows:

Wind speed groupings are defined as per Table 10 of CSA N288.1 14 [R-14]. Table 10 of CSA N288.1 14 is reproduced below in Table 25.

Table 25
Wind Speed Bins Used for the Generation of DJF and TJF Tables

Wind Speed Class	Wind Speed, u (m/s)
1	u ≤ 2
2	2 < u ≤3
3	3 < u ≤ 4
4	4 < u ≤ 5
5	5 < u ≤ 6
6	u > 6

The wind direction is then divided into 16 wind direction sectors with each sector being 22.5 degrees, as shown in Table 26.

Table 26
Wind Direction Sectors

Wind Sector (direction from which wind is blowing)	Wind Direction (θ) in degrees
N	θ > 348.75 or θ ≤ 11.25
NNE	11.25 < θ ≤ 33.75
NE	33.75 < θ ≤ 56.25
ENE	56.25 < θ ≤ 78.75
E	78.75 < θ ≤ 101.25
ESE	101.25 < θ ≤ 123.75
SE	123.75 < θ ≤ 146.25
SSE	146.25 < θ ≤ 168.75
S	168.75 25 < θ ≤ 191.25
SSW	191.25 < θ ≤ 213.75
SW	213.75 < θ ≤ 236.25
WSW	236.25 < θ ≤ 258.75
W	258.75 < θ ≤ 281.25
WNW	281.25 < θ ≤ 303.75
NW	303.75 < θ ≤ 326.25
NNW	326.25 < θ ≤ 348.75

The Pasquill-Gifford stability classes A to F were used. Stability class was estimated from the standard deviation of wind direction measured, taking into account night-time conditions and wind speeds [R-86]. A surface roughness of 0.4 m was assumed for all sectors. This value represents rural areas with mixed farming, tall bushes and small villages, consistent with CSA N288.2-14 [R-85]. Inclusion of surface roughness in the methodology for determining Pasquill-Gifford stability category is a refinement in the classification scheme, which results in shifting more cases towards the neutral D-stability class conditions with increased roughness [R-87].

For TJF, annual average and seasonal average data were calculated separately. The seasonal average TJF data account for the months of May to September inclusive.

The calculated DJF data for the Bruce Nuclear site are presented in Table 27 and Table 28.

Table 27
Annual Average DJF (Surrogate) for Bruce Power Site
for Year 2019 – 50 m Meteorological Tower at 10 m Height

Wind Direction (wind blowing from)	**Wind Speed, u (m/s)**						
	u ≤ 2	**2 < u ≤ 3**	**3 < u ≤ 4**	**4 < u ≤ 5**	**5 < u ≤ 6**	**u > 6**	**Total**
	Frequency (%) at 10 m Height						
N	1.71	0.88	1.00	0.80	0.42	0.50	**5.30**
NNE	1.77	1.02	1.10	0.72	0.31	0.34	**5.27**
NE	1.57	0.80	0.57	0.40	0.20	0.09	**3.62**
ENE	2.69	0.86	0.68	0.40	0.17	0.11	**4.90**
E	2.15	0.72	0.49	0.15	0.09	0.12	**3.72**
ESE	1.75	0.52	0.32	0.20	0.15	0.16	**3.09**
SE	2.66	0.92	0.56	0.35	0.22	0.19	**4.91**
SSE	4.00	1.70	1.08	0.54	0.31	0.37	**8.00**
S	4.31	1.60	1.42	1.05	0.61	0.64	**9.63**
SSW	3.30	1.62	1.44	1.17	1.20	1.54	**10.27**
SW	2.73	1.21	1.74	1.69	1.07	1.33	**9.77**
WSW	1.57	0.99	0.95	0.82	0.72	1.77	**6.81**
W	1.08	0.85	0.82	0.57	0.54	1.44	**5.30**
WNW	1.36	0.89	0.77	0.67	0.72	1.50	**5.89**
NW	1.56	0.92	0.77	0.80	0.63	1.16	**5.85**
NNW	2.24	1.37	1.24	1.00	0.71	1.10	**7.67**
Total	**36.44**	**16.85**	**14.95**	**11.32**	**8.07**	**12.37**	**100.00**

Table 28
Annual Average DJF (Surrogate) for Bruce Power Site
for Year 2019-50 m Meteorological Tower at 50 m Height

Wind Direction (wind blowing from)	Wind Speed, u (m/s)						
	u ≤ 2	2 < u ≤ 3	3 < u ≤ 4	4 < u ≤ 5	5 < u ≤ 6	u > 6	Total
	Frequency (%) at 50 m Height						
N	0.47	0.57	0.72	0.79	0.80	1.96	**5.30**
NNE	0.44	0.65	0.84	0.89	0.88	2.35	**6.05**
NE	0.46	0.60	0.79	0.74	0.59	1.21	**4.39**
ENE	0.40	0.68	0.96	0.96	0.74	0.74	**4.49**
E	0.43	0.80	1.04	0.71	0.33	0.40	**3.70**
ESE	0.38	0.71	0.93	0.45	0.25	0.41	**3.13**
SE	0.30	0.52	0.85	0.90	0.72	1.01	**4.31**
SSE	0.32	0.44	0.77	1.12	1.49	1.94	**6.08**
S	0.28	0.50	0.83	1.58	2.31	2.62	**8.12**
SSW	0.36	0.52	0.94	1.68	2.60	5.59	**11.69**
SW	0.56	0.76	1.16	1.56	1.78	4.49	**10.31**
WSW	0.40	0.63	0.91	0.85	0.70	3.52	**7.00**
W	0.39	0.65	0.68	0.56	0.55	2.76	**5.59**
WNW	0.43	0.60	0.61	0.56	0.62	3.03	**5.85**
NW	0.52	0.73	0.65	0.61	0.62	3.37	**6.50**
NNW	0.60	0.82	0.87	0.78	0.79	3.64	**7.49**
Total	**6.74**	**10.18**	**13.53**	**14.75**	**15.77**	**39.02**	**100.00**

5.4.6 External Gamma in Air

Environmental external gamma dose rates were measured using Harshaw EGM Thermoluminescent Dosimeters (TLDs) at air monitoring stations. The dosimeters were exposed for three month periods, collected quarterly and the annual doses are calculated as the sum of the quarterly results. The accuracy of the dosimeters is estimated to be ± 15 percent. The accuracy is verified by the quality control program described in the Ontario Power Generation 2018 Results of Radiological Environmental Monitoring program [R-88]. The external gamma dose rates and the provincial monitoring program samples are measured by the OPG Whitby Health Physics Laboratory. The location of the representative persons (Critical Groups) are detailed in Table 18 and shown graphically in Figure 19. The sampling locations in the vicinity of Bruce Power are detailed in Appendix D. Background dosimeters are also located at various locations around Ontario and are collected quarterly.

5.4.6.1 2019 External Gamma in Air Results

The dosimeter locations throughout the province show the range of background radiation levels experienced during the year. Bruce Power and Provincial Background results are detailed in Table 29.

The Bruce Power indicator sites are B2, B3, and B4, and are located closest to the Bruce Power site. The average external gamma dose in air at Bruce Power indicator sites B2, B3, and B4 was 51 ηGy/h.

Provincial background sites measure ambient external gamma radiation in air. The average of the provincial background sites was 58 ηGy/h. The average of the provincial background sites is slightly higher than the Bruce Power indicator sites. TLD measurements alone cannot resolve the very low gamma doses in air associated with station emissions or those observed provincially. As a result, a conservative modelling method of estimating noble gas activity in the environment using emission data and atmospheric dilution factors is used in the dose estimates. This demonstrates that the impact of Bruce Nuclear on the surrounding environment, with regards to gamma in air, is *de minimus*.

Table 29
2019 Annual External Gamma Dose Rate Measurements

Sample Location	Total Exposure Time (days)	Total Measured Dose in Air (μGy)	Annual Average Dose Rate in Air (ηGy/h)	Annualized Exposure (μGy)
Indicator				
B02-TLD	366	468	53	467
B03-TLD	364	464	53	466
B04-TLD	365	408	47	408
Average (Indicator)	365	447	51	447
Area Near				
B05-TLD	365	402	46	402
B07-TLD	365	421	48	421
B10-TLD	365	542	62	542
B11-TLD	365	513	59	513
Average (Area Near)	365	470	54	470
Area Far				

Sample Location	Total Exposure Time (days)	Total Measured Dose in Air (μGy)	Annual Average Dose Rate in Air (ηGy/h)	Annualized Exposure (μGy)
B06-TLD	365	401	46	401
B08-TLD	365	400	46	400
B09-TLD	365	409	47	409
Average (Area Far)	365	403	46	404
Provincial Background				
Bancroft	365	590	67	590
Barrie	354	517	61	533
Lakefield	365	546	62	546
Niagara Falls	365	415	47	415
North Bay	344	527	64	560
Ottawa	381	438	48	420
Thunder Bay	366	543	62	542
Windsor	368	457	52	454
Average (Provincial Background)	364	504	58	508

5.4.6.2 Historical External Gamma in Air Results

Figure 21 shows that Bruce Power external gamma values remain relatively constant over the past five years. This is primarily due to stabilization in atmospheric radiation levels from historical aboveground weapons testing fallout.

Bruce Power's levels have remained below provincial background for more than 10 years. Both Bruce Power and provincial measurements show similar trends.

A general linear model was performed and identified that there was no interaction between location and year for gamma in air (α=0.05). Analysis of Variance shows a significant difference (p<0.001 α=0.05) by site with the provincial site having the highest mean, the indicator and area near sites having no significant difference from each other and the area far sites having the lowest mean.

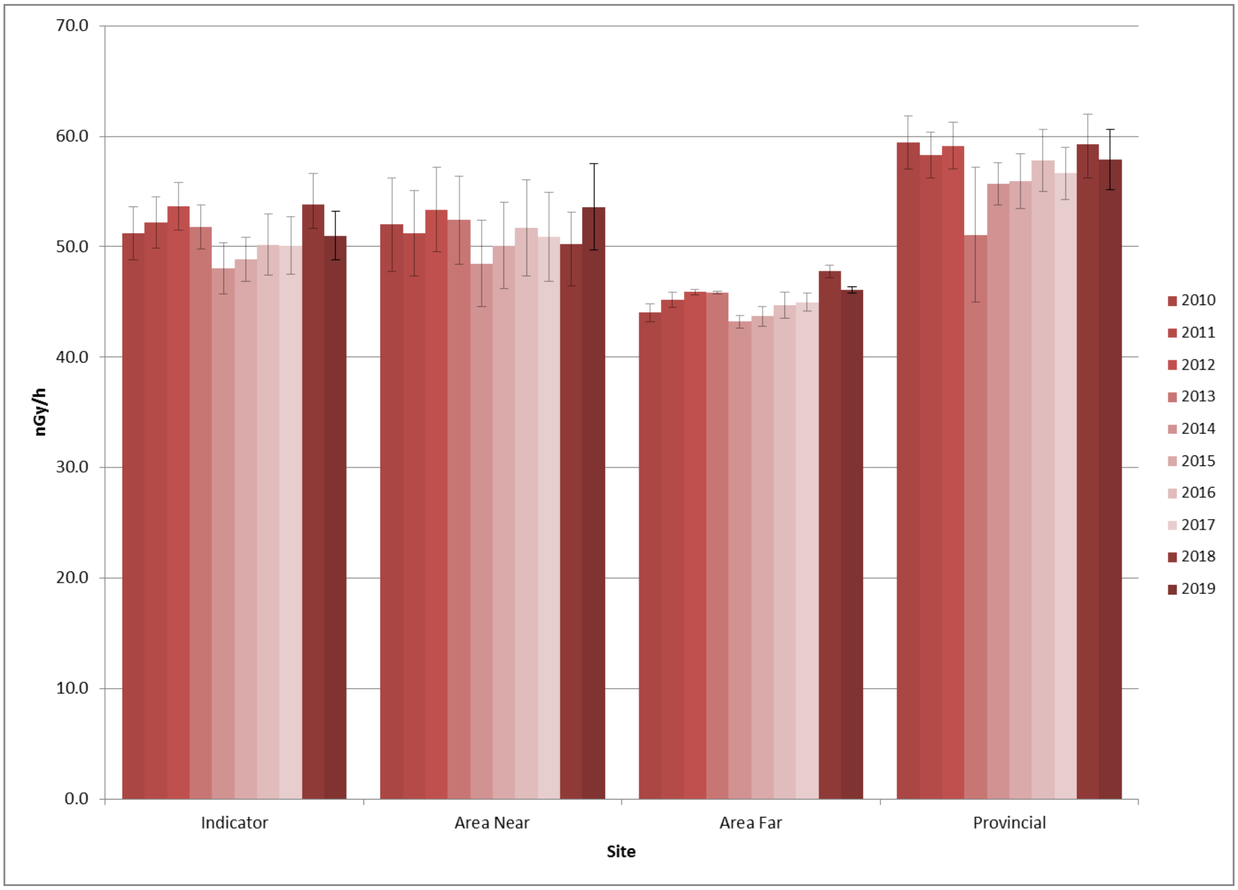


Figure 21
Annual Average External Gamma Dose Rates at Bruce Power Indicator Sites and Provincial Background Sites Over Time

5.4.7 Tritium in Air

5.4.7.1 Active Sampling Methodology

Tritium in air is collected using active samples. Water vapour is collected by passing air at a continuous rate through an absorbent material (molecular sieve). The water is extracted and analyzed monthly for tritium, and results are obtained by multiplying the specific activity of tritium in the extracted water by the average absolute humidity measured for the sampling period. The average absolute humidity is determined by dividing the mass of water collected on the molecular sieve by the volume of air sampled as measured by an integrating flow meter. Samples from the active samplers are collected and analyzed monthly. Monthly samples are averaged by location per year.

5.4.7.2 2019 Tritium in Air Results

The 2019 results of the active tritium air sampling are detailed in Table 30 and graphed in Figure 22 on a monthly basis. Locations of active samplers are depicted in Appendix D.

The 2019 annual average for tritium in air at indicator sites closest to Bruce Nuclear Site was 2.1 Bq/m3 while area near and area far, in general, were. The 2019 average is lower than the previous year (2.5 Bq/m^3) however the results of measurements near the Bruce Power site are consistently higher than provincial average airborne tritium, which was much lower in 2019 than in previous years. The elevated tritium in air results for July may be attributed to the outages and maintenance activities at Bruce A and Bruce B that occurred during the summer (Figure 22).

Table 30
2019 Annual Average Tritium in Air

Sample Location	Active Sampling[1] (Bq/m^3)
Indicator	
B02-ST	2.2
B03-ST	1.8
B04-ST	2.2
Average (Indicator)	**2.1**
Area Near	
B05-ST	1.5
B07-ST	1.8
B10-ST	1.1
B11-ST	0.7
Average (Area Near)	**1.3**
Area Far	
B06-ST	0.2
B08-ST	0.2
B09-ST	0.3
Average (Area Far)	**0.2**
Provincial Background	
Nanticoke	0.03

Note: [1] Tritium result is based on the arithmetic mean of the activity of two replicate samples.

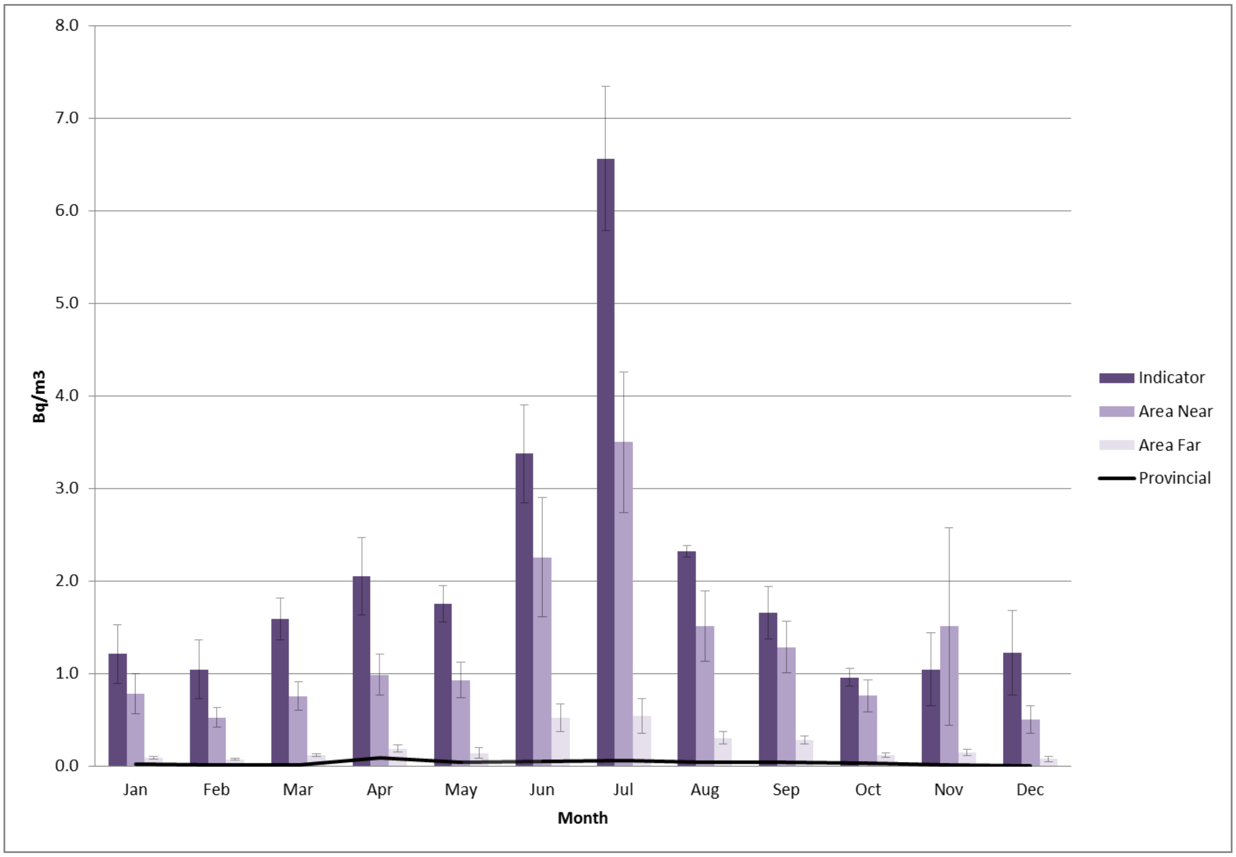


Figure 22
2019 Tritium Concentrations (Bq/m^3) in Air from Active Samplers Near the Bruce Power Site as Compared to the Provincial Average on a Monthly Basis

5.4.7.3 Historical Tritium in Air Results

Figure 23 shows the historical trendof tritium inair (obtainedby averaging results from all Bruce Power locations annually) surrounding the Bruce Power site. Tritium inair emissions increased after Unit1 and 2 were restarted in 2012 andin 2010 due to major outage evolutions. The annual average tritium inair decreased at indicator,area near and area far sites in 2019. CNSC IEMP tritium inair samples collectedin 2016 had values ranging from less than 2.5 Bq/m^3 and was well below the guideline/reference level of 340 Bq/m^3.

Analysis of variance shows a significant difference ($p<0.001$ $\alpha=0.05$) by site. The indicator site showed the highest mean concentration, followed by area near. The area far and provincial sites had thelowest mean concentrations and were significantly differenfrom each other. It is unclear why the 2018 Provincial valueis higher thanprior years.

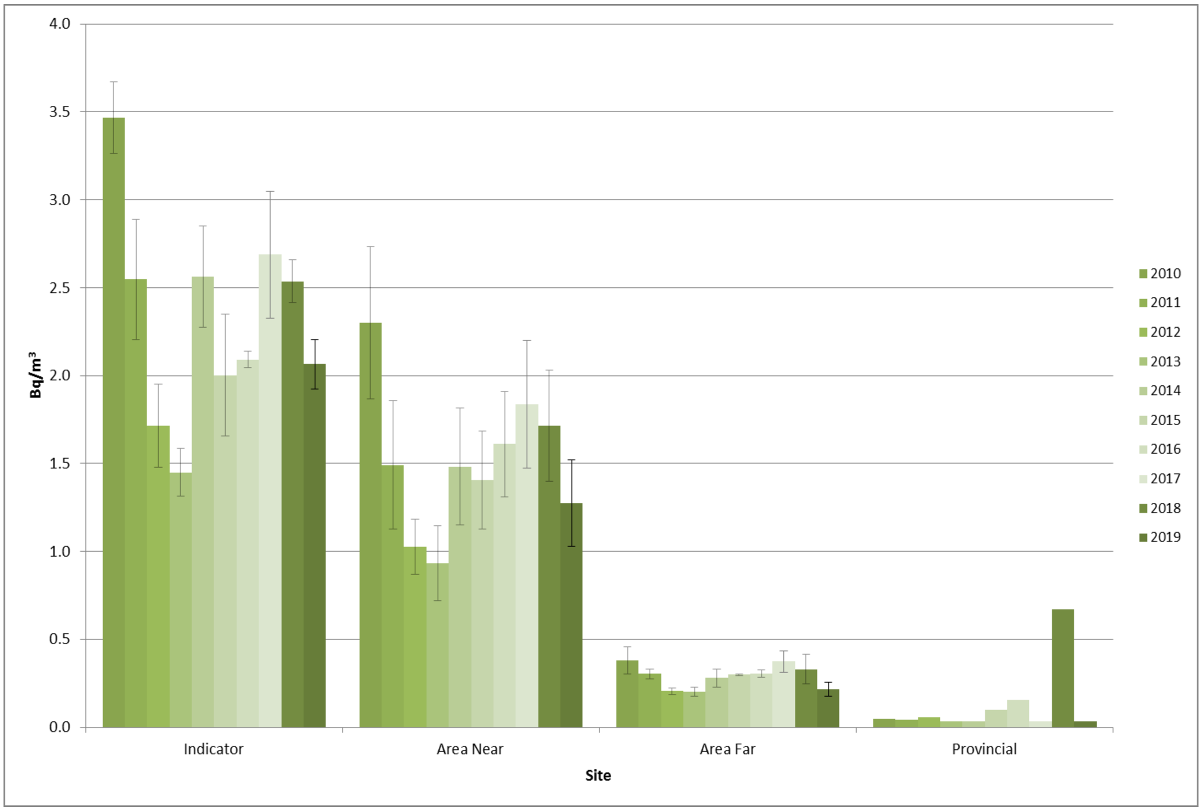


Figure 23
Annual Average Tritium in Air Concentrations (Bq/m^3) from Active Samplers At Bruce Power and Provincial Locations Over Time

5.4.8 Carbon-14 in Air

Carbon-14 (^{14}C) in air is collected using passive samplers. The ^{14}C passive samplers consist of mixed soda lime pellets to absorb CO_2 from air at a controlled rate. The CO_2 is released from the pellets in the laboratory by titration with acid, then collected and analyzed by liquid scintillations counting for ^{14}C content. The passive sampler samples are collected and analyzed quarterly. The sampling locations in the vicinity of Bruce Power are also detailed on Appendix D.

5.4.8.1 2019 Carbon-14 Air Sampling Results

The 2019 results of the passive ^{14}C in air sampling (on and off site) are detailed in Table 31 and depicted graphically in Figure 24 with Bruce Power locations showing slightly higher levels than provincial locations. Bruce Power 2018 results are consistent with provincial background as shown in Figure 24. The highest ^{14}C concentrations are localized around the source areas (WWMF, Bruce A, and Bruce B), which is as expected. The ^{14}C concentrations decrease with distance from the source areas, nearing provincial background levels at the site boundary.

Table 31
2019 Annual Average ^{14}C in Air from Passive Samplers

Sample Location	Passive Sampling
	^{14}C (Bq^{14}C/kgC)
Indicator	
B03-PC	248
Area Near	
B05-PC (#1)	260
B05-PC (#2)	249
B11-PC	225
BF01-PC	237
BF14-PC	253
BF23*-PC (formerly known as BDF11)	232
BR01-PC	248
BR11-PC	258
Average (Area Near)	**245**
On-Site	
C01-PC	336
C02-PC	378
C03-PC	7515
C04-PC	1167
C05-PC	1001
C06-PC	2103
C07-PC	419
C08-PC	417
C09-PC	328
C10-PC	354
C11-PC	651
C12-PC	462
C13-PC	1341
C14-PC	1963
Average (On-Site)	**1317**

Sample Location	Passive Sampling ^{14}C ($Bq^{14}C/kgC$)
Provincial Background	
Bancroft	209
Barrie	222
Nanticoke	199
Lakefield	232
Picton	207
Average (Provincial Background)	**214**

Note: Nanticoke has replaced Belleville as a Provincial monitoring station

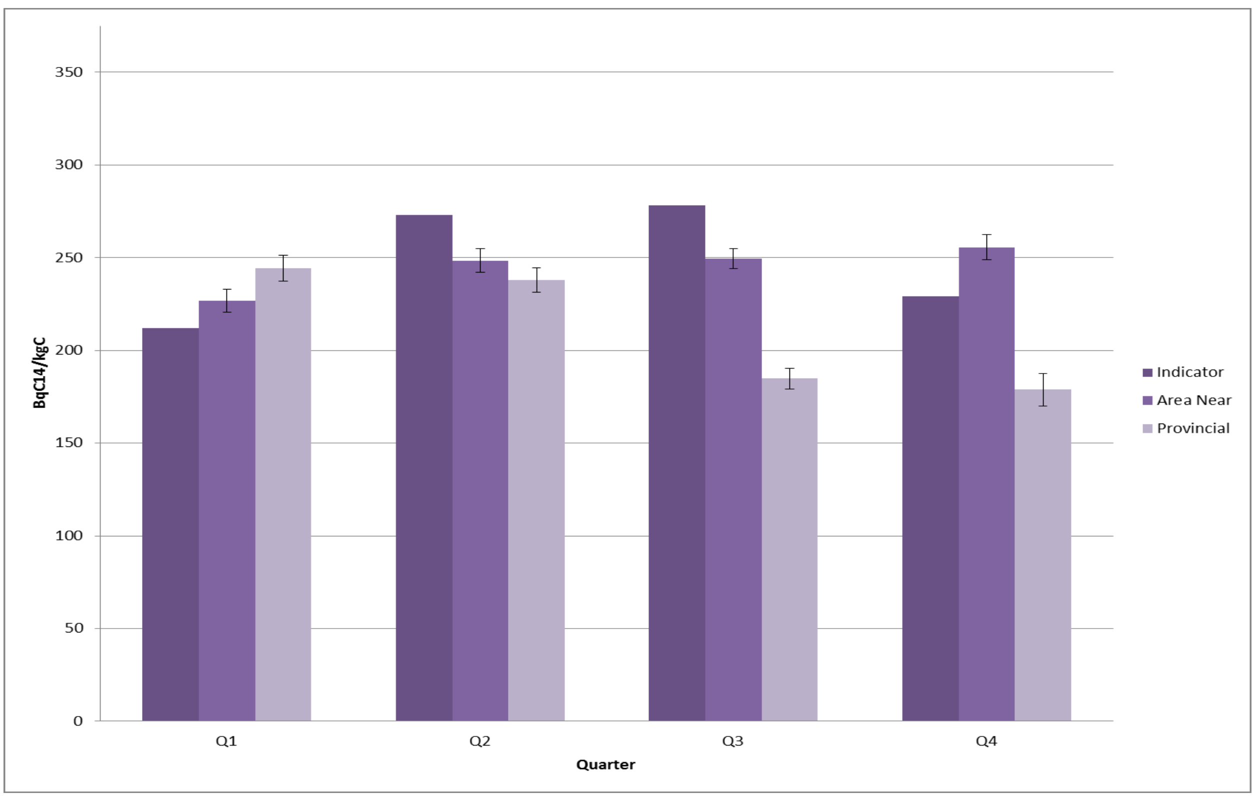


Figure 24
2019 ^{14}C Concentrations in Air from Passive Samplers Sampled Quarterly near the Bruce Power Site as Compared to the Provincial Average

5.4.8.2 Historical ^{14}C Air Sampling Results

In the historical ^{14}C in air sampling (as shown in in **Figure 25**), the Bruce Power annual average is above the provincial annual average consistently from year to year. Both Bruce Power and the provincial ^{14}C trends remain stable. The CNSC IEMP have not analyzed ^{14}C in air in 2013, 2015 or 2016. ^{14}C in air contribution to a representative person is well below the regulatory limit to a representative person's total exposure to radiation. Analysis of variance shows a significant difference (p<0.001 α=0.05) by site, with the provincial mean concentrations being lower. The indicator and area far sites showed the highest mean concentrations and were not significantly different from each other.

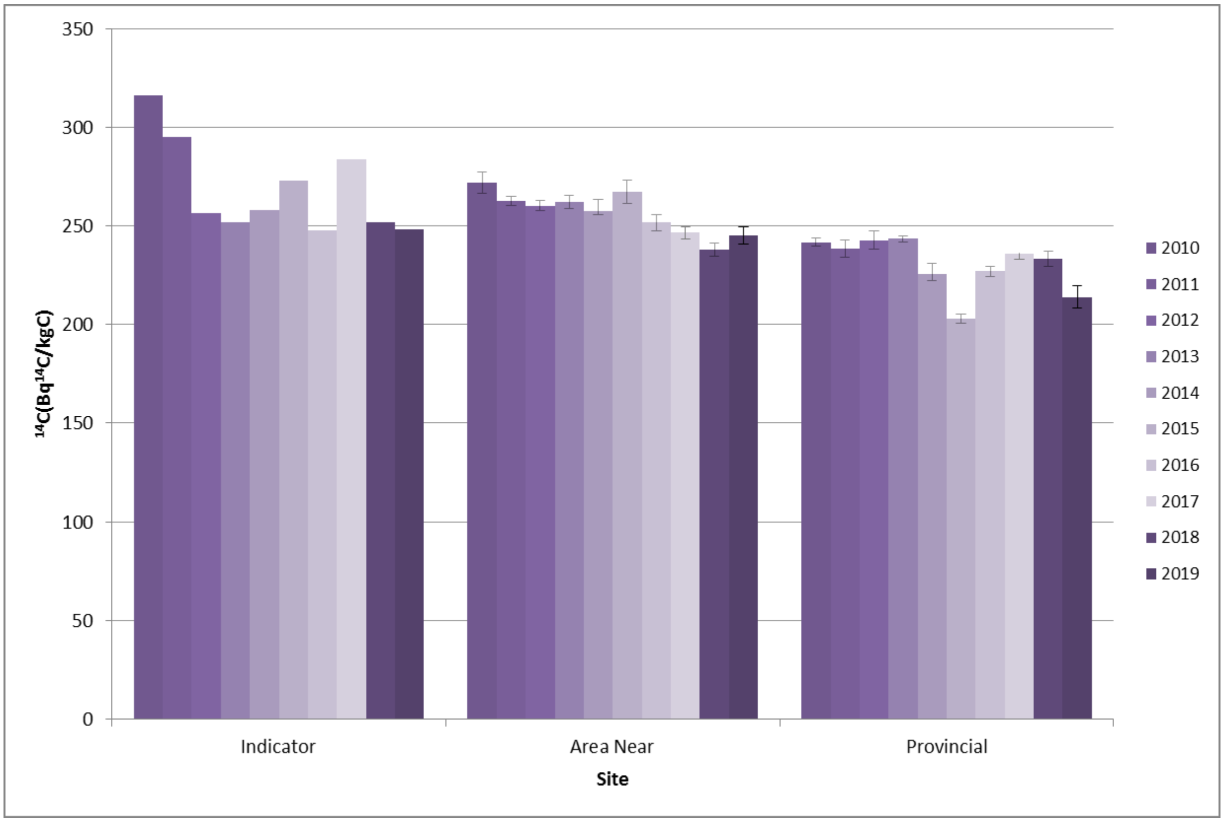


Figure 25
Annual Average ^{14}C in Air Concentrations at Bruce Power And Provincial Locations Over Time

5.4.9 Tritium and Gross Beta in Precipitation

The precipitation collector is a bucket on a stand at various locations near Bruce Power site (indictor, area, far). These collectors are changed out on a monthly basis, and the gathered precipitation is analyzed for tritium and gross beta.

5.4.9.1 2019 Tritium and Gross Beta in Precipitation Results

The 2019 annual average for tritium and gross beta in precipitation are presented in Table 32. The annual average for tritium in precipitation at indicator sites (closest to Bruce Nuclear Site) was 123 Bq/L, while the annual average was 75 Bq/L for sites within approximately 10 km indicating that tritium precipitation are elevated near site.

The annual average for gross beta in precipitation was 22 Bq/m2/month at Indicator Sites, while sites within approximately 10 km had an annual average of 23 Bq/m2/month indicating that there are no substantial impacts in precipitation from beta. Provincial data for gross beta in precipitation is not collected. Locations of sample sites can be found in Appendix D.

Table 32
2019 Annual Average Precipitation Data

Sample Location	Average Tritium Activity in Precipitation (Bq/L)	Average Gross Beta Deposition Rate (Bq/m^2/month)
Indicator		
B02-WP	140	23
B03-WP	96	22
B04-WP	132	23
Average (Indicator)	**123**	**22**
Area Near		
B05-WP	105	24
B07-WP	78	22
B10-WP	62	25
B11-WP	56	18
Average (Area Near)	**75**	**23**
Area Far		
B06-WP	12	20
B08-WP	17	21
B09-WP	22	20
Average (Area Far)	**15**	**21**

5.4.9.2 Historical Tritium PrecipitationResults

The historical trends oftritium inprecipitationat Bruce Power Indicator sites (B2, B3,and B4) are shown graphically inFigure 26. Precipitationwill invariably become surface water,ground water, and potentially a source of drinking water viashallow wells or surface water.

Figure 26 shows a downward trend for tritium from 2010 to 2013,likely due to increased precipitation(which dilutes concentrationlevels), taking intoconsiderationthat Bruce A tritium emissions haveincreased slightly after 2013 since the return to service of Unit 1 and Unit 2 at Bruce A in 2012. Another small increase occurred following the vacuum buildingoutage in 2016. In 2019 the tritium results at theindicator andare near locations continuedto decrease in comparison to previous years.. Analysis of variance shows a significant difference ($p<0.001$ $\alpha=0.05$). The indicator site showed the highest mean concentration, followed by area near, and the lowest being area far. There is no provincial samplingat this time

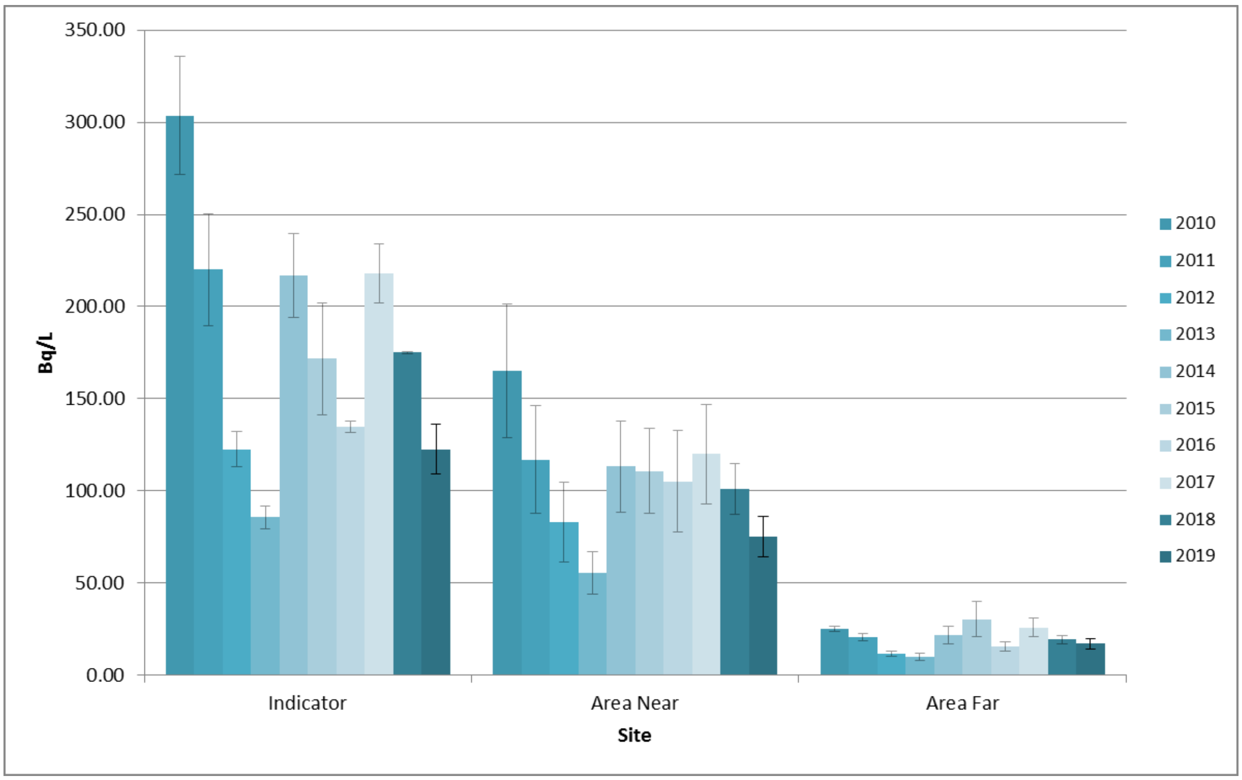


Figure 26
Annual Average Tritium Concentrations in Precipitation at the Bruce Power Site Over Time

5.4.10 Water

Bruce Power conducts drinking water testing (for radiological parameters) to quantify dose to public as required by the PROL. The sampling locations in the vicinity of Bruce Power are detailed in Appendix D.

5.4.10.1 Municipal Water Supply

Municipal drinking water sources are sampled twice per day during regular business hours from two Water Supply Plants (WSP) on Lake Huron near the Bruce Power site.

- Southampton Water Supply Plant, 22 km NE of Bruce A
- Kincardine Water Supply Plant, 15 km SSW of Bruce B

Municipal drinking water well samples are also collected and analyzed. Weekly composite samples are analyzed for tritium by liquid scintillation counting (a process that measures the activity of a sample of radioactive material) and monthly composite samples are analyzed for gross beta by proportional counting and a gross gamma screening. The 2019 annual average for tritium at the Kincardine WSP was 4.3 Bq/L and at the Southampton WSP was 11.6 Bq/L (Table 33). In 2019, the water from the WSPs were well below the annual average Ontario Drinking Water Standard of 7,000 Bq/L and also below the 100 Bq/L (annual average) objective set forth in a stakeholder commitment with the Municipalities [R-89].

The reported municipal drinking water well results are net values where background radiation has been subtracted. Negative values indicate that results are indistinguishable from background. Background subtraction in these cases results in net values that are close to 0, and sometimes negative.

5.4.10.2 Residential Wells

In addition to the WSPs in Southampton and Kincardine, water samples are collected from local residential wells. Samples are analyzed for tritium by liquid scintillation counting and for gross beta by proportional counting (where gross beta is detected). Results are shown in Table 33, and locations can be viewed in Appendix D; provincial results are shown in Table 33. The shallow wells are sampled bimonthly based on occupant availability. Deep wells are sampled semiannually. For shallow wells, the source of tritium can be attributed to tritium emission from the Bruce Power site related to precipitation washout migrating into the shallow wells. The shallow wells continue to have elevated tritium concentrations relative to provincial background levels. Although there are no regulatory standards which apply specifically to these wells, the 2019 sampling results are well below Ontario Drinking Water Standard of 7,000 Bq/L.

The reported results for residential deep wells are net values where background radiation has been subtracted. Negative values indicate that results are indistinguishable from background. Background subtraction in this case results in net values that are close to 0, and sometimes negative. Tritium concentrations in the deep wells continue to be negligible.

5.4.10.3 Lakes and Streams

Water samples are collected from Lake Huron and from streams within the vicinity of the Bruce Power site. Samples are analyzed for tritium by liquid scintillation counting and for gross beta by proportional counting. Results are shown in Table 33 and locations can be viewed in Appendix D. The Lake Huron and streams sites are sampled bimonthly when free of ice. Results for most radionuclides (i.e. ^{60}Co, ^{134}Cs and ^{137}Cs) measured are not distinguishable from background. Lake water at locations BR2 and BR39 have been renamed to BM20 and BM10, respectively, because the samples from these locations are lake water samples rather than residential samples.

The provincial background samples are collected from locations throughout the province on a quarterly basis for tritium and gross beta, presented in Table 33.

Table 33
2019 Annual Average Tritium and Gross Beta Concentrations

Water Source	Tritium Average (Bq/L)	Gross Beta (Bq/L)
Municipal Water Supply:		
K-WS (Kincardine surface water)	4.3	0.06
S-WS (Southampton surface water)	11.6	0.13
BM03-WW (Scott Point well)	-0.9	N/A
BM06-WW (Underwood well)	-0.01	N/A
BM12-WW (Tiverton well)	-0.4	N/A
BM13-WW (Tiverton well)	-0.5	N/A
Residential Deep Wells		
BR01-WW	no sample	N/A
BR08-WW	-1.1	N/A
BR25-WW	-1.2	N/A
BF01-WW	-0.5	N/A
BF14-WW	-1.0	N/A
BF23-WW (formerly known as BDF11)	-1.3	N/A
BM02-WW	-0.9	N/A
Residential Shallow Wells		
Area Near		
BR02-WW	58.6	0.01
BR03-WW	91.6	N/A

Water Source	Tritium Average (Bq/L)	Gross Beta (Bq/L)
BR04-WW	9.3	N/A
BR41-WW	28.1	N/A
BR42-WW	39.0	N/A
BF06-WW	13.9	N/A
BR32-WW	16.9	0.31
Average (Area Near)	**36.8**	**0.16**
Lakes and Streams		
On Site		
BM16-WL (ornamental pond)	196	N/A
BM21-WL (former sewage lagoon)	546	N/A
Indicator		
BC02-WC	83	0.11
BM04-WL	62	0.08
BM04-WL duplicate	64	0.08
Average (Indicator)	**70**	**0.09**
Area Near Creeks		
BC01-WC	27	0.14
BC03-WC	26	0.16
BC04-WC	69	0.06
Average Near Creeks	41	0.12
BM10-WL	16	0.07
BM20-WL	40	0.07
Average Near Lakes	**36**	**0.10**
Provincial Background		
Bancroft (Clark Lake)	0.9	0.03
Belleville (Bay of Quinte)	1.2	0.04
Cobourg (Lake Ontario)	2.6	0.08
Brockville (WSP)	3.4	0.11
Burlington (WSP)	4.1	0.11
Goderich (WSP)	3.1	0.10
Kingston (WSP)	3.1	0.10
Niagara Falls (WSP)	1.6	0.10

Water Source	Tritium Average (Bq/L)	Gross Beta (Bq/L)
North Bay	1.3	0.08
Parry Sound	2.7	0.05
St. Catharines	1.9	0.10
Thunder Bay	-0.6	0.05
Windsor	2.3	0.10
Average (Provincial Background)	**2.1**	**0.08**

Note: * For calculation of local averages where analyses were less than L_c (Bruce Power); and L_d (Provincial), uncensored analytical result was used.

- N/A is not available
- WSP Water Supply Plant
- Bancroft, Belleville, and Cobourg are not sampled during winter months (Q1 and Q4)

5.4.10.4 Historical Water Sample Results

Background levels of tritium are a combination of natural cosmogenic sources (produced by the action of cosmic rays) and residual fallout from historical nuclear weapons testing. Atomic Energy Canada Limited (AECL) developed a mathematical model for estimating background Lake Huron tritium activity from cosmogenic sources and fallout from nuclear weapons testing source [R-90]. A graphical representation of this is shown in **Figure 27**. Natural Lake Huron tritium levels in the absence of CANDU tritium emissions are estimated to be 1.6 Bq/L.

A recent project with CANDU® Owners Group reviewed the Great Lakes tritium concentration time model that was developed by Klukas, and updated with CANDU® emission data [R-90]. The model was found to have accurately reflected the recent Great Lakes tritium concentration by the incorporated CANDU® data.

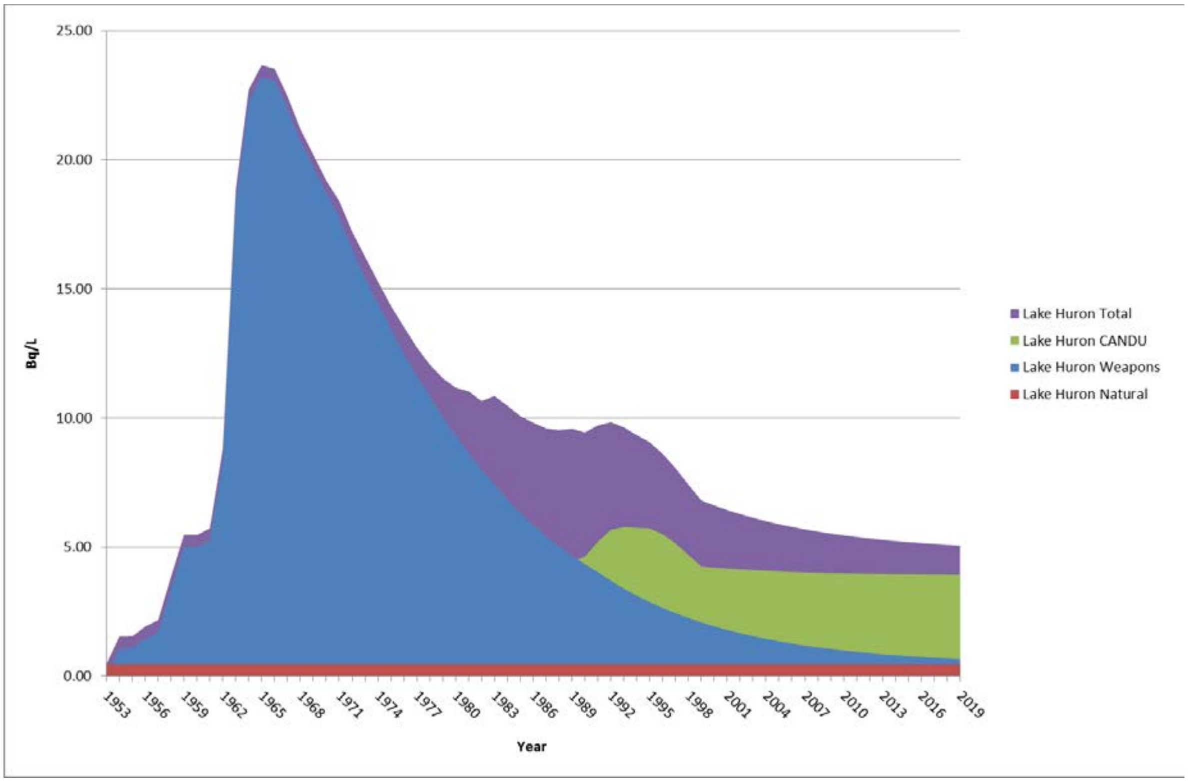


Figure 27
Historic Lake Huron Tritium Activity

The impact of site emissions on the local water supply plants varies and is dependent on the distance from the stations, lake current direction, and general dispersion conditions. In order to minimize the impact of emissions, Bruce Power has a long standing stakeholder commitment to keep the municipal water supply plants annual average tritium levels below 100 Bq/L [R-89]. As shown in Figure 28, the annual average tritium concentrations at all local water supply plants have remained relatively constant for the past years. Concentrations are well below 100 Bq/L and remain a small fraction of the provincial drinking water limit of 7,000 Bq/L. CNSC IEMP samples collected near Bruce Power in 2016 had values for lake surface water ranging from 5 Bq/L – 88.9 Bq/L, for creek surface between 21.8 Bq/L and 27.8 Bq/L samples, and 28.7 Bq/L for pond surface samples. All samples collected and analyzed by the CNSC for the IEMP were well below the guideline/reference level of 7,000 Bq/L. Tritium concentrations continue to remain well below provincial drinking water limits.

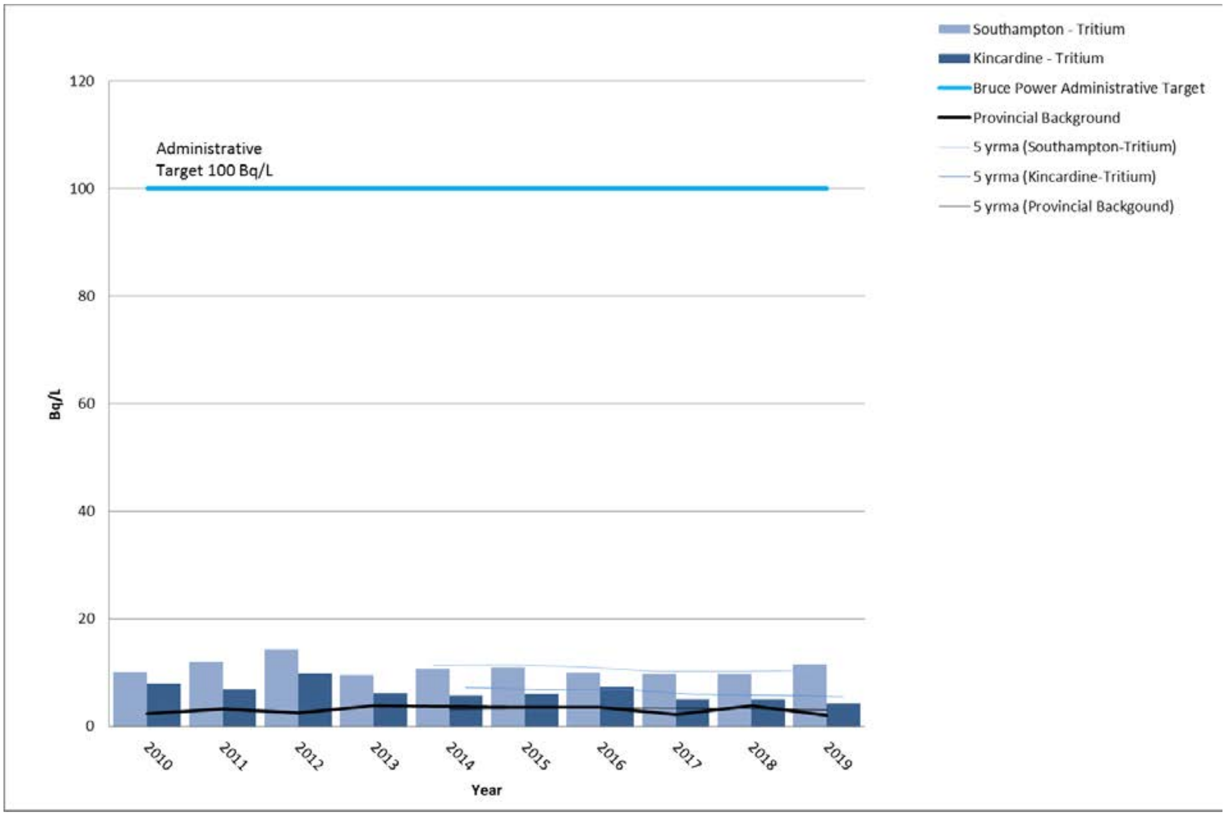


Figure 28
Annual Average Tritium Concentrations (Bq/L)
In Municipal Water Supply Plants Near The Bruce Power Site Over Time

Note: Bruce Power's commitment is 100 Bq/L at the Municipal Water Supply Plant (monthly and annual) Ontario Drinking Water Standard is 7,000 Bq/L at the Municipal Water Supply Plant (annual) [R-89].

Figure 29 shows tritium concentrations in water samples at multiple locations over time. In 2019, both the indicator and area near stream annual average tritium value decreased in comparison to the previous year, as did the indicator lake annual average. The area near lake average tritium value was marginally higher than in 2018.

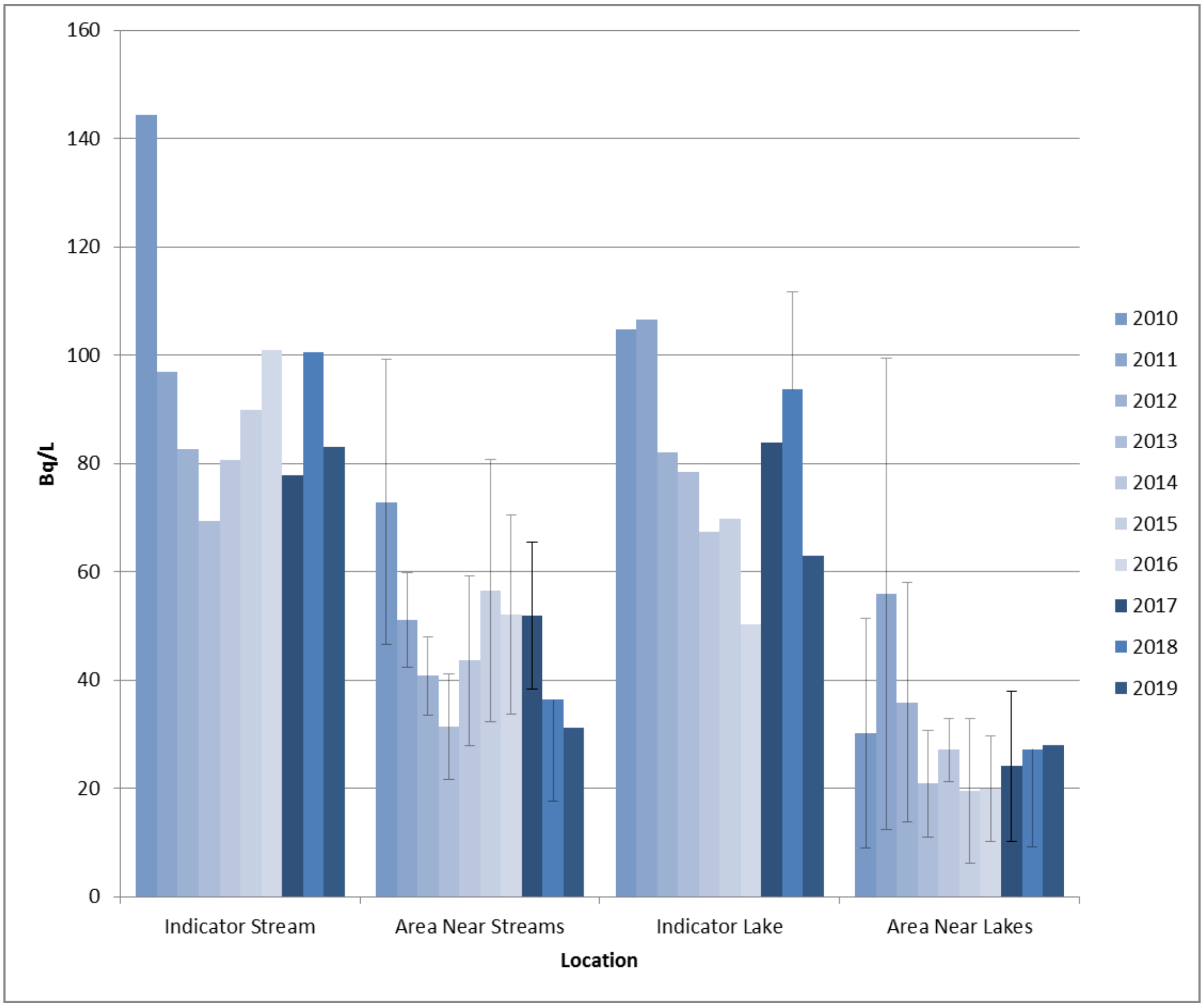


Figure 29
Annual Average Tritium Concentrations (Bq/L)
in Lake Huron and Streams Near Bruce Power Site Over Time

5.4.11 Milk

Milk samples are collected weekly from dairy farmers near the Bruce Power site. The milk samples are analyzed monthly for tritium and ^{14}C and weekly for ^{131}I. The milk receivedis analyzed by gamma spectrometry. Tritium, ^{14}C and ^{131}I concentrations inmilk are due to ingestionof feed, water and inhalationof air. Tritium resultis based on the arithmetic mean of the activity oftwo replicate samples of a monthly composite sample. ^{14}C result is based on the arithmetic meanof two counts of a monthly composite sample. ^{131}I result is based on a single sample, weekly composite of all locations, counted once.

5.4.11.1 2019 Milk Results

There are five sampling locations in the vicinity of Bruce Power detailed on Appendix D.

Milk results are shown in Table 34, alongside Provincial sampling results for 2019. The iodine result reported is the average of the weekly composite samples for the year, with background radiation subtracted from each sample. The net negative value indicates that results are indistinguishable from background. Background subtraction in this case results in net values that are close to 0, and sometimes negative.

Table 34
2019 Annual Average Concentration Tritium, ^{131}I, ^{14}C in Dairy Milk Samples

Sample Location	Tritium[i]	^{131}I[ii]	^{14}C[iii]
	(Bq/L)	(Bq/L)	(Bq/kg-C)
Area Near			
BDF01-MK	5.1	-0.01	232
BDF09-MK	15.6		236
BDF12-MK	9.1		235
BDF13-MK***	7.4		239
BDF15-MK	4.2		228
Average (Area Near)	**8.3**	**-0.01**	**234**
Provincial Background			
DF1 | Belleville- Sample A**	2.4	Not analyzed	225
DF1 | Belleville- Sample B**	2.8	Not analyzed	224
DF1 | Belleville- Sample C**	2.7	Not analyzed	224
DF2 | London**	1.5	Not analyzed	214
Average (Provincial Background)	**2.3**		**222**

Note: i. Tritium result is based on the arithmetic mean of the activity of two replicate samples of a monthly composite sample.
ii. ^{14}C result is based on the arithmetic mean of two counts of a monthly composite sample.
iii. ^{131}I result is based on a single sample, weekly composite of all locations, counted once.
*where monthly analytical values were less than L_c (Bruce Power), uncensored analytical result was used to create averages
***where monthly analytical values were less than L_d (Provincial), uncensored analytical result was used to create averages
***BDF13-MK is a new sample location, sampling began June 2019.

5.4.11.2 Historical Milk Results

Milk analysis was suspended in April 2012, but was resumed in Q2 2016 with cooperation with the Dairy farmers of Ontario Milk. CNSC IEMP tritium milk sample collected in 2016 near Bruce Power had a value of 1.7 Bq/kg fresh weight and was well below the guideline/reference level of 5,560 Bq/kg fresh weight. CNSC IEMP iodine milk sample collected in 2016 had a value of less than 0.3 Bq/kg fresh weight and was well below the guideline/reference level of 1.64 Bq/kg fresh weight.

Analysis of variance shows a significant difference ($p<0.001$ $\alpha=0.05$). The Bruce Power site showed the highest mean concentration, followed by Provincial.

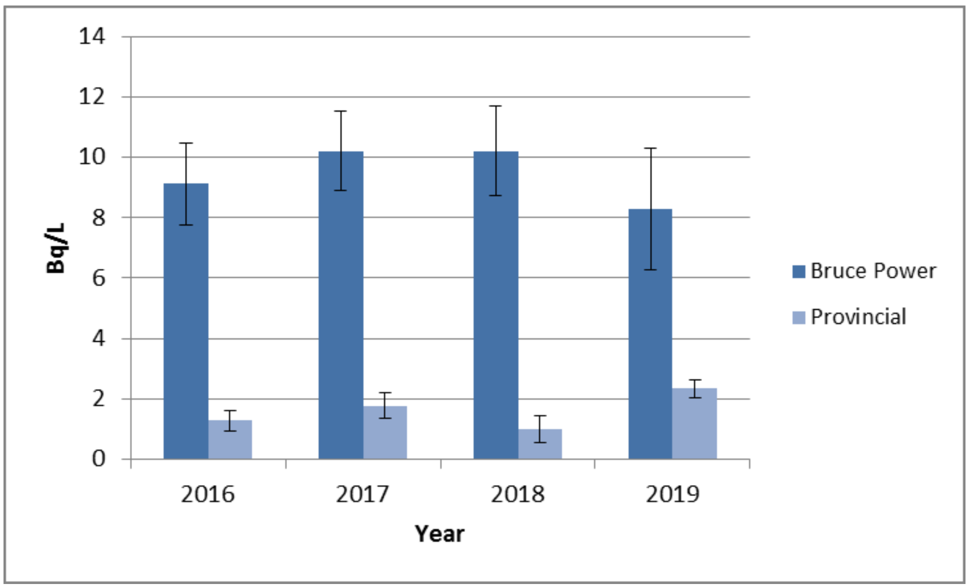


Figure 30
Annual Average Tritium Concentrations (Bq/L) in Milk Samples Collected Near the Bruce Power Site and Provincial Locations Over Time

5.4.12 Soil and Sediment

Samples of soil and sediment are collected once every five years from various locations in the vicinity of the Bruce Power site and further afield along the shore of Lake Huron. The samples are dried, sieved, packaged, and analyzed via gamma spectrometry (identification and/or quantification of radionuclides by analysis of the gamma ray energy spectrum). Onsite soil was last sampled in 2016.

The sampling locations in the vicinity of Bruce Power are shown in Appendix D. The results of the individual analyses for 2019 are detailed in Table 35, along with provincial background results. CNSC IEMP ^{137}Cs soil samples collected near Bruce Power in 2016 had values ranging from less than 1.5 Bq/kg dry weight to 3.8 Bq/kg dry weight and were well below the guideline/reference level of 58.6 Bq/kg dry weight.

Table 35
Soil and Sediment Data

Sample Location	^{40}K		^{60}Co		^{134}Cs		^{137}Cs	
	(Bq/kg) (dry weight)	± 2σ	(Bq/kg) (dry weight)	± 2σ	(Bq/kg) (dry weight)	± 2σ	(Bq/kg) (dry weight)	± 2σ
Sediment – Indicator								
Bruce A Discharge #1	417	34	-0.02	0.18	-0.23	0.14	1.46	0.18
Bruce A Discharge #2	395	32	0.16	0.18	0.12	0.12	1.10	0.16
Bruce A Discharge #3	387	32	0.07	0.18	0.03	0.12	1.23	0.16
Bruce A Discharge #4	372	30	-0.12	0.17	-0.04	0.12	1.02	0.15
Bruce B Discharge #1	184	15	0.03	0.14	0.00	0.10	0.31	0.10
Bruce B Discharge #2	188	16	0.13	0.14	-0.03	0.11	0.40	0.07
Bruce B Discharge #3	188	16	-0.05	0.13	-0.01	0.10	0.42	0.06
Bruce B Discharge #4	187	16	0.00	0.14	-0.02	0.11	0.38	0.08
Average (Sediment – Indicator)	**290**		**0.03**		**-0.02**		**0.79**	
Sediment - Area Near								
Baie du Dore Spar #5 - #1	303	25	0.01	0.16	-0.09	0.12	1.54	0.17
Baie du Dore Spar #5 - #2	297	24	-0.03	0.16	0.02	0.11	1.61	0.18
Baie du Dore Spar #5 - #3	309	25	0.08	0.14	0.01	0.11	1.49	0.16
Baie du Dore Spar #5 - #4	309	25	0.13	0.16	0.08	0.12	1.67	0.18
Baie du Dore Spar #6 - #1	282	23	0.08	0.16	-0.02	0.11	1.73	0.19
Baie du Dore Spar #6 - #2	276	23	0.08	0.16	0.07	0.12	1.66	0.16
Baie du Dore Spar #6 - #3	293	24	0.07	0.14	0.00	0.10	1.92	0.20
Baie du Dore Spar #6 - #4	301	25	-0.06	0.17	-0.04	0.13	2.26	0.30
Baie du Dore Spar #103 - #1	340	28	-0.07	0.16	0.13	0.11	1.93	0.20
Baie du Dore Spar #103 - #2	355	29	0.08	0.18	-0.71	0.17	1.93	0.21
Baie du Dore Spar #103 - #3	337	28	0.14	0.18	-0.19	0.14	1.70	0.20

Sample Location	^{40}K		^{60}Co		^{134}Cs		^{137}Cs	
	(Bq/kg) (dry weight)	± 2σ	(Bq/kg) (dry weight)	± 2σ	(Bq/kg) (dry weight)	± 2σ	(Bq/kg) (dry weight)	± 2σ
Baie du Dore Spar #103 - #4	338	28	-0.06	0.16	-0.07	0.11	2.00	0.18
Scott Point #1	272	23	0.08	0.25	-0.29	0.22	1.05	0.22
Scott Point #2	267	22	0.04	0.14	-0.16	0.11	1.23	0.12
Scott Point #3	273	23	0.03	0.16	-0.03	0.12	1.11	0.14
Scott Point #4	268	22	0.00	0.16	0.10	0.11	1.12	0.27
Inverhuron- R32	245	20	0.12	0.13	-0.15	0.11	0.66	0.08
Inverhuron- R32	247	20	0.00	0.15	-0.07	0.11	0.70	0.09
Inverhuron- R32	243	20	-0.07	0.16	-0.03	0.11	0.69	0.10
Inverhuron- R32	241	20	0.07	0.13	-0.30	0.12	0.72	0.19
Average (Sediment - Area Near)	**290**		**0.03**		**-0.09**		**1.44**	
Sediment - Area Far								
Sauble Beach #1	352	29	0.03	0.18	-0.07	0.14	0.74	0.13
Sauble Beach #2	345	28	0.05	0.15	0.06	0.11	0.91	0.10
Sauble Beach #3	311	26	-0.01	0.16	-0.08	0.11	0.76	0.13
Sauble Beach #4	333	27	0.00	0.17	0.05	0.11	0.74	0.13
Southampton # 2	259	22	0.02	0.32	-1.45	0.39	0.19	0.40
Average (Sediment - Area Far)	**335**		**0.02**		**-0.01**		**0.79**	
Sediment - Provincial Background								
Grand Bend - A	344	4.6	Not analyzed		Not analyzed		Not analyzed	
Grand Bend - B	342	4.5						
Grand Bend - C	339	5.4						
Grand Bend - D	403	5.1						
Average (Sediment - Provincial Background)	**357**							
Soil - Area Near								

Sample Location	^{40}K		^{60}Co		^{134}Cs		^{137}Cs	
	(Bq/kg) (dry weight)	± 2σ	(Bq/kg) (dry weight)	± 2σ	(Bq/kg) (dry weight)	± 2σ	(Bq/kg) (dry weight)	± 2σ
BM04-SO (Baie du Doré Beach - Lakeshore soil)	388	32	-0.01	0.20	-0.04	0.14	2.20	0.23
BM10-SO (Inverhuron Beach - Lakeshore soil)	257	21	-0.08	0.16	0.00	0.11	0.51	0.12
BM10-SO (Inverhuron Beach - Lakeshore soil #2)	269	22	-0.02	0.17	-0.11	0.09	0.69	0.09
BR04-SO (Scott Point) (beach sand)	291	24	-0.08	0.15	-0.04	0.04	1.97	0.18
Average (Soil – Near)	**301**		**-0.05**		**-0.05**		**1.34**	
Soil - Area Far								
Amberley Background #1 0-6″ core	476	39	0.26	0.26	0.00	0.09	4.74	0.46
Amberley Background #1 6-12″core	494	41	-0.06	0.27	0.10	0.19	1.47	0.46
Average (Soil – Far)	**485**		**0.10**		**0.05**		**3.11**	
Beach Sand - Provincial Background								
Cobourg - A	331	4.5	Not analyzed		Not analyzed		Not analyzed	
Cobourg - B	326	4.3	Not analyzed		Not analyzed		Not analyzed	
Cobourg - C	313	5.1	Not analyzed		Not analyzed		Not analyzed	
Cobourg - D	323	4.4	Not analyzed		Not analyzed		Not analyzed	
Cobourg - E	349	4.5	Not analyzed		Not analyzed		Not analyzed	
Cobourg - F	312	5	Not analyzed		Not analyzed		0.369	0.14
Cobourg - G	320	4.3	Not analyzed		Not analyzed		0.315	0.12
Cobourg - H	339	4.4	Not analyzed		Not analyzed		0.326	0.11
Goderich - A	350	4.6	Not analyzed		Not analyzed		Not analyzed	
Goderich - B	319	5.1	Not analyzed		Not analyzed		Not analyzed	
Average (Beach Sand – Provincial Background)	**328**						**0.337**	

5.4.12.1 Historical Sediment Results

Sediment is analyzed viagamma spectrometry and results for specific radionuclides including potassium-40, cobal-60, cesium-134 and cesium-137 are provided here.

The current practice for standard error and average will be reevaluated when techniques are standardized. Standard error bars were calculated on the total sample size, and include samples less than the limit of detection, which are shown as "< Ld". Average was calculated on quantitativedata less than the limitof detection (> Ld).

Potassium-40

Analysis of the samples indicates thatthe primary radionuclidepresent in the sediment samples is ^{40}K (see Figure 31), which is naturally occurring. ^{40}K concentrations have remained stable on all sites over time. Results from the Bruce Power site are similar to provincial background. ^{40}K concentrations showeda significantdifference in sedimentby site (p=0.002, α= 0.05). The area near sitewas significantly differentfrom area far while the indicator locationwas similar toboth the area near and the area far.

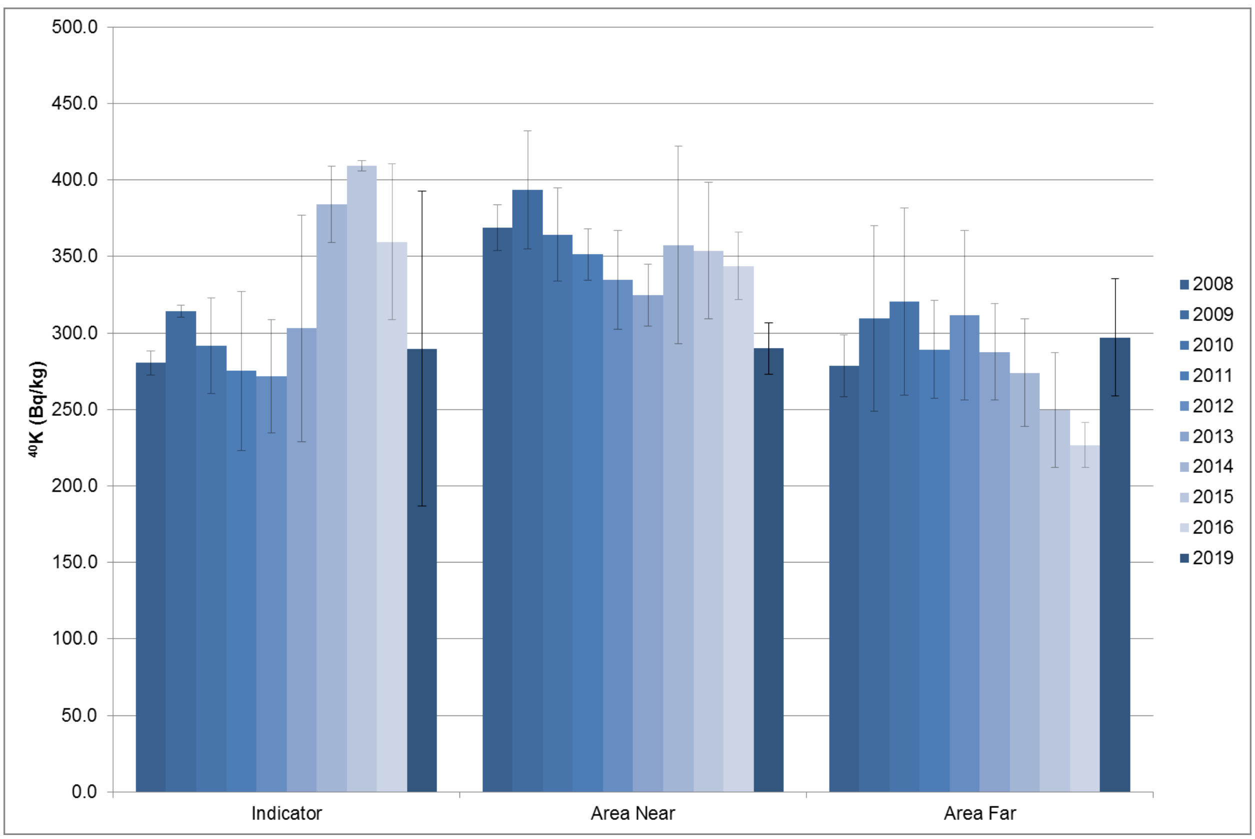


Figure 31
Annual Average Concentration of ^{40}K (Bq/Kg) in Sediment Samples (± Standard Error), 2008-2019

Cesium

Cesium 134 (^{134}Cs) was near the detection limits in all sediment samples at the Bruce Power site in 2019. Cesium 137 (^{137}Cs) (see Figure 32) is a fission product resulting from atmospheric nuclear weapons testing and from activities at the Bruce Power site. The elevated levels of cesium observed in Bruce A, Baie du Doré, and Scott Point (2007-2008), may be attributed to boiler tube leak at Bruce B and the predominant northern flow of Lake Huron's near shore current. The annual average ^{137}Cs concentrations have shown an increasing trend at locations near the Bruce Power site in recent years but have dropped since 2016. It is possible that the increase seen at the indicator and area near sites for 2016 could be attributed to water draining activities during the vacuum building outage at Bruce B.

^{137}Cs concentrations showed a significant difference in sediment by site ($p=0.001$, $\alpha= 0.05$). The indicator site was similar to the area near site and both were significantly different from area far site. CNSC IEMP ^{137}Cs sediment samples collected in 2016 near Bruce Power had values ranging from less than 0.5 Bq/kg dry weight and 6.6 Bq/kg dry weight and were well below the guideline/reference level of 37,300 Bq/kg dry weight.

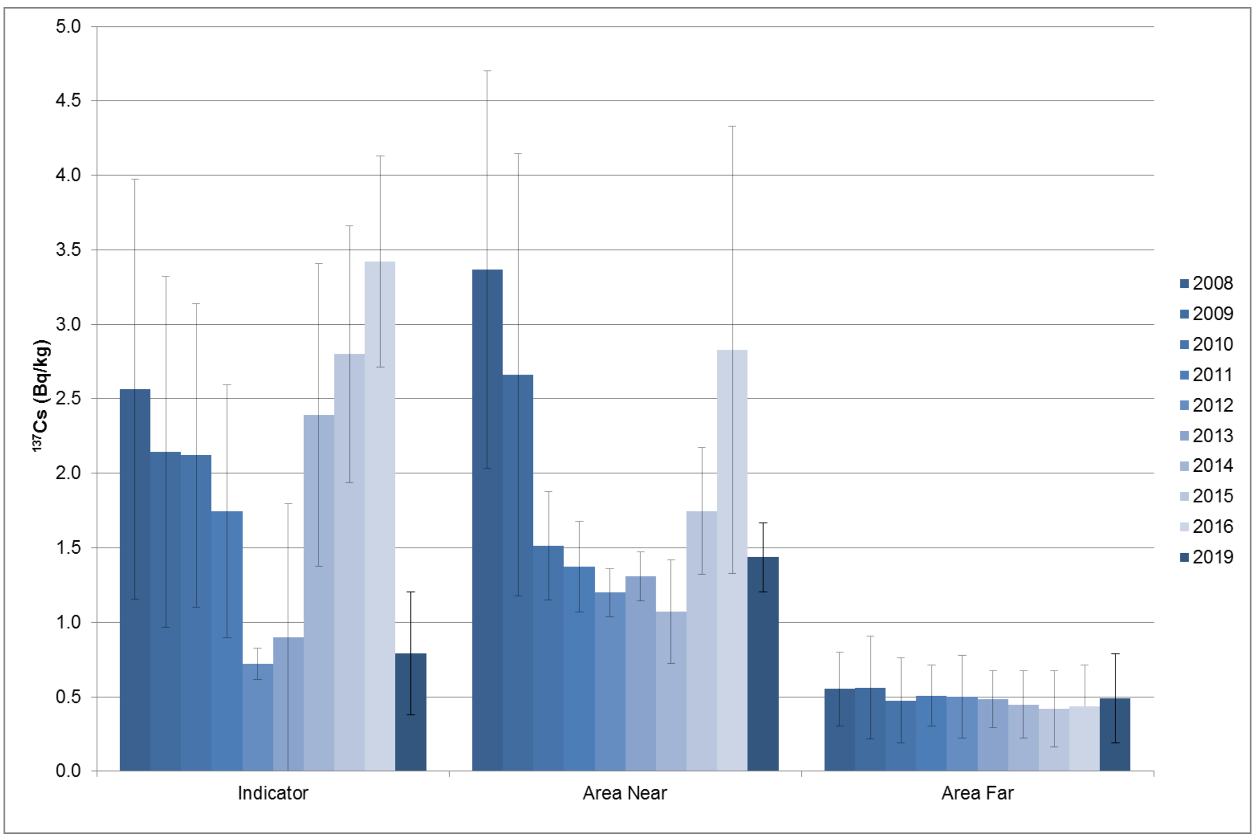


Figure 32
Annual Average Concentration of ^{137}Cs (Bq/Kg) in Sediment Samples (± Standard Error), 2009-2019

Cobalt

Cobalt 60 (^{60}Co) (see Figure 33) is not naturally occurring and results from the Bruce Power site and therefore attributed to effluent emissions. The annual average concentration of ^{60}Co has shown a steady decrease since 2008 at both the indicator and area near locations. The elevated levels of cobalt in 2008 may be attributed to a boiler tube leak at Bruce B and the predominant northern flow of Lake Huron's near shore current. Values in 2016 and 2019 were near or below the limit of detection at all sites. Area far has been consistently below or near the limit of detection.

^{60}Co concentrations showed a significant difference in sediment by site ($p<0.0001$, $\alpha = 0.05$). The area near site was similar to the area far site and was significantly different from indicator site. CNSC IEMP ^{60}Co sediment samples collected in 2016 near Bruce Power had values ranging from less than 1 Bq/kg dry weight and were well below the guideline/reference level of 5,870 Bq/kg dry weight.

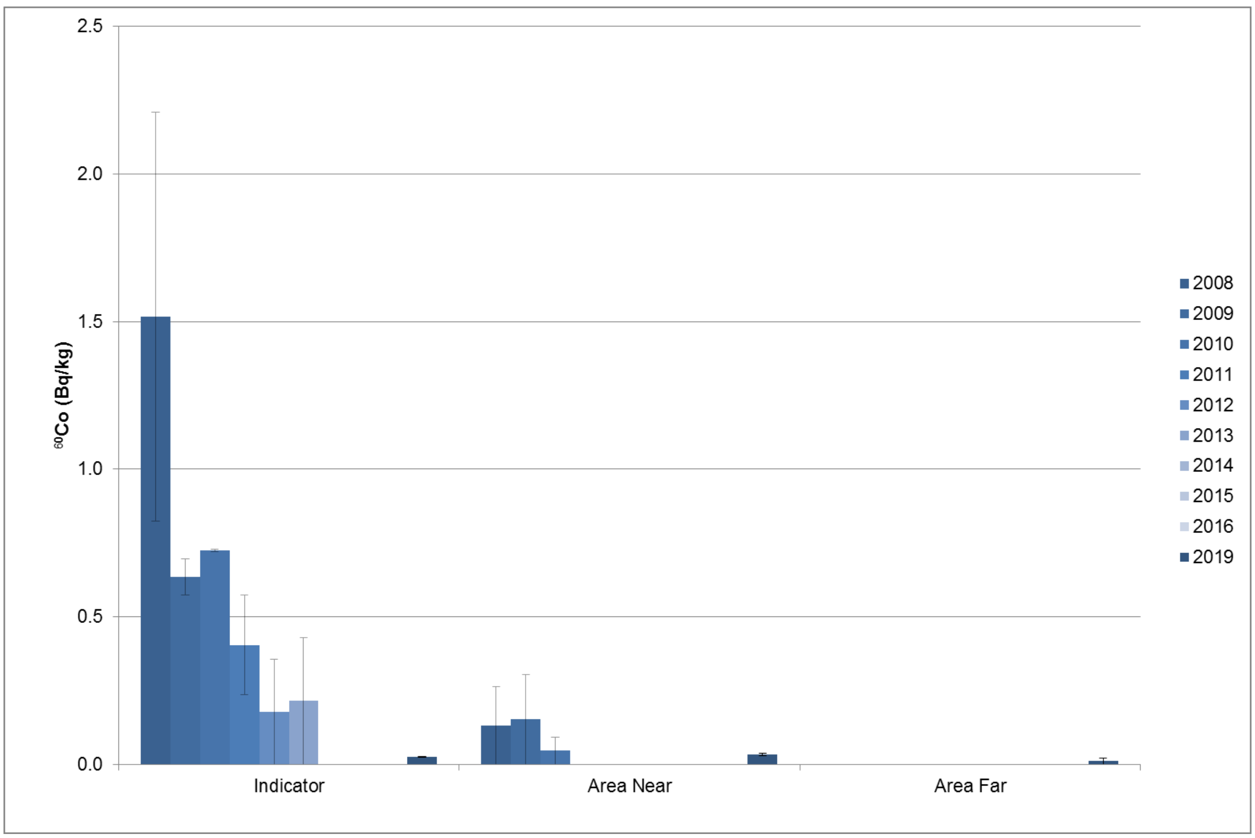


Figure 33
Annual Average Concentration of ^{60}Co (Bq/Kg) in Sediment Samples (± Standard Error), 2008-2019

5.4.13 Fish

Bruce Power monitors the health of local fish populations by collecting samples of benthic forager (bottom feeders) and pelagic forager (open water) fish species that are collected near the Bruce Power site, at a Bruce Power control site, and further afield at locations along the western shore of Lake Huron (see Figure 34). The analysis of a variety of species provides a comprehensive perspective of potential impacts for site operations on the lakebed (where benthic species inhabit) through open water ecosystems where pelagic fish inhabit.

In 2017, Bruce Power was informed that there are new policies in place not allowing Bruce Power to import fish samples into Canada unless the receiving lab has been certified as Level 2 In Vitro Facilities. Neither the Bruce Power's nor the Whitby Health Physics Lab has this certification and obtaining this certification would require a significant cost, and level of effort, and further would not have facilitated samples to be obtained in 2017. A new Canadian location for far field samples was selected in 2017.

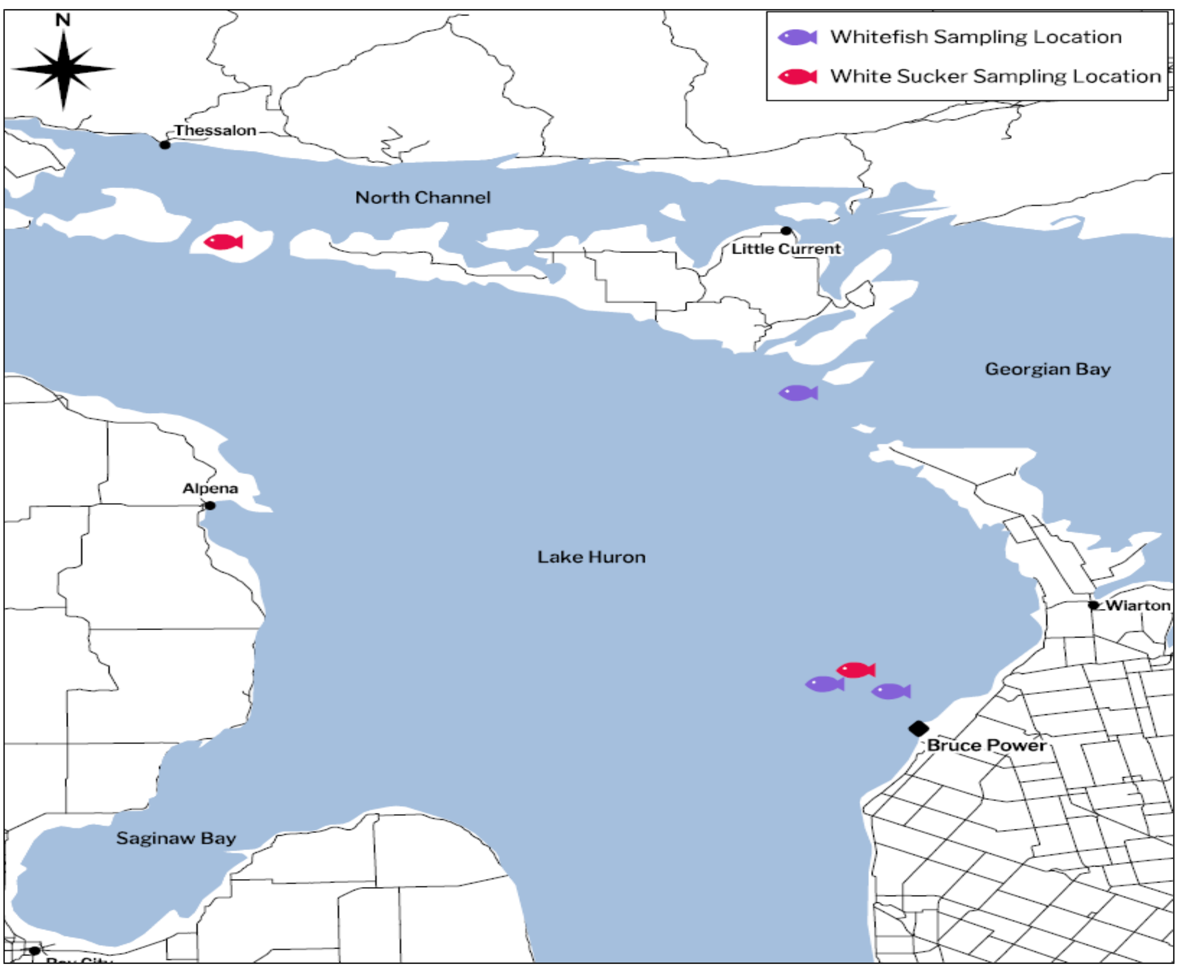


Figure 34
2018 Fish Sampling Locations

The target fish species representing both benthic and pelagic foragers are as follows:

- White Sucker (*Catostomus commersoni*) represents a benthic forager species. Brown Bullhead (*Ictalurus nebulosus*) is the alternate benthic species. Sample collection is conducted in the spring when adults are near shore to spawn.
- Lake Whitefish (*Coregonus clupeaformis*) represents a predominantly pelagic forager that feeds on a wide variety of organisms from invertebrates, to small fish, to plankton. Round Whitefish (*Prosopium cylindraceum*) is the alternate pelagic species. Collection is conducted in the fall when adults are near shore to spawn. The secondary alternative is Lake Trout (*Salvelinus namaycush*).

The fish flesh ventral to the lateral line is included in the samples prepared for analysis. Samples are analyzed for ^{40}K, ^{60}Co, ^{134}Cs, ^{137}Cs, ^{14}C, tritium oxide, and organically bound tritium (OBT), following the preparation and methods in Table 36.

Table 36
Fish Preparation and Methods

Analyte	Sample	Preparation	Method
^{40}K	Individual fish	Skinned, filleted, and flesh sliced	Gamma spectrometry
^{60}Co	Individual fish	Skinned, filleted, and flesh sliced	Gamma spectrometry
^{134}Cs	Individual fish	Skinned, filleted, and flesh sliced	Gamma spectrometry
^{137}Cs	Individual fish	Skinned, filleted, and flesh sliced	Gamma spectrometry
^{14}C	Two counts of a single sample per individual fish	Freeze-dried flesh combusted	Liquid scintillation counting
Tritium oxide	Average of two samples per individual fish	Water from freeze dried flesh	Liquid scintillation counting
Organically Bound Tritium (OBT)	Single composite by fish type	Solid residue (washed to remove free tritium oxide) combusted	Liquid scintillation counting

5.4.13.1 2019 Fish Results

The results of the fish analysis are detailed in Table 37 and Table 38 for Bruce Power data and Table 39 for provincial data. Tritium oxide, ^{14}C, ^{40}K and ^{137}Cs values are generally above the limit of detection, whereas ^{60}Co and ^{134}Cs are generally indistinguishable from background. The reported results are net values where background radiation has been subtracted. Negative values indicate that results are indistinguishable from background. Background subtraction in this case results in net values that are close to 0, and sometimes negative.

Table 37
2019 Annual Near - Field Fish Data

Sample Type/ Location	Fish Type	Tritium		^{14}C		OBT		^{40}K		^{60}Co	^{134}Cs	^{137}Cs	
		Bq/L	± 2σ	Bq/kg	± 2σ	Bq/L	± 2σ	Bq/kg	± 2σ	Bq/kg	Bq/kg	Bq/kg	± 2σ
Near-Field													
Baie du Doré Benthic	Sucker #1	5.8	2.6	260	28	3.2	3.3	109	9.3	0.0	-0.1	0.3	0.1
	Sucker #2	5.4	2.6	273	29			104	9.0	0.1	-0.2	0.3	0.1
	Sucker #3	7.1	2.7	222	28			109	9.4	0.0	-0.2	0.3	0.1
	Sucker #4	5.2	2.6	216	27			93	8.1	0.0	0.0	0.1	0.1
	Sucker #5	5.9	2.6	238	29			110	9.5	0.0	0.0	0.2	0.1
	Sucker #6	6.2	2.6	234	28			112	9.6	0.2	0.0	0.2	0.1
	Sucker #7	8.6	2.8	225	27			107	9.3	0.0	-0.2	0.2	0.1
	Sucker #8	7.1	2.7	228	28			118	10.2	0.1	-0.2	0.2	0.1
Average (Near-Field Benthic)		**6.6**		**228**		**3.2**		**108**		**0.1**	**-0.1**	**0.2**	
Baie du Doré Pelagic	Whitefish #1	3.7	2.5	263	31	2.9	3.1	120	10.2	0.0	-0.1	0.7	0.1
	Whitefish #2	4.1	2.5	266	32			116	9.9	0.0	-0.2	0.4	0.1
	Whitefish #3	4.4	2.8	232	28			108	9.2	0.1	-0.1	0.3	0.1
	Whitefish #4	3.4	2.7	267	30			117	9.9	0.0	-0.1	0.5	0.1
	Whitefish #5	4.5	2.8	264	32			119	10.1	0.0	-0.2	0.8	0.1
	Whitefish #6	3.8	2.7	236	29			112	9.5	0.1	0.1	0.7	0.1
	Whitefish #7	3.5	2.4	257	29			117	10.0	0.1	-0.1	0.5	0.1
	Whitefish #8	4.8	2.8	242	27			115	9.8	0.0	0.0	0.9	0.1
Average (Near-Field Pelagic)		**4.0**		**253**		**2.9**		**116**		**0.0**	**-0.1**	**0.6**	

Note: *For calculation of local averages where analyses were less than critical level (Bruce Power), uncensored analytical result was used.

Table 38
2019 Annual Far - Field Fish Data

Bruce Power Far-Field														
Sample Type/ Location	Fish type	Tritium		^{14}C		OBT		^{40}K		^{60}Co	^{134}Cs	^{137}Cs	
		Bq/L	± σ	Bq/kg	± 2σ	Bq/L	± 2σ	Bq/kg	± 2σ	Bq/kg	Bq/kg	Bq/kg	± 2σ
Lake Huron Benthic	White Sucker #1	7.8	2.9	208	27	2.3	3.1	115	9.9	-0.1	-0.1	0.0	0.2
	White Sucker #2	5.6	2.8	222	27			116	9.8	0.0	0.0	0.1	0.1
	White Sucker #3	3.3	2.4	197	27			124	10.6	-0.1	0.1	0.2	0.2
	White Sucker #4	6.8	2.8	212	27			121	10.2	0.0	-0.1	0.1	0.1
	White Sucker #5	6.6	2.8	238	28			117	10.0	0.0	0.0	0.0	0.2
	White Sucker #6	3.4	2.4	217	28			120	10.1	0.1	0.0	0.1	0.1
	White Sucker #7	7.7	2.9	219	27			119	10.2	0.1	0.0	0.1	0.1
	White Sucker #8	4.7	2.7	231	28			109	9.4	0.1	-0.1	0.2	0.2
Average (Far-Field Benthic)		**5.8**		**223**		**2.3**		**117**		**0.0**	**0.0**	**0.1**	
Lake Huron Pelagic	Whitefish #1	3.4	2.5	243	28	5.6	3.7	110	9.4	0.0	-0.1	0.3	0.1
	Whitefish #2	3.9	2.5	228	27			111	9.4	0.0	-0.1	0.5	0.1
	Whitefish #3	2.5	2.5	241	29			105	8.9	0.0	0.0	0.8	0.1
	Whitefish #4	4.5	2.9	231	28			114	9.6	0.1	0.0	0.3	0.1
	Whitefish #5	2.3	2.5	244	27			109	9.2	0.1	0.0	0.6	0.1
	Whitefish #6	2.5	2.5	261	29			111	9.4	0.1	0.0	0.3	0.1
	Whitefish #7	3.8	2.5	237	27			113	9.6	0.1	-0.1	1.0	0.1
	Whitefish #8	5.1	2.9	245	29			109	9.2	0.0	0.0	0.5	0.1
Average (Far-Field Pelagic)		**3.5**		**241**		**5.6**		**110**		**0.0**	**0.0**	**0.5**	
Note: For calculation of local averages where analyses were less than critical level (Bruce Power), uncensored analytical result was used													

Table 39
2019 Annual Provincial Fish Data

Provincial Background														
Sample Type/ Location	**Fish type**	**Tritium**		**^{14}C**		**OBT**		**^{40}K**		**^{60}Co**	**^{134}Cs**	**^{137}Cs**	
		Bq/L	**± 2σ**	**Bq(^{14}C)/ kgC**	**± 2σ**	**Bq/L**	**± 2σ**	**Bq/kg**	**± 2σ**	**Bq/kg**	**Bq/kg**	**Bq/kg**	**± 2σ**
Lake Huron Benthic	White Sucker A	8.6	2.6	261	20	49.2	3.5	144	3.1	N/A	N/A	N/A	
	White Sucker B	9	2.7	247	19			142	3.5				
	White Sucker C	9.7	2.7	253	19			137	2.9				
	White Sucker D	11.2	2.8	241	19			129	2.8				
	White Sucker E	10.7	2.7	250	19			135	3				
	White Sucker F	9.8	2.7	240	19			136	3.4				
	White Sucker G	10.3	2.7	237	18			133	3.3				
	White Sucker H	9.7	2.7	241	19			137	3				
Average (Provincial Background Benthic)		**9.9**		**246**		**49.2**		**136**					
Lake Huron Pelagic	Round White A	6.4	2.5	237	18	45.7	3.4	134	2.9	N/A	N/A	0.8	0.11
	Round White B	5.8	2.4	236	17			142	3.5			0.7	0.12
	Round White C	6.7	2.5	242	18			145	3.1			0.3	0.093
	Round White D	4.4	2.3	236	18			140	3			0.7	0.075
	Round White E	5.1	2.4	254	18			139	3.5			0.7	0.13
	Round White F	5.2	2.4	240	18			150	3.1			0.5	0.072
	Round White G	5.8	2.4	258	19			147	3			0.5	0.099
	Round White H	6.4	2.5	247	18			138	3			0.5	0.087
Average (Provincial Background Pelagic)		**5.7**		**244**		**45.7**		**142**				**0.6**	
Note: For calculation of local averages where analyses were less than detection level (Provincial),uncensored analytical result was used N/A not analyzed													

5.4.13.2 Historical Fish Sample Results

For the following figures, Bruce Power is the same as Near-Field; Bruce Power Control is the same as Bruce Power Far-Field.

Historical fish sampling results are provided in:

- Figure 35 for Tritium Oxide in Pelagic Fish
- Figure 36 for Tritium Oxide in Benthic Fish
- Figure 37 for C-14 in Pelagic Fish
- Figure 38 for C-14 in Benthic Fish
- Figure 39 for Cs-137 in Pelagic Fish
- Figure 40 for Cs-137 in Benthic Fish
- Figure 41 for K-40 in Pelagic Fish
- Figure 42 for K-40 in Benthic Fish
- Figure 43 for OBT in Pelagic Fish
- Figure 44 for OBT in Benthic Fish

<u>Tritium Oxide in Fish</u>

The 2019 annual average concentration of tritium oxide in pelagic fish was 4.0 Bq/L and in benthic fish was 6.6 Bq/L. The average Tritium oxide in pelagic fish tissue decreased in 2019, and remains less than provincial results (average 5.7 Bq/L). The average tritium oxide in benthic fish tissue also decreased in 2019 and was less than provincial results (average 9.9 Bq/L). The differences between benthic and pelagic may be attributed to the timing of catch, habitat, and correlation to operational activities. Levels remain consistent in the recent past in pelagic fish and have decreased since 2017 for benthic fish (see Figure 35 and Figure 36).

Kruskal Wallis analysis of variance showed a significant difference in both pelagic and benthic fish by site ($p<0.001$, $\alpha = 0.05$). The pelagic near field and far-field were not significantly different from each other; however both had higher concentrations compared to the provincial control. The benthic near-field had a significantly higher concentration than the far-field and provincial; these latter two were not significantly different from each other. CNSC IEMP tritium fish samples collected in 2016 near Bruce Power had values of 1.7 Bq/kg fresh weight and was well below the guideline/reference level of 5,560 Bq/kg fresh weight.

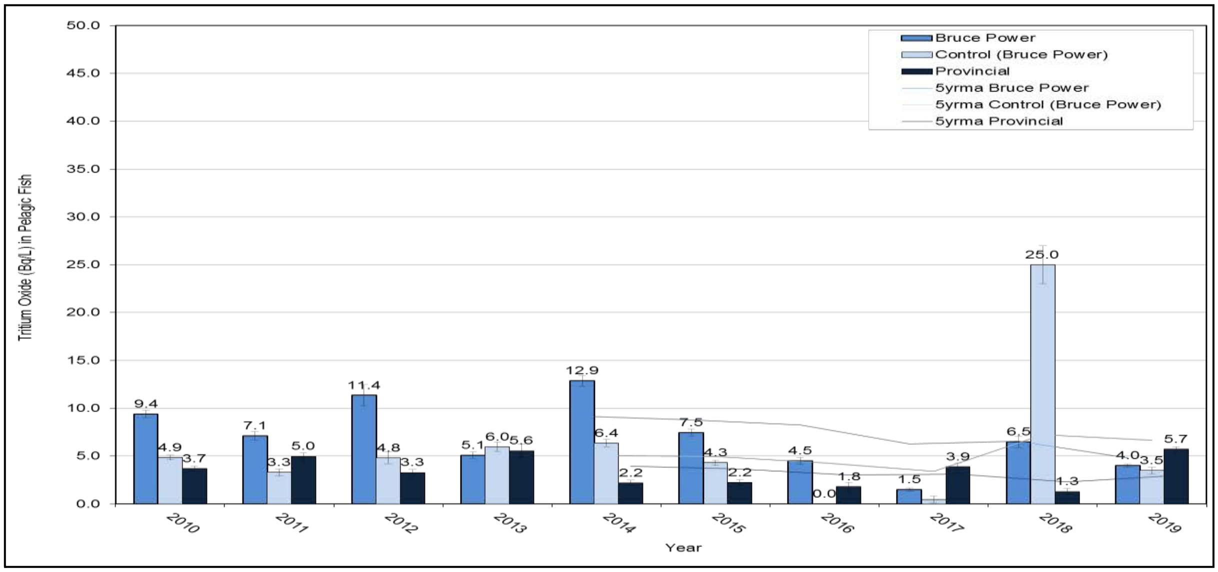


Figure 35
Annual Average Tritium Oxide (Bq/L) in Pelagic Fish Tissue by Year (± Standard Error)

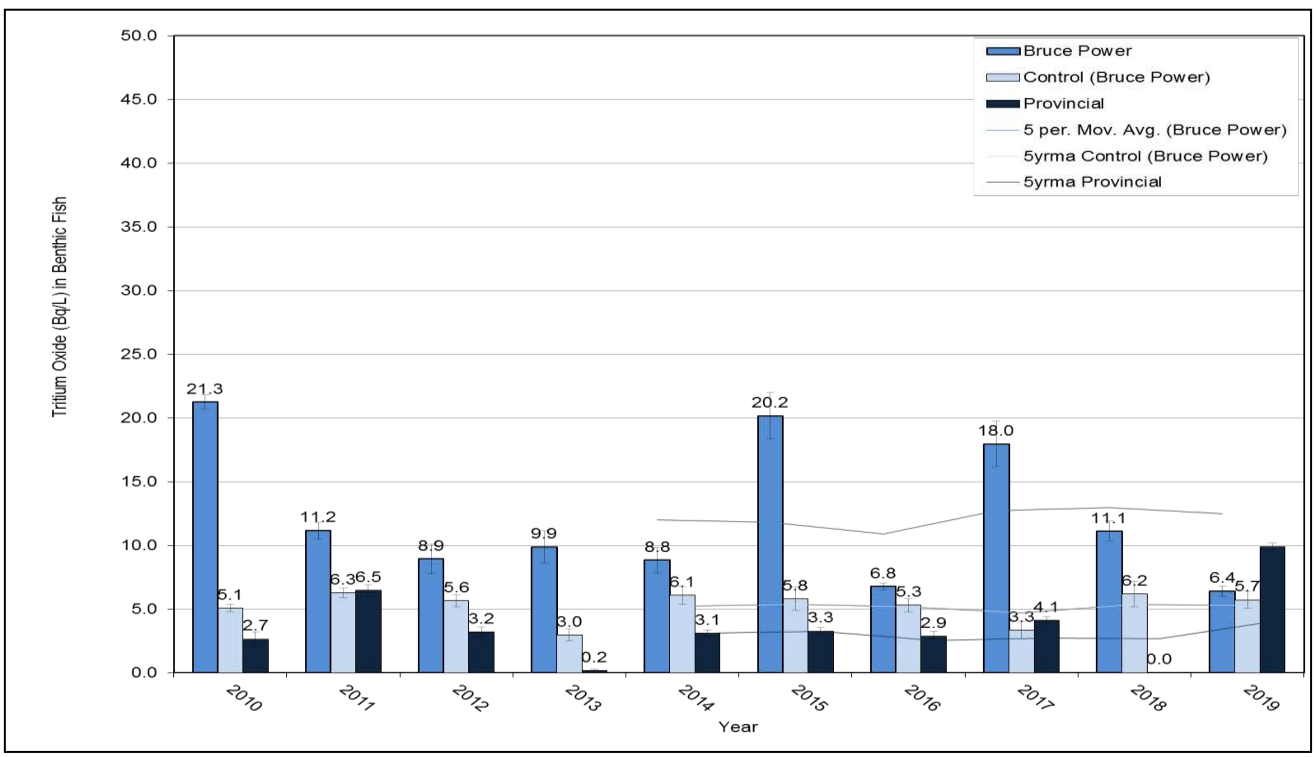


Figure 36
Annual Average Tritium Oxide (Bq/L) in Benthic Fish Tissue by Year (± Standard Error)

^{14}C in Fish

The 2019 annual average concentration of ^{14}C in pelagic fish was 253 Bq/kg and 237 Bq/kg in benthic fish. ^{14}C levels have remained steady over time in both pelagic and benthic fish tissue and are similar to the provincial values (2019 average was 246 Bq/kg for both pelagic and benthic fish).

Kruskal Wallis analysis of variance showed a significant difference for benthic fish by site ($p<0.001$, $\alpha = 0.05$), medians for near-field were higher than the far field and provincial sites medians (which were not significantly different from each other). Pelagic fish were not significantly different by site.

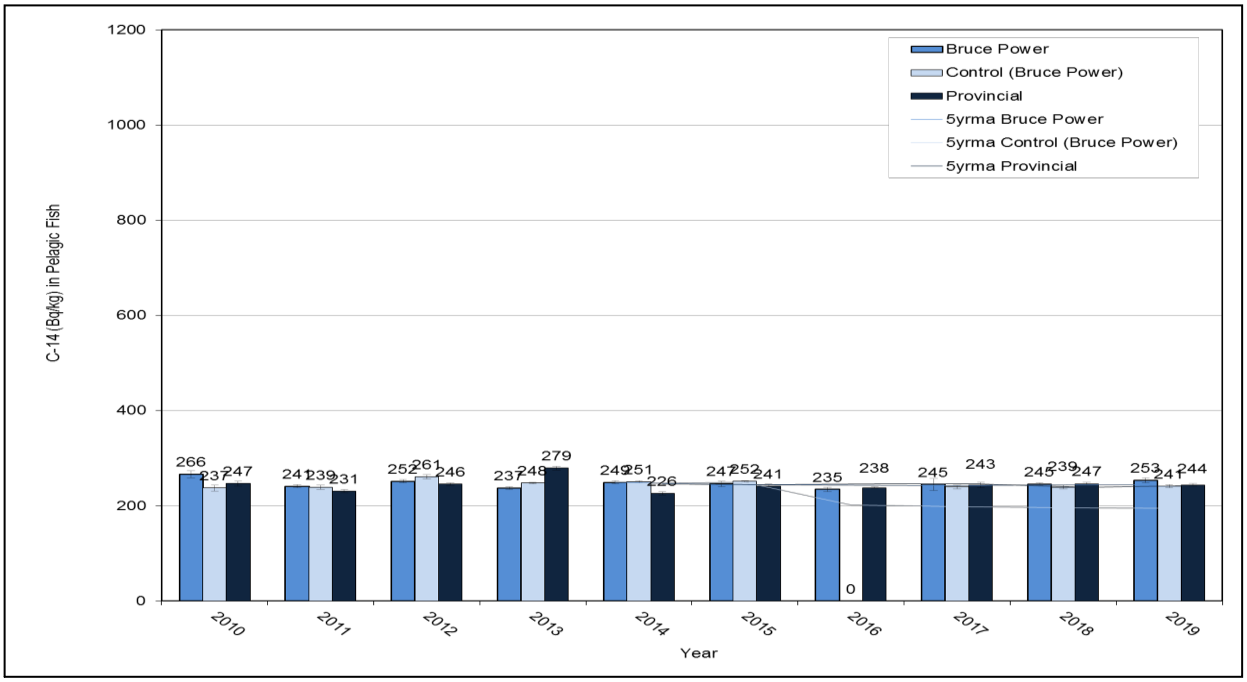


Figure 37
Annual Average ^{14}C in Pelagic Fish Tissue (± Standard Error)

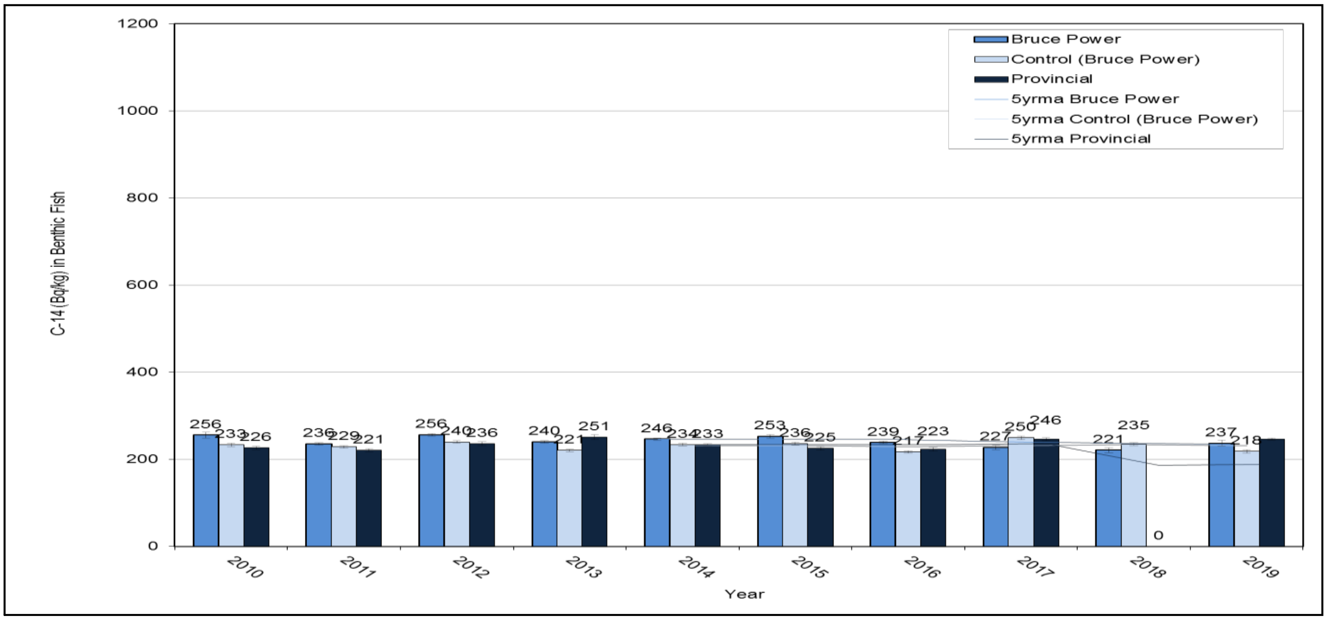


Figure 38
Annual Average ^{14}C in Benthic Fish Tissue (± Standard Error)

<u>^{137}Cs in Fish</u>

The 2019 annual average concentration of ^{137}Cs in pelagic fishwas 0.60 Bq/kg and 0.21 Bq/kg in benthic fish(Figure 39 and Figure 40). The average concentration for near-field pelagic fishis lower than the average Provincial value of0.57 Bq/kg (Kruskal-Wallace, $p=0.03$, $\alpha=0.05$). No Provincial results were available for benthic fish for the last two years. ^{137}Cs concentrations showed a significantdifference for both benthic and pelagic fishby site ($p<0.001$ $\alpha=0.05$).

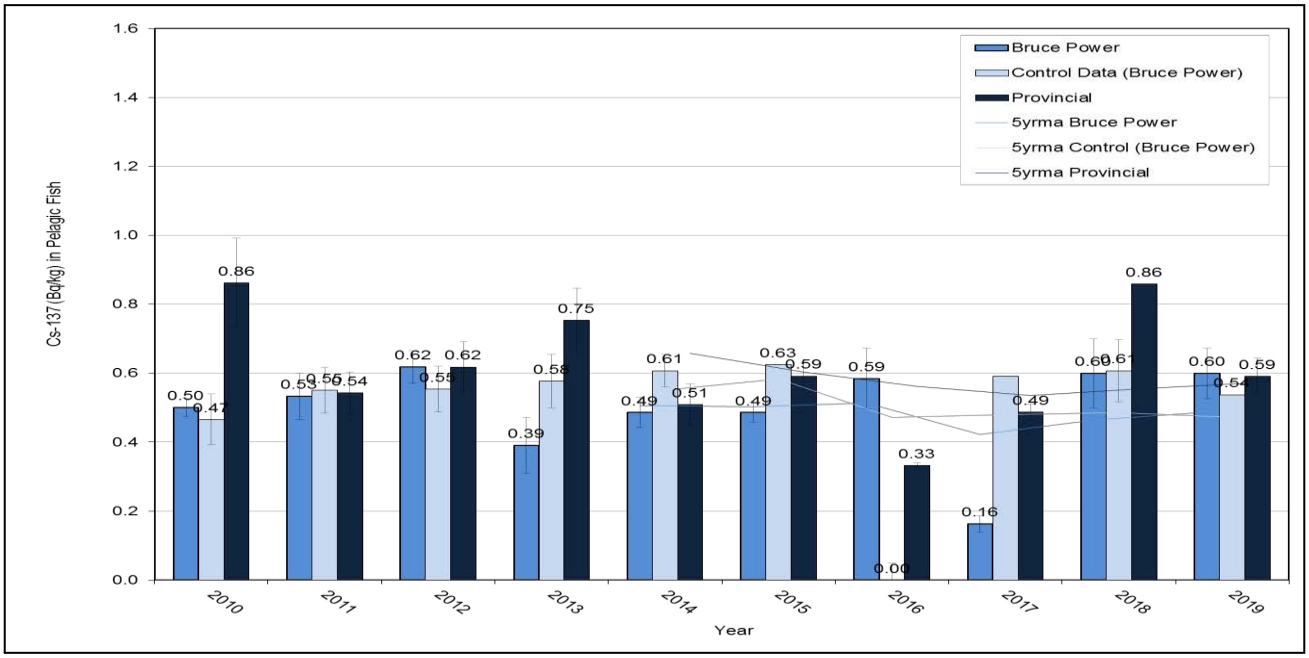


Figure 39
Annual Average ^{137}Cs in Pelagic Fish Tissue (± Standard Error)

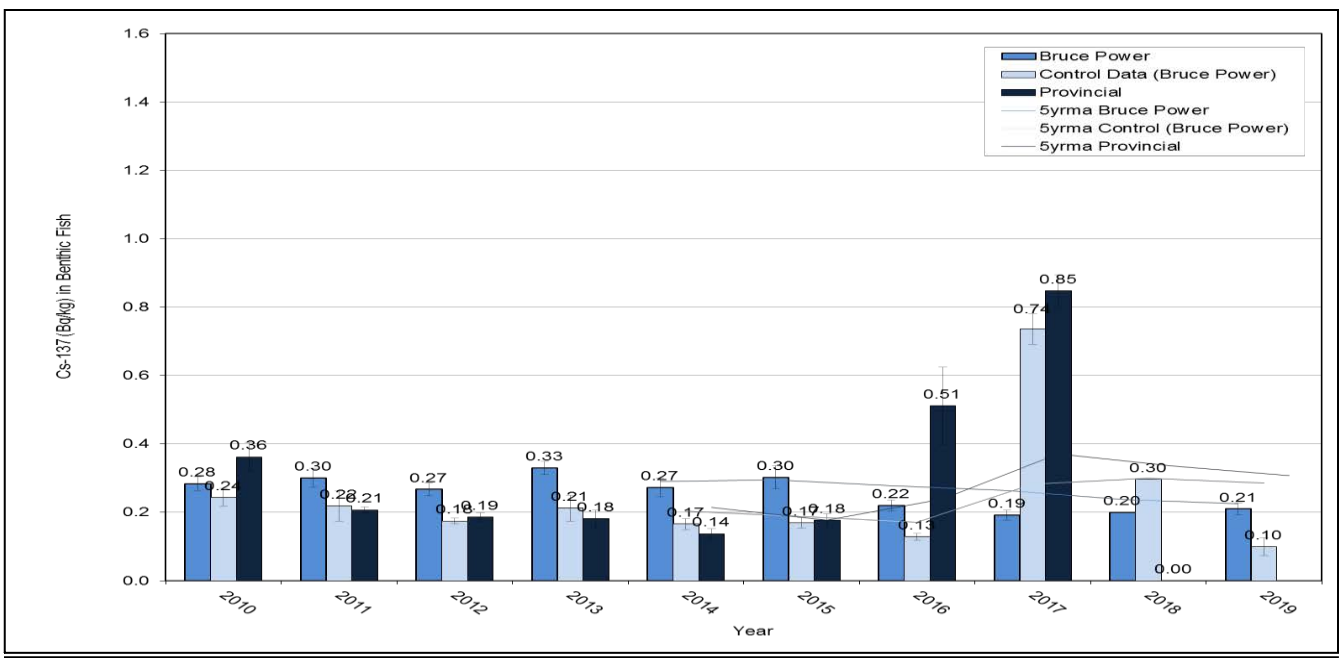


Figure 40
Annual Average ^{137}Cs in Benthic Fish Tissue (± Standard Error)

^{40}K in Fish

The 2019 annual average concentration of ^{40}K in pelagic fish was 116 Bq/kg and 108 Bq/kg in benthic fish. Average concentrations remain consistent over the last 10 years and are typically less than provincial values for both pelagic and benthic fish. ^{40}K concentrations showed significant differences in both pelagic and benthic fish by site ($p<0.001$, $\alpha= 0.05$). For both pelagic and benthic fish, Provincial values had a higher mean than near-field and far-field which were not significantly different from each other (Figure 41 and Figure 42).

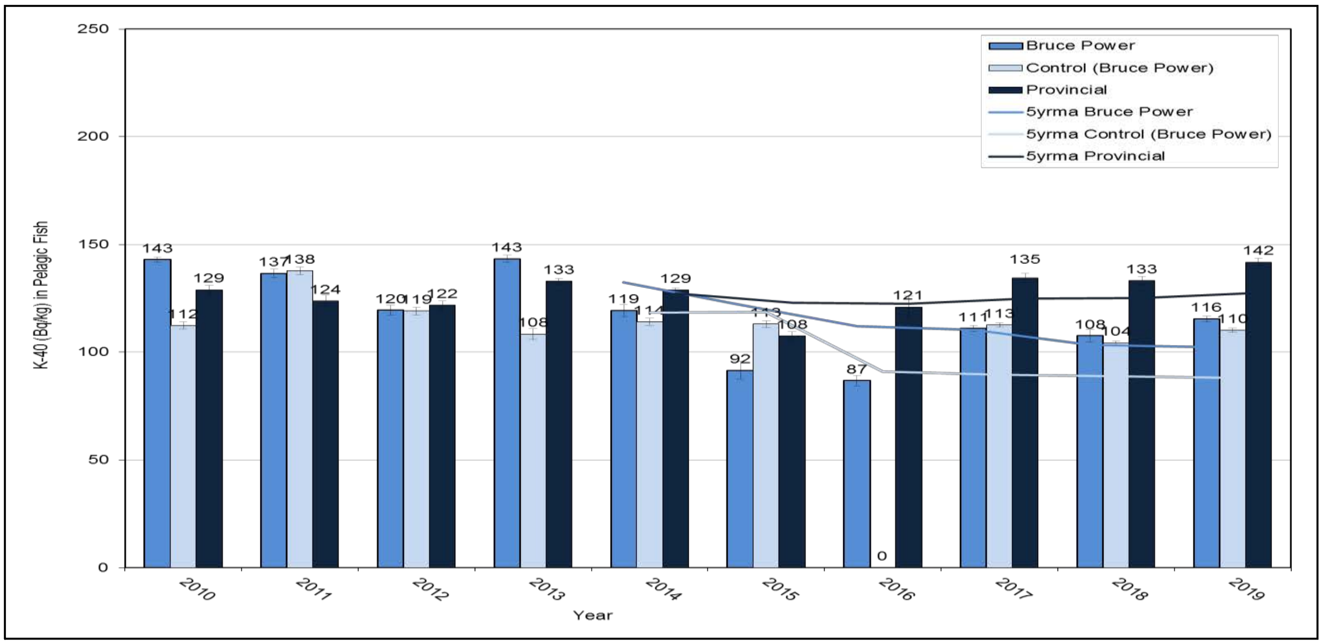


Figure 41
Annual Average ^{40}K in Pelagic Fish Tissue ($\pm$ Standard Error)

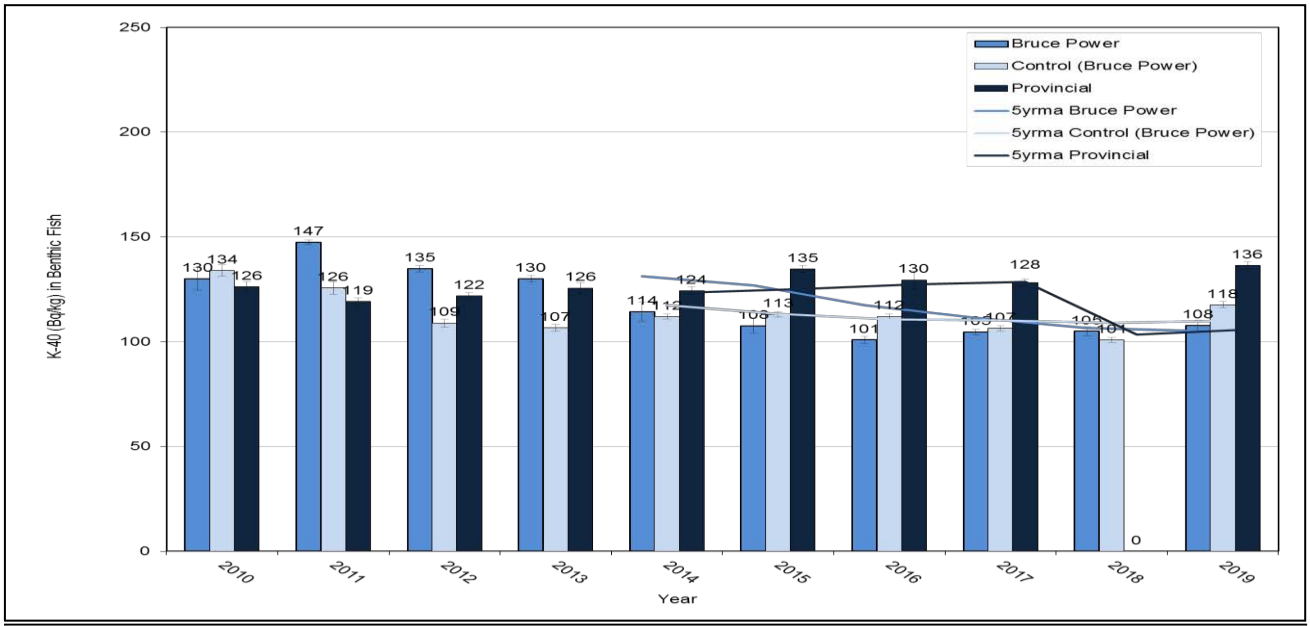


Figure 42
Annual Average ^{40}K in Benthic Fish Tissue (± Standard Error)

<u>OBT in Fish</u>

OBT results for the past 10 years are presented in Figure 48 and Figure 49 for pelagic and benthic fish, respectively. The 2019 Bruce Power and Bruce Power control results are in line with previous years and less than 10 Bq/L.

The methodology used to measure OBT in fish is not standardized. Bruce Power uses a different methodology than the Province and therefore the results cannot be directly compared. In the past several years the Provincial OBT results for Lake Huron pelagic and benthic fish have consistently been an order of magnitude higher than those at Bruce Power.

The 2017 OBT results for Bruce Power and Bruce Power control benthic and pelagic fish results were not available due to several factors including sample delivery, equipment reliability and QC failure.

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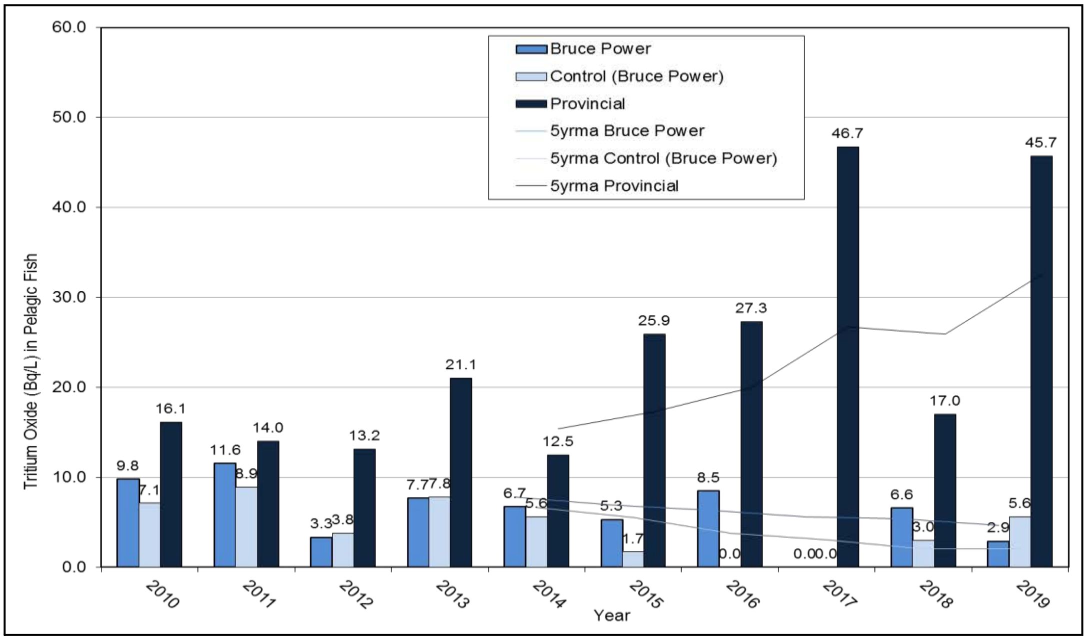

Figure 43
OBT in Pelagic Fish Tissue

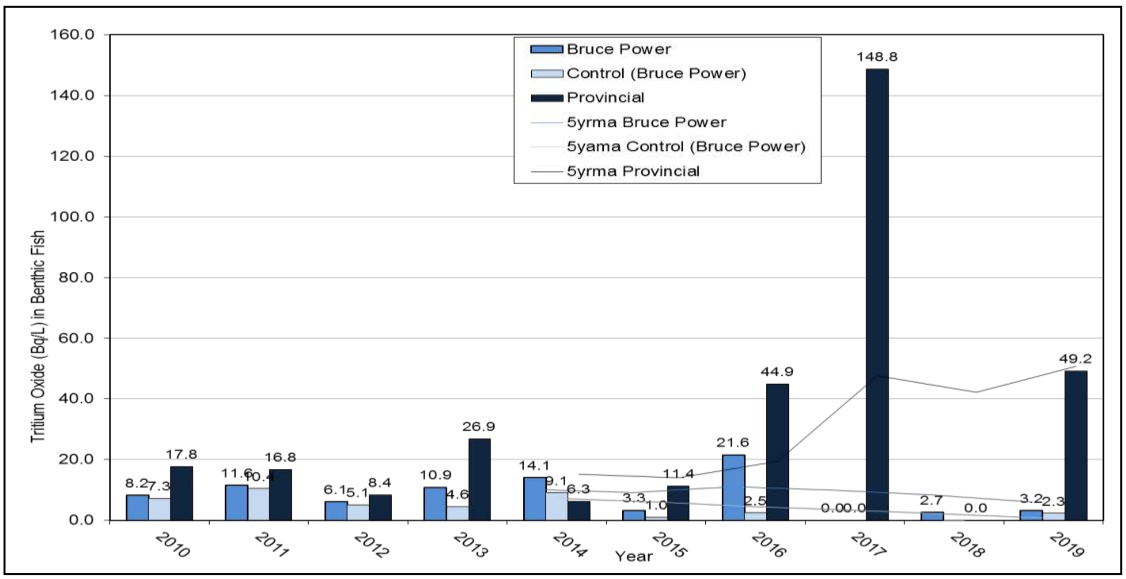

Figure 44
OBT in Benthic Fish Tissue

5.4.14 Agricultural Products

Bruce Power routinely samples a variety of terrestrial sources that are analyzed for tritium and ^{14}C by liquid scintillation counting. Some samples undergo gamma measurement of ^{40}K, ^{134}Cs, ^{137}Cs, and ^{60}Co. Only results for ^{40}K are shown where applicable, as ^{134}Cs, ^{137}Cs and ^{60}Co results were indistinguishable from background. In general, gamma spectrometry results represent a single count of a single sample, tritium results are an average of two subsamples, and ^{14}C results are an average of two counts of a single sample.

5.4.14.1 2019 Agricultural Products Results

Local farm BF14 has in the past supplied Bruce Power with samples of various animals raised on the farm and samples of animal feed for analysis. No livestock samples have been available since 2013. A number of farms supplied fruit and vegetables in 2019. Bruce Power collects eggs at BF24 in the spring and fall and honey at BR22 harvested near and far field. Bruce Power also collects and analyzes samples resulting from wild animal fatalities due to vehicular collisions on site. Provincial results are available for tritium and ^{14}C in eggs. Provincial values remain within the range of natural background. The results of these analyses are detailed in Table 40.

Table 40
2019 Annual Radionuclide Concentration in Animal & Agricultural Products Sampled Near the Bruce Power Site (±Standard Error)

Sample Location	Sample Type	Tritium		^{14}C		^{40}K	
		Bq/L	± 2σ	Bq^{14}C/kgC	± 2σ	Bq/L	± 2σ
Indicator							
On Site	Deer Meat #1	201	8	211	28	105	9
On Site	Coyote #1	220	9	298	29	N/A	
Area Near							
BF24	Eggs (spring)	16	3.3	247	27	N/A	
BF24	Eggs (fall)	29	4.1	236	27	N/A	
BR22-HO	Honey	62	5.1	254	29	9	2
Area Far							
BR22-HO	Honey	5.0	2.9	251	29	27	4
Provincial Background							
Picton (Sample A)	Poultry	0.7	2.3	203	18	N/A	
Picton (Sample B)	Poultry	4.5	2.5	215	18	N/A	
Picton (Sample C)	Poultry	2.1	2.3	238	19	N/A	
Picton (Sample D)	Poultry	1	2.3	225	19	N/A	
Picton	Poultry	2.9	2.4	232	19	N/A	

Sample Location	Sample Type	Tritium		^{14}C		^{40}K	
		Bq/L	± 2σ	$Bq^{14}C/kgC$	± 2σ	Bq/L	± 2σ
(Sample E)							
Picton (Sample F)	Poultry	1.5	2.3	227	19	N/A	
Picton (Sample G)	Poultry	1.7	2.3	233	19	N/A	
Picton (Sample H)	Poultry	0	2.2	209	18	N/A	
Average (Provincial Background Poultry)		**1.8**		**223**			
Picton A	Eggs	2.7		220		Not analyzed	
Picton B	Eggs	3.3		223		Not analyzed	
Picton C	Eggs	2.9		215		Not analyzed	
Average (Provincial Background Eggs)		**3.0**		**219**		Not analyzed	

Note: N/A = Not analyzed.
Provincial samples: Poultry is sampled annually. Eggs are sampled quarterly.
*Where analyses were less than detection level (Provincial), uncensored analytical result was used

Local farms supply Bruce Power with samples of various grains producedon lands in the vicinity ofthe Bruce Power site for analysis (locations depictedin Appendix E). The commercial alcohol plantat the Bruce Energy Centre (BEC) also provides Bruce Power with samples of corn mash for analysis (analyzed for tritium only, not ^{14}C) as detailed in Table 41. As animal products availablefor sampling differ betweenBruce Power and provincial data, comparisons cannot be made.

Table 41
2019 Annual Grains, Forage Data and Animal Feed

Sample Location	Sample Type	Tritium		^{14}C	
		(Bq/kg)	± 2σ	$(Bq^{14}C/kg\text{-}C)$	± 2σ
Area Near					
NEAR-NE-GR	Beans	3.5	2.7	217	26
NEAR-ENE-GR	No Sample	N/A		N/A	
NEAR-E-GR	Beans	10.6	3.3	224	26
NEAR-ESE-GR	Corn	33.6	4.2	233	27
NEAR-SE-GR	Beans	22.6	3.8	227	26
NEAR-SSE-GR	Beans	35.8	4.3	218	26
NEAR-S-GR	*No sample available				

Sample Location	Sample Type	Tritium		^{14}C	
		(Bq/kg)	± 2σ	(Bq ^{14}C/kg-C)	± 2σ
Bruce Energy Centre Q1	Corn Mash	22.9	3.6	N/A	
Bruce Energy Centre Q2	Corn Mash	12.8	3.4	N/A	
Bruce Energy Centre Q3	Corn Mash	16.0	3.3	N/A	
Bruce Energy Centre Q4	Corn Mash	32.0	4.0	N/A	
Average (Area Near)		**21.2**		226	
Provincial Background					
DF1 - A	Animal Feed-S1	6.0	2.5	240	21
DF1 - B	Animal Feed-S1	4.4	2.4	241	21
DF1 - C	Animal Feed-S1	4.5	2.4	229	21
DF1 - D	Animal Feed-S1	6.4	2.5	229	20
DF1 - A	Animal Feed-S2	1.7	2.5	224	19
DF1 - B	Animal Feed-S2	2.1	2.5	225	19
DF1 - C	Animal Feed-S2	3.7	2.6	228	19
DF1 - D	Animal Feed-S2	4.0	2.6	223	19
Average (Provincial Background)		**4.1**		**230**	

Note:N/A = Not analyzed.

*Where analyses were less than detection (Provincial), uncensored analytical result was used

5.4.14.2 2019 Fruits and Vegetable Produce Results

Samples of fruit and vegetables are collected in the vicinity of the Bruce Power site and at provincial background locations. These samples are analyzed for tritium and ^{14}C (see Table 42). Where multiple sample types are found at the same location, the samples were combined into composite samples for analysis. Provincial fruit and vegetable samples are composited and therefore direct comparison to the Bruce Power site data (apples and above ground, below ground, and leafy vegetables) cannot be made at this time.

Table 42
2019 Produce Data

Sample Location	Sample Type	Tritium (Free Water)		^{14}C	
		Bq/L	± 2σ	(Bq ^{14}C/kg-C)	± 2σ
Area Near (Fruit)					
BF 14-FR	Apple	82.9	5.6	245	27

Sample Location	Sample Type	Tritium (Free Water)		^{14}C	
		Bq/L	± 2σ	($Bq^{14}C/kg-C$)	± 2σ
BF 24-FR	Apple	30.8	3.9	238	27
NEAR-ENE-FR	Apple	73.6	5.3	249	27
NEAR-E-FR	Apple	92.2	5.8	254	28
NEAR-ESE-FR	Apple	51.0	4.7	257	27
NEAR-SE-FR	Apple	72.1	5.3	251	27
NEAR-SSE-FR	Apple	102	6.1	252	27
NEAR-S-FR	Apple	70.6	5.3	240	27
Average (Area Near Fruit)		**71.9**		**248**	
Area Far (Fruit)					
B06-FR (Background)	Apple	8.3	3.0	235	27
Near Area (Vegetable)					
NEAR-ENE-VE	Leafy	45.2	4.6	258	27
NEAR-ESE-VE	Leafy	20.8	3.7	244	29
NEAR-SE-VE	Leafy	32.9	4.2	242	27
NEAR-SSE-VE	Leafy	58.8	5.0	256	27
NEAR-S-VE	Leafy	15.0	3.5	229	27
Average (Area Near Leafy Vegetable)		**34.5**		**246**	
NEAR-ENE-VE	Above Ground	41.8	4.5	255	28
NEAR-E-VE	Above Ground	27.0	3.9	248	28
NEAR-SSE-VE	Above Ground	49.4	4.7	246	27
NEAR-S-VE	Above Ground	25.6	3.9	262	29
Average (Area Near Above Ground Vegetable)		**36.0**		**253**	
NEAR-ENE-VE	Below Ground	24.7	3.8	253	27
NEAR-SSE-VE	Below Ground	35.3	4.3	237	27
NEAR-S-VE	Below Ground	5.9	3.0	257	28
Average (Area Near Below Ground Vegetable		**22.0**		**249**	

Sample Location	Sample Type	Tritium (Free Water)		^{14}C	
		Bq/L	± 2σ	($Bq^{14}C/kg\text{-}C$)	± 2σ
Average Vegetable (Area Near Leafy, Above Ground, Below Ground Vegetable)		**31.9**		**249**	
Provincial Fruit					
Bancroft A	Fruit Composite	1.1	2.2	220	17
Bancroft B		3.5	2.3	236	18
Lakefield A	Fruit Composite	2.2	2.2	211	17
Lakefield B		3	2.3	223	18
Picton A	Fruit Composite	3.3	2.3	220	17
Picton B		1.7	2.2	222	17
Sarnia A	Fruit Composite	1.3	2.2	217	17
Sarnia B		1.6	2.2	218	17
Average (Provincial Background - Fruit)		**2.2**		**221**	
Provincial Vegetable					
Bancroft A	Vegetable Composite	1	2.3	208	18
Bancroft B		0.2	2.2	210	18
Lakefield A	Vegetable Composite	0.7	2.3	201	18
Lakefield B		0	2.2	216	19
Picton A	Vegetable Composite	2.2	2.3	219	19
Picton B		0.6	2.3	236	19
Sarnia A	Vegetable Composite	1.9	2.3	214	19
Sarnia B		0.8	2.3	232	19
Average (Provincial Background - Vegetable)		**0.9**		**217**	

Note: *Where analyses were less than critical level (Bruce Power), detection level (Provincial) uncensored analytical result was used.

5.4.14.3 Historical Agricultural Produce, Fruits and Vegetables Results

The annual average trend of tritium in fruits and vegetables can be seen graphically in Figure 45 and Figure 46 , respectively. The 2019 average tritium value in fruit was similar to the previous year, but was lower in vegetables compared to 2018. Fruit and vegetables near Bruce Power are consistently higher than that of provincial levels. The annual average trend of ^{14}C is shown graphically in Figure 47 and Figure 48. ^{14}C values in fruit and vegetables remain consistent with historic trends and similar to provincial values. CNSC IEMP tritium in fruits and vegetable samples collected near Bruce Power in 2016 had values ranging from less than 1.5 Bq/kg fresh weight to 7.1 Bq/kg fresh weight and were well below the guideline/reference level of 104,000 Bq/kg fresh weight to 123,000 Bq/kg fresh weight.

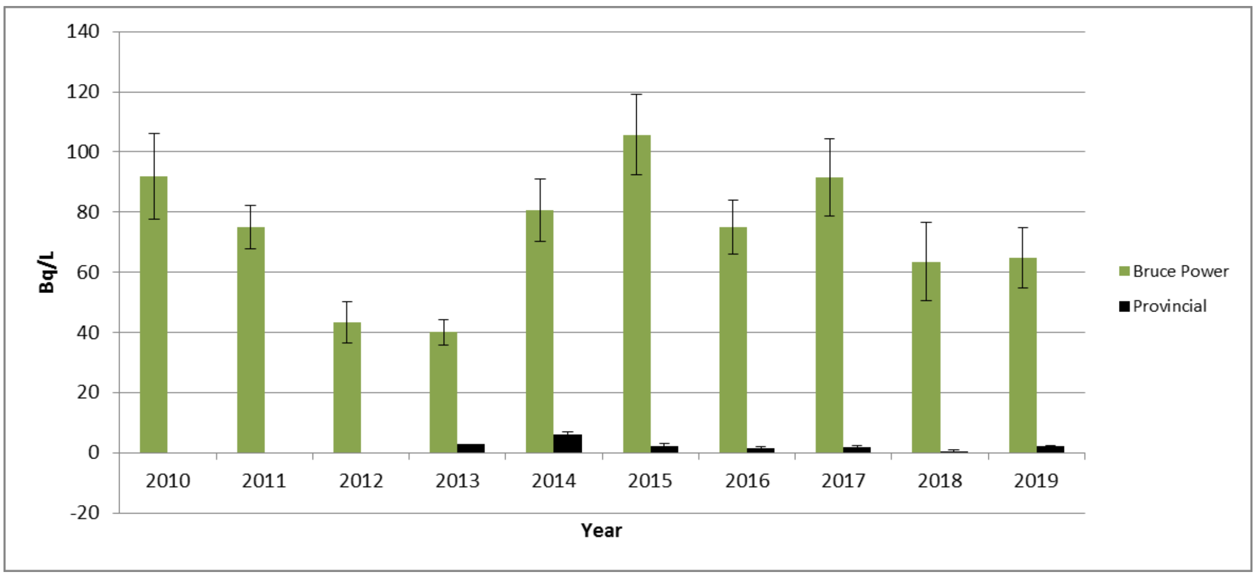

Figure 45
Annual Average Tritium in Fruit Trend

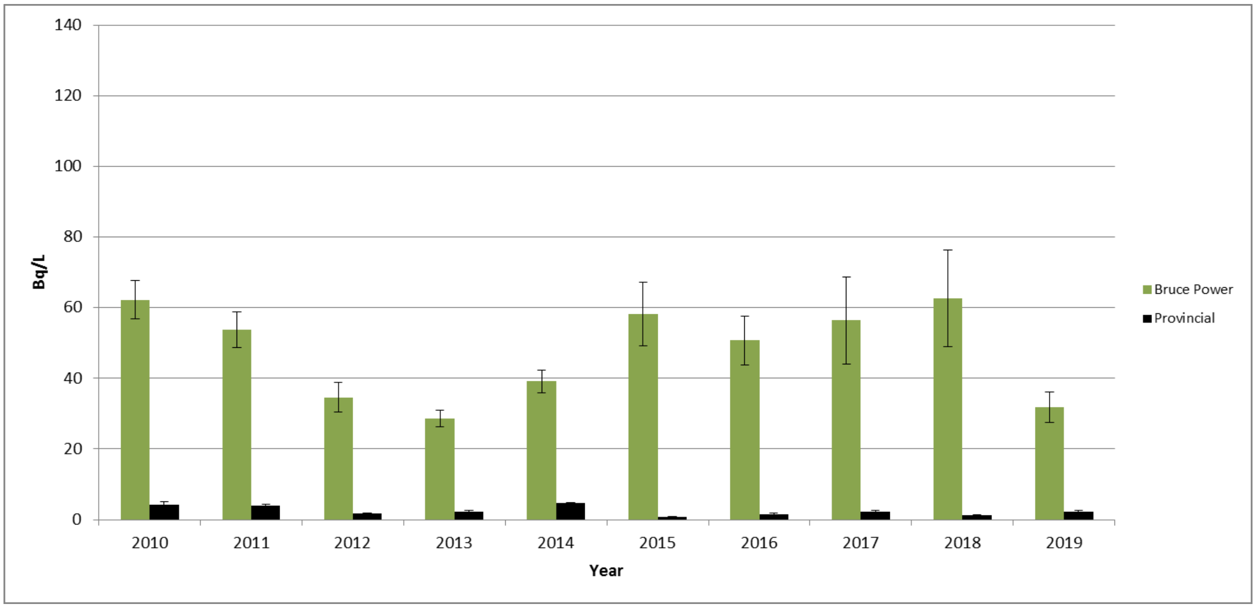

Figure 46
Annual Average Tritium in Vegetable Trend

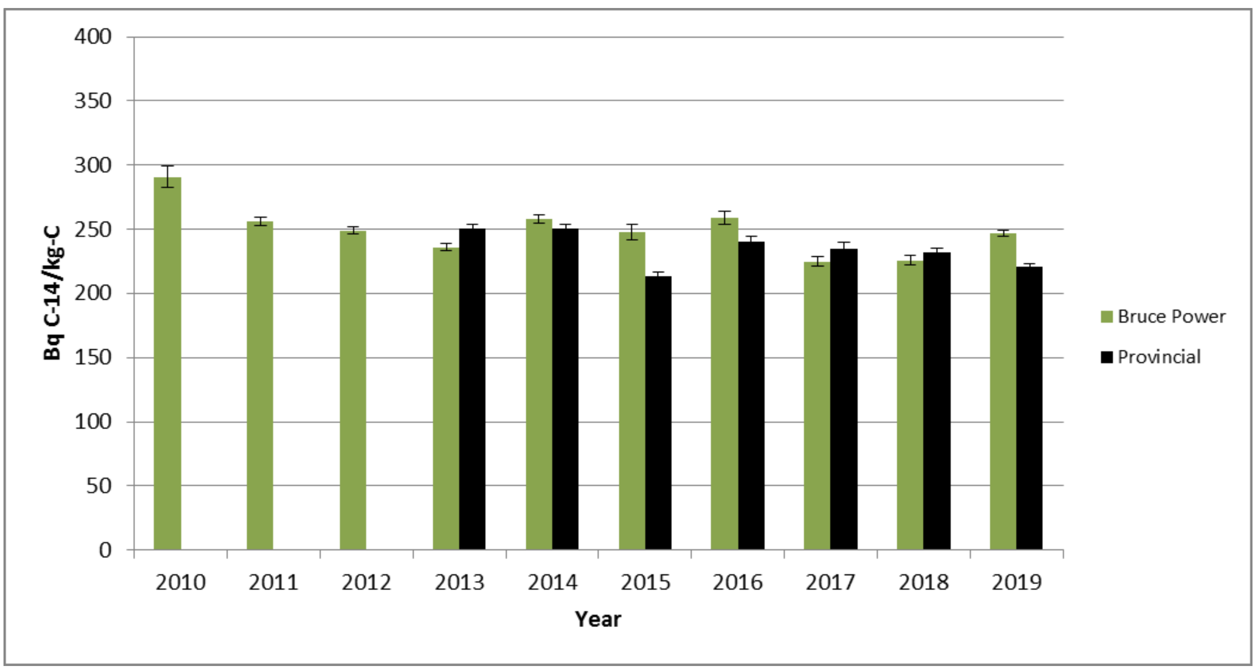

Figure 47
Annual Average ^{14}C in Fruit Trend

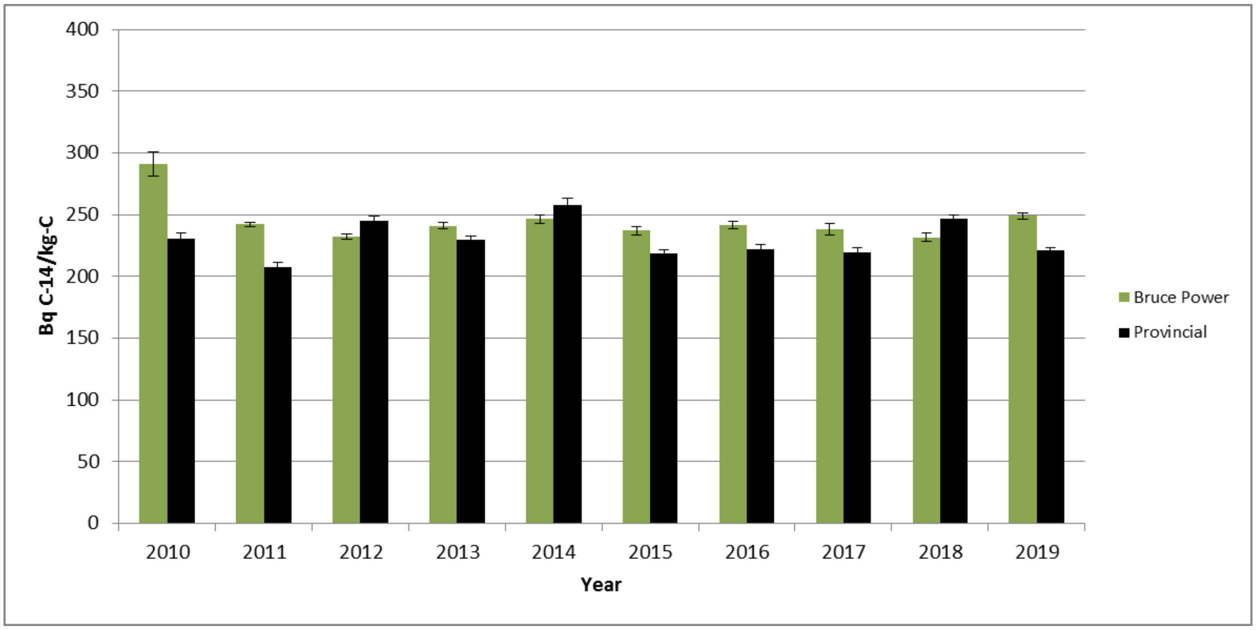

Figure 48
Annual Average ^{14}C in Vegetable Trend

5.5 Conventional (Non-Radiological) Environmental Monitoring

The conventional environmental monitoring program is designed to meet the requirements of CSA N288.4-10 [R-3]. This program monitors for conventional (non-radiological) contaminants, physical stressors, potential biological effects and pathways for both human and non-human biota. The objectives are to:

- Demonstrate compliance with limits on the concentration and/or intensity of conventional contaminants and physical stressors in the environment and/or their effect on the environment;
- Check, independently of conventional effluent monitoring, on the effectiveness of contaminant and effluent control; and
- Verify predictions, refine models and reduce uncertainty in predictions as needed for the Environmental Risk Assessment (ERA).

Conventional environmental monitoring conducted by Bruce Power is described in BP-PROC-00977 [R-94]. The data gathered from the 2019 monitoring program is summarized in this report, with earlier data summarized in the 2017 ERA [R-12]. Updates to Ecological Land Classification, Wildlife Habitat, Wildlife Bioinventory, Bat Monitoring, Breeding Bird Surveys, Migratory Bird Surveys, Creel, Soil and Sediment and lake water quality monitoring were completed in 2016, 2017 and/or 2018 and the frequency of updates is not annual thus further work was not done in these areas in 2019. Reporting frequency for permits is provided in Table 43.

Table 43
2019 Bruce Power Regulator Reporting for Conventional Environmental Monitoring

Conventional Monitoring (Section Reference)	Report Title (Document Control Numbering)	Regulatory Agency	Submission Date (Frequency)
Avian Permits (See s 5.5.6.4)	Migratory Bird Permit (B-CORR-00521-00181)	ECCC	a) Egg destruction details within 30 days of permit expiry. b) Nest destruction or relocation of nests and eggs within 30days of permit expiry. c) Bird relocation details within 30 days of permit expiry. d) Bird kill details within15 days of permit expiry.
Pesticide (See s 5.5.6.5)	Pesticide Use (B-CORR-00541-00336)	MECP	Annually
Fisheries Authorization	BP-CORR-00531-00118	Department of Fisheries and Oceans	Based on contingencies beingmet: a)Various dates and commitments b)Annual report due March 31st

5.5.1 Amphibians

Amphibians aremonitored as an indicator for ecosystem healthas they have a dual life cycle (water and land) and are sensitiveto pollutants during all life stages. Targeted nocturnal amphibianvocalization surveys wereconducted in the Spring/Summer 2019 season, following the Marsh Monitoring Program methodology. A total of three evening surveys were completed in 2019. In additionto the targeted vocalizationsurveys, pedestrian surveys and incidental observations made during other field studies were also completed to document any potential amphibianbreeding evidence (e.g.egg masses, larvae, spermatophores, daytime calling, etc.)

A total of 6 species of frogs were recorded during the amphibian vocalization surveys, consisting of Spring Peeper (*Pseudacris crucifer*), Gray Tree Frog (Hyla versicolor), Northern Leopard Frog (*Lithobates pipiens),* American Toad (*Anaxyrus americanus*), Green Frog (Lithobates clamitans) and Wood Frog (*Lithobates sylvaticus*) (listed in order of abundance). Frogs are sensitive to changes such as weather conditions, which may impact yearly survey results. Taking into consideration natural annual variability in monitoring amphibian's species, both the diversity and densities of frog species has remained relatively consistent among sites and monitoring years.

5.5.2 Reptiles

Investigations specific to reptiles have been conducted in the form of pedestrian surveys from 2016-2019 to locate and characterize the herpetofauna assemblage and to identify potential habitat within the project area. Data collection has included consideration of turtle and snake habitat use at various life stages for overwintering, breeding, and foraging. This includes hibernacula, grassland, wetlands, and other surface water features. As well, site investigations have included surveys under conditions appropriate to note individuals of this group (e.g., basking or utilizing cover for temperature regulation). Field data was used to identify and characterize reptile habitat.

In conjunction with the above surveys, a database was initiated to record and track incidental reptile observation on site. Long-term monitoring resulted in additional signage on County Road 20 and on Tie Road, indicating the use of the areas by snakes and turtles. The Wildlife Vehicle Interaction survey (see Section 5.5.6.1) continued in 2019 on a weekly basis which helped to locate areas of higher density of reptiles both off site and along the main access roads to site.

In 2019, reptiles identified included Dekay's Brown Snake (*Storeria dekayi*), Eastern Gartersnake (*Thamnophis sirtalis sirtalis*), Midland Painted Turtle (*Chrysemys picta marginata*), Eastern Ribbon Snake (*Thamnophis sauritus),* and Snapping Turtle (*Chelydra serpentina*). This observation is consistent with the species present in 2017-2018.

In 2018, reptiles identified included: Midland Painted Turtle, Snapping Turtle, Dekay's Brownsnake and Eastern Gartersnake. In 2017, Eastern Ribbon Snake, Northern Water Snake (*Nerodia sipedon*) and Red-bellied Snake (*Storeria occipitomaculata*) were also observed.

5.5.3 Waterfowl and Shorebird Surveys

The purpose of waterfowl and shorebird surveys is to monitor overwintering and stopover migration areas to trend species abundance and distribution over time. The shoreline of Bruce Power is surveyed for waterfowl and shorebirds with both binoculars and a spotting scope from a set of 10 viewpoints which were selected to cover most of the shoreline with very little overlap. Two areas in Baie de Doré have been classified as potential stopover waterfowl migration habitat.

In 2019, a total of 3,034 individual birds were observed and comprised of 44 different species. The most abundant species observed was the Double-Crested Cormorant (*Phalacorax auritus*) with a total of 631 individuals. The next most common species were the Ring-Billed Gull (*Larus delawarensis*) and Herring Gull (*Larus argentatus*), with a total of 449 and 401 individuals respectively. Twenty species of duck were observed accounting for 150 individuals; the most abundant being the Bufflehead (*Bucephala albeola*). Only two shore/wading bird species were recorded, the Greater Yellowlegs (*Tringa melanoleuca*) and the Spotted Sandpiper (*Actitis macularius*). A greater number of species were observed in 2019 than previous years and the most abundant species remain consistent year to year.

5.5.4 Winter Raptor Surveys

Bald Eagles (*Haliaeetus leucocephalus*) are currently listed as Special Concern in Ontario and are an important indicator of ecosystem health. Bruce Power monitors habitat use by Bald Eagles and other raptors in the vicinity of the Bruce Power Site over the wintering period between November and early March. Observations continued at the consistent seven locations using binoculars and a spotting scope.

Bald Eagle wintering surveys are conducted over four days between November and February. In 2019, the highest numbers of Bald Eagles were observed along the south-east end of Baie du Doré, which has several large trees that are utilized as perches. In 2019, the lowest numbers of eagles were observed at the southwest corner of the Bruce Power property bordering Inverhuron Provincial Park. This is relatively consistent with previous years. In past years, the lowest abundance has also been observed at the south end of site. In total, 97 Bald Eagles were recorded over the four day survey in 2019, consisting of 41 juveniles and 56 adults. Bald Eagle abundance has been consistent over the past three years, averaging 93 individuals observed with about 1/3 of those being observed in Baie du Doré. There are a high proportion of juveniles, indicative of a healthy population.

Raptor wintering surveys are conducted over three days between January and early March. Surveys were conducted in the same manner as those in prior years, in open or meadow areas that were adjacent to woodlots. Only two raptors were observed during the three monitoring days. A Snowy Owl (*Bubo scandiacus*) was observed on the 28th of February flying from a northerly to southerly direction on the OPG monitoring site and an actively hunting Northern Harrier (*Circus hudsonius*) was observed by the sewage lagoons on Concession 2. No raptors were recording during the 2017 survey and only one Red-Tailed Hawk (*Buteo jamaicensis*) was observed in 2018. Some of the common incidental bird species recorded included Northern Shrike (*Lanius borealis*), Ring-Billed Gull (*Larus delawarensis*), Herring Gull (*Larus argentatus*) and American Black Duck (*Anas rubripes*).

5.5.5 Stream C Redd Surveys

In the early spring and late fall, salmonids migrate upstream to reach suitable cool-cold water spawning grounds. The female selects a nest site and begins excavating a pit, referred to as a redd. This redd is where eggs will be deposited for fertilization by one or more males. Redd surveys are a tool for assessing the productivity and health of a watercourse, as presence and success of spawning salmonids indicates the watercourse has necessary environmental conditions to promote healthy spawning/hatching and rearing (i.e. substrate, temperature and flow regimes). Timing of the start for the survey varies depending on conditions like water temperature, rainfall and stream water levels. Stream C surveys are conducted in the spring to capture the migration of Rainbow Trout (*Onchorynkus mykiss*) and in the fall to observe various salmon species, which may include both Chinook (*Oncorhynchus tshawytscha*) and Coho (*Oncorhynchus kisutch)* salmon, and historically Brown Trout (*Salmo trutta*) and Brook Trout (*Salvelinus fontinalis*).

A total of four spring and four fall surveys were completed in 2019. The 2019 spring surveys resulted in a total of 42 Rainbow Trout redds observed (7 with trout on or near the redd, and 6 with a pair of trout). The spring surveys have seen increased redds from 2017 to 2019 (4, 30, and 42 respectively). The 2019 fall survey resulted in a total of 30 salmon redds observed. Of the 30 redds, 8 of them had paired spawning Coho Salmon on or near the redd. The fall surveys have seen variable redds counts from 2017-2019 (20, 37, and 30 respectively). The large increase in 2018 may be attributed to two additional survey dates.

5.5.6 Wildlife Interactions

5.5.6.1 Deer Collisions

White-tailed deer (*Odocoileus virginianus*) are abundant throughout the local area. Biological population sizes naturally fluctuate from year to year depending on hunting, predation and natural mortality. The local area represented by the Ontario Ministry of Natural Resources and Forestry (MNRF) Wildlife Management Unit 84 (WMU 84), which includes the Bruce Power site, Figure 49. Harvesting tags are distributed through the MNRF and are reflective of sustainable harvest. Harvesting data from the MMNRF WMU 84 estimates a total of 15,877 white-tail deer were harvested between 2008 and 2018 [R-95].

In 2019, a total of one deer-vehicle collision occurred and resulted in fatality. Figure 50 shows the annual deer-vehicle collision and collision mortality between 2007 and 2019. Between 2012 and 2019, a total of 15 deer vehicle collisions occurred and resulted in 7 deer mortalities. On-site deer mortality from vehicle collisions represents less than 0.1% of the total loss due to harvest from 2008 to 2018. Since the loss due to harvesting is considered to be sustainable to the local population, the loss associated from collisions with vehicles on Site is considered to have a negligible effect on the local deer population. Bruce Power will continue to monitor deer-vehicle collisions as the Bruce site is expected to have increased traffic during Major Component Replacement.

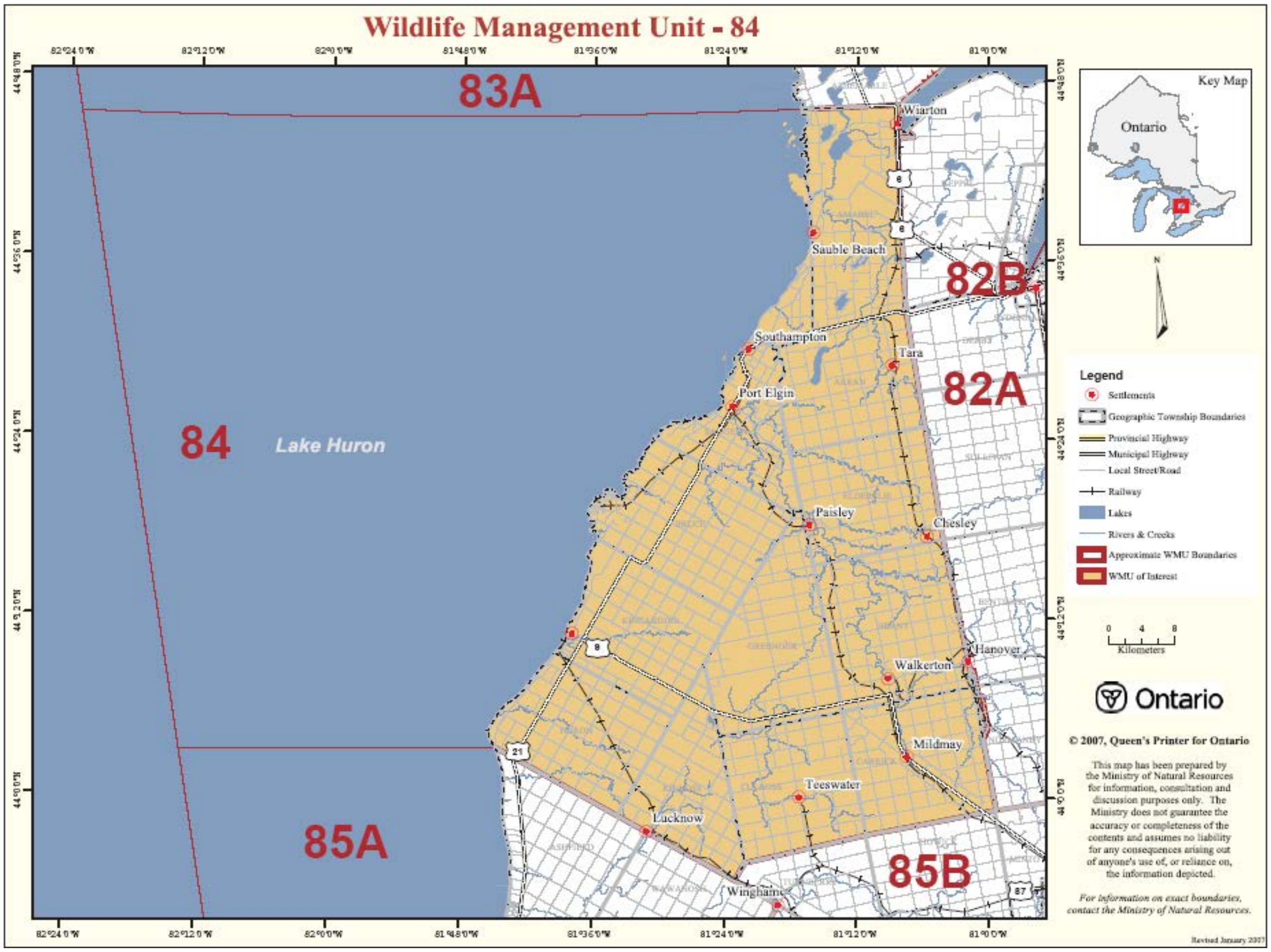

Figure 49
Ontario Ministry of Natural Resources and Forestry Wildlife Management Unit 84

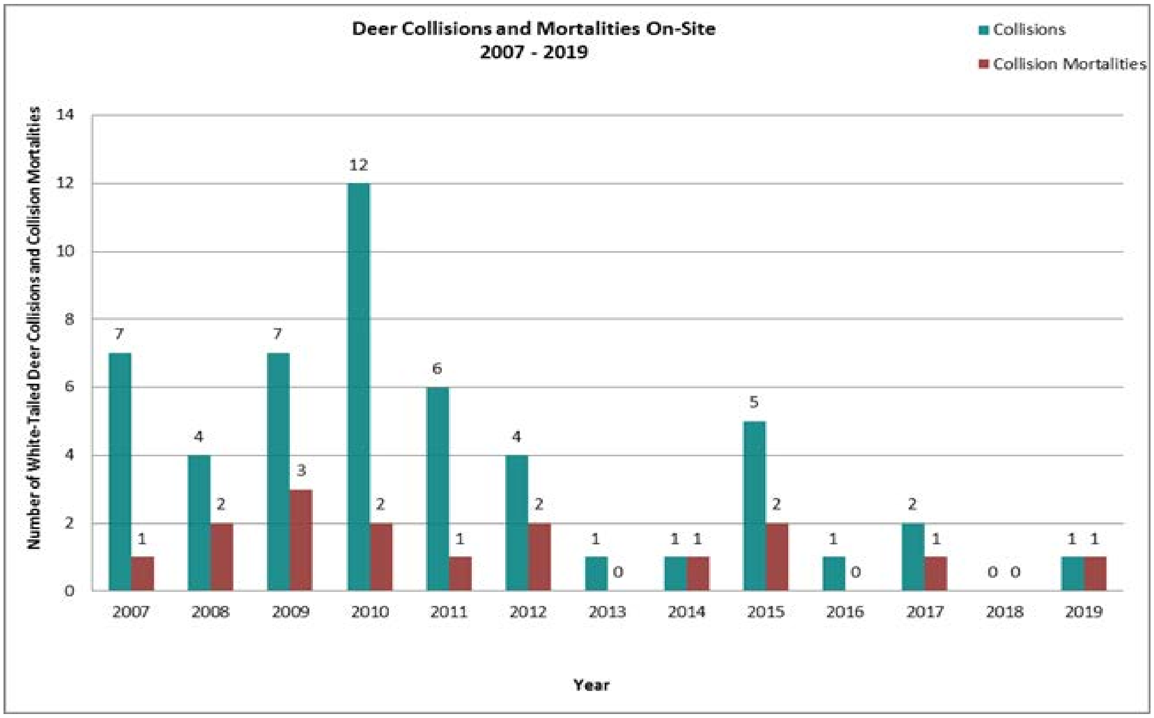

Figure 50
Deer Collisions and Mortalities on the BNPD Site by Year

5.5.6.2 Vehicle-Wildlife Monitoring

Beginning in the summer of 2017, Bruce Power initiated a standardized approach to collecting vehicle-wildlife collision data at the site to improve understanding of collision risk to various species of wildlife occupying the site and local area.

Two pass surveys were conducted on the main access roads to site (Bruce Road 20 and Concession 2 to Highway 21) and the main roads on site as these have the most traffic. Concession 6 was added as a result of increased traffic around the Farrell Drive industrial complex creating an additional route from Highway 21 to site. The survey frequency was once per week after 9:00 a.m. when peak morning traffic had subsided. Surveys were conducted by an experienced biologist in a vehicle travelling at a maximum of 30 km/h and remain ongoing.

All carcasses were identified to species to the extent possible, photographed, and georeferenced. Wildlife carcasses observed incidentally along roads on site outside of the standardized survey were also georeferenced, and recorded as incidental observations within the database. Incidental wildlife sighting by employees were also tracked and recorded.

The risk of vehicle-wildlife collisions is not uniform among species. Highly mobile species such as bats and most birds have a lower mortality risk than slower species such as amphibians and reptiles because they are more capable of avoiding collision. Further adding to this risk is the tendency for many species of amphibian and reptiles to use warm road surfaces for thermoregulation. Larger species are also at lower mortality risk because they are more likely to be seen and avoided by drivers.

In total there were 48 survey days with 85 wildlife carcasses recorded in 2019, including 15 observed incidentally. Mammals constituted 41%, amphibians 25%, reptiles 18%, insects (Monarch) 8% and birds were 7% of the total carcasses recorded. The most recorded species were: Northern Leopard Frog, Eastern Cottontail, Eastern Grey Squirrel, Eastern Garter Snake and the Monarch Butterfly. Three species of concern were recorded during 2019 (6 Snapping Turtles and 7 Monarch Butterflies (both Special Concern in Ontario) and 3 Midland Painted Turtles (Specially Protected under the Ontario Fish and Wildlife Conservation Act)).

The roads coming into site, Bruce Road 20 and Concession 2, accounted for 43% of recorded mortalities. Traffic on these roads is also from other local businesses, mainly the industrial complex on Farrell Drive on Bruce Road 20 and Inverhuron Park on Concession 2. Both of these roads are dissected by the Algonquin Bluff which is a key wildlife corridor. Road signs warning drivers of turtle and snake crossings were posted on Bruce Road 20 in 2018 and have been requested to be installed on Concession 2 as well. The posting was made where there are wetlands on each side of the road as this is a key corridor for reptiles and amphibians.

Monitoring has been completed now for three seasons. Mortalities are relatively consistent with 46 observations in 2017 (July to Dec only), 90 in 2018 and 85 total mortalities in 2019.

Seasonal trends have been observed, with the months of June and September having the most amphibians recorded; this is reflective of the time of the year when they are the most active and are searching out the breeding or hibernation areas. Monitoring will remain ongoing and traffic volumes are expected to be higher in 2020 with the addition of MCR staff travelling to site.

5.5.6.3 Bird Interactions with Structures

CSA N288.4-10 identifies structures as potential physical stressors to birds [R-3]. Spring and fall migration have been identified as periods of increased collision risk for migratory birds. Two buildings (B10 and B31) on site have large window installations and see the most bird collisions of the onsite buildings. B10 is the tallest building onsite with glass and is located centrally near a woodlot. B31 is a one story building in the vicinity of woodlot and open field. Standardized collision monitoring was initiated in June 2017 and is ongoing. Surveys were conducted weekly on foot by an experience biologist, with the perimeter of each building walked slowly in each direction, completing two full perimeter passes. Surveys were conducted before 2:00 p.m. to the extent possible as most bird collisions with buildings occur in the hours between early morning and early afternoon. All carcasses were identified to species to the extent possible, photographed, and georeferenced. Bird carcasses observed incidentally around the two monitored buildings outside of the scheduled survey period were also recorded and georeferenced.

In 2019, one Northern Flicker (*Colaptes auratus*) and one Song Sparrow (*Melospiza melodia*) carcass were recorded. Both bird mortalities were recorded at building B31. Three years of bird collision monitoring of these two buildings resulting in eight recorded bird carcasses. All recorded species are associated with forests which may reflect the presence of woodlots in the vicinity of the buildings.

In addition, birds have been incidentally reported as colliding with B23 and this building will be added to the monitoring program starting in January 2020.

5.5.6.4 Avian Permits

In the instance that geese or gull eggs or nests create an unsafe work environment and damage to property, the removal or relocation of eggs or nests must be done in accordance with a permit issued under the Migratory Birds Regulation [R-96] as proscribed by authority of the Migratory Birds Convention Act, 1994 [R-97].

In 2019, Bruce Power received a damage or danger permit, DA-OR-2019-3949 [R-98], for mitigating Canadian Geese (*Branta canadensis*), Herring Gull (*Larus argentatus*), and Ring Billed Gull (*Larus delawarensis*) populations on site. Geese nests or eggs are relocated as required. Gull eggs and nests need to be controlled on a continual basis once nesting season has started, usually from April to June. Sterilization via oiling eggs is preferred as this will deter gulls from continuing to lay new eggs; however, gulls may remain in the area.

5.5.6.5 Pesticide

Pesticides are used by Bruce Power to control pests and weeds only when doing so is an essential business need, commonly relating to health and safety or security matters. Bruce Power works to ensure the use of pesticides is done in compliance with the requirements of essential and cosmetic applications as described by the Ontario Pesticide Act and as implemented by Ontario Regulation 63/09 [R-99][R-100]. Bruce Power has two staff licensed for onsite pesticide application. In 2019, no pesticides were applied by Bruce Power licensed exterminators.

5.5.7 Fisheries Act Authorization

Bruce Power received a Fisheries Act Authorization from Fisheries and Oceans Canada (DFO) in December 2019 [R-102]. The Authorization requires Bruce Power to quantify fish losses through continued monitoring fish impingement and entrainment, and then to quantify fish gains through monitoring improvements to the Lake Huron watershed.

Bruce Power will continue to monitor I&E in alignment with CSA N288.4 standard, and utilizing additional guidance provided by CSA N288.9 [R-103] as appropriate. In addition, a draft I&E Monitoring Plan [R-104] was submitted to DFO as part of the Fisheries Act Authorization, and this outlines ongoing I&E monitoring through to 2028. Bruce Power will provide DFO a final I&E monitoring plan in 2023, and Indigenous Nations and Communities will be engaged in the finalization of this plan.

The Authorization [R-102] also stipulates a biomass value (estimated in Habitat Productivity Index (HPI)) that is not to be exceeded in any year. Additional reporting to DFO is required if a higher than expected number of fish is impinged, or if any Species at Risk are identified as impinged or entrained.

An Authorization under Paragraph 35(2)(b) of the Fisheries Act [R-102] requires the proponent to undertake offsetting. This consists of remediation projects which are designed to increase fish biomass within the greater Lake Huron watershed, and are intended to offset on site losses that occur from fish I&E.

Bruce Power has partnered with the Lake Huron Fishing Club and the Municipality of Brockton to complete a partial removal of the Truax Dam on the Saugeen River in Walkerton Ontario. The dam has long been identified as a major barrier to upstream passage of fish. The dam was removed in August and September 2019, with a partial removal allowing fish passage while maintaining a recreational area for the town.

The headpond was slowly lowered over the course of 4 days from Aug 12-15, 2019. A concerted effort was made during this time to ensure that no fish or macroinvertebrates were stranded as the headpond elevation lowered. Volunteers from the Lake Huron Fishing Club (LHFC) systematically walked the entire lengths of the stream banks every morning and evening from Aug 12-15. A fact sheet on freshwater mussels was prepared by Bruce Power and provided to the volunteers to ensure proper protocols were in place in case a Rainbow Mussel was observed to be stranded. No Rainbow Mussels were found during any of the river bank patrols. Biologists from Bruce Power and Biotactic Inc. were on-hand during the decommissioning of the fish ladder to assist with relocation of fish and macroinvertebrates that were stranded in the fishway as the water was lowered. The engineering firm overseeing the removal, GSS Engineering, was also at the project site during all hours of construction. The Site Manager from GSS Engineering was at the shoreline near the dam on many occasions and patrolled this area.

The removal of the Truax Dam in Walkerton Ontario has improved fish passage on the Saugeen River. The Saugeen River has a large watershed which drains into Lake Huron in Southampton, Ontario. The system supports a diverse fish community and is valued for recreation including fishing and canoeing. The Truax Dam was a major year-round barrier to upstream fish passage and movement of both salmonids and the warm-water fish community. The removal of the dam is expected to restore the natural connectivity, increasing upstream fish passage ability and reduce uneven fish distribution throughout the watershed. The dam removal has already started to allow the re-establishment of natural riffle-pool flow sequences [R-105]. It is expected that the dam removal will result in access to more spawning grounds and a corresponding increase in production.

Monitoring of the impact of Truax Dam removal project is following a before after control impact approach. This means that the monitoring is being conducted both before and after the dam is removed to understand how fish biomass changes as a result of the removal. Control sites are used beyond the study area to understand how the fish community is changing over time in an area not affected by the dam removal and thus the changes due to natural variation can be understood and used to normalize the before/after results.

Pre-monitoring of the fish community in the stretch of the Saugeen River near to and upstream of the Truax Dam occurred in 2018 and 2019. This consisted of habitat assessments in the main river, both near and farther from the dam location as well as in the associated tributaries. Electrofishing was completed at all sites to monitor species distribution. Abundance, lengths and weights of individual fish caught was recorded. This information was then used to calculate the standing biomass at each of the 22 monitoring sites.

Monitoring will continue post dam removal, planned for 2020 and beyond. Results will be analyzed to quantify the biomass gained from the project, predicted to be much larger than that lost via station operations. This work is being further supplemented using video graphic surveys, redd counts and radio telemetry to obtain a larger picture of fish movement within the Saugeen River.

In addition to the Truax Dam removal, Bruce Power is conducting two other offset measures. One is a joint environmental monitoring program with the Saugeen Ojibway Nation as a complementary measure. The objective is to increase the understanding of the overall aquatic ecology in the Lake Huron watershed, with an emphasis on the aquatic ecosystem in the vicinity of Bruce Power. The other is engaging with Indigenous Nations and Communities to develop an offsetting plan focused on improving fish and fish habitat in the Lake Huron watershed. A minimum of three cost-effective projects are to be planned for implementation within the duration of the Fisheries Act Authorization [R-102].

Lake Trout stocking was included in draft offsetting plans as this is a program implemented by the Ontario Ministry of Natural Resources in Lake Huron for the stabilization of key predators in the Lake Huron fish community. Deep water fish, like Lake Trout, are specialized to fill in missing links in the deep-water food webs that are now only marginally occupied. Re-establishment provides an enriched community that is capable of supporting more stable fisheries [R-106]. Lake trout rearing begins 18 months in advance for stocking with Bruce Power supporting this work for spring 2019 and 2020 campaigns. This was started in anticipation of the issuance of the Fisheries Act Authorization. In consultation with Indigenous Nations and Communities and DFO, this was subsequently removed as an officially credited offsetting measure when the Fisheries Act Authorization was issued as this was not supported by Indigenous Nations and Communities.

5.5.7.1 Impingement Monitoring

Fish impingement monitoring was completed at both Bruce A and Bruce B. Fish baskets are routinely monitored for debris loading on a daily basis at Bruce A and Bruce at each unit. In 2019, monitoring of fish baskets occurred 1,435 and 1,456 times at Bruce A and Bruce B respectively (see routines in Figure 51). This represents completion of >98% of all planned monitoring. The total number of fish impinged in 2019 was lower than that observed in 2017 and 2018. Field QA/QC and oversight of impingement was implemented in 2012 at Bruce A and in 2013 at Bruce B. This continuedon a regular basis atthe both stations in2019 and is ongoing in 2020.

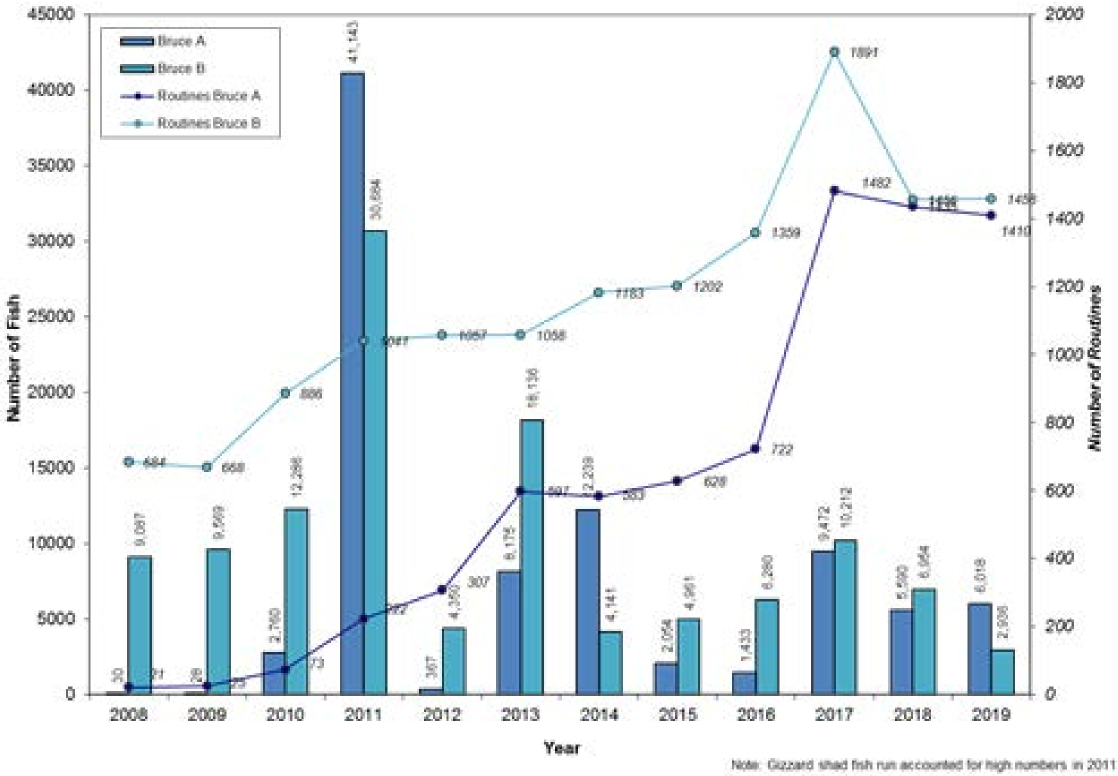

Figure 51
Fish Impingement Routine Completion and Total Fish Count

A total of 8,946 fish were collected in 2019. A total of 447 were too decomposed to initially assign to a species therefore the distribution ofspecies present inthe week of impingement was used to determine the probable species. These 447 species were reassigned andare accounted for in Table 1.

A total of 8,946 fish were collected in 2019, with a distribution by species shownin Table 44. The total loss of fish productionin 2019 due to impingementand entrainmentwas 2,806 kg using the HPI metric (Table 44). This is anestimated quantity based onthe actual (measured) loss due to impingement in2019, and the estimated annual entrainmentloss. Entrainment was not measured in 2019, so the 2,806 kg loss value includes a conservative estimate of entrainment based on the highest value observed (by species) inthe 2013 and 2014 monitoring campaigns. Background details on the HPI metric and its suitability for use as a common metric to compare impingement and entrainment losses to gains experienced from offset projects are found in Bruce Power's application for a Fisheries Act Authorization, [R-107] and [R-108]. This estimated loss for 2019 of2,806 kg was below the 4,500 kg/yr threshold authorized in the FAA. The nominal total weight(less Round Goby) of impingedfish in 2019 was 2,456 kg.

Table 44
Impingement and Entrainment Fish Losses at Bruce A and Bruce B in 2019

Species	2019 Impingement		2013/2014 Entrainment[1]		Total
	Count (#)	Nominal Weight (g)	Count (# of age-1 equivalents)	Age-1 Weight (g)	2019 HPI Losses (kg yr^{-1})
Alewife	293	1,486	6	24	2.3
Bloater	-	-	14,124	790,944	510.4
Brown Trout	12	15,554	-	-	3.3
Bullhead	3	768	-	-	0.3
Burbot	207	153,064	9,089	78,165	198.2
Carp	47	40,590	-	-	10.1
Channel Catfish	47	67,170	-	-	13.9
Chinook Salmon	8	23,516	2,208	266,285	139.0
Cisco	-	-	17,545	538,632	428.9
Coho Salmon	9	16,280	-	-	3.1
Cyprinid	-	-	431	259	0.8
Deepwater Sculpin	-	-	2,610	3,654	8.6
Freshwater Drum	16	35,268	-	-	6.3
Gizzard Shad	4,540	1,496,469	-	-	519.2
Lake Trout	49	84,072	-	-	16.4
Lake Whitefish	35	72,818	8,547	639,316	400.4
Rainbow Smelt	974	13,291	16,898	152,082	200.4
Rainbow Trout	26	21,613	-	-	5.4

Rock Bass	3	343	-	-	0.2
Round Goby	2,018	18,685	2,529	2,529	32.7
Salmonid	-	-	427	8,028	7.6
Smallmouth Bass	16	7,095	-	-	2.2
Spottail Shiner	105	3,862	-	-	2.9
Suckers	359	217,921	5,089	26,972	170.7
Walleye	133	181,208	75	8,730	46.1
White Bass	2	770	-	-	0.3
White Perch	1	361	-		0.1
Yellow Perch	43	3,892	10,512	81,994	108.9
Total					**2,838.6**
Total (less Round Goby)					**2,805.9**

[1] Entrainment is estimated from data collected in 2013 and 2014 at Bruce A. Shown here is the count and age-1 weight for the higher of the two years, yielding the most conservative estimate based on the 2013/2014 data.

5.5.8 Thermal Monitoring

5.5.8.1 Physical monitoring of lake temperature and water currents

Temperatures of water discharged from both Bruce A and Bruce B are monitored year round, and the discharge points have environmental compliance approvals (ECA) limiting the extent of thermal emissions from site to Lake Huron. These thermal limits are set by the Ministry of Environment, Conservation and Parks at levels that limit habitat alteration and negative effects to fish habitat and behavior. As documented in the 2017 ERA, thermal effluent is a physical stressor to aquatic life as egg hatching and larval survival are known to be affected by thermal changes.

Temperature and current monitoring in Lake Huron continued in 2019 to collect verification data for the MIKE3 atmospheric-hydrothermal modelling platform. This modelling platform was developed for Bruce Power by Golder Associates to provide atmospheric and hydrothermal understanding of Lake Huron lake-wide and locally. In 2019, Golder Associates won an Award of Excellence in Water Resources for their work with Bruce Power on Bridging the Hydrometric Modelling Data Gap, Lake Huron [R-109].

The thermal validation sites include eighteen locations that extended from south of Bruce B (McRae Point) to north of Bruce A (MacGregor Point) to a depth of 20 m. Each year a Notice to Shipping is provided to the Canadian Coast Guard for boater awareness. Thermal monitoring is ongoing and will continue in 2020. To measure current speed and direction, an ADCP was deployed off of Gunn Point (south of Bruce B) at a depth of 20 meters. Fall weather challenged retrieval of the 2019 data, however this is planned for retrieval in 2020.

5.5.8.2 Thermal Environmental Compliance Approval

Bruce A has a temporary amendment of thermal ECA to allow operational flexibility conditions that permit an increase in the maximum effluent temperature limit by 2.3°C to 34.5°C for a maximum of 30 aggregate days and for no more than a maximum of 15 consecutive days for each event, during the ECA window of June 15 to September 30 each year. At no point during the 2019 year did the effluent exceed the ECA limit at both stations.

Bruce Power provided monthly updates throughout the ECA window to SON, MNO and HSM. Discussions remain ongoing.

5.5.9 Smallmouth Bass Nesting

Smallmouth bass nesting surveys to monitoring local populations continued in 2019 at Bruce A and Bruce B discharge channels and in Baie du Doré (12.0Appendix A:). Two temperature loggers were placed at each location. Nests were monitored throughout the season (early May to mid-July) to observe nest development and success. Observations were made by running transects in a small boat (16 ft.) and stopping to observe any nesting sites with a translucent viewing box (aquarium) which minimized glare and allowed for a clear view of the nest.

The location of each nest was recorded via GPS and the development stage documented during each of 7 surveys for Bruce A and Bruce B discharge channels and 6 surveys in Baie du Doré. Once a nest was observed, it was given a unique identification number. Nests were re visited during each subsequent survey, with the development stage code recorded on each visit. The coding method followed a standardized protocol that was developed during historic monitoring studies and is shown below in Table 45. A nest was considered ‘successful’ if it had reached development stage 6 8 (risen fry to green fry), ‘unsuccessful’ if it was abandoned and ‘remained active’ if it had reached development stage 1 5 during the extent of the survey. Monitoring continued past the opening of bass season on the last Saturday in June until mid-July. The longer time period of monitoring was needed as a second cohort of nesting began in mid to late June and these were monitored through development. The second cohort was subject to fishing pressure at the opening of bass season. The percentage of ‘successful’ nests at the end of the season includes those coded as stage 6 8 as these fry are likely to still disperse following the opening of bass season.

Table 45
Smallmouth Bass Nesting Survey Development Stage Codes

Code	Code Description	Field Indicators
0	Pairing	A pair of adult Smallmouth Bass with no nest observed.
1	Cleared nest	A cleared nest with no observed guarding male
2	Cleared nest; bass guarding	A cleared nest with a guarding bass, but no observed eggs or fry
3	Eggs	A cleared nest was present and eggs were observed in the nest.
4	Yolk-sac larvae	Transparent yolk-sac fry that had not risen off the bottom observed in the nest
5	Fry risen; tight to bottom	Fry, observed at or very near the bottom
6	Fry <2 cm risen; suspended	Fry <2 cm total length, observed swimming suspended in the water column
7	Fry >2 cm risen; dispersed	Fry >2 cm total length, observed swimming suspended in the water column and starting to disperse
8	Green fry	Fry with a green colouration, which occurs at approximately 1.5 cm total length, observed in proximity ofnest
A	Abandoned	Nest was observed to be abandoned by male adult Smallmouth Bass or an abrupt absence of eggs, fry, or adults was observed. This code includes nests that are abandoned as the result of natural physical destruction(e.g., nest silted up).

Quality assurance (QA) and quality control (QC) procedures were applied during field sampling, data entry, and data analysis. Field equipment was calibrated according to manufacturers' recommendations. Data sheets were checked at the end of each field day for completeness and accuracy, then scanned and saved as electronic copies. All data were entered into an electronic spreadsheet, with entered data validated by a second person to identify and correct any transcriptional errors. Tables containing calculated values and data summaries were reviewed, and values were verified by a second, independent individual.

Nests are consistently located in similar geographic areas from one year to the next, which is likely due to site fidelity. Males are known to return to the same location year after year, with the majority returning to within 140m of prior nesting sites [R-110]. Nests in Bruce A in 2019 were found near the sheltered dock area, along the bedrock shelves and also in between the crevices within the large boulders that line the north and south areas of the discharge channel. This is consistent between all monitoring years and is likely a result of physical conditions, (i.e. substrate type, water velocity). In the Bruce B discharge, the majority of the nests were located on the north side, which is an area sheltered by the Bruce B dock, and in the shallow areas along the discharge groyne. The sheltered shoreline areas of Baie du Doré and areas around the submerged island which separates the bay into east and west sections under high water conditions, continued to be highly utilized for bass nesting in 2019.

A total of 56 nests in the Bruce A discharge channel, 74 nests in the Bruce B discharge channel, and 150 nests in Baie du Doré were recorded during the 2019 Smallmouth Bass nesting surveys. At the end of the survey, most nests recorded at Bruce A and Bruce B were classified as either successful (Stages 6-8) or abandoned (Stage A). A total of seven active nests (Stages 0-5) were recorded at Bruce A discharge at the end of the survey, five active nets were recorded at Bruce B at the end of the survey and at Baie du Doré and the final survey only included one active nest. Overall, the monitoring effort in 2019 captured the period of nest maturation and success. The percentage of successful nests ranged from 61% at Bruce A to 78% at Bruce B.

5.5.10 Historical Smallmouth Bass nesting

Both the total number of nests and the number of successful nests observed in 2019 were the highest recorded since surveys began in 2010. The total number of unsuccessful nests observed in Baie du Doré was intermediate, with 37 out of 150 nests being unsuccessful, and similar to counts of unsuccessful nests in 2011, 2012, 2017, and 2018. Percent nest success (75%) was relatively high compared to previous years.

In May and June 2019, water levels at Lake Huron were higher than in all previous sampling years, inundating more shallow areas and creating new (compared to 2010-2013 monitoring years) habitat suitable for Smallmouth Bass spawning in Baie du Doré. This finding was similar to the 2014 to 2018 results, as shown in Figure 52, Figure 53 and Figure 54, when water levels were also relatively high. With the exception of the newly inundated shallow water areas, the nest locations utilized by Smallmouth Bass were similar between survey years.

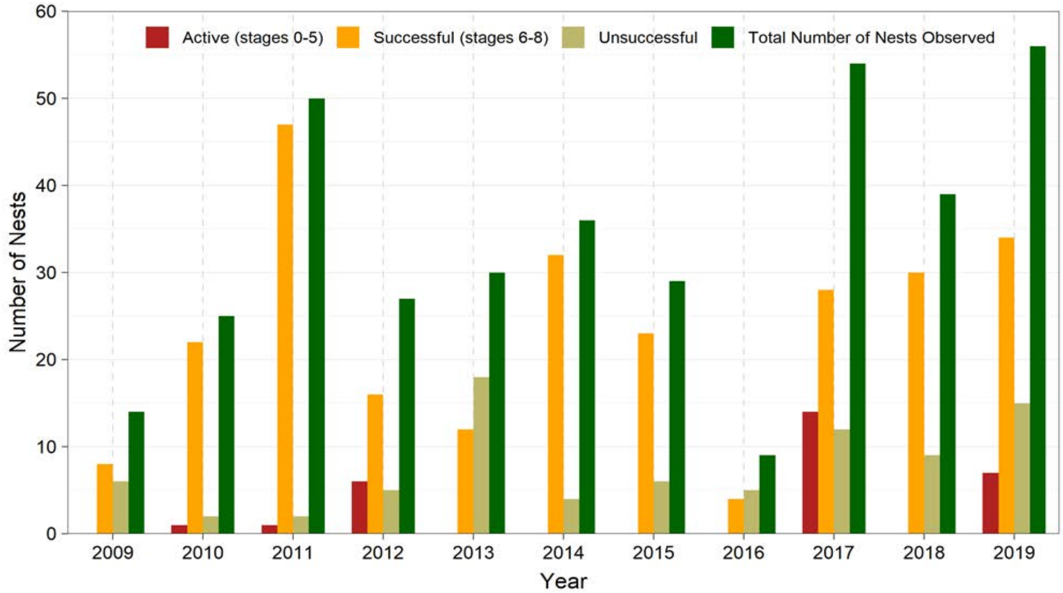

Figure 52
Bruce A Nesting Results 2009-2019

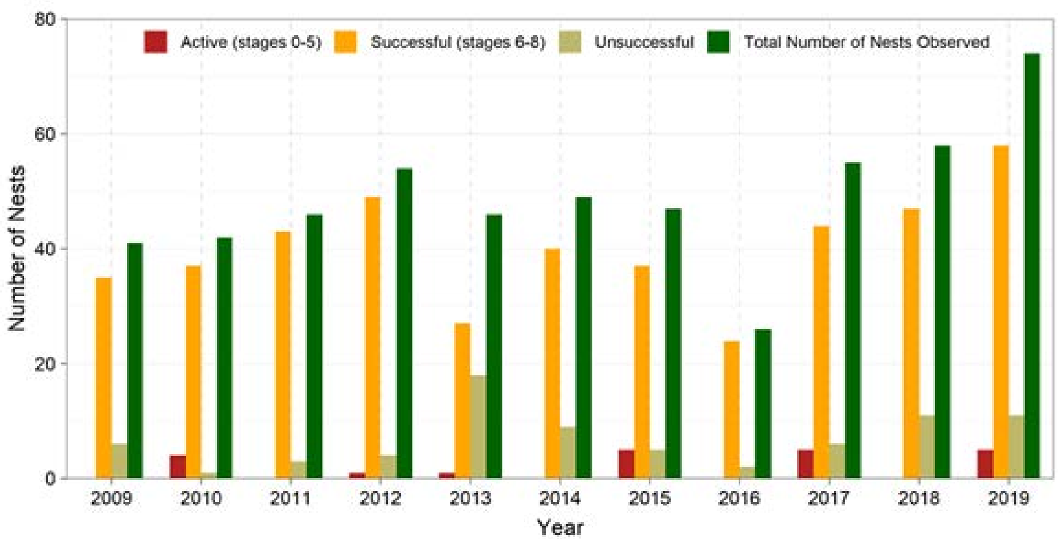

Figure 53
Bruce B Nesting Results 2009-2019

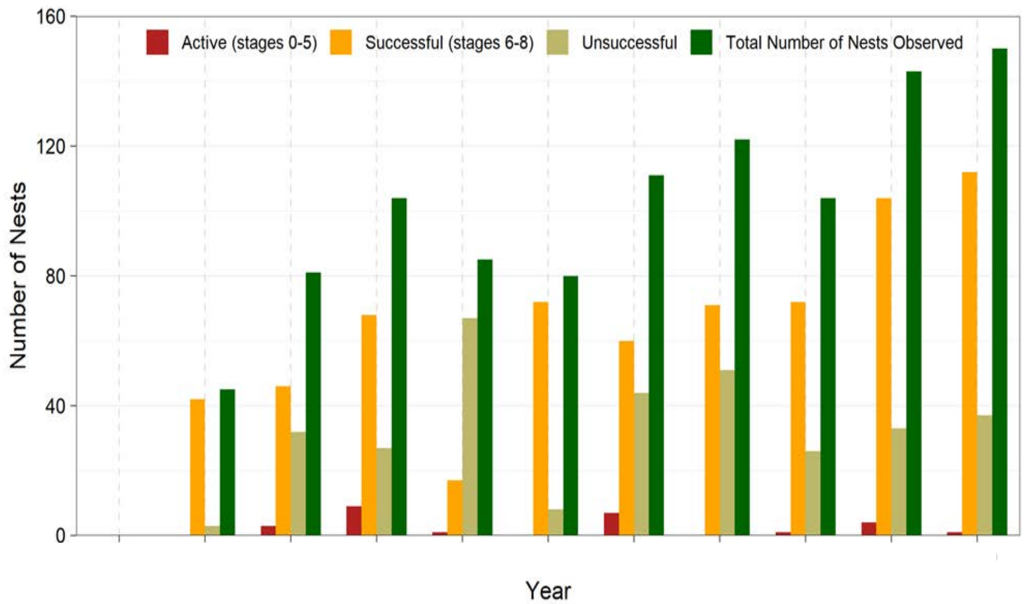

Figure 54
Baie du Doré Nesting Results 2009-2019

5.5.11 Storm Water Monitoring

Storm water is an episodic or event-based vector for contamination to enter waterways and impact aquatic life. Short term surface runoffs occur from heavy-volume rainfall and rapidly melting snow, which have the potential to suspend residual chemicals and sediments that release pollutants to the water column. These short-term runoff events may cause long-term effects in the receiving water body. As such, monitoring is performed quarterly to provide a reasonable probability to capture the response to events.

Storm water monitoring is ongoing. Water quality data is collected by Saugeen Valley Conservation Authority. Samples are collected on a quarterly basis at 5 locations on site and analyzed for E.coli, total suspended solids (TSS), pH, alkalinity, conductivity, nitrates, total nitrogen, total phosphorus, chloride and sulphate. These locations represent all the surface water features that traverse the Bruce Power site and eventually drain to Lake Huron. Supplemental sampling was completed at two locations on Stream C.

Along with laboratory analysis of water samples collected, field parameters are also recorded at each sample collection location. These field parameters include pH, temperature, dissolved oxygen, electrical conductivity and Formazin Nephelometric Unit (FNU) or turbidity.

Recently, two YSI EXO 2 sondes water quality meters were installed which collect hourly baseline data for temperature, specific conductivity, total dissolved solids, dissolved oxygen and turbidity.

These results are compared to the Canadian Council of Ministers of the Environment (CCME) Water Quality Guidelines for the protection of aquatic life [R-111] and the CCME long-term and short-term exposure limits [R-112]. Elevated E. coli and phosphorous concentrations were observed which are not due to Site operations. This corresponds with agricultural activities, such as tillage and fertilization of crop fields that occurs in fall and spring and therefore elevated runoff concentrations during snow melt and spring precipitation events are expected. Studies along the shoreline of Lake Huron have identified agricultural land uses as the source of phosphorous and E. coli [R-113]. As a result, elevated levels of E.coli and phosphorous are not considered emissions due to the nature of industrial activities at Bruce Site and are reflective of agricultural activities in the vicinity of site. Storm water sampling will continue in 2020.

5.6 Quality Assurance – Environmental Monitoring

5.6.1 Radiological Environmental Monitoring

5.6.1.1 Meteorological Data Analysis

The meteorological data analysis documented in this report was conducted in accordance with the Kinectrics NSSQA Quality Assurance program [R-114]. The Kinectrics NSS Quality Assurance program is ISO 9001 registered and the scope of the ISO 9001:2000 registration covers "consulting, scientific and engineering services to nuclear and other industries to support siting, safety, licensing, design and operations by providing specialized: asset management, project management, procurement, software, environmental, integrated analytical and engineering solutions and services consulting to nuclear and other industries to support design and operations by providing specialized: software, integrated analytical and engineering solutions and services". The Kinectrics NSS Quality Assurance program is regularly audited by organizations such as CANPAC and has consistently been assessed as compliant with requirements of CSA Z299.1 85 [R-115] and the applicable sections of CSA N286 12 [R-63].

5.6.1.2 Public Dose Calculations

The 2019 public dose calculations were conducted using the IMPACT 5.5.2 software. All inputs to the IMPACT model were verified based on Bruce Power environmental and emissions data. A verification tool was utilized to ensure that all numerical entries to the IMPACT model were inputted correctly, and the results of this IMPACT model verification were recorded. The results of the IMPACT calculation were independently verified.

The development of IMPACT 5.5.2 has been guided by, and subject to, an overall Tool Qualification Program (TQP), which follows the CSA N286.7-99 (Canadian Standards Association, 1999) Quality assurance of analytical, scientific, and design computer programs for nuclear power plants [R-126].

5.6.1.3 Provincial Background– OPG Whitby Laboratory

The OPG Whitby Laboratory performed the TLD gamma analyses and most of the provincial sample analyses. Details regarding the OPG QA program are described in the OPG report *2017 Results of Environmental Monitoring Programs* [R-88].

5.6.1.4 Bruce Power Health Physics Lab

The Bruce Power Health Physics Lab operates a comprehensive QA program, which includes quality control samples, blank/background samples, process control samples, and externally generated proficiency testing samples.

5.6.1.5 Sample Availability

The Bruce Power Health Physics Lab collected and analyzed 997 analyte samples against a target of 1,028 for an overall sample availability of 97%. Sample unavailability is due to several factors, notably seasonal conditions (such as variations in agricultural yields) or due to the nature of seasonal residences closed for certain months of the year, making the wells unavailable for sampling. Details of the sample availability for 2019 are presented in Table 46 below.

Table 46
2019 Sample Availability Data

Sample Types	Collection Frequency	Bruce Power		
		Planned	Actual	% Complete
Atmospheric				
Air Effluents	Monthly (^3H)	120	120	100%
	Quarterly (^3H, ^{14}C)	156	156	100%
Environmental Gamma	Quarterly (GS)	64	64	100%
Precipitation/Particulate*	Monthly (^3H, GB)	120	118	98%
Water				
Water Supply Plants	Weekly Composite (^3H)	96	96	100%
	Monthly Composite (GB)	24	24	100%
Domestic Water	Weekly Composite (^3H)	0	0	0%
Resident Well & Lake Water*	Bi-Monthly (^3H, GB)	64	57	89%
	Semi-Annually (^3H, GB, GS)	74	59	80%

Sample Types	Collection Frequency	Bruce Power		
		Planned	Actual	% Complete
Local Streams*	Bi-Monthly (^{3}H)	36	31	86%
	Semi-Annually (GB)	8	8	100%
Site Ground Water	Semi-Annually (^{3}H)	52	52	100%
Aquatic				
Fish	Annually (^{3}H, ^{14}C, GS, OBT)	32	32	100%
Sediment	Annually (GS)	36	33	92%
Terrestrial				
Milk	Weekly Composite (GS)	52	52	100%
	Monthly Composite (^{3}H, ^{14}C)	54	54	100%
Fruits & Vegetables	Annually (^{3}H, ^{14}C)	15	16	107%
Honey	Annually	2	2	100%
Eggs	Annually	2	2	100%
Grains	Annually (^{3}H, ^{14}C)	6	6	100%
	Quarterly (^{3}H)	4	4	100%
Animal Meat & Feed	Annually (^{3}H, ^{14}C, GS)	2	2	100%
Soil & Sand	Annually (GS)	9	9	100%
Overall Site Sample Availability		**877**	**1,028**	**997**

Note: GB = Gross Beta

GS= Gross Scan

*Samples may have been unavailable because of seasonal conditions (e.g.,freezing of water samples and seasonal residences that are closed for certain months of the year).

5.6.1.6 Laboratory Analysis Summary

A total of 1,303 laboratory analyses were conducted in support of the Bruce Power REMP this year (2019). The analyses included tritium, gross beta, ^{14}C, ^{131}I, TLD gamma (under contract to OPG), gamma spectrometry and organically bound tritium (OBT). Table 47 provides a summary of the number of samples analyzed for each analysis method.

Table 47
2019 Laboratory Analysis Summary

Laboratory Analysis	Number of Analyses
^{3}H	643
Gross Beta	185
^{14}C	270
^{131}I	52
TLD Gamma*	52
Gamma Spectrometry - ^{134}Cs, ^{137}Cs, ^{40}K, ^{60}Co	149
Organically Bound Tritium (OBT)	4
Total	**1303**

Note:*52 TLD Gamma Analysis Completed by OPG Whitby Laboratory

5.6.1.7 Laboratory Quality Assurance and Quality Control

The purpose of inter-laboratory proficiency testing is to provide independent assurance to Bruce Power, the CNSC, and external stakeholders that the laboratory's analytical performance is adequate and the accuracy of the measurements meets required standards. Table 48 presents a summary of the Bruce Power REMP QA/QC program.

Table 48
Summary of the QA/QC Program

Analyses		**Tritium**			**Gross Beta**	**^{14}C**	**Gamma Spec**		
Medium		**OBT**	**Water**	**Air**	**Water**	**Produce**	**Water**	**Sediment**	**Soil**
Reality Check	Historical	X	X	X	X	X		X	X
	Relative	X	X	X		X		X	X
External Benchmarks	Inter-lab Comparison		Eckert & Ziegler Analytics		Eckert & Ziegler Analytics		Eckert & Ziegler Analytics	Eckert & Ziegler Analytics	Eckert & Ziegler Analytics
Internal Quality Control	Bias	QC Sample			QC Sample (^{137}Cs)	QC Sample (Sawdust)	Mixed Gamma QC Sample		
	Precision	QC Sample			QC Sample (^{137}Cs)	QC Sample (Sawdust)	Mixed Gamma QC Sample		
	Background	Low TritiumWater			Blank	Blank	Blank		
	Process Controls	Contamination			Contamination (de-min water)	Contamination (Coal)			

5.6.1.8 Laboratory Quality Control

Various quality control samples are utilized to estimate the precision and accuracy of analytical results and to indicate errors introduced by laboratory practices. There are two types of quality control samples used to accompany the analyses of the environmental samples collected for the REMP: process control samples and quality control samples.

Process Control Samples

Process Control samples are low analyte samples that are treated as actual samples and go through the same handling process. These are intended to detect contamination and specific sources of error. The following main process control samples are used for REMP samples:

- Low tritium reference water samples kept open to the air during sample handling to detect if tritium contamination is picked up
- Coal (low ^{14}C) samples to detect anomalies with ^{14}C analyses
- Demineralized water samples run as low gross beta samples to detect contamination

- Blank TLDs to detect radiation exposure during shipping to and from the OPG Whitby laboratory

Quality Control Samples

Quality control samples are samples which contain known values of the analyte (usually derived from traceable standards), which are included for analysis. Statistically based quality control charts are used to evaluate validity of environmental sample results; results are considered valid when the values for the accompanying quality control samples are within ± 3 standard deviations of the known or expected value for the respective control chart.

5.6.1.9 External Laboratory Comparisons

The main purpose of inter-laboratory comparison programs is to provide independent assurance to Bruce Power, the CNSC, and external stakeholders that the laboratory's analytical proficiency is adequate and the accuracy of the measurements meets required standards. The comparison program forms a crucial part of the overall laboratory QA program and demonstrates that the laboratory is performing within acceptable limits as measured against external unbiased standards.

Proficiency testing service is operated by Eckert & Ziegler Analytics Inc. of Atlanta, Georgia. On a quarterly basis Eckert & Ziegler Analytics provides samples containing known quantities of radionuclides to the Bruce Power Health Physics Laboratory. The samples are environmental matrices which are analogous to the samples collected for the REM program. These samples include:

- Tritium in water
- Beta emitters in water
- Iodine in milk
- Gamma emitters in water
- Gamma emitters in soil
- Iodine-131 in iodine cartridge (annually)
- Gamma emitters on particulate filter (annually)

Upon completion of analysis, the Bruce Power analytical values are submitted to Eckert & Ziegler Analytics, which subsequently provides a final report for Bruce Power, detailing the expected values and the ratio of the laboratory value to the expected value.

5.6.1.10 Acceptance Criteria

All results obtained from Eckert & Ziegler Analytics shall meet the following self-imposed pass/fail investigation criteria:

$$\frac{(V_L + 1\sigma_L)}{V_A} \geq 0.75 \text{ AND } \frac{(V_L - 1\sigma_L)}{V_A} \leq 1.2$$

Where:

V_L = HPL value

σ_L = HPL one sigma uncertainty value

V_A = Analytics Supplier value

The results for the proficiency testing are presented in Appendix B. All results meet the acceptance criteria in SEC-DOS-00028, Radiological Analysis Proficiency Testing [R-117]. All results are acceptable.

5.6.2 Conventional Environmental Monitoring

5.6.3 Smallmouth Bass

Quality assurance and quality control procedures were applied during field sampling, data entry, and data analysis. Field equipment was calibrated according to manufacturer's recommendations. Data sheets were checked at the end of each field day for completeness and accuracy, then scanned and saved as electronic copies. All data were entered into an electronic spreadsheet, with entered data validated by a second person to identify and correct any transcriptional errors. Tables containing calculated values and data summaries were reviewed, and values were verified by a second, independent individual.

5.6.4 Impingement and Entrainment

There are several levels of QA and QC checks with the impingement and entrainment data. One level is at the data entry stage where data from field sheets is entered into a database and then a minimum of 10% of the data entered was checked to verify it was entered correctly. A second level of data entry is in the field. Impingement monitoring was overseen by an independent third party in the field. The third party aided in field fish identification, verified identification of samples in the freezer, and ensured forms were completed in a consistent manner. Samples that were frozen included Whitefish, Spottail Shiners, and any other individuals that required verification of identification. Form completion and QA results are communicated weekly to the stations. The independent third party submitted bi-weekly impingement audits. Audits were reconciled with the original datasheets, and the database was updated accordingly.

5.7 Updates to Environmental Monitoring

Bruce Power conducted a local population survey in 2016. The purpose of this survey is to understand the current human, social, economic, and natural environment surrounding Bruce Power's site. The survey is performed every five years to support regulatory requirements set by the federal and provincial governments. This information is essential for Bruce Power's Environmental Monitoring Program, which supports our commitment to protect local residents and the environment.

The purpose of the survey is to gather feedback about the food and water that is consumed by the people who live at residences as well as their specific lifestyle and activities. Additionally, the survey results will be shared with the local municipalities to support emergency preparedness planning. Individual answers will be kept confidential and will not be released or used for any purpose other than for this survey. A summary of the survey findings after the survey was completed has been provided to those requested and involved with the survey. Incorporation of survey results into environmental monitoring occurred in 2017.

5.7.1 Radiological Environmental Monitoring

For the 2018 dose calculations, there was a change in the approach taken when REM data included values that were less than the associated detection limit (Ld) or critical level (Lc). In previous years' dose calculations, values <Ld or <Lc were assumed to be half of the respective limit for background samples, and equivalent to the limit for local samples. In 2018, those values were taken as reported. For example, in the calculation of local or background averages where some measured values were reported as less than Lc or Ld, the uncensored analytical results were used in the calculation. This change in procedure is intended to achieve consistency in reporting of REM data and also to achieve consistency with other procedures where those data are also used (e.g. ERA). The implications of this change to the reported doses are very minor. In most cases, the resulting doses are slightly higher in following the new approach. This approach was continued for 2019 data.

The transition to an electronic workflow was completed in 2018, and 2019 marks the first full year using the new laboratory information management system (with NuclearIQ at the core). The system reduces the potential for human error in data processing, and provides improvements in traceability, and access to additional measurement parameters (e.g. sample specific detection limits) for Environment Programs.

5.7.2 Conventional Environmental Monitoring

Baseline wildlife inventories along with procedural updates are occurring to align with N288.4.

6.0 INSPECTIONS AND AUDITS

6.1 Inspections

The Canadian Nuclear Safety Commission (CNSC) conducts regulatory activities such as compliance field and Type II inspections under the authority of the Nuclear Safety and Control Act to assess licensee compliance with regulatory requirements. The purpose of inspections is to verify:

- Compliance with the licence and other regulatory documents
- Compliance with licensee documentation and procedures

- Implementation and execution is consistent with CNSC requirements, and follows industry standards and best practices.

The methodologies used to collect information were the following:

- Document review
- Database review
- Observations such as field, laboratory, sampling techniques
- Discussions with licensee staff

Inspections were conducted in the areas of Environmental Monitoring, Effluent Control and Monitoring and waste. Table 49 presents the inspections conducted by the CNSC throughout 2019.

Table 49
Environmental Monitoring Inspection Recommendations

MONTH	INSPECTION TYPE	SUBJECT AREA	# OF MAJOR FINDINGS	# OF MINOR FINDINGS	GENERAL CONCLUSION
MAR 2019	Field	Environmental Monitoring	0	0	Compliant with Environmental Monitoring
MAR 2019	Field	Effluent Monitoring	0	0	Compliant with Effluent Monitoring
MAR 2019	Field	Bruce A and Bruce B Hazardous Waste Management	0	1	Bruce A - Compliant Bruce B - One of the chem waste drums staged for offsite shipment did not have the SAM/BARREL MONITOR RESULTS: PASS box checked off on FORM-13799
SEPT 2019	Type II	Effluent Control and Monitoring	0	0	Based on the scope of the inspection, CNSC staff concludes that Bruce Power met the regulatory requirements. CNSC recommend that Bruce Power evaluates their operation of monitoring equipment at Bruce A and consider expediting the replacement of Bruce A stack monitors.

Based on the scope of the inspection, CNSC staff concluded that Bruce Power met all regulatory requirements. CNSC staff did not find evidence of unsafe operations that would result in undue risk to the health and safety of persons, the environment, or that would compromise respect for Canada's international obligations.

7.0 ENVIRONMENTAL RISK ASSESSMENT

To account for continued Operations, including Major Component Replacement, the 2015 ERA was updated in 2017 to accommodate the PROL renewal process for Major Component Replacement (MCR) and submitted as part of the 2018 licence submission package. The Environmental Quantitative Risk Assessment included a Predictive Effects Assessment (PEA) to demonstrate consideration of environmental protection during future site activities, including MCR activities. The ERA, PEA and associated tables are a retrospective and predictive ERA respectively that has been prepared following the guidance of CSA N288.6 12. An updated version of ERA was submitted in December 2018 and incorporated comments from CNSC and Indigenous groups as applicable and applied a different approach to the thermal risk assessment. The ERA and PEA were combined in one document with associated appendices in a separate document (see [R-12][R-13]). The ERA fulfills the environmental protection requirements under the Nuclear Safety and Control Act. The Canadian Environmental Assessment Act does not apply. An important area of focus related to this regulatory item is public and Indigenous engagement and consultation activities that were integrated into routine communications.

CNSC and Environment and Climate Change Canada (ECCC) staff reviewed the ERA and PEA submissions and updates. They concluded that the potential risk from physical stressors and from radiological and non-radiological releases to the environment are generally low to negligible and that the ERA was completed consistent with the overall methodology of N288.6-12 [R-118].

The ERA found that operation of the Site has not resulted in adverse effects on human health or nearby residents or visitors due to exposure to non-radiological substances. Risks to ecological receptors from exposure to non-radiological substances were limited to exposure to soil in a small number of former industrial areas onsite. These included the former construction landfill, and the fire training facility. A small number of non-human receptors were identified as potentially at risk. However, it should be noted that the conservative nature of the assessment likely overestimates the actual risks.

Risks to fish and wildlife populations due to physical stressors were generally considered to be negligible, with a low to moderate risk related to thermal effects for cold water species such as Round Whitefish. This low to moderate risk is expected to be limited to a small geographic area and thermal monitoring and modelling will continue in order to further refine the risk related to thermal effluent and cold water fish species.

The radiation doses to members of the public residing in the area surrounding the Site are less than 1% of the CNSC effective dose limit for a member of the public (1 mSv/y). With a hazard quotient of less than 0.01, and with the uncertainties in the assessment (e.g., concentrations reported as less than a detection limit) addressed in a conservative manner, there is no radiological risk to human health for members of the public resulting from normal operations on the Site.

The radiation dose rates to non-human biota residing on or near the Site are less than 10% of the applicable United Nations Scientific Committee of the Effects of Atomic Radiation (UNSCEAR) benchmark value. With an exposure ratio of less than 0.1, and with many of the uncertainties in the assessment (e.g., occupancy factors and ingestion parameters) addressed in a conservative manner, it is reasonable to assert that there is no radiological risk to non-human biota resulting from normal operations on the Site.

Based on the review of the past Bruce Power-specific related concerns raised by Indigenous communities, all technical considerations within the construct of the CSA N288.6 framework have been dispositioned. Bruce Power has taken action in response to many of these concerns and continues to work to address these issues. Bruce Power remains committed to having ongoing consultation and discussions with all three Indigenous communities to ensure we can enhance our monitoring programs to address areas of concern and interest. Bruce Power provided copies of the entire licence application, and any further applications associated with environmental regulatory approvals to SON, MNO and HSM, and as previously communicated with all three communities, will make any necessary time beyond our routine meetings to discuss content and concerns.

During the 2018 licence renewal process, Bruce Power presented their commitment to working with SON, MNO and HSM in a manner that best suits their communities, to enhance involvement in environmental monitoring. Recognizing that every community has a unique set of interests, in 2020 we will continue to work with each community to determine where they see their involvement in Environmental Monitoring.

Over the course of 2019, Bruce Power worked with SON, MNO and HSM to discuss any outstanding concerns or issues as it relates to regulatory items (i.e. Mitigation Assessment, Fisheries Act, Thermal ECA). Over the course of 2020, Bruce Power is working with all three communities to continue discussions, with a focus on developing plans for fish improvement projects.

The design and use of mitigation technologies have been implemented to minimize impacts to the greatest extent possible. The Bruce Power site location, situated on the Douglas Point headland, was strategically picked because of its high energy zone with access to cold, deep water. The headland juts into Lake Huron providing a natural feature for dispersion of thermal effluent and the shoreline location itself is naturally low in diversity of fish species due to high wave action and winter ice movement. Bruce Power has measured and evaluated the results of the past activities in relation to Bruce A restart of Units 3 & 4 and Refurbishment of Units 1 & 2; this extensive evaluation program has positioned us well to predict the potential impacts of Major Component Replacement (MCR) activities. This experience, and improved processes and materials, has further enhanced the rigour of our current Environmental Risk Assessment (ERA) Process. Prior Environmental Assessments (EA) and Follow-up

Monitoring Programs confirmed that there were no unreasonable risks to the natural environment from either restart or refurbishment work.

The ERA process is meant to provide an on-going analysis of a company's interaction with the environment enhancing oversight from the previous process where a single EA and follow-up program would have been required. Completion of the ERA on a 5-year cycle is supported by the annual EPR reports and both documents are subject to in-depth regulatory review. The next ERA will be submitted in 2022.

Bruce Power complies with Federal Regulations, programs, and standards, which protect human health and the environment under the Nuclear Safety and Control Act. The Class I Nuclear Facilities Regulations under the Nuclear Safety and Control Act set out requirements related to environmental protection that must be met. The General Nuclear Safety and Control Regulations require every licensee to take all reasonable precautions to protect the environment and to control the release of radioactive nuclear substances or hazardous substances within the Site and into the environment as a result of the licensed activity.

Comprehensive environmental monitoring programs have been in place for nearly 40 years, since the pre-construction phases of Bruce A and Bruce B. This monitoring continued throughout construction and operation phases and several comprehensive assessments have been conducted over the years to ensure ongoing on-site and off-site environmental protection. This includes the Bruce Power Development Ecological Effects Review (OPG 2000) [R-119], monitoring associated with EAs completed since 2001 under the Canadian Environmental Assessment Act (e.g., for the Restart of Bruce A), as well as associated EA follow-up programs, environmental permitting and environmental monitoring. In the last 20 years alone these have included:

- 2017 Environmental Quantitative Risk Assessment
- Annual Environmental Assessment Follow-up Monitoring Reports for Unit 1&2 Restart (2007-2015)
- Annual Environmental Monitoring Program Reports (pre 2001 to present)
- 2015 Environmental Quantitative Risk Assessment
- 2008 Environmental Impact Statement for the Bruce New Nuclear Power Plant Project
- 2006 EA Study Report for the Bruce A Refurbishment Project (Units 1&2 Restart)
- 2004 EA Study Report for the Bruce B New Fuel Project
- 2001 EA Study Report for the Bruce A Units 3&4 Restart
- 2000 Bruce Nuclear Power Development Ecological Effects Review

- 1999 Bruce B Environmental Effects Report for Units 5-8
- 1998 Phase 1 Environmental Site Assessment for the Bruce Heavy Water Plant
- 1997 Phase 1 Environmental Assessment Bruce Nuclear Power Development
- 1997 Bruce Used Fuel Dry Storage Facility Environmental Assessment

The ERA provides sufficient information to the CNSC to support their preparation of an EA under the Nuclear Safety Control Act as indicated in REGDOC-2.9.1[R-8]. The information provided in the ERA is as per the known status of projects as of June 1, 2017. Existing environmental monitoring will be retained as required to confirm predictions and be reported through the annual Environmental Monitoring Program (EMP) findings, which have been in place since 2001.

One of the benefits of using the ERA construct is the regular check-in points with regulators and the public as an ERA reoccurs every 5 years on an ongoing basis. This gives all parties an opportunity to contribute and identify concerns. This process allows for the identification of emerging trends and identifies any new risks that may arise, which is a further enhancement from past assessment processes. Indigenous groups and other members of the public had the opportunity to participate in and provide feedback on many of these recent impact assessments and will continue to do so in the future. We are actively engaging and providing Indigenous groups and the public opportunities to discuss topics of interest such as thermal effluent and impingement and entrainment of fish. However, this dialogue is not new and the company's future operations will not differ from what has been experienced and monitored since 2001; the company is confident in its conclusions and will continue to monitor and confirm the facility operates within these limits.

As outlined earlier, prior Environmental Assessments are a one-time process, are only triggered when a major change to operations is proposed, and predictions were verified with a follow-up monitoring program that does not need to follow the construct of the CSA N288 suite. The new process combines the one-time rigour of the previous process with an ongoing requirement that continually verifies performance in a number of important areas.

Bruce Power continues to be engaged in understanding the impacts from climate change predictions and considering how they may affect future operations and the local environment. As climate change prediction models become more advanced and/or the environment changes, the ERA will continue to be updated to determine if and how such change impacts the operation of Bruce Power's facilities and, if required, assess what changes are necessary to ensure continued environmental protection.

Finally, Bruce Power acknowledges the need to address the cumulative environmental effect of multiple stressors when and where it is warranted. The science behind the determination of cumulative effects is at its infancy: there is no consensus on a definition of "cumulative impact" and assessment methods are largely absent. Understanding cumulative impacts to a system first begins by evaluating its individual stressors. Bruce Power has done this and none of the individual stressors poses an unreasonable risk to the environment. Thus it is unlikely that the combination of single stressors with low to no risk will result in a cumulative impact or approach an unreasonable risk. Over, forty (40) years of operations of the Bruce site and continued monitoring and assessment has provided empirical evidence of little to no risk to the local environment.

8.0 WASTE MANAGEMENT

Bruce Power manages many different forms of waste to ensure they are disposed of safely without polluting the environment:

- Hazardous waste (oils, chemicals lighting lamps and ballasts – some of these are recycled)
- Recyclable waste (glass, plastic, metal, cardboard, paper, wood, batteries and electronics)
- Organic waste (compost)
- Radiological waste (low-, intermediate-, and high-level radiological waste is taken to the on-site Western Waste Management Facility, which is operated by Ontario Power Generation)
- Landfill waste (for those items that are neither hazardous, recyclable, organic, nor radiological)

Bruce Power complies with all waste regulations and requirements of the relevant Federal, Provincial, and Municipal authorities. Further, Bruce Power has taken an active role for many years to reduce all forms of waste: from an environmental and financial standpoint waste reduction is good for our company and the community in which we reside. Our philosophy employs a whole life-cycle approach in that we reduce waste at the consumer level, generate less waste at the company level, find opportunities to reuse products (on-site, off-site donations, or sell them at auction), and implement recycling programs that are available in the ever-changing recycling market. To minimize the amount of waste sent to landfill each day, Bruce Power has implemented a number of initiatives that apply the principles of reduce, reuse, recycle, and recover. Wherever its fate, each waste stream generated at Bruce Power is processed and disposed of in a safe and environmentally-responsible manner.

Table 50 summarizes the waste management and pollution prevention reports submitted to regulatory agencies.

Table 50
Bruce Power Waste Regulatory Reporting

Waste	Report Title (Document Control Number)	Regulatory Agency	Submission Date (Frequency)
Conventional Waste (See s8.1)	Report of a Waste Reduction Work Plan (2019) O Reg 102/94	Internal Report	Q1 2020 (Annual)
Conventional Waste (See s8.1)	Report of a Waste Audit (2019) O Reg 102/94	Internal Report	Q1 2020 (Annual)
Hazardous (See s8.2)	Generator Registration Report (O Reg 347) Records	Ministry of Environment, Conservation and Parks	13JAN2020 (Annual)
Waste & Pollution Prevention - PCB (See s8.2.2)	Federal PCB Regulations Bruce Power 2019 Annual Report Declaration (BP-CORR-00521-00004)	Environment and Climate Change Canada	31MAR2020 (Annual)
Waste & Pollution Prevention - PCB (See s8.2.2)	2019 Annual Bruce A Polychlorinated Biphenyl (PCB) Waste Storage Report for Bruce A Storage Facility # 10400A003 (BP-CORR-00541-00006)	Ministry of Environment, Conservation and Parks	29JAN2020 (Annual)
	2019 Annual WCTF Polychlorinated Biphenyl (PCB) Waste Storage Report for Storage Facility # 10402A001 (BP-CORR-00541-00005)	Ministry of Environment, Conservation and Parks	29JAN2020 (Annual)

8.1 Conventional Waste

The primary objectives of the Conventional Waste Program are to process wastes in a safe and environmentally responsible manner while achieving waste minimization through the application of reduce, reuse, recover, and recycle principles.

Conventional waste at Bruce Power is managed and disposed of in accordance with regulatory requirements including:

- The Ontario Environmental Protection Act [R-58] Ontario Regulation 347, General Waste Management [R-120]
- Ontario Regulation 103/94, Industrial, Commercial and Institutional Source Separation Programs [R-121]
- Ontario Regulation 102/94, Waste Audits and Waste Reduction Work Plans [R-122]

- Transport Canada's Transportation of Dangerous Goods (TDG) Act [R-123]

Management of conventional waste includes all non-hazardous and non-radiological items: recyclables, compost, and waste destined for landfill. As defined in Ontario Reg. 103/94 [R-121], Bruce Power is considered to be a large manufacturing establishment and is mandated to have recycling programs in place for the following materials:

- Aluminum
- Cardboard (corrugated)
- Fine paper
- Glass
- Newsprint
- Polyethylene (high density) jugs, pails, crates, totes, and drums
- Polyethylene (linear low density and low density) film*
- Polystyrene (expanded) foam*
- Polystyrene trays, reels and spools*
- Steel
- Wood (not including painted, treated, or laminated wood)

*Limitations apply depending on the availability of service providers able to recycle these materials.

In addition to these recycling programs, Bruce Power has an established composting program for organic waste including food, paper towels, coffee cups and lids, and biodegradable containers.

Bruce Power utilizes approved waste disposal contractors to collect conventional wastes on site. Waste disposal vendors are bound by Environmental Compliance Approvals (ECA) that stipulate approved wastes that can be accepted by the landfill or facility.

Table 51
Conventional Waste Generated at Bruce Power from 2016 to2019
(1 metric ton (mt)= 100kg)

Year	Landfill (mt)	Compost: Zebra Mussels (mt)	Compost: Other (mt)	Recycling (mt)	Total (mt)	Number of Workers*	Waste Generated per Worker* (kg)
2016	555	162	103	1,145	1,965	8,201	240
2017	462	195	97	1,042	1,795	8,584	209
2018	572	58	111	1,226	1,967	9,654	204
2019	609	58	61	1,288	2,016	10,010	218
Note: * Includes all categories of active workers: Regular, Temporary, Casual, Augmented Staff, Student, and External Non-Time Reporting workers.							

The total amount of conventional waste produced in the last 4 years at Bruce Power has remained relatively constant (Table 51). In 2019, 2,016 metric tons of conventional waste was generated, which was only slightly higher than in 2016 and 2018 (2.5% increase from 2018).

In 2019, 30% of Bruce Power's conventional waste was sent to landfill (a 70% diversion rate), 5.9% was composted, and the remainder was processed via several different recycling streams (Figure 55). Historically, the total amount of conventional waste generated by Bruce Power has not changed markedly; it has ranged between 1,550–2,400 metric tons over the last 12 years, although the distribution among different waste streams has changed significantly over time depending on the types of activities occurring at the company (commissioning/decommissioning) and the different recycling processes available in the global waste management market Figure 56.

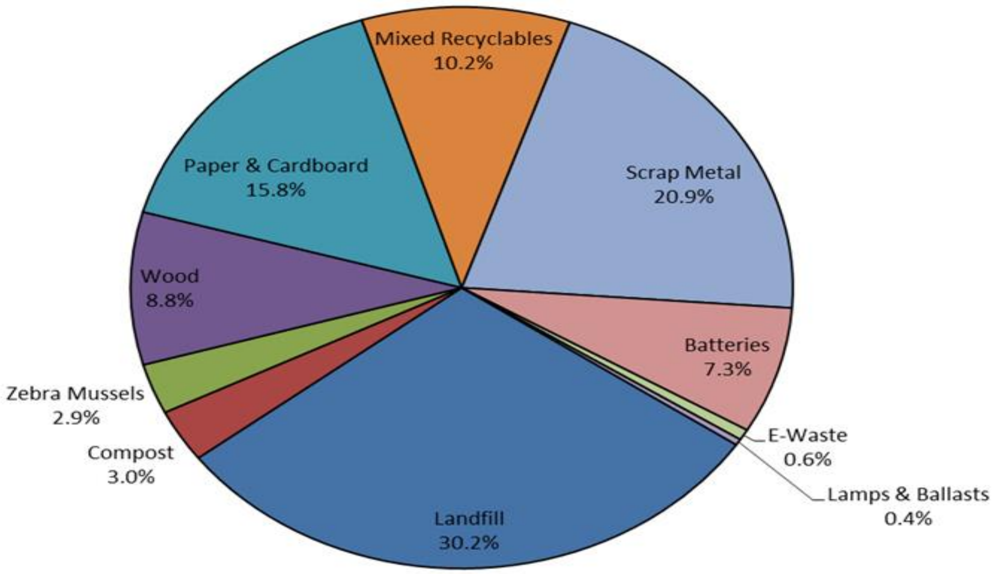

Figure 55
Distribution of all waste streams generated at Bruce Power in 2019, with the exception of zebra mussels, compost (both are sent to an organics processing facility) and landfill. All waste streams are processed at recycling facilities.

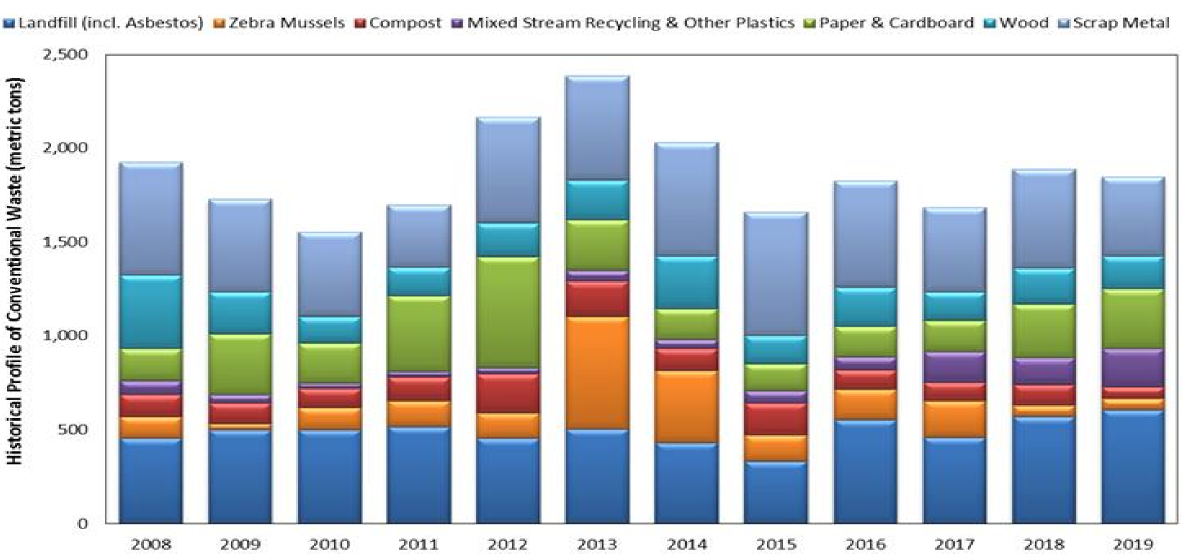

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Figure 56
Historical amount and distribution of all conventional waste generated at Bruce Power between 2008 and 2019. Not shown are the relativity small amounts of batteries, electronic wastes and lamps and ballasts which made up 138, 109, 78 and 167 metric tons (mt) in 2016, 2017, 2018 and 2019 respectively.

As per Ontario Reg. 102/94, Bruce Power must also perform an annual conventional waste audit. The waste audit must be completed by a third-party vendor, and a waste audit report that includes a waste reduction work plan must be prepared for Bruce Power. Independent assessments of Bruce Power's performance in conventional waste management have occurred annually for many years. The auditor's assessments consistently show that Bruce Power is performing well in comparison to other large industrial facilities.

8.2 Hazardous Waste

Waste programs are in place across Bruce Power to safely handle and dispose of hazardous wastes in accordance with regulatory requirements outlined in the Environmental Protection Act, O Reg. 347, General Waste Management [R-120].

Hazardous wastes, such as chemicals, oils, batteries, and fluorescent tubes, are generated at numerous locations on-site. They are carefully tracked to ensure all hazardous waste is safely disposed of in accordance with all applicable regulatory requirements. Bruce Power has an excellent network of external waste vendors (certified to carry and/or receive hazardous wastes) who frequently work with us to dispose of all our hazardous waste streams in an industrially and environmentally safe manner. Hazardous wastes are routinely diverted from landfill by recycling batteries, lamps, and electronic waste.

8.2.1 Hazardous Waste Inspections

In January and June of 2019, the MECP completed inspections of the Centre of Site and Bruce A PCB Storage Facilities, respectively. There were no significant findings and no follow-up actions were required. Routine Bruce Power inspections of both PCB Storage Facilities continue to occur monthly.

8.2.2 Polychlorinated biphenyl (PCB)

According to the PCB regulations (SOR/208-273) [R-124], equipment containing PCBs in a concentration of at least 50 parts per million but less than 500 parts per million, must have the equipment removed from site by December 31, 2025. This includes electrical transformers and their auxiliary electrical equipment, lighting ballasts, and capacitors. Electrical cables in any concentration must also be removed so that they are not "abandoned in place" which is a violation of the Environmental Protection Act [R-58]. Currently there is no regulatory removal date for PCB cables. In 2018 a plan was created for PCB removal, focusing on the above equipment, in order to meet the regulatory deadline of December 31, 2025. This plan is reviewed and updated on a regular basis to ensure that Bruce Power will complete the regulatory deadline.

8.3 Radiological Waste

The volume of radiological waste is managed and minimized through effective material management, decontamination and segregation techniques, and by utilizing the principles of reduce, reuse, recycle, and recover wherever possible. Radiological wastes are processed in a safe, environmentally responsible manner that recognizes key factors such as ALARA principles, environmental footprint reduction, and full compliance with regulatory requirements.

Following on the excellent work done in 2017, overall volumes of low-level waste continued to trend below what was planned for 2018. An increased awareness amongst staff to minimize overall material usage and improved segregation efforts by all allowed for a greater emphasis on overall volume reduction and an increase in the amount of material diverted to recycling rather than being disposed of as waste. This trend in volume reduction is expected to continue through to 2019 and beyond.

9.0 AUDITS

9.1 External Audit – ISO 14001

External audits of the EMS are annually performed by the registrar, currently SAI Global. Every three years a re-registration audit occurs, and that registration then stands for three years. The re-registration audit is longer and greater in scope than the surveillance audits which are conducted in-between the re-registration cycle. Surveillance audits are conducted to examine a slice of the management system and assess ongoing conformance to the elements of the standard.

In the fall of 2017, Bruce Power was re-registered to the new version of the CSA ISO 14001 standard released in 2015 as well as completed a successful surveillance audit in 2018 and again in 2019. The external audit generally identifies Non-Conformances (NCs) to the standard, Areas of Concern (AoC) or Opportunities for Improvement (OFIs). There have been no non-conformance or areas of concern identified in 2018 or 2019, or for the previous six years, Table 52.

In 2019, the audit was successfully completed with no non-conformances, no system weaknesses, and a demonstration of continual improvement. Overall, the auditor was satisfied with Bruce Power's Environmental Management System and implementation of environmental programs. Bruce Power management, including the Board of Directors, continues to demonstrate and maintain a high level of commitment to the implementation of the environmental management system. Environmental safety is considered one of the four pillars of safety of the facility.

Table 52
Historical Bruce Power External Audit

Year	Opportunities For Improvements	Areas of Concern	Non Conformances
2012	6	0	0
2013	4	0	0
2014	7	0	0
2015	5	0	0

2016	8	0	0
2017	6	0	0
2018	8	0	0
2019	4	0	0

9.2 Internal Independent Oversight Audits

9.2.1 ISO 14001 – Environmental Management System Audit

Internal Independent Oversight Audits are performed once annually against the ISO 14001 standard [R-11]. These audits are performed to ensure Bruce Power's environmental management system (EMS) continually conforms to the standard. These audits are generally more in depth than the external audits and can be used to focus on certain environmental program areas each year. All programs are required to be audited once in a three year period. This three year period aligns with the external re-registration timeframe set out by the accreditation body. The 2019 Environmental Management System Audit, AU-2019-00004, concluded that Bruce power has a mature EMS that is effectively implemented and maintained in accordance with the requirements of both the organization and the ISO 14001 Standard [R-11].

9.2.2 N288.4 and N288.5 Environmental and Effluent Monitoring Programs

The N288.4 and N288.5 [R-4][R-15] environmental standards require an audit to be performed once every five years to help ensure that the effluent and environmental monitoring programs operate in compliance with their procedures and elements. The initial Independent Oversight Audit against N288.4 and N288.5, AU-2018-00001, was performed in the spring of 2018. Bruce Power addressed all audit finding and is in compliance with these standards.

10.0 SUPPLEMENTARY STUDIES

10.1 Environment Research Programs

The environmental research programs at the Nuclear Innovation Institute (NII) [R-125] aim to support research examining the overall health of Lake Huron and the Great Lakes, including exploring concerns such as invasive species, climate change and changes in population of native fish species such as Whitefish. These research programs will enhance our knowledge of the impacts of plant operations on the surrounding aquatic life with the following long-term goals:

- Fully understand the thermal, ecological and environmental impacts of once-through cooling on the surrounding aquatic environment.
- Determine the potential implications of climate change scenarios and other stressors for the overall ecological health of Lake Huron.

- Predict the potential impact of climate change scenarios for the use of once-through cooling on Lake Huron, including warming lake temperatures, increased biofouling, and changes in species composition.
- Contribute to the basic science surrounding the impacts of changing temperature and water conditions on the aquatic environment.

10.1.1 Aquatic Biota (2018-2022)

This research program will continue to investigate the research gaps identified in the course of the previous Whitefish research program.

A Mitacs grant application was successfully submitted in 2017 seeking support for four Post-doctoral fellows for an additional five years of research. These post-doctoral fellows will engage in research on the following areas:

1. Determine the genetic population structure of Lake Whitefish, Round Whitefish, and Yellow Perch using advanced DNA analysis techniques.

2. Examine potential mechanisms causing mortality during embryogenesis and reduced fitness later in life by comparing transcriptomes of fish using advanced DNA analysis techniques.

3. Determine the survival and fitness of Lake and Round Whitefish subjected to thermal discharges during embryonic development.

4. Assess the survival of embryos from a model species (Yellow Perch) reared in varying temperatures reflective of thermal discharges.

An NSERC application was submitted in 2018 in support of research addressing three remaining key questions:

1. Thermal effects in Lake and Round Whitefish hatchlings and juveniles: What are the effects of variable and increased incubation temperatures on Lake and Round Whitefish hatchlings and juveniles?

2. Thermal effects in spring spawning fish: Using Yellow Perch as a model species, what are the effects of variable and increased incubation temperatures on the embryonic, hatchling and juvenile stages of spring spawning fish?

3. Population structure of Lake and Round Whitefish and Yellow Perch: What are the underlying population structures and habitat use of Lake and Round Whitefish and Yellow Perch in Lake Huron and near Bruce Power? In particular, what are the boundaries of the populations near Bruce Power?

10.1.1.1 Research Activities and Results

Developmental effects of elevated rearing temperatures on Lake and Round Whitefish larval and juvenile stages

This research is investigating whether thermal stress experienced during embryonic development of Lake Whitefish impacts fitness of fish during the larval and juvenile lifestages. The objectives are to compare response of the following between species (Lake Whitefish and Round Whitefish) and among different thermal groups.

An R-based analysis of embryo size (morphometrics) measurements was developed. Data collection from 2018 larvae is complete and data analysis and manuscript preparation is ongoing.

In the fall of 2018, Lake and Round Whitefish embryos from Lake Huron, Ontario, Superior and Simcoe were collected. Additional Lake Whitefish embryos were collected from Lake Diefenbaker in Saskatchewan.

In 2018-2019, the experimental set-up was designed and the first studies of the thermal preferences of juvenile Lake Whitefish were completed. The 2019 studies examined the post-hatch survival, feeding, growth and behaviour effects of seasonal and elevated seasonal thermal regimes on post-hatch development.

Developmental effects of elevated rearing temperatures on Lake and Round Whitefish embryos

In 2018-2019, Round and Lake Whitefish embryos collected in the fall of 2018 were incubated under seasonal regimes starting at 8°C or 6°C and dropping by 1°C/week until 2°C, then staying at 2°C or 5°C per week for 6 weeks, followed by a rise of 1°C per week until hatch. An elevated seasonal regime was tested at +4°C above the seasonal regime. Data analysis is ongoing for these experiments but has been complicated by high overall mortality across experimental thermal regimes.

Testing of acute heat shocks early in the seasonal decline for Lake Whitefish was also completed in 2018-2019. A threshold temperature of mortality was observed in one of the early incubation acute heat shock experiments, where exposure to 8 or 10 °C during early life had no effect while exposure to 12 °C induced an increase in embryonic mortality.

Performance effects of elevated rearing temperatures on Lake and Round Whitefish larval and juvenile stages

The performance effects examined in this research look at the long-term effects of sub-optimal rearing temperatures on 1) swim performance and metabolism and 2) thermal stress responsiveness using transcriptomics. Experiments will continue to examine the effects of sub-optimal incubation temperatures and daily heat shocks on thermal tolerance in Lake Whitefish.

Swim tunnels were attempted unsuccessfully with 18-month-old Lake Whitefish but may be tried again with 2.5-year-old Lake Whitefish in the future.

Juvenile Lake Whitefish (embryos reared at 0, 2 or 5°C °C and held at 14-16°C) aged 19 to 20 months old were exposed to 6°C heat shocks for two hours followed by varied recovery periods of 4-48 hours in length. Transriptomic (mRNA) profiles will be obtained from this experiment.

Lake Whitefish embryos were reared at seasonal, elevated seasonal or seasonal plus daily heat shock groups. Larvae from the elevated seasonal group in this experiment were found to hatch earlier and have a higher critical thermal maximum than those in the seasonal or seasonal plus daily heat shock group. No morphometric differences were found between groups. Heat shock experiments were completed on these larvae to examine the threshold for heat shock protein induction with heat shocks from 0 to 12°C. Work examining stress genes in larvae from these groups is ongoing.

<u>Thermal effects in spring spawning fish</u>

Obtaining yellow perch embryos for experiments continues to be challenging and researchers are working to develop a collaborative network at multiple site across Ontario to ensure embryos are obtained during the very short spring 2020 spawning season.

<u>Population structure of Lake and Round Whitefish and Yellow Perch</u>

The research continues to expand upon the population structure work from prior Whitefish research. The recent focus has been on developing the use of single nucleotide polymorphisms (SNPs) as a tool for investigating Whitefish population structure. The data analysis has explored the trade-off between the cost of DNA sequencing and the resolution power provided by the resulting SNP data. Specifically, Search Bay shows relatively strong differentiation from the other sites within the lake, while North Point and Hammond Bay showed slight differentiation in the ordination and maximum likelihood approaches. The area around Bruce Power shows no genetic differentiation in all three analyses with Scougall Bay, Douglas Point, McRae Point and Fishing Islands having very little differentiation. This indicates that there is not likely a distinct lake whitefish population in the Bruce Power area. On a larger scale, preliminary results suggest that the genetic diversity of Lake Whitefish may be higher outside of the Great Lakes region. The SNP Whitefish genetic population structure manuscript has been accepted for publication.

Researchers are continuing to develop a network to facilitate the collection of Round Whitefish specimens from additional sites in Lake Huron. This species is not commercially harvested and is therefore only available via targeted netting, such as that done by government and tribal biologists for population monitoring. These specimens will be used to delineate the population structure of Round Whitefish in Lake Huron using SNPs.

Researchers are also developing a network to collect Yellow Perch specimens from Lake Huron. Two specimens are currently available and will be used to pilot basic genomic characterization for Yellow Perch.

Lab evaluation is in progress for the completion of bulk- and compound-specific stable isotopes analyses of Lake and Round Whitefish and Yellow Perch from a variety of sites in Lake Huron.

10.1.1.2 Outcomes

Table 53
Scientific reports for Aquatic Biota

Graham, C.F., Boreham, D.R., Manzon, R.G., Stott, W., Wilson, J.Y., and Somers C.M. How "simple" methodological decisions affect interpretation of population structure based on reduced representation library DNA sequencing: a case study using the lake whitefish. Accepted to PLOS One	Publication
Mitz, C., Thome, C., Cybulski, M.E., Somers, C.M., Manzon, R.G., Wilson, J.Y., and Boreham, D.R., 2019. Thermal dependence of size-at-hatch in the lake whitefish (Coregonus clupeaformis). Canadian Journal of Fisheries and Aquatic Sciences 76:2069-2079.	Publication
Eme, J., Mueller, C.A., Lee, A.H., Melendez,C., Manzon, R.G., Somers, C.M., Boreham, D.R., and Wilson, J.Y. 2018. Daily, repeating fluctuations in embryonic incubation temperature alter metabolism and growth of Lake whitefish (Coregonus clupeaformis). Journal of Comparative Physiology B, 226:49-56.	Publication
Lim, M., Manzon, R.G., Somers, C.M., Boreham, D.R., and Wilson, J.Y., 2018. Impacts of temperature, morpholine, and chronic radiation on the embryonic development of round whitefish (Prosopium cylindraceum). Environmental Toxicology and Chemistry, 37:2593-2608.	Publication
Hulley, E.N., Taylor, N.D.J., Zarnke, A.M., Somers, C.M., Mazon, R,G., Wilson, J.Y., and Boreham, D.R., 2018. DNA barcoding vs. morphological identification of larval fish and eggs in Lake Huron: advantages to a molecular approach. Journal of Great Lakes Research 44: 1110-1116.	Publication
Morgan, T.D.; Graham, C.F.; McArthur, A.G.; Raphenya, A.R.; Boreham, D.R.; Manzon, R.G.; Wilson, J.Y., Lance, S.L.; Howland, K.L.; Patrick, P.H.; Somers, C.M., 2018. Genetic population structure of the round whitefish (Prosopium cylindraceum) in North America: multiple markers reveal glacial refugia and regional subdivision. Canadian Journal of Fisheries and Aquatic Sciences, 75:836-849.	Publication
Sreetharan, S., Thome, C., Tsang, K.K.; Somers, C.M.; Manzon, R.G.; Boreham, D.R.; Wilson, J.Y., 2018. Micronuclei formation in rainbow trout cells exposed to multiple stressors: morpholine, heat shock, and ionizing radiation. Toxicology In Vitro 47:38-47.	Publication

10.1.1.3 2020 Research Plan

<u>Thermal effects in Lake and Round Whitefish hatchlings and juveniles</u>

Researchers will continue experiments examining the effects of embryonic sub-optimal temperature on temperature preferences in Lake Whitefish. Tissue processing and preparation of samples for RNA seq submission will continue along with transcriptome assembly and transcriptomics data analysis.

Pending sufficient embryos, researchers will conduct sub-optimal incubation temperature experiment to assess the short-term impacts of embryonic incubation temperature on the stress response using transcriptomics. Also pending sufficient embryos, chronic irradiation exposures and repeat assessment of proposed thermal regulatory limits will be repeated in Round Whitefish.

<u>Thermal effects in spring spawning fish</u>

Researchers plan to initiate studies on rearing and development of Yellow Perch embryos and on sub-optimal temperature in Yellow Perch embryos and juveniles.

<u>Population structure of Lake and Round Whitefish and Yellow Perch</u>

Researchers will publish the manuscript on developing the use of single nucleotide polymorphisms (SNPs) as a tool for investigating Whitefish population structure. Collaborative network development for specimen collection for Round Whitefish and Yellow Perch in Lake Huron will continue. Stable isotope contract services will be established.

10.1.2 Thermal Study (2016-2020)

The Thermal Study research program is intended to develop and improve technology for substrate temperature monitoring. This includes examining the accuracy of aerial thermal scans. The program intends to explore the effect of the substrate on temperature changes experienced by aquatic biota.

10.1.2.1 Research Activities and Results

Data from 2 winters of simulated thermal flume Lake Whitefish embryo incubations was compiled into a manuscript that was submitted for publication in 2019.

10.1.2.2 Outcomes

Table 54
Scientific Reports for the Thermal Study Research

Ciezaldo, M., 2018. Assessing the effectiveness of airborne thermal technology for delineating environmental thermal effluence. Lakehead University, Thunder Bay, 2018	MSc thesis

10.1.2.3 2020 Research Plan

Researcher plan to complete the publication of work related to the modifying effects of spawning ground substrate on the temperatures experienced by Lake Whitefish embryos incubating within the substrate.

10.1.3 Biodiversity (2019-2020)

Spotted Turtles (*Clemmys guttata)* are an endangered species in Ontario, and worldwide. The Biodiversity research program is working towards enhancing the knowledge about this endangered species in Ontario.

The project will examine the daily movements, location, range, hibernation site and average daily movement of Spotted Turtles during low and high lake-level years. The project will also examine the impact of flooding events on the reproductive rates of the population and the risk of population extinction. This will provide information regarding the impact of climate change on aquatic systems and impacts on threatened or endangered species.

Both mark-recapture and radio transmitters are being used to survey Spotted Turtle populations.

10.1.3.1 2020 Research Plan

Data collection for the project will continue until December 2020.

10.2 Public Health Research Programs

The public health low-dose radiation effects research programs at NII are focused on improving our understanding of how radiation impacts biological systems. Programs explore both cancer and non-cancer endpoints related to removing background radiation, radiation exposure during sensitive life stages and to specific organs during medical diagnostics, with a focus on the low-dose range. Goals of the public health low-dose radiation effects research programs include:

- Contribute to basic radiation science, particularly in the low dose range, to understand how radiation impacts biological systems
- Inform regulations and practices for medical and occupational radiation exposure in Canada and internationally

10.2.1 Ultra-Low Dose (2016-2022)

The laboratory established in the Sudbury Neutrino Observatory Laboratory (SNOLAB) will allow researchers to examine the biological effects of prolonged exposure to a sub-natural background radiation environment. The 2 km of overhead rock effectively shields out cosmic radiation. Because living organisms have evolved in the continual presence of natural background ionizing radiation, researchers believe it is essential for life and helps to maintain genomic stability. Prolonged exposure to sub-background radiation environments will therefore be detrimental to biological systems.

The ultra-low dose research program has explored the effect of ultra-low levels of background radiation on Lake Whitefish embryo survival and development. Single-cell models grown in typical ambient radiation and under ultra-low dose Sudbury Neutrino Observatory Laboratory (SNOLAB) conditions will be evaluated for markers of cancer development including mutation frequency, chromosomal aberrations and differentiation. The effect of irradiation on single cell models and Lake Whitefish embryos raised under ambient and ultra-low-dose conditions was determined and the results have been submitted for publication.

In 2018, this project successfully received a 5-year NSERC grant to match the Bruce Power funding and will now be extended until 2022. Additional matching funding from Mitacs for a SNOLAB postdoctoral fellow was obtained in 2019 for three years.

10.2.1.1 Research Activities and Results

Low-Radon Specialized Tissue Culture Incubator

Due to radiological decay in the surrounding rock, underground radon levels are higher than on the surface (approximately 130 Bq/m^3 underground compared to 5 Bq/m^3 on surface). A low-radon specialized tissue culture incubator was installed underground to reduce radon levels below natural background and allow researchers to achieve much lower radiation levels underground compared to the surface.

In 2019, training and testing of specialized tissue culture incubator monitoring systems was completed. This included work to quantify and calculate the levels of natural background radiation (NBR) components (i.e., radon, gamma, neutrons) in the SNOLAB, both in the underground Researching the Effects of the Presence and Absence of Ionizing Radiation (REPAIR) laboratory and within the custom low-radon glovebox, and above ground laboratory. This work demonstrated that the low-radon specialized tissue culture incubator successfully reduced the major component gamma, neutron and radon radiological contaminants to a sub-NBR environment. Methodology for the transportation and growth of cell lines in the underground laboratory was tested in preparation for longer-term experiments.

Cell Culture System

Preliminary work has been progressing in the NOSM laboratory with the cell culture systems and endpoints to be used underground. In 2019, the radiation dose response for cell transformation (i.e. how often a normal cell becomes tumorigenic) characterization began.

Adaptive Response in Yeast

The adaptive response is a process where cells previously exposed to low doses of a stressor obtain a level of resistance as a form of protection against subsequent higher doses of the same or different environmental stress. A number of different stressors have been shown to induce the adaptive response, particularly ionizing radiation and thermal stress. To better understand the adaptive response and the molecular mechanisms underlying the biological effects of low dose stressors, three different strains of yeast (*Saccharomyces cerevisiae*) were used as test organisms and subjected to thermal stress. The three strains of yeast include the

BY4743 wild type strain which is the parental strain used to create collections of gene deletion mutants and two genetically engineered strains provided by the BioSentinel Group at NASA Ames Research Center. The BioSentinel strains consist of a wild type strain and a radiosensitive rad51 deletion mutant strain. Collaboration between NOSM/NII and NASA will study how these yeast strains respond to high dose space radiation (while travelling in deep space) compared to ultra-low shielded space radiation in SNOLAB.

Heat shock response in the three yeast strains was assessed to determine a) the degree of cell killing and b) the optimal timing for the delivery of a priming heat shock to initiate an adaptive response prior to a higher heat shock. After determining the optimal dose of thermal stress to induce an adaptive response, whole transcriptomic analysis was performed to identify all the molecular pathways involved in initiating and maintaining this adaptive response. Evaluation of the transcriptomic data revealed that all three strains of *Saccharomyces cerevisiae* showed a distinct molecular response to the thermal stress when compared to the untreated controls. Preliminary data suggest that genes associated with protein folding, nutrient metabolism and reproduction are significantly altered during the thermal adaptive response in this study.

Low dose radiation and tumorigenesis

The research lab utilizes the CGL1 human hybrid cell system to study the effects of Low Dose Radiation (LDR) on tumorigenesis (i.e., tumor growth). This cell-line was derived from the hybridization of a tumorigenic HeLa cell and a normal human fibroblast resulting in a non-tumorigenic cell line. Research has demonstrated that LDR inhibits the baseline levels of tumorigenesis in the CGL1 model. Consequently, LDR reduces cancer risk and risk is not linear and proportional to dose. The project is studying the molecular mechanism responsible for LDR-mediated inhibition of tumorigenesis using advanced omics-based approaches. Researchers have established the CRISPR gene editing technology at NOSM. The research lab is now capable of augmenting research with precise gene-editing technology enabling the lab to perform state-of-the-art molecular mechanistic studies.

Epigenetic biomarkers for low dose radiation exposures

LDR can alter the “molecular marks” on the DNA without causing gene mutation. The “molecular marks” on the DNA allows the cells to alter its function depending on the location of these “marks”. These “molecular marks” are referred to as “epigenetic modifications”. Epigenetic modification can result in altered cellular functions that can ultimately translate into altered health outcomes. The overall objective of this research project is to investigate whether LDR mediated epigenetic changes are an underlying mechanism by which LDR alters cell phenotypes.

10.2.1.2 Outcomes

Table 55
Scientific reports for the Ultra-low dose (SNOLAB) research

Pirkkanen, J., Boreham, D., Mendonca, M., 2017. The CGL1 (HeLa × normal skin fibroblast) human hybrid cell line: A history of ionizing radiation induced effects on neoplastic transformation and novel future directions in SNOLab. Radiation Research 188(4.2):512-524	Publication
Thome, C., Tharmalingam, S., Pirkkanen, J., Zarnke, A., Laframboise, T., Boreham, D., 2017. The REPAIR project: Examining the biological impacts of sub-background radiation exposure within SNOLAB, a deep underground laboratory. Radiation Research 188(4.2):470-474	Commentary
Pirkkanen J, Tharmalingam S, Morais IH, Lam-Sidun D, Thome C, Zarnke AM, Benjamin LV, Losch AC, Borgmann AJ, Sinex HC, Mendonca MS, Boreham DR, 2019. Transcriptomic profiling of gamma ray induced mutants from the CGL1 human hybrid cell system reveals novel insights into the mechanisms of radiation-induced carcinogenesis. Free Radical Biology and Medicine, 145:300-311. doi: 10.1016/j.freeradbiomed.2019.09.037.	Publication

10.2.1.3 2020 Research Plan

The results of the specialized tissue culture incubator bio-dosimetry, showing that the system is as close to zero radiation as experimentally possible, will be prepared for publication and submitted.

The radiation dose response for cell transformation (i.e. how often a normal cell becomes tumorigenic) characterization will be completed.

Cell culture experiments will begin underground in 2020. Researchers will begin to determine the level of reactive oxygen species (ROS) as a result of ultra-low dose background radiation and the gene expression of ROS scavenging proteins. These studies will include the comparison of data from the surface labs in Sudbury and Thunder Bay and the underground SNOLAB.

Over the next year, the yeast strain genes that have shown the greatest alterations will be further evaluated using strains of yeast that are mutated to specifically delete the major genes identified in the adaptive response. The differentially expressed genes will be analysed using sophisticated bioinformatics software designed to determine which molecular pathways are associated with the altered gene expression. The transcriptomic data produced will link the adaptive response phenotype to the molecular mechanisms involved in this response. The work will support NASA in understanding cellular response to environmental stress.

Additionally, adaptive response in yeast research in the next year will include looking at the adaptive response induced by ionizing radiation and evaluating the transcriptomic response. This work is in preparation to duplicate these studies within the sub-natural background radiological (NBR) environment of the SNOLAB. This part of the study aims to explore the hypothesis that the absence of NBR will lead to the absence of the adaptive response.

Human cells adapted in an ultra-low dose environment (SNOLAB), and above ground low dose exposure will be used to identify epigenetic biomarkers that underlie ultra-low dose and low dose radiation exposures.

10.2.2 Radiation Hormesis (2018-2020)

More than 90% of animals are arthropods and of these, insects crucially mediate health and function of diverse terrestrial and most freshwater ecosystems. Radiation contamination can significantly impact arthropod function, density and diversity, but the subject remains understudied. NII (in association with the Mitacs and NSERC funding Agencies) has supported comprehensive studies of radiation impacts on a model insect – the domestic cricket, *Acheta domesticus*. Lifetime studies of radiation impacts on longevity, growth, maturation, reproduction, cognition and behaviour can be obtained in months with crickets (rather than years required for vertebrates). The small size of crickets allows large sample sizes and low costs. Most results with insects, including biomarkers of stress and radiation impacts, can be extrapolated to vertebrates due to similar regulatory and functional aspects.

Gene expression is associated with methylation status, and methylation-supporting diets have proven effective in offsetting impacts of mutations. In general, radiation reduces global methylation and methylation also declines with age. Some suggest that radiation initially reduces methylation but that methylation may subsequently increase as a defensive response. Alterations in methylation status have been reported from radiation-contaminated environments. As a result, a dietary supplement that would enhance methylation processes under radiation exposure might be of value in limiting losses or potentially enhancing defense. A radio-protective antioxidant enhanced diet will be tested in crickets. This diet may have applications in the space program, the military and the nuclear power industry.

10.2.2.1 Research Activities and Results

Juvenile crickets (*Acheta domesticus*) were irradiated and followed for growth, maturation, longevity, fecundity, motor and cognitive status, reproductive impacts and immune system function.

The impact of radiation on the growth, reproduction and social and sexual behaviour of crickets is being examined. Experiments exposed crickets to 2Gy to 12Gy of radiation as 2-week old juveniles. Cricket mating is dependent on male acoustic cues and both male and female chemical cues. At lower radiation dose ranges, no change in acoustic mating cues was noted but at higher doses radiation damage to wings interfered with singing to the degree that mating was no longer possible. A paper was submitted describing these changes. Growth, maturation time and maturation mass of male crickets irradiated as juveniles were recorded along with hatching success and biomarkers for immunological changes, DNA damage and stress resistance.

The radio-protective antioxidant enhanced diet irradiations are in progress. Preliminary results show that the radioprotective diet effectively protects crickets and alters maturation rate.

10.2.2.2 Outcomes

Table 56
Scientific reports for the Ultra-low dose (SNOLAB) research

Lemon J.A., Aksenov, V., Samigullina, R., Aksenov, S., Rodgers, W.H., Rollo C.D., Boreham, D.R. 2016. A multi-ingredient dietary supplement abolishes large-scale brain cell loss, improves sensory function, and prevents neuronal atrophy in aging mice. Environ. Mol. Mutag. 57: 382-404.	Publication
Tran, J. 2017. Impacts of low-dose ionizing radiation on life history and immunity in the cricket, Acheta domesticus L. M.Sc Thesis Online by McMaster, 2018: https://macsphere.mcmaster.ca/handle/11375/22131	MSc Thesis
Shephard, A.M. 2017. Effects of early life ionizing radiation exposure on the life-history of the cricket, Acheta domesticus. M.Sc Thesis, McMaster University September 2017 Online McMaster 2018: http://hdl.handle.net/11375/22201	MSc Thesis
Shephard, A., Aksenov, V., Rollo, C.D. 2018. Hormetic effects of early juvenile radiation on adult reproduction and offspring performance in the cricket (Acheta domesticus)" Dose Response July-September 2018:1-7	Publication
Fuciarelli, T. 2019. Transgenerational and reproductive impacts of acute early-life radiation on the house cricket, Acheta domesticus. M.Sc. Thesis, McMaster University. Published Online by McMaster University.	MSc Thesis

10.2.2.3 2020 Research Plan

Chemical cricket mating cue, growth, maturation time and mass and hatching success data analysis will be completed for the irradiated crickets. Biomarker analysis is in progress. Experiments examining the potential for early irradiation to induce resistance to subsequent doses will be completed.

10.2.3 Fetal Programming (2015-2020)

The fetal programming research program explores the effects of radiation exposure during pregnancy (fetal programming) in mice on cardiovascular and metabolic disease endpoints in offspring. The effect of low-dose radiation in attenuating induced fetal programming will also be explored. This research is important for the medical community to help characterize risks associated with radiation exposure during pregnancy. Sources of radiation exposure include both diagnostic imaging exposure and occupational exposure.

The research is relevant to NII in adding to the knowledge base used to set dose limits and determine regulations surrounding occupational radiation exposure in pregnancy.

NII funding for this research is matched by a peer-reviewed NSERC grant.

10.2.3.1 Research Activities and Results

In 2018, two additional cohorts of mice were irradiated *in utero* at 10, 100 and 1000mGy to assess changes in lung development. One of the cohorts received an induced acute lung injury to assess radiation-induced pulmonary immune response. Also in 2018, a cohort of C57Bl/6J mice received no treatment, a sham saline injection or a dexamethasone steroid injection to examine the effects of glucocorticoid-induced fetal programming.

In 2019, behavioural testing and gene expression data analysis was completed to correlate changes in offspring behaviour with cellular changes. From the mice that underwent behavioral testing, tissue analysis of gene expression was completed to look at various genes involved in a number of cellular pathways and to look for reactive oxidative species that would indicate potential stress that did not show a behavioral response. Gene expression changes were only detected for one gene at 1000 mGy. There were no significant changes in protein expression. There was a significant increase in glycogen content in the heart at higher doses, indicating increased glucose storage in heart tissue in response to adverse conditions. There were significant changes in enzyme activity related to the cellular response to oxidative stress caused by radiation. This data was incorporated with micro Positron Emission Tomography (PET) data for publication (currently under review).

The assessment of the outcomes of glucocorticoid-induced fetal programming including PET imaging, glucose tolerance tests and tissue collection was completed in 2019. PET imaging showed some significant differences in glucose uptake in the brown adipose (fat) tissue related to dexamethasone treatments but no differences in the body weight of offspring or in the weight or size of the adipose (i.e., fat) tissue.

Additional work related to the development of pulmonary testing endpoints and the development of an Acute Lung Injury Model to include prenatal radiation exposure continues in collaboration with Study #5 (Prenatal Exposure to Diagnostic Radiation) in the Genetic Models of Risk project.

10.2.3.2 Outcomes

Table 57
Scientific reports produced for Fetal Programming research

Sreetharan, S., 2017. Prenatal ionizing radiation exposure effects on cardiovascular health and disease in C57B1 mice. MSc thesis, McMaster University, September 2017	MSc thesis
Sreetharan S, Thome C, Tharmalingam S, Jones DE, Kulesza AV, Khaper N, Lees SJ, Wilson JY, Boreham DR and Tai TC. Ionizing radiation exposure during pregnancy: effects on postnatal development and life. Radiation Research 187(6):647-658	Publication
Puukila, S., Lemon, J., Lees, S., Tai, T., Boreham, D., Khaper, N., 2017. Impact of ionizing radiation on the cardiovascular system: A review. Radiation Research 188:539-546	Publication
Tharmalingam S, Sreetharan S, Kulesza AV, Boreham DR and Tai TC. Low dose ionizing radiation exposure, oxidative stress and epigenetic programming of health and disease. Radiation Research 188(4.2):525-538	Publication
Davidson, C., Phenix, C.P., Tai, T.C., Khaper, N.K., Lees, S.J., 2018. Search for a novel PET probe for cardiac inflammation detection. Am. J. Nucl. Med. Mol. Imaging. In Press.	Publication
Sreetharan S, Stoa L, Cybulski ME, Jones DR, Lee AH, Tharmalingam S, Kulesza AV, Boreham DR, Tai TC and Wilson JY. (2019). Cardiovascular and growth outcomes of C57Bl mice offspring exposed to maternal stress and ionizing radiation during pregnancy. International Journal of Radiation Biology. 95(8): 1085-1093.	Publication

Davidson CQ, Phenix CP, Tai TC, Khaper N and Lees SJ. (2018) Searching for novel PET radiotracers: imaging cardiac perfusion, metabolism and inflammation. American Journal of Nuclear Medicine and Molecular Imaging. 8(3): 200.	Publication

10.2.3.3 2020 Research Plan

The x-ray irradiation cabinet set-up will be completed. This will allow mice to be irradiated within the animal facility, minimizing transportation stress.

Behavioural testing and gene expression data analysis results will be submitted for publication.

The assessment of the outcomes of glucocorticoid-induced fetal programming including PET imaging, glucose tolerance tests and tissue collection and protein expression studies examining various antioxidant proteins results will be submitted for publication.

The results of the effects of radiation exposure on modulating an acute lung injury stimulus will be submitted for publication.

10.2.4 Genetic Models of Risk (2016-2019)

The genetic models of risk program explores the effects of low dose radiation in three ways. First, the biological effects of low-dose radon exposure are being explored in cellular and invertebrate models. Second, the effects of low-dose radiation on immune function are being examined. Finally, the association between low-dose radiation exposure and acute lung injury in both animal models and human hospital patients is being observed.

10.2.4.1 Research Activities and Results

<u>2019 RESEARCH COMPLETED</u>

Study #1: Immunological Effects

Aim: To conduct an assessment of the acute immunological effects of clinically relevant radiation doses in a rat model.

Progress: Institutional ethics approval obtained. Rats (n=90) were irradiated using the X-RAD 320 (Precision X-Ray) with whole body single doses of 0 (sham), 20, 200 mGy or 4Gy before assessment at 30 min, 4 and 24 h post irradiation. A manuscript describing the effect of irradiation on the pulmonary and immune function of Sprague Dawley rat model was submitted in 2019. Spleen tissue underwent gene array analysis for DNA damage, apoptosis, cell cycle panels and RNA.

A manuscript will be prepared in 2020 to publish the results of the gene array analysis.

Study #2: ICU Radiation Exposure

Aim: To conduct a retrospective audit of daily and cumulative radiation exposure over the course of hospital admission in Intensive Care Unit (ICU) patients and in pregnancy.

Progress: A chart audit for radiation exposure received by pregnant women admitted to hospital received ethical approval in 2019. Data collection and analysis are complete and a manuscript was submitted for review.

Publication of a manuscript describing diagnostic radiation exposure in pregnant women admitted to hospital is expected in early 2020.

Study #3: Cell Lines

Aim: To understand the effect of both diagnostic (i.e., x-rays) and occupational (i.e., radon) radiation on cell viability, proliferation, RNA and protein expression.

Progress: Irradiations were completed using the X-Rad 320 irradiator for diagnostic exposure (200mGy) of respiratory epithelial cell line A549. The more radiation sensitive CGL1 cell lines was established and irradiated.

Cell lines will be transported to radon chamber and radon exposure will be initiated for both A549 and CGL1 cell lines in 2020.

Study #4: Radon Exposure

Aim: To examine the acute immunological effects of environmentally and occupationally relevant doses of inhaled radon gas in a healthy rat model.

Progress: This research program continued to examine clinically and environmentally relevant doses of x-ray and inhaled radon radiation on pulmonary immune response. These immune responses include oxidative stress, acute physiological and longer-term tissue repair and fibrosis in rat models. Parallel *in vitro* experimental programs have been being established at Flinders University and at NOSM laboratories. These programs will examine radon and x-ray effects on cell lines at doses ranging from absolute zero (SNOLAB) to those mimicking diagnostic, environmental and occupational exposures. A radon chamber was built at Flinders Medical Centre. Dosimetry of the new chamber was established in 2019. A manuscript is in preparation to describe radon chamber dosimetry.

In 2020, pilot animal studies will start in the radon chamber. The radon chamber dosimetry manuscript will be submitted for publication.

Study #5: Prenatal Exposure to Diagnostic Radiation

Aim: To investigate the developmental effects on the respiratory system and pulmonary immunology of ionizing radiation-induced fetal programming in an acute lung injury model. This is in collaboration with the Fetal Programming project.

Progress: Two cohorts of mice were irradiated to establish the baseline model in C57/BL6 mice and to examine the effect of radiation on induced Acute Lung Injury (ALI). Data collection and tissue analysis was completed for the cohorts examining the effects of radiation on induced ALI. Manuscript preparation and submission of the results for both cohorts are in progress.

In 2020, a manuscript describing the results of radiation-induced acute lung injury in rats will be submitted for publication.

Study #6: Lipopolysaccharide Radiation Exposure Study

Aim: To examine the acute immunological effects of environmentally relevant doses of radiation in a lipopolysaccharide male Sprague-Dawley rat model. Lipopolysaccharides (LPS) are endotoxins and are trigger high levels of immune response. LPS are linked to septic shock and other acute immune-response related illnesses in human.

In 2018, Male Sprague-Dawley rats (n=28) were inoculated with 3mg/kg of LPS. After 20 hours rats were irradiated (X-RAD 320) with whole body single dose of 20 mGy or 0 (sham). In 2019, data analysis for cell response, physiology and protein expression was completed and a manuscript submitted to describe the results. Publication of this manuscript is expected in 2020.

10.2.4.2 Outcomes

Table 58
Scientific reports produced for Genetic Models of Risk research

Puukila, S., C. Thome, A.L. Brooks, G. Woloschak, and D.R. Boreham. 2017. The role of radiation induced injury on lung cancer. Cancers. 9:89	Publication
McEvoy, J., Hooker, A.M., Boreham, D., Dixon, D.L., 2019. Audit of single and cumulative diagnostic radiation exposures in patients admitted to the intensive care unit. J Citr Care. 21(3):212	Publication
Puukila, S., Muise, S., McEvoy, J., Hooker, A.M., Boreham, D.R. Dixon, D.I., 2019. The effect of low dose diagnostic level radiation on the lung and spleen in an In Vivo model. Int J Rad Biol, 29:1-32.	Publication
Jobson, S., 2018. Modulation of the immune response to viral and bacterial stimulants. B Med Sci (Honours), Flinders University, Adelaide, Australia	BSc Thesis
McEvoy, J., 2019. Diagnostic exposure of ionizing radiation and its long-term effects. PhD cotutelle between Flinders University, Adelaide, Australia and McMaster University, Hamilton, Canada	PhD Thesis

10.2.5 Radiation Tools (2015-2019)

The radiation tools research programs aims to develop new radiation detectors to measure the dose and impact of realistic low-dose radiation exposure. Funding is being provided jointly by the CANDU Owners Group and Bruce Power as part of a larger NSERC CRD project. Bruce Power funding is being used for proton microbeam detector development.

10.2.5.1 Research Activities and Results

A microbeam is a vital probe in modern radiation biology experiments. However, instrumentation of a proton or alpha microbeam facility is extremely challenging and only a small number of laboratories offer these microbeams worldwide. The McMaster proton microbeam project began in 2005 and a dedicated proton collimation and control system has been built. To conduct radiation biology experiments using a microbeam, the number of protons hitting a cell, or another biological target must be accurately controlled and therefore, reliable operation of the proton counter is vital.

In 2019, researchers fabricated a 50μm thick CVD diamond detector and tested its signal performance using an alpha source.

10.2.5.2 Outcomes

Table 59
Scientific reports produced for Radiation Tools research

Tong, X., Thompson, J., Byun, S.H., in press. Development of a scCVD diamond detector as a transmission-type alpha particle counter. Nucl. Instr. Meth. A.	Publication

10.2.5.3 2020 Research Plan

In 2020, researchers are fabricating a thinner diamond detector (10μm thick) and the technology required to fabricate it. Once the thinner diamond detector is fabricated, it will be performance tested.

10.2.6 Lens of the Eye (2017-2021)

10.2.6.1 Research Activities and Results

The lens of the eye program aims to investigate the development of cataracts following exposure to ionizing radiation. Ionizing radiation exposure to the lens of the eye is a known cause of cataracts. Historically, it was believed that the threshold dose for cataract formation was 5 Sv and annual equivalent dose limits to the lens were set at 150 mSv. The International Commission on Radiological Protection (ICRP) and International Atomic Energy Agency (IAEA) have now reduced their threshold dose estimate for deterministic effects to 0.5 Gy and are now recommending an occupational limit of 20 mSv per year, averaged over 5 years, up to a maximum of 50 mSv in a single year.

In 2018 and 2019, an epidemiological study was completed to examine the association between patient exposure to multiple head CT scans and subsequent cataract formation. A research proposal was submitted to the Institute for Clinical Evaluative Sciences (ICES) outlining a project to identify if there is a correlation between CT scans and cataract surgery in Ontario. The data set contained all individuals residing in Ontario between 1994 and 2015 (22 years), resulting in a sample size of over 16 million. Several groups were excluded from the analysis: individuals with a history of congenital/trauma induced cataracts or anyone receiving radiotherapy for head and neck cancers. Data were extracted on the presence/timing of cataract extraction surgery as well as the number and timing of head CT scans received. Subjects were grouped based on the number of CT scans they received from 0 to 10+ (5-year lag) or 6+ (10-year lag). Data were also extracted for covariates to include in the analysis, which have previously been linked to cataract formation. This included age, sex, diabetes, hypertension and previous intraocular surgery. The full data set was analyzed using a multivariate cox proportional hazards survival model with 5-year and 10-year lags. There is a known latency period between radiation exposure and cataract formation, so it is unlikely that any cataract occurring within several years of a CT scan is due to radiation. The 5-year and 10-year lag omitted any CT scan from the analysis that occurred within 5 or 10 years of a cataract surgical procedure respectively. Overall, the multivariable cox model did not show any significant correlation between head CT scans and cataract extraction surgery. Individuals receiving 1 – 3 head CT scans did have a small increased risk of cataract surgery. However, individuals receiving 4 or more head CT scans did not have an increased risk. In general, an inverse dose response was observed, where the cataract risk decreased as the number of CT scans increased. Therefore, the conclusion of this study is that ionizing radiation exposure associated with head CT scans does not increase the risk of cataract formation. The paper was accepted for publication in January 2020.

During 2019, researchers also began in-vitro studies to investigate the mechanism behind radiation induced cataracts. Despite the large number of epidemiological studies on radiation cataracts, the exact mechanism by which radiation exposure in the lens can progress to opacifications still remains unknown. It is hypothesized that radiation primarily interacts with lens epithelial cells (LEC), one of the two cell types found within the human lens. DNA damage and oxidative stress in LEC may result in impaired differentiation proliferation and migration. This could lead to a buildup of cells thereby reducing the normal transparency of the lens resulting in a cataract. Researchers are testing this hypothesis using a LEC cell line cultured in the laboratory.

10.2.6.2 Outcomes

Table 60
Scientific reports produced as part of the Lens of the Eye collaboration

Thome, C., Chambers, D.B., Hooker, A.M., Thompson, J.W. and Boreham, D.R., 2017. Deterministic effects to the lens of the eye following ionizing radiation exposure: Is there evidence to support a reduction in threshold dose? Health Physics. 114(3): 328-343	Publication
Gaudreau K*, Thome C*, Weaver B, Boreham DR. Cataract formation and low dose radiation exposure from head computed tomography (CT) scans in Ontario, Canada, 1994 – 2015. Radiat Res. February 4, 2020, online ahead of print. *Co-first author.	Publication

10.2.6.3 2020 Research Plan

In 2020, lens epithelial cell lines will be exposed to ionizing radiation at different doses and dose rates. Researchers will investigate whether there is a dose rate dependency for radiation induced effects as well as determine what the threshold is for long term physiological changes. Overall, these mechanistic studies will help to further our understanding regarding the level of risk for cataract formation following low dose exposures.

10.2.7 Environment, Radiation & Health (2015-2019)

The Environment, Radiation and Health program is exploring the effects of adaptive immunity in prostate cancer patients who have received radiation therapy. A review of the Linear No Threshold (LNT) radiation science model is also in progress. Bruce Power funding for this research is matched by a Mitacs grant.

10.2.7.1 Research Activities and Results

Adaptive immunity in prostate cancer patients

Ethics approval for the low-dose half-body irradiation clinical trial was granted by the Hamilton Integrated Research Ethics Board in June 2017. The clinical trial has 15 patients currently enrolled or completed to date.

In 2019, the clinical trial continued to recruit three additional patients. No major side effects were reported, the most common minor problems were fatigue and minor short-term decreases in white blood cell count, platelet and hemoglobin levels. Recruitment, data collection and analysis will continue. An amended ethical approval has been submitted to allow recruitment of five additional patients who are not on testosterone deprivation therapy as these patients have a more positive response to the half body irradiation therapy.

A decision regarding the amended ethical approval for the half body irradiation trial for prostate cancer is expected in 2020. The recruitment of five additional patients is planned if ethics approval is received. If not approved, results will be complied for publication in 2020.

LNT Review – Literature review

This project has substantially contributed to a comprehensive, industry-led, international review of low dose radiation (LDR) biology. The project involved collaboration with world renowned radiation biologists resulting in numerous manuscripts that were published as a special edition in the journal of Chemic-Biological Interactions. These manuscripts collectively challenge the current model used for radiation risk prediction, known as the linear no-threshold (LNT) model. This model states that radiation is always considered harmful with no safety threshold. These publications dispute this model and shows that low doses of radiation provide numerous cellular advantages.

Three literature reviews were published in 2019, including reviews of: 1) cellular effects of radiation, 2) a review of the Biological Effects of Ionizing Radiation (BEIR) VI Radon report and 3) the epidemiological modeling of the effect of ionizing radiation exposures (Tharmalingham et al., 2019, Zarnke et al., 2019 and Ricci and Tharmalingham, 2019). All manuscripts associated with this project have now been published.

LNT review – Data re-analysis

Researchers have been working to investigate cancer risk due to inhaled beta-gamma emitting radionuclides in beagle dogs. From the late 1960s through the 1970's the Lovelace Respiratory Research Institute conducted lifespan studies on beagles that inhaled a single dose of ^{144}Ce, ^{90}Sr, ^{90}Y or ^{91}Y imbedded in an insoluble fused aluminosilicate matrix. This existing data is being used to complete several studies.

Study #1 (*Dose rate*) is examining the role of dose-rate on cancer induction in the lung following inhalation of beta-gamma emitting radionuclides. Using the data collected from the Lovelace studies, Bruce Power-funded researchers are re-analyzing the dose-rates of dogs that developed lung cancer. Previous work calculated the dose rate using the cumulative dose at death and over the lifespan. Since each emitter has a different half-life, the dose rate used for previous work is believed to be incorrect. This study aims to calculate the correct dose rate and examine its association with lung cancer induction. A manuscript of this work was published in 2019.

Work related to other Lovelace data re-analyses is complete and published.

10.2.7.2 Outcomes

Table 61
Scientific reports for Environment, Radiation & Health

Puukila, S., Thome, C., Brooks, A., Woloschak, G., Boreham, D., 2017. The role of Radiation Induced Injury on Lung Cancer. Cancers 9(89)	Publication
Tharmalingam, S., Sreetharan, S., Kulesza, A., Boreham, D., Tai, T., 2017. Low-dose ionizing radiation exposure, oxidative stress and epigenetic programming of health and disease. Radiation Research 188:525-538	Publication
Leblanc, A., 2017. Préconcentration du plutonium dans les possions entiers par extraction au point trouble couplé à la spectrométrie alpha: Rapport préliminaire. M.Sc. Université Laval	Preliminary report
Tharmalingam, S., Sreetharan, S., Brooks, A. L., and Boreham, D. R. (2019) Re-evaluation of the linear no-threshold (LNT) model using new paradigms and modern molecular studies. Chemico-biological interactions 301, 54-67	Publication
Zarnke, A. M., Tharmalingam, S., Boreham, D. R., and Brooks, A. L., 2019. BEIR VI radon: The rest of the story. Chemico-biological interactions 301:81-87	Publication
Ricci, P.F., and Tharmalingam, S., 2019. Ionizing radiations epidemiology does not support the LNT model. Chemico-biological interactions 301:128-140	Publication
Puukila, S., Thome, C., Brooks, A.L., Woloschak, G., Boreham, D.R. , 2018. The influence of changing dose rate patterns from inhaled beta-gamma emitting radionuclides on lung cancer. Int J Radiat Biol. 94(11):955-966	Publication
Scott, B. R., and Tharmalingam, S., 2019. The LNT model for cancer induction is not supported by radiobiological data. Chemico-biological interactions 301:34-53	Publication
Golden, R., Bus, J., Calabrese, E., Costantini, D., Borremans, B., Scott, B., Tharmalingam, S., Sreetharan, S., Brooks, A. L., Boreham, D. R., Zarnke, A. S., Kobets, A. M., Williams, G., Clewell, R. A., Clewell, H.,	Publication

Thompson, C., Ricci, P. F., and Williams, R. A. , 2019. An examination of the linear no-threshold hypothesis of cancer risk assessment: Introduction to a series of reviews documenting the lack of biological plausibility of LNT. Chemico-biological interactions 301:147

10.2.8 NEUDOSE (2019-2022)

Started in 2015, **NEU**tron **DOS**imetry & **E**xploration (NEUDOSE, pronounced "new dose") is a satellite mission that is being designed and built by researchers at McMaster University to measure the properties of radiation to which astronauts are exposed while performing spacewalks in low-Earth orbit. The official website for the NEUDOSE satellite project is updated weekly and can be accessed at https://mcmasterneudose.ca/.

10.2.8.1 Research Activities and Results

In 2019, the NEUDOSE project successfully completed the following Canadian Space Agency milestones:

- **Mission Concept Review** – hosted by McMaster University on January 15th and 16th, 2019
- **Preliminary Design Review** – hosted by Western University on October 10th and 11th, 2019

The project also implemented software for configuration and data management and obtained licenses for basic and advanced radio licensing for team members to allow for communication and commanding of the radio transceiver on the satellite.

Initial modelling work was completed on the electrical and power subsystem. A custom mechanical structure was designed. A prototype flight computer was designed and is being fabricated. Initial ground-station design and testing is underway for the tracking telemetry and command station. The final engineering model for the data acquisition instruments to measure the properties of radiation in space was redesigned and tested successfully.

10.2.8.2 2020 Research Plan

The solar power electrical and power subsystem prototype will be built and tested. A preliminary mechanical structure engineering model will be produced. The thermal responses from the 2018 High Altitude Student Platform (HASP) balloon launch are being incorporated into future thermal models. The potential for passive altitude control to improve communication response and power generation is being investigated. The prototype flight computer will be tested. Tracking telemetry and command ground station testing will continue. The final data acquisition instruments will be fabricated and tested.

10.3 Conventional Water Effluent

On August 23, 2018, quarterly EMEL samples were collected from the process effluent Control Point 0100 and shipped for analysis. Final results were provided on August 31, 2018 with Rainbow Trout at 60% mortality and 20% immobility; Daphnia Magna had 0% mortality and 0% immobility. Further sample analysis indicated that elevated levels of nitrite were the likely cause of the failure. Corrective actions to prevent reoccurrence include an enhanced monitoring program including pre-release sampling for nitrite to ensure levels are acceptable prior to each batch discharge. This enhanced monitoring program provides Bruce Power the ability to identify and prevent the discharge of toxic effluent, and to better trend and understand the potential source for of nitrite generation. To date, we have not seen elevated levels of nitrite in this process effluent sump [R-127].

Following the Bruce A CP 0100 EMEL Acute Toxicity Failure in 2018, pre-discharge sampling for nitrite was initiated for one year with review to determine long term requirements. This sampling was done to both prevent the discharge of toxic effluent and to monitor for nitrite in an attempt to identify its source. Upon completion of one year of sampling no conclusive determination of the source could be identified and although nitrite was detected regularly at no time did the level approach known toxic levels.

11.0 CONCLUSION

Bruce Power's mission is to provide clean, affordable and reliable energy for the province of Ontario, as well as to provide life-saving medical isotopes, while protecting the environment and supporting our communities. Bruce Power has focused on innovation, returning the site to its full operating potential, which contributes to the efforts of the Province to combat the impacts of climate change by providing clean energy. Ensuring environmental protection has been a focus of the business since Bruce Power was formed in 2001.

The Environmental Protection Program at Bruce Power implements the requirements in REGDOC-2.9.1, Environmental Protection Policies, Programs and Procedures utilizing the framework outlined in ISO 14001, Environmental Management Systems. This program ensures the protection of human health and the environment.

The environmental protection program includes effluent monitoring, environmental monitoring, waste management, spills management and sustainability. Together, these programs ensure Bruce Power adheres to all regulatory requirements as well as adopted environmental standards and upholds Bruce Power's social responsibility. The N288 series of environmental standards, many of which are included in the licence, provide instruction and guidance to continue to improve the environmental protection program and strive for industry excellence.

This report describes the effluent and environmental monitoring programs related to Bruce Power's operations, as well as an overview of waste management. These programs are within Bruce Power's environmental management framework. They are developed, implemented, periodically reviewed and enhanced where possible to ensure environmental protection. Monitoring of radiological, non-radiological (conventional and hazardous) substances and assessing the effect on human and non-human biota forms the basis for demonstrating environmental protection at a nuclear facility. The effluent and environmental monitoring programs are important to our facility because at they ensure, through sampling and analysis, that there are no negative effects from our plant operations on the environment and the public.

Bruce Power strives to maintain a positive working relationship with those who have an interest in our business. We are committed to open communications with community members, Indigenous communities and all stakeholders. This report includes a summary of Bruce Power's key environmental protection and stewardship activities, beyond compliance obligations, that occur within the local communities.

This report on environmental protection fulfills the reporting requirement outlined in section 3.3 of the licence as well as section 3.5 of REGDOC-3.1.1, Reporting Requirements for Nuclear Power Plants.

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APPENDIX A: SMALLMOUTH BASS NEST LOCATIONS

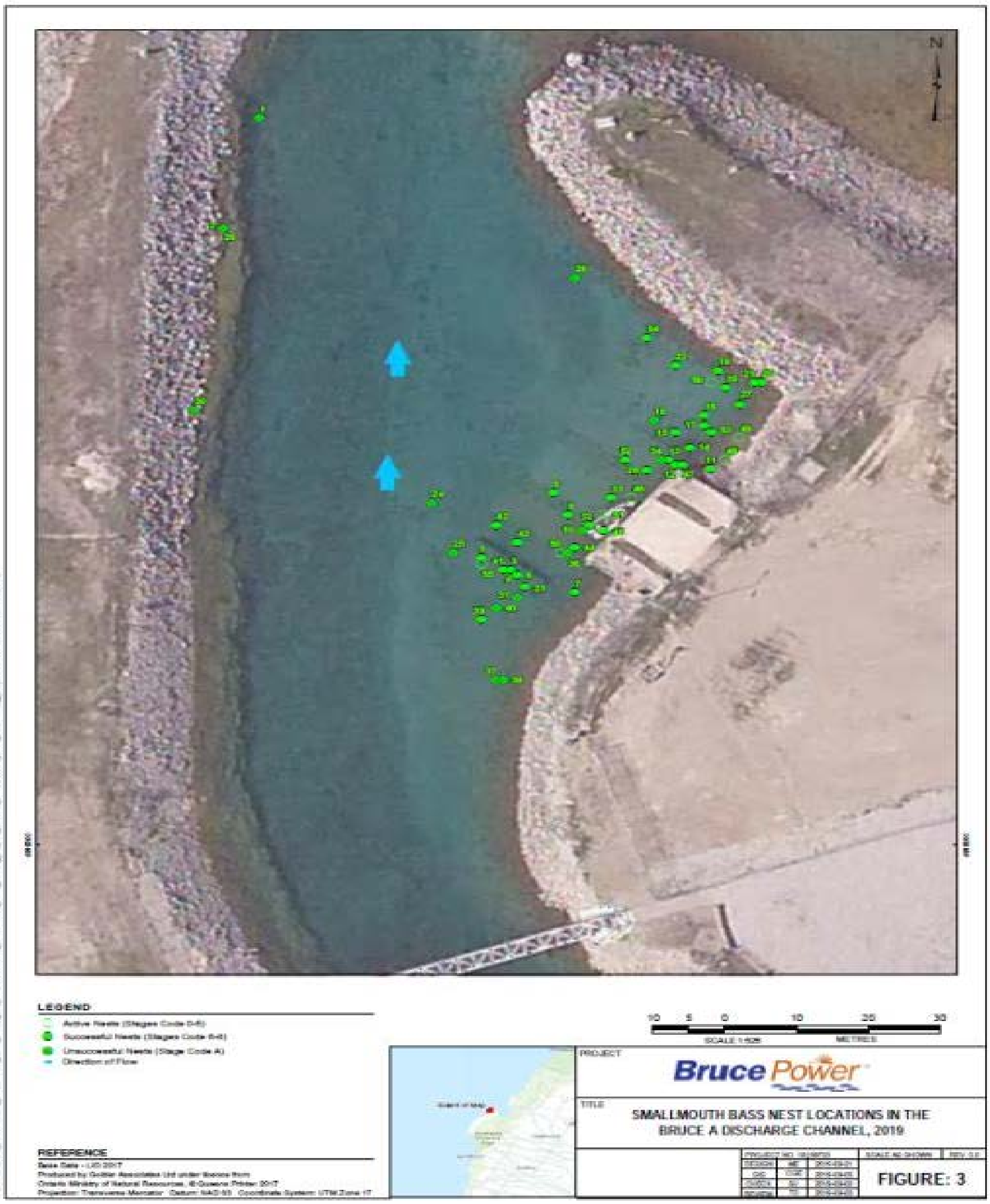

Figure 57
Smallmouth Bass Nest Locations in the Bruce A Discharge Channel, 2019

Appendix A (Continued)

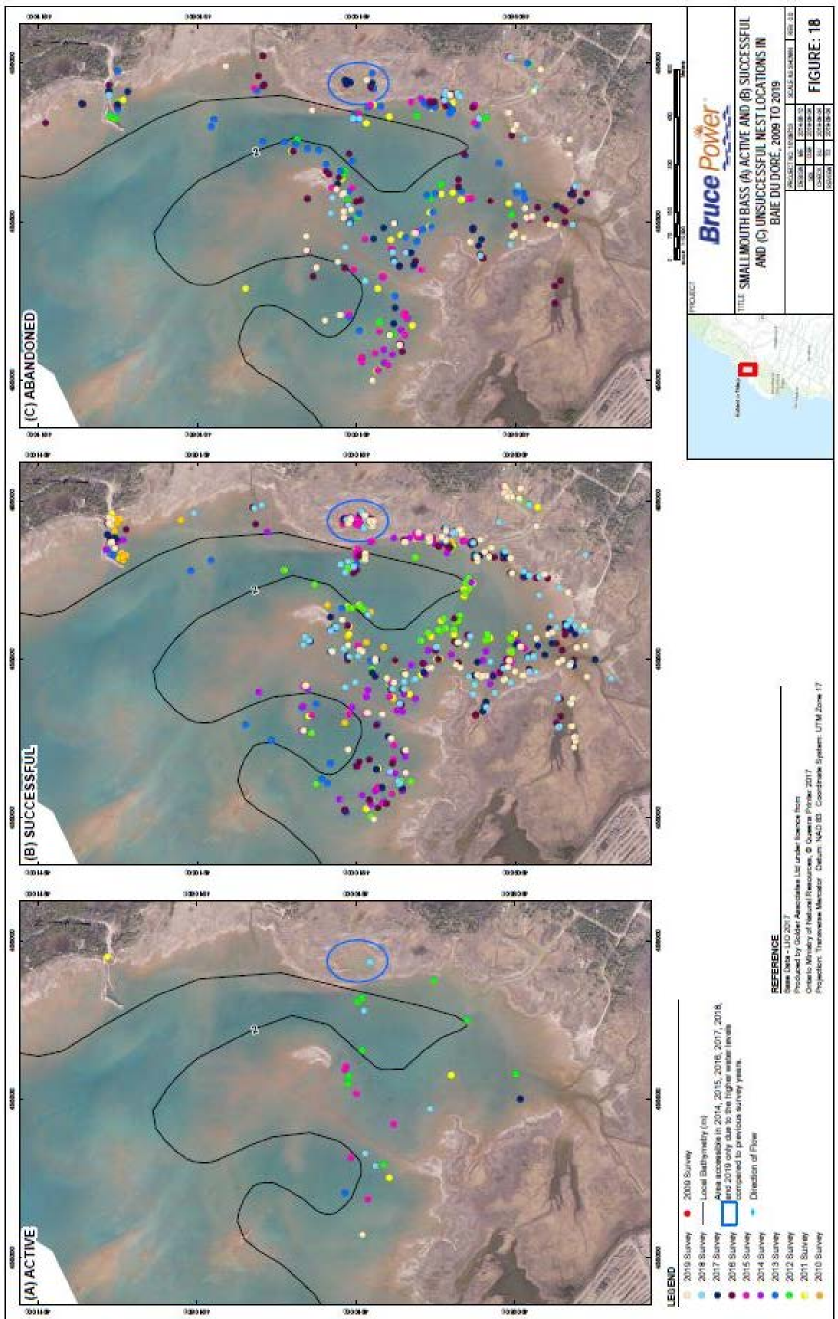

Figure 58
Smallmouth Bass (A) Active, (B) Successful, (C) Abandoned) Nest Location in the Bruce A Discharge Channel 2009 2019

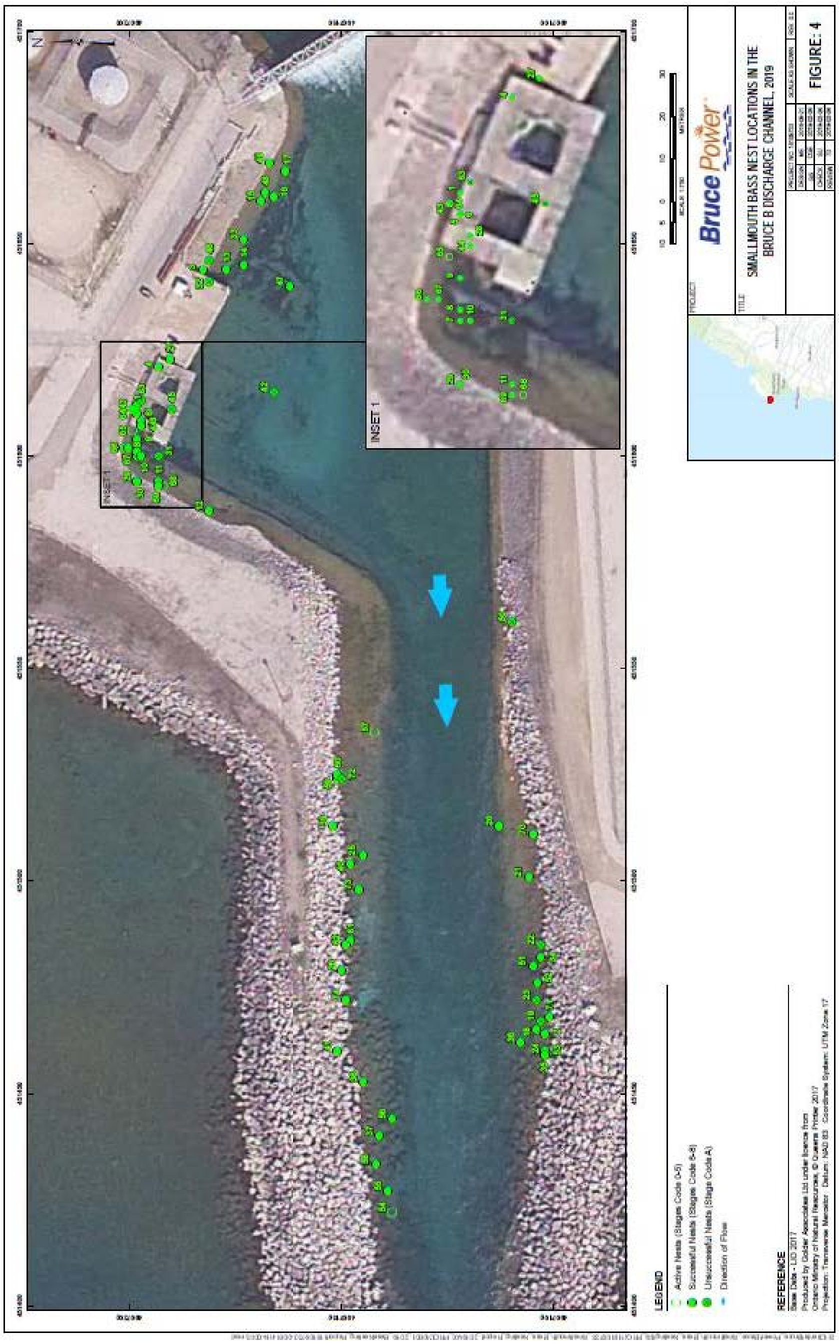

Figure 59
Smallmouth Bass Nest Locations in the Bruce B Discharge Channel, 2019

Appendix A (Continued)

Figure 60
Smallmouth Bass (A) Active, (B) Successful, (C) Abandoned) Nest Location in the Bruce B Discharge Channel 2009 2019

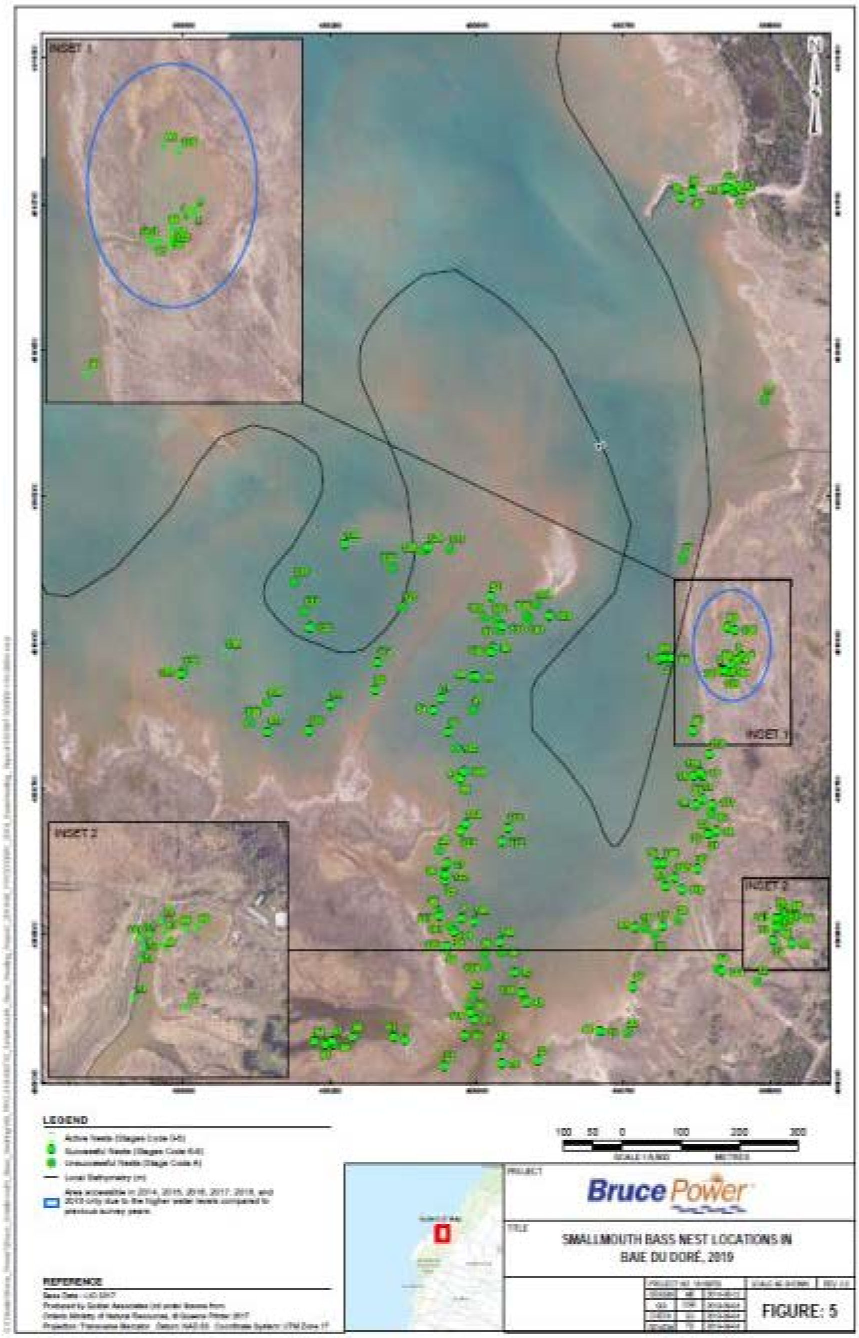

Figure 61
Smallmouth Bass Nest Locations in Baie du Doré, 2019

Appendix A (Continued)

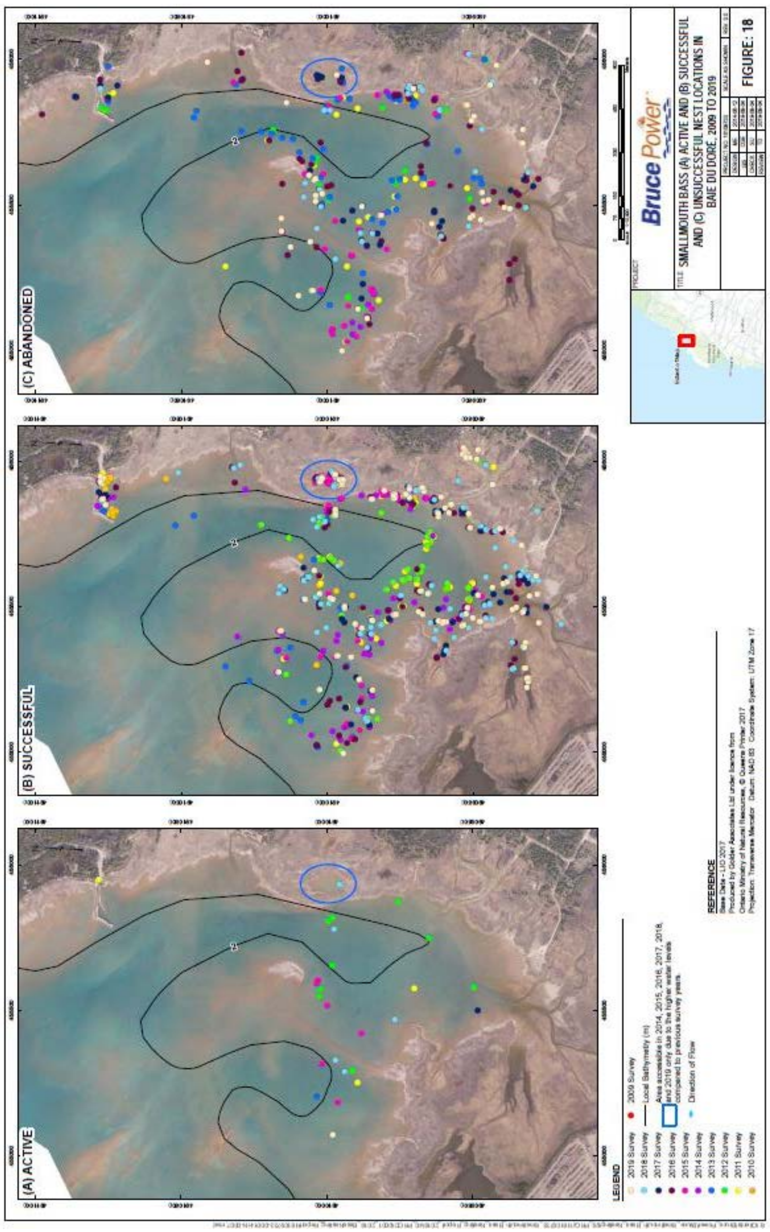

Figure 62
Smallmouth Bass (A) Active, (B) Successful, (C) Abandoned) Nest Location in Baie du Doré, 2009-2019

APPENDIX B: RADIOLOGICAL ENVIRONMENTAL MONITORING QUALITY ASSURANCE TESTING

Table 62
2019 - Eckert & Ziegler Analytics Test Results for Tritium in Water

Quarter	Bruce Power Value V_L (pCi/L)	1 Standard Deviation (S_L)	Eckert & Ziegler Analytics Value VA (pCi/L)	$(V_L+S_L)/V_A$	$(V_L-S_L)/V_A$
Q1	4.79E+02	1.26E+01	4.83E+02	102%	97%
Q2	5.15E+02	6.92E+00	5.15E+02	101%	99%
Q3	5.00E+02	5.57E+00	5.19E+02	97%	95%
Q4	1.81E+01	3.87E+00	1.87E+01	117%	76%

Table 63
2019 - Eckert & Ziegler Analytics Test Results for Gross Beta in Water

Quarter	Bruce Power Value V_L (pCi/L)	1 Standard Deviation (S_L)	Eckert & Ziegler Analytics Value VA (pCi/L)	$(V_L+S_L)/V_A$	$(V_L-S_L)/V_A$
Q1	1.23E+01	8.27E-01	1.07E+01	123%	107%
Q2	7.97E+00	5.35E-01	7.36E+00	116%	101%
Q3	1.12E+01	7.49E-01	1.03E+01	116%	101%
Q4	9.20E+00	6.18E-01	8.64E+00	114%	99%

Table 64
2019 - Eckert & Ziegler Analytics Test Results for Iodine in Milk

Quarter	Bruce Power Value V_L (pCi/L)	1 Standard Deviation (S_L)	Eckert & Ziegler Analytics Value VA (pCi/L)	$(V_L+S_L)/V_A$	$(V_L-S_L)/V_A$
Q1	3.27E+00	2.09E-01	3.31E+00	105%	92%

Q2	2.98E+00	1.27E-01	3.01E+00	103%	95%
Q3	3.40E+00	1.73E-01	3.41E+00	105%	95%
Q4	3.43E+00	1.38E-01	3.50E+00	102%	94%

Appendix B (Continued)

Table 65
2019 - Eckert & Ziegler Analytics Test Results for Gamma in a Filter

Annual	Bruce Power Value	1 Standard Deviation (S_L)	Eckert & Ziegler Analytics Value VA (pCi/L)	$(V_L+S_L)/V_A$	$(V_L-S_L)/V_A$
	V_L (pCi/L)				
Cerium-141	3.35E+00	1.19E-01	3.43E+00	101%	94%
Cobalt-58	3.45E+00	1.02E-01	3.72E+00	95%	90%
Cobalt-60	4.73E+00	9.24E-02	4.76E+00	101%	97%
Chromium-51	1.01E+01	3.82E-01	9.97E+00	105%	97%
Cesium-134	4.45E+00	9.17E-02	4.66E+00	97%	94%
Cesium-137	4.21E+00	1.36E-01	4.20E+00	103%	97%
Iron-59	3.51E+00	9.68E-02	3.60E+00	100%	95%
Manganese-54	5.41E+00	1.75E-01	5.35E+00	104%	98%
Zinc-65	6.54E+00	1.77E-01	6.56E+00	102%	97%

Table 66
2019 - Eckert & Ziegler Analytics Test Results for I131 in a Cartridge

Annual	**Bruce Power Value**	**1 Standard Deviation (S_L)**	**Eckert & Ziegler Analytics Value VA (pCi/L)**	$(V_L+S_L)/V_A$	$(V_L-S_L)/V_A$
	V_L (pCi/L)				
Iodine-131	3.07E+00	1.52E-01	3.49E+00	92%	84%

Appendix B (Continued)

Table 67
2019 - Eckert & Ziegler Analytics Test Results for Gamma in Water

Quarter	Analyte	Bruce Power Value V_L (pCi/L)	1 Standard Deviation (S_L)	Eckert & Ziegler Analytics Value V_A (pCi/L)	$(V_L+S_L)/V_A$	$(V_L-S_L)/V_A$
Q1	Chromium-51	CE-141	4.82E+00	3.19E-01	4.20E+00	122%
	Manganese-54	CO-58	5.59E+00	2.64E-01	5.14E+00	114%
	Cobalt-58	CO-60	1.18E+01	2.16E-01	1.07E+01	112%
	Iron-59	CR-51	1.18E+01	1.04E+00	1.05E+01	122%
	Cobalt-60	CS-134	6.26E+00	1.26E-01	5.74E+00	111%
	Zinc-65	CS-137	8.04E+00	2.19E-01	7.05E+00	117%
	Iodine-131	FE-59	6.24E+00	1.78E-01	5.70E+00	113%
	Cesium-134	I-131	3.47E+00	5.84E-01	3.20E+00	127%
	Cesium-137	MN-54	5.85E+00	1.67E-01	5.13E+00	117%
	Cerium-141	ZN-65	8.43E+00	2.69E-01	7.90E+00	110%
Q2	Cerium-141	CE-141	6.26E+00	2.72E-01	5.38E+00	121%
	Cobalt-58	CO-58	4.57E+00	1.42E-01	4.52E+00	104%
	Cobalt-60	CO-60	8.14E+00	1.61E-01	8.00E+00	104%
	Chromium-51	CR-51	1.42E+01	9.92E-01	1.36E+01	112%
	Cesium-134	CS-134	5.54E+00	1.11E-01	5.67E+00	100%
	Cesium-137	CS-137	6.71E+00	1.89E-01	6.79E+00	102%
	Iron-59	FE-59	5.88E+00	2.99E-01	5.70E+00	108%
	Iodine-131	I-131	3.32E+00	1.99E-01	3.30E+00	107%
	Manganese-54	MN-54	7.69E+00	2.07E-01	7.66E+00	103%
	Zinc-65	ZN-65	9.55E+00	2.92E-01	1.00E+01	98%
Q3	Cerium-141	CE-141	5.26E+00	2.80E-01	4.68E+00	118%
	Cobalt-58	CO-58	4.99E+00	2.27E-01	4.91E+00	106%

	Cobalt-60	CO-60	6.35E+00	1.55E-01	5.91E+00	110%
	Chromium-51	CR-51	1.01E+01	8.29E-01	9.28E+00	118%
	Cesium-134	CS-134	6.12E+00	1.46E-01	5.81E+00	108%
	Cesium-137	CS-137	4.77E+00	2.35E-01	4.23E+00	118%
	Iron-59	FE-59	4.15E+00	1.65E-01	4.16E+00	104%
	Iodine-131	I-131	3.46E+00	2.05E-01	3.33E+00	110%
	Manganese-54	MN-54	4.62E+00	1.67E-01	4.33E+00	111%
	Zinc-65	ZN-65	8.64E+00	3.26E-01	8.22E+00	109%
Q4	Cerium-141	CE-141	3.24E+00	1.87E-01	3.11E+00	110%
	Cobalt-58	CO-58	3.23E+00	1.09E-01	3.37E+00	99%
	Cobalt-60	CO-60	4.38E+00	1.65E-01	4.32E+00	105%
	Chromium-51	CR-51	9.31E+00	6.83E-01	9.04E+00	111%
	Cesium-134	CS-134	4.26E+00	9.13E-02	4.23E+00	103%
	Cesium-137	CS-137	3.80E+00	1.23E-01	3.81E+00	103%
	Iron-59	FE-59	3.27E+00	1.08E-01	3.26E+00	104%
	Iodine-131	I-131	3.46E+00	1.72E-01	3.50E+00	104%
	Manganese-54	MN-54	4.82E+00	1.40E-01	4.86E+00	102%
	Zinc-65	ZN-65	5.70E+00	2.42E-01	5.95E+00	100%

Appendix B (Continued)

Table 68
201 - Eckert & Ziegler Analytics Test Results for Gamma in Soil

Quarter	Analyte	Bruce Power Value V_L (pCi/L)	1 Standard Deviation (S_L)	Eckert & Ziegler Analytics Value V_A (pCi/L)	$(V_L+S_L)/V_A$	$(V_L-S_L)/V_A$
Q1	CE-141	7.59E+00	3.15E-01	6.76E+00	117%	108%
	CO-58	7.69E+00	2.04E-01	8.27E+00	95%	91%
	CO-60	1.64E+01	2.81E-01	1.73E+01	96%	93%
	CR-51	1.65E+01	8.46E-01	1.69E+01	103%	93%
	CS-134	8.68E+00	1.34E-01	9.25E+00	95%	92%
	CS-137	1.40E+01	3.69E-01	1.41E+01	102%	97%
	FE-59	8.51E+00	1.85E-01	9.19E+00	95%	91%
	MN-54	7.93E+00	2.15E-01	8.26E+00	99%	93%
	ZN-65	1.18E+01	3.24E-01	1.27E+01	95%	90%
Q2	CE-141	9.58E+00	3.53E-01	9.99E+00	99%	92%
	CO-58	7.56E+00	2.00E-01	8.39E+00	92%	88%
	CO-60	1.38E+01	2.33E-01	1.49E+01	94%	91%
	CR-51	2.38E+01	9.99E-01	2.53E+01	98%	90%
	CS-134	9.22E+00	1.34E-01	1.05E+01	89%	87%
	CS-137	1.40E+01	3.40E-01	1.53E+01	94%	89%
	FE-59	9.63E+00	2.12E-01	1.06E+01	93%	89%
	MN-54	1.34E+01	3.24E-01	1.42E+01	97%	92%
	ZN-65	1.74E+01	4.33E-01	1.86E+01	96%	91%
Q3	CE-141	1.04E+01	4.65E-01	1.02E+01	107%	97%
	CO-58	1.00E+01	3.10E-01	1.07E+01	96%	91%
	CO-60	1.26E+01	2.61E-01	1.29E+01	100%	96%
	CR-51	2.00E+01	1.06E+00	2.03E+01	104%	93%
	CS-134	1.17E+01	2.13E-01	1.27E+01	94%	90%
	CS-137	1.15E+01	3.50E-01	1.19E+01	100%	94%
	FE-59	8.57E+00	2.26E-01	9.08E+00	97%	92%
	MN-54	8.79E+00	2.91E-01	9.44E+00	96%	90%
	ZN-65	1.71E+01	5.05E-01	1.79E+01	98%	93%
Q4	CE-141	8.01E+00	3.00E-01	7.97E+00	104%	97%
	CO-58	7.86E+00	2.03E-01	8.64E+00	93%	89%
	CO-60	1.04E+01	1.80E-01	1.11E+01	95%	92%
	CR-51	2.24E+01	9.53E-01	2.32E+01	101%	92%
	CS-134	9.84E+00	1.71E-01	1.08E+01	93%	90%

	CS-137	1.18E+01	2.89E-01	1.25E+01	97%	92%
	FE-59	7.78E+00	1.73E-01	8.36E+00	95%	91%
	MN-54	1.18E+01	3.10E-01	1.24E+01	98%	93%
	ZN-65	1.42E+01	3.45E-01	1.52E+01	96%	91%

APPENDIX C: ASSIGNED RADIONUCLIDE LEVELS AT REPRESENTATIVE PERSONS LOCATIONS

Table 69
Dose to Representative Person Located at BR1

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Adult (16-70 yrs)	C-14	5.18E-04	5.95E-07	6.25E-06	1.22E-09	5.84E-11	2.40E-08	1.98E-03	2.01E-01	2.11E-01	4.15E-01
	Co-60	7.38E-07	2.80E-08	1.39E-04	6.17E-03	2.39E-03	5.19E-04	3.23E-04	1.53E-05	1.33E-06	9.56E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.91E-04	2.16E-03	0.00E+00	0.00E+00	2.65E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.47E-04	0.00E+00	0.00E+00	2.72E-03
	HTO[2]	2.59E-01	0.00E+00	9.04E-03	4.22E-03	0.00E+00	0.00E+00	1.46E-04	8.26E-02	3.12E-02	3.86E-01
	I(mfp)	1.43E-05	9.65E-07	0.00E+00	0.00E+00	1.93E-06	0.00E+00	0.00E+00	5.36E-05	5.26E-05	1.23E-04
	Noble Gases	0.00E+00	1.81E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.81E-01
Total		2.59E-01	1.81E-01	9.18E-03	1.04E-02	2.40E-03	3.48E-03	4.86E-03	2.84E-01	2.42E-01	**9.97E-01**
Child (6-15 yrs)	C-14	7.39E-04	5.95E-07	3.43E-06	1.22E-09	1.27E-10	2.97E-07	1.78E-03	2.19E-01	1.68E-01	3.89E-01
	Co-60	1.05E-06	2.80E-08	1.79E-04	6.17E-03	2.39E-03	5.22E-04	6.79E-04	3.73E-05	2.29E-06	9.98E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.97E-04	1.04E-03	0.00E+00	0.00E+00	1.53E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.53E-03	1.24E-04	0.00E+00	0.00E+00	2.65E-03
	HTO[2]	3.08E-01	0.00E+00	4.50E-03	3.52E-03	0.00E+00	0.00E+00	1.23E-04	7.77E-02	1.89E-02	4.12E-01

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
	I(mfp)	3.21E-05	9.65E-07	0.00E+00	0.00E+00	1.94E-06	0.00E+00	0.00E+00	9.71E-05	1.09E-04	2.41E-04
	Noble Gases	0.00E+00	1.81E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.81E-01
Total		3.09E-01	1.81E-01	4.68E-03	9.69E-03	2.40E-03	3.55E-03	3.74E-03	2.96E-01	1.87E-01	**9.96E-01**
Infant (0-5 yrs)	C-14	5.04E-04	5.95E-07	0.00E+00	4.11E-11	2.16E-10	6.55E-07	1.21E-03	1.79E-01	1.90E-01	3.71E-01
	Co-60	7.72E-07	3.64E-08	0.00E+00	7.23E-05	3.11E-03	6.84E-04	5.68E-04	4.16E-05	2.24E-06	4.48E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.45E-04	4.04E-04	0.00E+00	0.00E+00	1.05E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-03	5.05E-05	0.00E+00	0.00E+00	3.34E-03
	HTO[2]	2.12E-01	0.00E+00	0.00E+00	1.23E-04	0.00E+00	0.00E+00	8.78E-05	8.16E-02	2.41E-02	3.18E-01
	I(mfp)	3.84E-05	1.25E-06	0.00E+00	0.00E+00	2.53E-06	0.00E+00	0.00E+00	1.50E-04	2.94E-04	4.87E-04
	Noble Gases	0.00E+00	2.34E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.34E-01
Total		2.13E-01	2.34E-01	0.00E+00	1.95E-04	3.11E-03	4.62E-03	2.32E-03	2.61E-01	2.14E-01	**9.33E-01**

Note: All doses reported in units ofµSv/a.
[1] includes dose due to external exposure to progeny of Cs-137 in air, water, soil, and sediment
[2] includes dose incurred via ingestion of OBT in fish, plant produce and animal products.

Table 70
Dose to Representative Persons Located at BR17

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Adult (16-70 yrs)	C-14	2.20E-04	2.53E-07	2.79E-06	1.18E-09	7.96E-12	2.40E-08	1.98E-03	1.28E-01	1.12E-01	2.43E-01
	Co-60	5.08E-07	1.93E-08	1.39E-04	6.17E-03	2.58E-03	5.19E-04	3.23E-04	1.55E-05	1.35E-06	9.74E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.91E-04	2.16E-03	0.00E+00	0.00E+00	2.65E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.47E-04	0.00E+00	0.00E+00	2.72E-03
	HTO[2]	1.77E-01	0.00E+00	9.04E-03	4.22E-03	0.00E+00	0.00E+00	1.46E-04	1.04E-01	2.67E-02	3.21E-01
	I(mfp)	9.87E-06	6.64E-07	0.00E+00	0.00E+00	1.45E-06	0.00E+00	0.00E+00	4.09E-05	4.37E-05	9.66E-05
	Noble Gases	0.00E+00	1.24E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.24E-01
Total		1.77E-01	1.24E-01	9.18E-03	1.04E-02	2.58E-03	3.48E-03	4.86E-03	2.33E-01	1.39E-01	**7.04E-01**
Child (6-15 yrs)	C-14	3.14E-04	2.53E-07	1.53E-06	1.18E-09	1.73E-11	2.97E-07	1.78E-03	1.35E-01	1.08E-01	2.46E-01
	Co-60	7.25E-07	1.93E-08	1.79E-04	6.17E-03	2.58E-03	5.22E-04	6.79E-04	3.77E-05	2.33E-06	1.02E-02
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.97E-04	1.04E-03	0.00E+00	0.00E+00	1.53E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.53E-03	1.24E-04	0.00E+00	0.00E+00	2.65E-03
	HTO[2]	2.10E-01	0.00E+00	4.50E-03	3.52E-03	0.00E+00	0.00E+00	1.23E-04	9.32E-02	1.70E-02	3.28E-01
	I(mfp)	2.21E-05	6.64E-07	0.00E+00	0.00E+00	1.45E-06	0.00E+00	0.00E+00	7.41E-05	9.88E-05	1.97E-04
	Noble Gases	0.00E+00	1.24E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.24E-01

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Total		2.10E-01	1.24E-01	4.68E-03	9.69E-03	2.58E-03	3.55E-03	3.74E-03	2.28E-01	1.26E-01	**7.13E-01**
Infant (0-5 yrs)	C-14	2.14E-04	2.53E-07	0.00E+00	2.31E-11	2.94E-11	6.55E-07	1.21E-03	1.18E-01	1.48E-01	2.67E-01
	Co-60	5.31E-07	2.50E-08	0.00E+00	7.23E-05	3.35E-03	6.84E-04	5.68E-04	4.20E-05	2.28E-06	4.72E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.45E-04	4.04E-04	0.00E+00	0.00E+00	1.05E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-03	5.05E-05	0.00E+00	0.00E+00	3.34E-03
	HTO[2]	1.45E-01	0.00E+00	0.00E+00	1.23E-04	0.00E+00	0.00E+00	8.78E-05	9.22E-02	2.28E-02	2.60E-01
	I(mfp)	2.64E-05	8.64E-07	0.00E+00	0.00E+00	1.89E-06	0.00E+00	0.00E+00	1.15E-04	2.81E-04	4.25E-04
	Noble Gases	0.00E+00	1.61E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.61E-01
Total		1.45E-01	1.61E-01	0.00E+00	1.95E-04	3.35E-03	4.62E-03	2.32E-03	2.10E-01	1.71E-01	**6.98E-01**

Note: All doses reported in units of μSv/a.
[1] includes dose due to external exposure to progeny of Cs-137 in air, water, soil, and sediment
[2] includes dose incurred via ingestion of OBT in fish, plant produce and animal products.

Table 71
Dose to Representative Persons Located at BR25

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Adult (16-70 yrs)	C-14	5.21E-04	5.99E-07	6.05E-06	1.22E-09	1.36E-11	2.40E-08	1.98E-03	2.02E-01	2.12E-01	4.17E-01
	Co-60	8.15E-07	3.09E-08	1.39E-04	6.17E-03	3.03E-03	5.19E-04	3.23E-04	1.66E-05	1.49E-06	1.02E-02
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.91E-04	2.16E-03	0.00E+00	0.00E+00	2.65E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.47E-04	0.00E+00	0.00E+00	2.72E-03
	HTO[2]	2.86E-01	0.00E+00	9.04E-03	4.22E-03	0.00E+00	0.00E+00	1.46E-04	1.10E-01	3.26E-02	4.42E-01
	I(mfp)	1.58E-05	1.06E-06	0.00E+00	0.00E+00	2.18E-06	0.00E+00	0.00E+00	6.07E-05	5.75E-05	1.37E-04
	Noble Gases	0.00E+00	1.98E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.98E-01
Total		2.86E-01	1.98E-01	9.18E-03	1.04E-02	3.03E-03	3.48E-03	4.86E-03	3.12E-01	2.45E-01	**1.07E+00**
Child (6-15 yrs)	C-14	7.44E-04	5.99E-07	3.32E-06	1.22E-09	2.94E-11	2.97E-07	1.78E-03	2.21E-01	1.68E-01	3.91E-01
	Co-60	1.16E-06	3.09E-08	1.79E-04	6.17E-03	3.03E-03	5.22E-04	6.79E-04	4.05E-05	2.56E-06	1.06E-02
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.97E-04	1.04E-03	0.00E+00	0.00E+00	1.53E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.53E-03	1.24E-04	0.00E+00	0.00E+00	2.65E-03
	HTO[2]	3.40E-01	0.00E+00	4.50E-03	3.52E-03	0.00E+00	0.00E+00	1.23E-04	1.04E-01	1.94E-02	4.71E-01
	I(mfp)	3.54E-05	1.06E-06	0.00E+00	0.00E+00	2.18E-06	0.00E+00	0.00E+00	1.10E-04	1.15E-04	2.64E-04
	Noble Gases	0.00E+00	1.98E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.98E-01

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Total		3.40E-01	1.98E-01	4.68E-03	9.69E-03	3.03E-03	3.55E-03	3.74E-03	3.24E-01	1.88E-01	**1.08E+00**
Infant (0-5 yrs)	C-14	5.08E-04	5.99E-07	0.00E+00	4.04E-11	5.01E-11	6.55E-07	1.21E-03	1.82E-01	1.91E-01	3.75E-01
	Co-60	8.52E-07	4.02E-08	0.00E+00	7.23E-05	3.94E-03	6.84E-04	5.68E-04	4.50E-05	2.49E-06	5.31E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.45E-04	4.04E-04	0.00E+00	0.00E+00	1.05E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-03	5.05E-05	0.00E+00	0.00E+00	3.34E-03
	HTO[2]	2.34E-01	0.00E+00	0.00E+00	1.23E-04	0.00E+00	0.00E+00	8.78E-05	1.10E-01	2.46E-02	3.69E-01
	I(mfp)	4.23E-05	1.38E-06	0.00E+00	0.00E+00	2.85E-06	0.00E+00	0.00E+00	1.70E-04	3.01E-04	5.18E-04
	Noble Gases	0.00E+00	2.57E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.57E-01
Total		2.35E-01	2.57E-01	0.00E+00	1.95E-04	3.94E-03	4.62E-03	2.32E-03	2.93E-01	2.15E-01	**1.01E+00**

Note: All doses reported in units of µSv/a.

[1] includes dose due to external exposure to progeny of Cs-137 in air, water, soil, and sediment

[2] includes dose incurred via ingestion of OBT in fish, plant produce and animal products.

Table 72
Dose to Representative Persons Located at BR27

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Adult (16-70 yrs)	C-14	5.21E-04	5.99E-07	1.29E-05	1.25E-09	1.36E-11	2.40E-08	1.98E-03	2.02E-01	2.12E-01	4.17E-01
	Co-60	8.15E-07	3.09E-08	1.96E-04	6.17E-03	2.20E-03	5.19E-04	3.23E-04	1.79E-05	1.83E-06	9.43E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.91E-04	2.16E-03	0.00E+00	0.00E+00	2.65E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.47E-04	0.00E+00	0.00E+00	2.72E-03
	HTO[2]	2.86E-01	0.00E+00	1.31E-02	4.26E-03	0.00E+00	0.00E+00	1.46E-04	1.10E-01	3.28E-02	4.46E-01
	I(mfp)	1.58E-05	1.06E-06	0.00E+00	0.00E+00	2.07E-06	0.00E+00	0.00E+00	5.72E-05	5.50E-05	1.31E-04
	Noble Gases	0.00E+00	1.98E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.98E-01
Total		2.86E-01	1.98E-01	1.33E-02	1.04E-02	2.20E-03	3.48E-03	4.86E-03	3.12E-01	2.45E-01	**1.08E+00**
Child (6-15 yrs)	C-14	7.44E-04	5.99E-07	7.09E-06	1.25E-09	2.94E-11	2.97E-07	1.78E-03	2.21E-01	1.68E-01	3.91E-01
	Co-60	1.16E-06	3.09E-08	2.53E-04	6.17E-03	2.20E-03	5.22E-04	6.79E-04	4.36E-05	3.15E-06	9.88E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.97E-04	1.04E-03	0.00E+00	0.00E+00	1.53E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.53E-03	1.24E-04	0.00E+00	0.00E+00	2.65E-03
	HTO[2]	3.40E-01	0.00E+00	6.50E-03	3.55E-03	0.00E+00	0.00E+00	1.23E-04	1.04E-01	1.95E-02	4.73E-01
	I(mfp)	3.54E-05	1.06E-06	0.00E+00	0.00E+00	2.08E-06	0.00E+00	0.00E+00	1.04E-04	1.12E-04	2.54E-04
	Noble Gases	0.00E+00	1.98E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.98E-01

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Total		3.40E-01	1.98E-01	6.76E-03	9.72E-03	2.20E-03	3.55E-03	3.74E-03	3.24E-01	1.88E-01	**1.08E+00**
Infant (0-5 yrs)	C-14	5.08E-04	5.99E-07	0.00E+00	7.27E-11	5.01E-11	6.55E-07	1.21E-03	1.82E-01	1.91E-01	3.75E-01
	Co-60	8.52E-07	4.02E-08	0.00E+00	7.76E-05	2.86E-03	6.84E-04	5.68E-04	4.88E-05	3.01E-06	4.24E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.45E-04	4.04E-04	0.00E+00	0.00E+00	1.05E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-03	5.05E-05	0.00E+00	0.00E+00	3.34E-03
	HTO[2]	2.34E-01	0.00E+00	0.00E+00	1.58E-04	0.00E+00	0.00E+00	8.78E-05	1.10E-01	2.46E-02	3.69E-01
	I(mfp)	4.23E-05	1.38E-06	0.00E+00	0.00E+00	2.71E-06	0.00E+00	0.00E+00	1.60E-04	2.98E-04	5.04E-04
	Noble Gases	0.00E+00	2.57E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.57E-01
Total		2.35E-01	2.57E-01	0.00E+00	2.35E-04	2.86E-03	4.62E-03	2.32E-03	2.93E-01	2.15E-01	**1.01E+00**

Note: All doses reported in units of µSv/a.
[1] includes dose due to external exposure to progeny of Cs-137 in air, water, soil, and sediment
[2] includes dose incurred via ingestion of OBT in fish, plant produce and animal products.

Table 73
Dose to Representative Persons Located at BR32

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Adult (16-70 yrs)	C-14	5.21E-04	5.99E-07	2.47E-05	1.52E-09	1.57E-10	2.40E-08	1.98E-03	2.02E-01	2.12E-01	4.17E-01
	Co-60	8.03E-07	3.05E-08	1.41E-04	6.15E-03	6.46E-03	5.19E-04	3.23E-04	1.47E-05	3.49E-06	1.36E-02
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.91E-04	2.16E-03	0.00E+00	0.00E+00	2.65E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.47E-04	0.00E+00	0.00E+00	2.72E-03
	HTO[2]	2.82E-01	0.00E+00	2.07E-02	4.52E-03	0.00E+00	0.00E+00	1.46E-04	1.10E-01	3.26E-02	4.50E-01
	I(mfp)	1.56E-05	1.05E-06	0.00E+00	0.00E+00	2.04E-06	0.00E+00	0.00E+00	5.61E-05	5.43E-05	1.29E-04
	Noble Gases	0.00E+00	1.97E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.97E-01
Total		2.83E-01	1.97E-01	2.09E-02	1.07E-02	6.46E-03	3.48E-03	4.86E-03	3.12E-01	2.45E-01	**1.08E+00**
Child (6-15 yrs)	C-14	7.44E-04	5.99E-07	1.36E-05	1.52E-09	3.41E-10	2.97E-07	1.78E-03	2.21E-01	1.68E-01	3.91E-01
	Co-60	1.15E-06	3.05E-08	1.82E-04	6.15E-03	6.46E-03	5.22E-04	6.79E-04	3.63E-05	6.09E-06	1.40E-02
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.97E-04	1.04E-03	0.00E+00	0.00E+00	1.53E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.53E-03	1.24E-04	0.00E+00	0.00E+00	2.65E-03
	HTO[2]	3.35E-01	0.00E+00	1.03E-02	3.76E-03	0.00E+00	0.00E+00	1.23E-04	1.04E-01	1.95E-02	4.73E-01
	I(mfp)	3.49E-05	1.05E-06	0.00E+00	0.00E+00	2.04E-06	0.00E+00	0.00E+00	1.02E-04	1.11E-04	2.51E-04
	Noble Gases	0.00E+00	1.97E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.97E-01

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Total		3.36E-01	1.97E-01	1.05E-02	9.91E-03	6.46E-03	3.55E-03	3.74E-03	3.24E-01	1.88E-01	**1.08E+00**
Infant (0-5 yrs)	C-14	5.08E-04	5.99E-07	0.00E+00	1.00E-10	5.81E-10	6.55E-07	1.21E-03	1.82E-01	1.91E-01	3.75E-01
	Co-60	8.40E-07	3.96E-08	0.00E+00	1.13E-05	8.39E-03	6.84E-04	5.68E-04	3.95E-05	5.66E-06	9.70E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.45E-04	4.04E-04	0.00E+00	0.00E+00	1.05E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-03	5.05E-05	0.00E+00	0.00E+00	3.34E-03
	HTO[2]	2.31E-01	0.00E+00	0.00E+00	1.53E-04	0.00E+00	0.00E+00	8.78E-05	1.10E-01	2.46E-02	3.67E-01
	I(mfp)	4.18E-05	1.36E-06	0.00E+00	0.00E+00	2.66E-06	0.00E+00	0.00E+00	1.57E-04	2.96E-04	5.00E-04
	Noble Gases	0.00E+00	2.55E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.55E-01
Total		2.32E-01	2.55E-01	0.00E+00	1.64E-04	8.40E-03	4.62E-03	2.32E-03	2.93E-01	2.15E-01	**1.01E+00**

Note: All doses reported in units of µSv/a.
[1] includes dose due to external exposure to progeny of Cs-137 in air, water, soil, and sediment
[2] includes dose incurred via ingestion of OBT in fish, plant produce and animal products.

Table 74
Dose to Representative Persons Located at BR48

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Adult (16-70 yrs)	C-14	4.60E-04	5.29E-07	5.63E-06	1.21E-09	5.84E-11	2.40E-08	1.98E-03	1.81E-01	1.92E-01	3.75E-01
	Co-60	1.07E-06	4.04E-08	1.39E-04	6.17E-03	5.15E-03	5.19E-04	3.23E-04	2.08E-05	2.03E-06	1.23E-02
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.91E-04	2.16E-03	0.00E+00	0.00E+00	2.65E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.47E-04	0.00E+00	0.00E+00	2.72E-03
	HTO[2]	3.75E-01	0.00E+00	9.04E-03	4.22E-03	0.00E+00	0.00E+00	1.46E-04	7.65E-02	3.75E-02	5.02E-01
	I(mfp)	2.07E-05	1.39E-06	0.00E+00	0.00E+00	3.00E-06	0.00E+00	0.00E+00	8.46E-05	7.41E-05	1.84E-04
	Noble Gases	0.00E+00	2.60E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.60E-01
Total		3.75E-01	2.60E-01	9.18E-03	1.04E-02	5.16E-03	3.48E-03	4.86E-03	2.58E-01	2.29E-01	**1.16E+00**
Child (6-15 yrs)	C-14	6.56E-04	5.29E-07	3.09E-06	1.21E-09	1.27E-10	2.97E-07	1.78E-03	2.00E-01	1.56E-01	3.58E-01
	Co-60	1.52E-06	4.04E-08	1.79E-04	6.17E-03	5.15E-03	5.22E-04	6.79E-04	5.10E-05	3.47E-06	1.28E-02
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.97E-04	1.04E-03	0.00E+00	0.00E+00	1.53E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.53E-03	1.24E-04	0.00E+00	0.00E+00	2.65E-03
	HTO[2]	4.46E-01	0.00E+00	4.50E-03	3.52E-03	0.00E+00	0.00E+00	1.23E-04	7.74E-02	2.14E-02	5.53E-01
	I(mfp)	4.63E-05	1.39E-06	0.00E+00	0.00E+00	3.01E-06	0.00E+00	0.00E+00	1.53E-04	1.34E-04	3.38E-04
	Noble Gases	0.00E+00	2.60E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.60E-01

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Total		4.46E-01	2.60E-01	4.68E-03	9.69E-03	5.16E-03	3.55E-03	3.74E-03	2.77E-01	1.78E-01	**1.19E+00**
Infant (0-5 yrs)	C-14	4.48E-04	5.29E-07	0.00E+00	3.78E-11	2.16E-10	6.55E-07	1.21E-03	1.69E-01	1.82E-01	3.53E-01
	Co-60	1.11E-06	5.25E-08	0.00E+00	7.23E-05	6.70E-03	6.84E-04	5.68E-04	5.62E-05	3.30E-06	8.08E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.45E-04	4.04E-04	0.00E+00	0.00E+00	1.05E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-03	5.05E-05	0.00E+00	0.00E+00	3.34E-03
	HTO[2]	3.07E-01	0.00E+00	0.00E+00	1.23E-04	0.00E+00	0.00E+00	8.78E-05	8.80E-02	2.60E-02	4.22E-01
	I(mfp)	5.53E-05	1.81E-06	0.00E+00	0.00E+00	3.92E-06	0.00E+00	0.00E+00	2.37E-04	3.24E-04	6.23E-04
	Noble Gases	0.00E+00	3.37E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.37E-01
Total		3.08E-01	3.37E-01	0.00E+00	1.95E-04	6.70E-03	4.62E-03	2.32E-03	2.57E-01	2.08E-01	**1.12E+00**

Note: All doses reported in units of µSv/a.

[1] includes dose due to external exposure to progeny of Cs-137 in air, water, soil, and sediment

[2] includes dose incurred via ingestion of OBT in fish, plant produce and animal products.

Table 75
Dose to Representative Persons Located at BF8

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Adult (16-70 yrs)	C-14	1.86E-04	2.13E-07	6.74E-06	1.16E-09	1.36E-11	2.40E-08	1.92E-03	1.84E-01	1.40E-01	3.26E-01
	Co-60	3.05E-07	1.16E-08	1.67E-03	6.11E-03	1.29E-03	5.19E-04	3.13E-04	1.85E-04	9.91E-06	1.01E-02
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.91E-04	2.10E-03	0.00E+00	0.00E+00	2.59E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.39E-04	0.00E+00	0.00E+00	2.71E-03
	HTO[2]	1.04E-01	0.00E+00	1.97E-02	4.17E-03	0.00E+00	0.00E+00	1.42E-04	1.24E-01	3.73E-02	2.89E-01
	I(mfp)	5.92E-06	3.99E-07	0.00E+00	0.00E+00	8.38E-07	0.00E+00	0.00E+00	4.23E-05	3.19E-05	8.14E-05
	Noble Gases	0.00E+00	7.44E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.44E-02
Total		1.04E-01	7.44E-02	2.14E-02	1.03E-02	1.29E-03	3.48E-03	4.71E-03	3.08E-01	1.77E-01	**7.05E-01**
Child (6-15 yrs)	C-14	2.65E-04	2.13E-07	3.70E-06	1.16E-09	2.94E-11	2.97E-07	1.72E-03	1.89E-01	1.07E-01	2.98E-01
	Co-60	4.35E-07	1.16E-08	2.15E-03	6.11E-03	1.29E-03	5.22E-04	6.59E-04	4.30E-04	1.59E-05	1.12E-02
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.97E-04	1.01E-03	0.00E+00	0.00E+00	1.50E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.53E-03	1.20E-04	0.00E+00	0.00E+00	2.65E-03
	HTO[2]	1.23E-01	0.00E+00	9.82E-03	3.48E-03	0.00E+00	0.00E+00	1.19E-04	1.24E-01	1.85E-02	2.79E-01
	I(mfp)	1.33E-05	3.99E-07	0.00E+00	0.00E+00	8.39E-07	0.00E+00	0.00E+00	7.40E-05	6.22E-05	1.51E-04
	Noble Gases	0.00E+00	7.44E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.44E-02

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Total		1.23E-01	7.44E-02	1.20E-02	9.59E-03	1.29E-03	3.55E-03	3.63E-03	3.13E-01	1.26E-01	**6.67E-01**
Infant (0-5 yrs)	C-14	1.81E-04	2.13E-07	0.00E+00	1.05E-11	5.01E-11	6.55E-07	1.18E-03	1.69E-01	1.13E-01	2.83E-01
	Co-60	3.19E-07	1.50E-08	0.00E+00	0.00E+00	1.68E-03	6.84E-04	5.51E-04	4.93E-04	1.39E-05	3.42E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.45E-04	3.92E-04	0.00E+00	0.00E+00	1.04E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-03	4.90E-05	0.00E+00	0.00E+00	3.34E-03
	HTO[2]	8.49E-02	0.00E+00	0.00E+00	7.97E-05	0.00E+00	0.00E+00	8.51E-05	1.40E-01	1.87E-02	2.43E-01
	I(mfp)	1.59E-05	5.18E-07	0.00E+00	0.00E+00	1.09E-06	0.00E+00	0.00E+00	1.17E-04	1.62E-04	2.97E-04
	Noble Gases	0.00E+00	9.64E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.64E-02
Total		8.51E-02	9.64E-02	0.00E+00	7.97E-05	1.68E-03	4.62E-03	2.25E-03	3.09E-01	1.32E-01	**6.31E-01**

Note: All doses reported in units of μSv/a.

[1] includes dose due to external exposure to progeny of Cs-137 in air, water, soil, and sediment

[2] includes dose incurred via ingestion of OBT in fish, plant produce and animal products.

Table 76
Dose to Representative Persons Located at BF14

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Adult (16-70 yrs)	C-14	5.96E-04	6.86E-07	1.11E-05	1.22E-09	1.36E-11	2.40E-08	1.92E-03	3.45E-01	3.50E-01	6.98E-01
	Co-60	8.03E-07	3.05E-08	1.67E-03	6.11E-03	2.54E-03	5.19E-04	3.13E-04	1.89E-04	1.05E-05	1.14E-02
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.91E-04	2.10E-03	0.00E+00	0.00E+00	2.59E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.39E-04	0.00E+00	0.00E+00	2.71E-03
	HTO[2]	2.82E-01	0.00E+00	1.97E-02	4.17E-03	0.00E+00	0.00E+00	1.42E-04	2.36E-01	5.13E-02	5.93E-01
	I(mfp)	1.56E-05	1.05E-06	0.00E+00	0.00E+00	2.09E-06	0.00E+00	0.00E+00	1.05E-04	6.69E-05	1.90E-04
	Noble Gases	0.00E+00	1.97E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.97E-01
Total		2.83E-01	1.97E-01	2.14E-02	1.03E-02	2.54E-03	3.48E-03	4.71E-03	5.81E-01	4.02E-01	**1.50E+00**
Child (6-15 yrs)	C-14	8.51E-04	6.86E-07	6.11E-06	1.22E-09	2.94E-11	2.97E-07	1.72E-03	3.67E-01	2.32E-01	6.02E-01
	Co-60	1.15E-06	3.05E-08	2.15E-03	6.11E-03	2.54E-03	5.22E-04	6.59E-04	4.42E-04	1.68E-05	1.24E-02
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.97E-04	1.01E-03	0.00E+00	0.00E+00	1.50E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.53E-03	1.20E-04	0.00E+00	0.00E+00	2.65E-03
	HTO[2]	3.35E-01	0.00E+00	9.82E-03	3.48E-03	0.00E+00	0.00E+00	1.19E-04	2.18E-01	2.43E-02	5.91E-01
	I(mfp)	3.49E-05	1.05E-06	0.00E+00	0.00E+00	2.10E-06	0.00E+00	0.00E+00	1.83E-04	1.02E-04	3.23E-04
	Noble Gases	0.00E+00	1.97E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.97E-01

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Total		3.36E-01	1.97E-01	1.20E-02	9.59E-03	2.54E-03	3.55E-03	3.63E-03	5.85E-01	2.57E-01	**1.41E+00**
Infant (0-5 yrs)	C-14	5.81E-04	6.86E-07	0.00E+00	3.28E-11	5.01E-11	6.55E-07	1.18E-03	3.07E-01	2.02E-01	5.11E-01
	Co-60	8.40E-07	3.96E-08	0.00E+00	0.00E+00	3.30E-03	6.84E-04	5.51E-04	5.06E-04	1.47E-05	5.06E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.45E-04	3.92E-04	0.00E+00	0.00E+00	1.04E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-03	4.90E-05	0.00E+00	0.00E+00	3.34E-03
	HTO[2]	2.31E-01	0.00E+00	0.00E+00	7.97E-05	0.00E+00	0.00E+00	8.51E-05	2.29E-01	2.29E-02	4.83E-01
	I(mfp)	4.18E-05	1.36E-06	0.00E+00	0.00E+00	2.74E-06	0.00E+00	0.00E+00	2.89E-04	2.09E-04	5.44E-04
	Noble Gases	0.00E+00	2.55E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.55E-01
Total		2.32E-01	2.55E-01	0.00E+00	7.97E-05	3.31E-03	4.62E-03	2.25E-03	5.37E-01	2.25E-01	**1.26E+00**

Note: All doses reported in units of µSv/a.

[1] includes dose due to external exposure to progeny of Cs-137 in air, water, soil, and sediment

[2] includes dose incurred via ingestion of OBT in fish, plant produce and animal products.

Table 77
Dose to Representative Persons Located at BF16

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Adult (16-70 yrs)	C-14	2.20E-04	2.53E-07	7.09E-06	1.16E-09	7.96E-12	2.40E-08	1.92E-03	2.42E-01	1.57E-01	4.02E-01
	Co-60	5.08E-07	1.93E-08	1.67E-03	6.11E-03	2.39E-03	5.19E-04	3.13E-04	1.88E-04	1.04E-05	1.12E-02
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.91E-04	2.10E-03	0.00E+00	0.00E+00	2.59E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.39E-04	0.00E+00	0.00E+00	2.71E-03
	HTO[2]	1.77E-01	0.00E+00	1.97E-02	4.17E-03	0.00E+00	0.00E+00	1.42E-04	1.64E-01	4.31E-02	4.07E-01
	I(mfp)	9.87E-06	6.64E-07	0.00E+00	0.00E+00	1.43E-06	0.00E+00	0.00E+00	7.23E-05	4.88E-05	1.33E-04
	Noble Gases	0.00E+00	1.24E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.24E-01
Total		1.77E-01	1.24E-01	2.14E-02	1.03E-02	2.39E-03	3.48E-03	4.71E-03	4.06E-01	2.01E-01	**9.50E-01**
Child (6-15 yrs)	C-14	3.14E-04	2.53E-07	3.89E-06	1.16E-09	1.73E-11	2.97E-07	1.72E-03	2.44E-01	1.18E-01	3.63E-01
	Co-60	7.25E-07	1.93E-08	2.15E-03	6.11E-03	2.39E-03	5.22E-04	6.59E-04	4.39E-04	1.66E-05	1.23E-02
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.97E-04	1.01E-03	0.00E+00	0.00E+00	1.50E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.53E-03	1.20E-04	0.00E+00	0.00E+00	2.65E-03
	HTO[2]	2.10E-01	0.00E+00	9.82E-03	3.48E-03	0.00E+00	0.00E+00	1.19E-04	1.43E-01	2.08E-02	3.88E-01
	I(mfp)	2.21E-05	6.64E-07	0.00E+00	0.00E+00	1.43E-06	0.00E+00	0.00E+00	1.27E-04	8.13E-05	2.32E-04
	Noble Gases	0.00E+00	1.24E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.24E-01

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Total		2.10E-01	1.24E-01	1.20E-02	9.59E-03	2.39E-03	3.55E-03	3.63E-03	3.87E-01	1.39E-01	**8.92E-01**
Infant (0-5 yrs)	C-14	2.14E-04	2.53E-07	0.00E+00	1.22E-11	2.94E-11	6.55E-07	1.18E-03	2.14E-01	1.20E-01	3.36E-01
	Co-60	5.31E-07	2.50E-08	0.00E+00	0.00E+00	3.11E-03	6.84E-04	5.51E-04	5.03E-04	1.46E-05	4.87E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.45E-04	3.92E-04	0.00E+00	0.00E+00	1.04E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-03	4.90E-05	0.00E+00	0.00E+00	3.34E-03
	HTO[2]	1.45E-01	0.00E+00	0.00E+00	7.97E-05	0.00E+00	0.00E+00	8.51E-05	1.38E-01	2.04E-02	3.04E-01
	I(mfp)	2.64E-05	8.64E-07	0.00E+00	0.00E+00	1.86E-06	0.00E+00	0.00E+00	2.00E-04	1.85E-04	4.14E-04
	Noble Gases	0.00E+00	1.61E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.61E-01
Total		1.45E-01	1.61E-01	0.00E+00	7.97E-05	3.11E-03	4.62E-03	2.25E-03	3.53E-01	1.41E-01	**8.11E-01**

Note: All doses reported in units of μSv/a.
[1] includes dose due to external exposure to progeny of Cs-137 in air, water, soil, and sediment
[2] includes dose incurred via ingestion of OBT in fish, plant produce and animal products.

Table 78
Dose to Representative Persons Located at BSF2

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Adult (16-70 yrs)	C-14	1.86E-04	2.13E-07	2.31E-06	1.16E-09	1.36E-11	2.40E-08	8.61E-03	4.47E-01	2.84E-01	7.40E-01
	Co-60	3.05E-07	1.16E-08	0.00E+00	6.11E-03	9.75E-04	5.19E-04	1.40E-03	9.20E-06	9.26E-07	9.02E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.91E-04	9.41E-03	0.00E+00	0.00E+00	9.90E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	1.07E-03	0.00E+00	0.00E+00	3.54E-03
	HTO[2]	1.04E-01	0.00E+00	9.79E-03	4.17E-03	0.00E+00	0.00E+00	6.37E-04	1.99E-01	5.93E-02	3.77E-01
	I(mfp)	5.92E-06	3.99E-07	0.00E+00	0.00E+00	7.97E-07	0.00E+00	0.00E+00	9.45E-05	8.94E-05	1.91E-04
	Noble Gases	0.00E+00	7.44E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.44E-02
Total		1.04E-01	7.44E-02	9.79E-03	1.03E-02	9.75E-04	3.48E-03	2.11E-02	6.46E-01	3.43E-01	**1.21E+00**
Child (6-15 yrs)	C-14	2.65E-04	2.13E-07	1.27E-06	1.16E-09	2.94E-11	2.97E-07	7.73E-03	4.80E-01	2.57E-01	7.46E-01
	Co-60	4.35E-07	3.64E-08	0.00E+00	7.23E-05	9.75E-04	5.22E-04	2.95E-03	2.33E-05	1.86E-06	4.55E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.97E-04	4.51E-03	0.00E+00	0.00E+00	5.01E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.53E-03	5.37E-04	0.00E+00	0.00E+00	3.07E-03
	HTO[2]	1.23E-01	0.00E+00	4.87E-03	3.48E-03	0.00E+00	0.00E+00	5.33E-04	1.98E-01	4.85E-02	3.78E-01
	I(mfp)	1.33E-05	3.99E-07	0.00E+00	0.00E+00	7.98E-07	0.00E+00	0.00E+00	1.72E-04	2.60E-04	4.46E-04
	Noble Gases	0.00E+00	7.44E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.44E-02

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Total		1.23E-01	7.44E-02	4.87E-03	3.55E-03	9.75E-04	3.55E-03	1.63E-02	6.78E-01	3.06E-01	**1.21E+00**
Infant (0-5 yrs)	C-14	1.81E-04	2.13E-07	0.00E+00	1.03E-11	5.01E-11	6.55E-07	5.27E-03	4.03E-01	3.24E-01	7.32E-01
	Co-60	3.19E-07	1.50E-08	0.00E+00	0.00E+00	1.27E-03	6.84E-04	2.47E-03	2.38E-05	2.38E-06	4.45E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.45E-04	1.76E-03	0.00E+00	0.00E+00	2.40E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-03	2.20E-04	0.00E+00	0.00E+00	3.51E-03
	HTO[2]	8.49E-02	0.00E+00	0.00E+00	7.97E-05	0.00E+00	0.00E+00	3.82E-04	2.12E-01	7.75E-02	3.75E-01
	I(mfp)	1.59E-05	5.18E-07	0.00E+00	0.00E+00	1.04E-06	0.00E+00	0.00E+00	2.54E-04	8.43E-04	1.11E-03
	Noble Gases	0.00E+00	9.64E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.64E-02
Total		8.51E-02	9.64E-02	0.00E+00	7.97E-05	1.27E-03	4.62E-03	1.01E-02	6.15E-01	4.02E-01	**1.22E+00**

Note: All doses reported in units of μSv/a.

[1] includes dose due to external exposure to progeny of Cs-137 in air, water, soil, and sediment

[2] includes dose incurred via ingestion of OBT in fish, plant produce and animal products.

Table 79
Dose to Representative Persons Located at BSF3

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Adult (16-70 yrs)	C-14	1.86E-04	2.13E-07	2.31E-06	1.16E-09	1.36E-11	2.40E-08	8.61E-03	5.24E-01	2.84E-01	8.16E-01
	Co-60	3.05E-07	1.16E-08	0.00E+00	6.11E-03	1.30E-03	5.19E-04	1.40E-03	1.19E-05	1.20E-06	9.34E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.91E-04	9.41E-03	0.00E+00	0.00E+00	9.90E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	1.07E-03	0.00E+00	0.00E+00	3.54E-03
	HTO[2]	1.04E-01	0.00E+00	9.79E-03	4.17E-03	0.00E+00	0.00E+00	6.37E-04	2.72E-01	5.93E-02	4.50E-01
	I(mfp)	5.92E-06	3.99E-07	0.00E+00	0.00E+00	8.38E-07	0.00E+00	0.00E+00	1.00E-04	9.50E-05	2.03E-04
	Noble Gases	0.00E+00	7.44E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.44E-02
Total		1.04E-01	7.44E-02	9.79E-03	1.03E-02	1.30E-03	3.48E-03	2.11E-02	7.96E-01	3.43E-01	**1.36E+00**
Child (6-15 yrs)	C-14	2.65E-04	2.13E-07	1.27E-06	1.16E-09	2.94E-11	2.97E-07	7.73E-03	5.46E-01	2.57E-01	8.12E-01
	Co-60	4.35E-07	1.16E-08	0.00E+00	6.11E-03	1.30E-03	5.22E-04	2.95E-03	3.01E-05	2.42E-06	1.09E-02
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.97E-04	4.51E-03	0.00E+00	0.00E+00	5.01E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.53E-03	5.37E-04	0.00E+00	0.00E+00	3.07E-03
	HTO[2]	1.23E-01	0.00E+00	4.87E-03	3.48E-03	0.00E+00	0.00E+00	5.33E-04	2.38E-01	4.85E-02	4.19E-01
	I(mfp)	1.33E-05	3.99E-07	0.00E+00	0.00E+00	8.40E-07	0.00E+00	0.00E+00	1.83E-04	2.76E-04	4.73E-04
	Noble Gases	0.00E+00	7.44E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.44E-02

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Total		1.23E-01	7.44E-02	4.87E-03	9.59E-03	1.30E-03	3.55E-03	1.63E-02	7.85E-01	3.06E-01	**1.32E+00**
Infant (0-5 yrs)	C-14	1.81E-04	2.13E-07	0.00E+00	1.03E-11	5.01E-11	6.55E-07	5.27E-03	4.57E-01	3.24E-01	7.86E-01
	Co-60	3.19E-07	1.50E-08	0.00E+00	0.00E+00	1.69E-03	6.84E-04	2.47E-03	3.07E-05	3.08E-06	4.87E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.45E-04	1.76E-03	0.00E+00	0.00E+00	2.40E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-03	2.20E-04	0.00E+00	0.00E+00	3.51E-03
	HTO[2]	8.49E-02	0.00E+00	0.00E+00	7.97E-05	0.00E+00	0.00E+00	3.82E-04	2.22E-01	7.75E-02	3.84E-01
	I(mfp)	1.59E-05	5.18E-07	0.00E+00	0.00E+00	1.10E-06	0.00E+00	0.00E+00	2.70E-04	8.96E-04	1.18E-03
	Noble Gases	0.00E+00	9.64E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.64E-02
Total		8.51E-02	9.64E-02	0.00E+00	7.97E-05	1.69E-03	4.62E-03	1.01E-02	6.79E-01	4.02E-01	**1.28E+00**

Note: All doses reported in units of µSv/a.
[1] includes dose due to external exposure to progeny of Cs-137 in air, water, soil, and sediment
[2] includes dose incurred via ingestion of OBT in fish, plant produce and animal products.

Table 80
Dose to Representative Persons Located at BDF1

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Adult (16-70 yrs)	C-14	2.20E-04	2.53E-07	2.14E-06	1.16E-09	7.96E-12	2.40E-08	2.15E-03	2.36E-01	2.01E-01	4.40E-01
	Co-60	5.08E-07	1.93E-08	0.00E+00	6.11E-03	2.26E-03	5.19E-04	3.51E-04	9.89E-06	1.28E-06	9.25E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.91E-04	2.35E-03	0.00E+00	0.00E+00	2.84E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.68E-04	0.00E+00	0.00E+00	2.74E-03
	HTO[2]	1.77E-01	0.00E+00	7.64E-03	4.17E-03	0.00E+00	0.00E+00	1.59E-04	1.03E-01	4.70E-02	3.39E-01
	I(mfp)	9.87E-06	6.64E-07	0.00E+00	0.00E+00	1.41E-06	0.00E+00	0.00E+00	8.25E-05	1.18E-04	2.13E-04
	Noble Gases	0.00E+00	1.24E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.24E-01
Total		1.77E-01	1.24E-01	7.65E-03	1.03E-02	2.26E-03	3.48E-03	5.28E-03	3.40E-01	2.48E-01	**9.18E-01**
Child (6-15 yrs)	C-14	3.14E-04	2.53E-07	1.18E-06	1.16E-09	1.73E-11	2.97E-07	1.93E-03	2.50E-01	1.87E-01	4.39E-01
	Co-60	7.25E-07	1.93E-08	0.00E+00	6.11E-03	2.26E-03	5.22E-04	7.38E-04	2.44E-05	2.70E-06	9.66E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.97E-04	1.13E-03	0.00E+00	0.00E+00	1.62E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.53E-03	1.34E-04	0.00E+00	0.00E+00	2.66E-03
	HTO[2]	2.10E-01	0.00E+00	3.80E-03	3.48E-03	0.00E+00	0.00E+00	1.33E-04	9.99E-02	2.84E-02	3.46E-01
	I(mfp)	2.21E-05	6.64E-07	0.00E+00	0.00E+00	1.41E-06	0.00E+00	0.00E+00	1.46E-04	3.72E-04	5.43E-04
	Noble Gases	0.00E+00	1.24E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.24E-01

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Total		2.10E-01	1.24E-01	3.80E-03	9.59E-03	2.26E-03	3.55E-03	4.07E-03	3.50E-01	2.16E-01	**9.24E-01**
Infant (0-5 yrs)	C-14	2.14E-04	2.53E-07	0.00E+00	1.22E-11	2.94E-11	6.55E-07	1.32E-03	2.08E-01	2.45E-01	4.54E-01
	Co-60	5.31E-07	2.50E-08	0.00E+00	0.00E+00	2.93E-03	6.84E-04	6.18E-04	2.48E-05	3.81E-06	4.26E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.45E-04	4.39E-04	0.00E+00	0.00E+00	1.08E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-03	5.49E-05	0.00E+00	0.00E+00	3.34E-03
	HTO[2]	1.45E-01	0.00E+00	0.00E+00	7.97E-05	0.00E+00	0.00E+00	9.54E-05	1.06E-01	3.61E-02	2.87E-01
	I(mfp)	2.64E-05	8.64E-07	0.00E+00	0.00E+00	1.84E-06	0.00E+00	0.00E+00	2.15E-04	1.25E-03	1.49E-03
	Noble Gases	0.00E+00	1.61E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.61E-01
Total		1.45E-01	1.61E-01	0.00E+00	7.97E-05	2.93E-03	4.62E-03	2.52E-03	3.14E-01	2.82E-01	**9.13E-01**

Note: All doses reported in units of µSv/a.

[1] includes dose due to external exposure to progeny of Cs-137 in air, water, soil, and sediment

[2] includes dose incurred via ingestion of OBT in fish, plant produce and animal products.

Table 81
Dose to Representative Persons Located at BDF9

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Adult (16-70 yrs)	C-14	1.86E-04	2.13E-07	1.81E-06	1.16E-09	0.00E+00	2.40E-08	2.15E-03	2.17E-01	1.94E-01	4.14E-01
	Co-60	3.05E-07	1.16E-08	0.00E+00	6.11E-03	1.10E-03	5.19E-04	3.51E-04	4.91E-06	6.31E-07	8.08E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.91E-04	2.35E-03	0.00E+00	0.00E+00	2.84E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.68E-04	0.00E+00	0.00E+00	2.74E-03
	HTO[2]	1.04E-01	0.00E+00	7.64E-03	4.17E-03	0.00E+00	0.00E+00	1.59E-04	1.03E-01	5.87E-02	2.77E-01
	I(mfp)	5.92E-06	3.99E-07	0.00E+00	0.00E+00	8.12E-07	0.00E+00	0.00E+00	4.72E-05	6.76E-05	1.22E-04
	Noble Gases	0.00E+00	7.44E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.44E-02
Total		1.04E-01	7.44E-02	7.65E-03	1.03E-02	1.10E-03	3.48E-03	5.28E-03	3.20E-01	2.53E-01	**7.79E-01**
Child (6-15 yrs)	C-14	2.65E-04	2.13E-07	9.92E-07	1.16E-09	0.00E+00	2.97E-07	1.93E-03	2.27E-01	2.08E-01	4.37E-01
	Co-60	4.35E-07	1.16E-08	0.00E+00	6.11E-03	1.10E-03	5.22E-04	7.38E-04	1.21E-05	1.34E-06	8.48E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.97E-04	1.13E-03	0.00E+00	0.00E+00	1.62E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.53E-03	1.34E-04	0.00E+00	0.00E+00	2.66E-03
	HTO[2]	1.23E-01	0.00E+00	3.80E-03	3.48E-03	0.00E+00	0.00E+00	1.33E-04	9.99E-02	6.58E-02	2.96E-01
	I(mfp)	1.33E-05	3.99E-07	0.00E+00	0.00E+00	8.14E-07	0.00E+00	0.00E+00	8.37E-05	2.13E-04	3.11E-04
	Noble Gases	0.00E+00	7.44E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.44E-02

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Total		1.23E-01	7.44E-02	3.80E-03	9.59E-03	1.10E-03	3.55E-03	4.07E-03	3.27E-01	2.74E-01	**8.21E-01**
Infant (0-5 yrs)	C-14	1.81E-04	2.13E-07	0.00E+00	1.03E-11	0.00E+00	6.55E-07	1.32E-03	1.89E-01	3.07E-01	4.98E-01
	Co-60	3.19E-07	1.50E-08	0.00E+00	0.00E+00	1.42E-03	6.84E-04	6.18E-04	1.23E-05	1.89E-06	2.74E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.45E-04	4.39E-04	0.00E+00	0.00E+00	1.08E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-03	5.49E-05	0.00E+00	0.00E+00	3.34E-03
	HTO[2]	8.49E-02	0.00E+00	0.00E+00	7.97E-05	0.00E+00	0.00E+00	9.54E-05	1.06E-01	1.24E-01	3.15E-01
	I(mfp)	1.59E-05	5.18E-07	0.00E+00	0.00E+00	1.06E-06	0.00E+00	0.00E+00	1.23E-04	7.13E-04	8.53E-04
	Noble Gases	0.00E+00	9.64E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.64E-02
Total		8.51E-02	9.64E-02	0.00E+00	7.97E-05	1.43E-03	4.62E-03	2.52E-03	2.95E-01	4.31E-01	**9.17E-01**

Note: All doses reported in units of µSv/a.

[1] includes dose due to external exposure to progeny of Cs-137 in air, water, soil, and sediment

[2] includes dose incurred via ingestion of OBT in fish, plant produce and animal products.

Table 82
Dose to Representative Persons Located at BDF12

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Adult (16-70 yrs)	C-14	2.20E-04	2.53E-07	2.14E-06	1.16E-09	7.96E-12	2.40E-08	2.15E-03	2.81E-01	2.11E-01	4.94E-01
	Co-60	5.08E-07	1.93E-08	0.00E+00	6.11E-03	2.27E-03	5.19E-04	3.51E-04	9.96E-06	1.29E-06	9.27E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.91E-04	2.35E-03	0.00E+00	0.00E+00	2.84E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.68E-04	0.00E+00	0.00E+00	2.74E-03
	HTO[2]	1.77E-01	0.00E+00	7.64E-03	4.17E-03	0.00E+00	0.00E+00	1.59E-04	1.51E-01	5.37E-02	3.93E-01
	I(mfp)	9.87E-06	6.64E-07	0.00E+00	0.00E+00	1.41E-06	0.00E+00	0.00E+00	8.27E-05	1.18E-04	2.13E-04
	Noble Gases	0.00E+00	1.24E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.24E-01
Total		1.77E-01	1.24E-01	7.65E-03	1.03E-02	2.27E-03	3.48E-03	5.28E-03	4.32E-01	2.64E-01	**1.03E+00**
Child (6-15 yrs)	C-14	3.14E-04	2.53E-07	1.18E-06	1.16E-09	1.73E-11	2.97E-07	1.93E-03	2.88E-01	2.10E-01	5.00E-01
	Co-60	7.25E-07	1.93E-08	0.00E+00	6.11E-03	2.27E-03	5.22E-04	7.38E-04	2.46E-05	2.72E-06	9.67E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.97E-04	1.13E-03	0.00E+00	0.00E+00	1.62E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.53E-03	1.34E-04	0.00E+00	0.00E+00	2.66E-03
	HTO[2]	2.10E-01	0.00E+00	3.80E-03	3.48E-03	0.00E+00	0.00E+00	1.33E-04	1.28E-01	4.36E-02	3.90E-01
	I(mfp)	2.21E-05	6.64E-07	0.00E+00	0.00E+00	1.41E-06	0.00E+00	0.00E+00	1.47E-04	3.73E-04	5.43E-04
	Noble Gases	0.00E+00	1.24E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.24E-01

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Total		2.10E-01	1.24E-01	3.80E-03	9.59E-03	2.27E-03	3.55E-03	4.07E-03	4.16E-01	2.54E-01	**1.03E+00**
Infant (0-5 yrs)	C-14	2.14E-04	2.53E-07	0.00E+00	1.22E-11	2.94E-11	6.55E-07	1.32E-03	2.38E-01	2.95E-01	5.34E-01
	Co-60	5.31E-07	2.50E-08	0.00E+00	0.00E+00	2.95E-03	6.84E-04	6.18E-04	2.50E-05	3.84E-06	4.29E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.45E-04	4.39E-04	0.00E+00	0.00E+00	1.08E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-03	5.49E-05	0.00E+00	0.00E+00	3.34E-03
	HTO[2]	1.45E-01	0.00E+00	0.00E+00	7.97E-05	0.00E+00	0.00E+00	9.54E-05	1.17E-01	7.04E-02	3.32E-01
	I(mfp)	2.64E-05	8.64E-07	0.00E+00	0.00E+00	1.84E-06	0.00E+00	0.00E+00	2.15E-04	1.25E-03	1.49E-03
	Noble Gases	0.00E+00	1.61E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.61E-01
Total		1.45E-01	1.61E-01	0.00E+00	7.97E-05	2.96E-03	4.62E-03	2.52E-03	3.54E-01	3.66E-01	**1.04E+00**

Note: All doses reported in units of μSv/a.

[1] includes dose due to external exposure to progeny of Cs-137 in air, water, soil, and sediment

[2] includes dose incurred via ingestion of OBT in fish, plant produce and animal products.

Table 83
Dose to Representative Persons Located at BDF13

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Adult (16-70 yrs)	C-14	1.86E-04	2.13E-07	1.81E-06	1.16E-09	0.00E+00	2.40E-08	2.15E-03	2.62E-01	2.03E-01	4.67E-01
	Co-60	3.05E-07	1.16E-08	0.00E+00	6.11E-03	8.53E-04	5.19E-04	3.51E-04	3.94E-06	5.03E-07	7.84E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.91E-04	2.35E-03	0.00E+00	0.00E+00	2.84E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.68E-04	0.00E+00	0.00E+00	2.74E-03
	HTO[2]	1.04E-01	0.00E+00	7.64E-03	4.17E-03	0.00E+00	0.00E+00	1.59E-04	1.51E-01	4.50E-02	3.11E-01
	I(mfp)	5.92E-06	3.99E-07	0.00E+00	0.00E+00	7.81E-07	0.00E+00	0.00E+00	4.51E-05	6.45E-05	1.17E-04
	Noble Gases	0.00E+00	7.44E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.44E-02
Total		1.04E-01	7.44E-02	7.65E-03	1.03E-02	8.54E-04	3.48E-03	5.28E-03	4.13E-01	2.48E-01	**8.67E-01**
Child (6-15 yrs)	C-14	2.65E-04	2.13E-07	9.92E-07	1.16E-09	0.00E+00	2.97E-07	1.93E-03	2.65E-01	2.30E-01	4.97E-01
	Co-60	4.35E-07	1.16E-08	0.00E+00	6.11E-03	8.53E-04	5.22E-04	7.38E-04	9.70E-06	1.07E-06	8.24E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.97E-04	1.13E-03	0.00E+00	0.00E+00	1.62E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.53E-03	1.34E-04	0.00E+00	0.00E+00	2.66E-03
	HTO[2]	1.23E-01	0.00E+00	3.80E-03	3.48E-03	0.00E+00	0.00E+00	1.33E-04	1.28E-01	3.44E-02	2.93E-01
	I(mfp)	1.33E-05	3.99E-07	0.00E+00	0.00E+00	7.82E-07	0.00E+00	0.00E+00	7.99E-05	2.03E-04	2.97E-04
	Noble Gases	0.00E+00	7.44E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.44E-02

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Total		1.23E-01	7.44E-02	3.80E-03	9.59E-03	8.54E-04	3.55E-03	4.07E-03	3.93E-01	2.65E-01	**8.78E-01**
Infant (0-5 yrs)	C-14	1.81E-04	2.13E-07	0.00E+00	1.03E-11	0.00E+00	6.55E-07	1.32E-03	2.19E-01	3.54E-01	5.75E-01
	Co-60	3.19E-07	1.50E-08	0.00E+00	0.00E+00	1.11E-03	6.84E-04	6.18E-04	9.87E-06	1.51E-06	2.42E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.45E-04	4.39E-04	0.00E+00	0.00E+00	1.08E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-03	5.49E-05	0.00E+00	0.00E+00	3.34E-03
	HTO[2]	8.49E-02	0.00E+00	0.00E+00	7.97E-05	0.00E+00	0.00E+00	9.54E-05	1.17E-01	5.34E-02	2.55E-01
	I(mfp)	1.59E-05	5.18E-07	0.00E+00	0.00E+00	1.02E-06	0.00E+00	0.00E+00	1.17E-04	6.80E-04	8.15E-04
	Noble Gases	0.00E+00	9.64E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.64E-02
Total		8.51E-02	9.64E-02	0.00E+00	7.97E-05	1.11E-03	4.62E-03	2.52E-03	3.36E-01	4.08E-01	**9.34E-01**

Note: All doses reported in units of µSv/a.

[1] includes dose due to external exposure to progeny of Cs-137 in air, water, soil, and sediment

[2] includes dose incurred via ingestion of OBT in fish, plant produce and animal products.

Table 84
Dose to Representative Persons Located at BDF14

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Adult (16-70 yrs)	C-14	1.86E-04	2.13E-07	1.81E-06	1.16E-09	0.00E+00	2.40E-08	2.15E-03	2.17E-01	2.03E-01	4.23E-01
	Co-60	3.05E-07	1.16E-08	0.00E+00	6.11E-03	7.06E-04	5.19E-04	3.51E-04	3.35E-06	4.27E-07	7.69E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.91E-04	2.35E-03	0.00E+00	0.00E+00	2.84E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.68E-04	0.00E+00	0.00E+00	2.74E-03
	HTO[2]	1.04E-01	0.00E+00	7.64E-03	4.17E-03	0.00E+00	0.00E+00	1.59E-04	1.03E-01	4.50E-02	2.64E-01
	I(mfp)	5.92E-06	3.99E-07	0.00E+00	0.00E+00	7.62E-07	0.00E+00	0.00E+00	4.37E-05	6.26E-05	1.13E-04
	Noble Gases	0.00E+00	7.44E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.44E-02
Total		1.04E-01	7.44E-02	7.65E-03	1.03E-02	7.07E-04	3.48E-03	5.28E-03	3.20E-01	2.48E-01	**7.74E-01**
Child (6-15 yrs)	C-14	2.65E-04	2.13E-07	9.92E-07	1.16E-09	0.00E+00	2.97E-07	1.93E-03	2.27E-01	2.30E-01	4.59E-01
	Co-60	4.35E-07	1.16E-08	0.00E+00	6.11E-03	7.06E-04	5.22E-04	7.38E-04	8.26E-06	9.06E-07	8.09E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.97E-04	1.13E-03	0.00E+00	0.00E+00	1.62E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.53E-03	1.34E-04	0.00E+00	0.00E+00	2.66E-03
	HTO[2]	1.23E-01	0.00E+00	3.80E-03	3.48E-03	0.00E+00	0.00E+00	1.33E-04	9.98E-02	3.44E-02	2.65E-01
	I(mfp)	1.33E-05	3.99E-07	0.00E+00	0.00E+00	7.64E-07	0.00E+00	0.00E+00	7.75E-05	1.97E-04	2.89E-04
	Noble Gases	0.00E+00	7.44E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.44E-02

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Total		1.23E-01	7.44E-02	3.80E-03	9.59E-03	7.07E-04	3.55E-03	4.07E-03	3.27E-01	2.65E-01	**8.11E-01**
Infant (0-5 yrs)	C-14	1.81E-04	2.13E-07	0.00E+00	1.03E-11	0.00E+00	6.55E-07	1.32E-03	1.89E-01	3.54E-01	5.45E-01
	Co-60	3.19E-07	1.50E-08	0.00E+00	0.00E+00	9.18E-04	6.84E-04	6.18E-04	8.41E-06	1.28E-06	2.23E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.45E-04	4.39E-04	0.00E+00	0.00E+00	1.08E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-03	5.49E-05	0.00E+00	0.00E+00	3.34E-03
	HTO[2]	8.49E-02	0.00E+00	0.00E+00	7.97E-05	0.00E+00	0.00E+00	9.54E-05	1.06E-01	5.34E-02	2.44E-01
	I(mfp)	1.59E-05	5.18E-07	0.00E+00	0.00E+00	9.96E-07	0.00E+00	0.00E+00	1.14E-04	6.60E-04	7.92E-04
	Noble Gases	0.00E+00	9.64E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.64E-02
Total		8.51E-02	9.64E-02	0.00E+00	7.97E-05	9.19E-04	4.62E-03	2.52E-03	2.95E-01	4.08E-01	**8.93E-01**

Note: All doses reported in units of µSv/a.

[1] includes dose due to external exposure to progeny of Cs-137 in air, water, soil, and sediment

[2] includes dose incurred via ingestion of OBT in fish, plant produce and animal products.

Table 85
Dose to Representative Persons Located at BDF15

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Adult (16-70 yrs)	C-14	1.86E-04	2.13E-07	1.81E-06	1.16E-09	0.00E+00	2.40E-08	2.15E-03	2.17E-01	1.69E-01	3.88E-01
	Co-60	3.05E-07	1.16E-08	0.00E+00	6.11E-03	8.42E-04	5.19E-04	3.51E-04	3.89E-06	4.98E-07	7.83E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.91E-04	2.35E-03	0.00E+00	0.00E+00	2.84E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	2.68E-04	0.00E+00	0.00E+00	2.74E-03
	HTO[2]	1.04E-01	0.00E+00	7.64E-03	4.17E-03	0.00E+00	0.00E+00	1.59E-04	1.03E-01	3.98E-02	2.58E-01
	I(mfp)	5.92E-06	3.99E-07	0.00E+00	0.00E+00	7.80E-07	0.00E+00	0.00E+00	4.50E-05	6.44E-05	1.16E-04
	Noble Gases	0.00E+00	7.44E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.44E-02
Total		1.04E-01	7.44E-02	7.65E-03	1.03E-02	8.43E-04	3.48E-03	5.28E-03	3.20E-01	2.09E-01	**7.34E-01**
Child (6-15 yrs)	C-14	2.65E-04	2.13E-07	9.92E-07	1.16E-09	0.00E+00	2.97E-07	1.93E-03	2.27E-01	1.43E-01	3.73E-01
	Co-60	4.35E-07	1.16E-08	0.00E+00	6.11E-03	8.42E-04	5.22E-04	7.38E-04	9.59E-06	1.06E-06	8.23E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.97E-04	1.13E-03	0.00E+00	0.00E+00	1.62E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.53E-03	1.34E-04	0.00E+00	0.00E+00	2.66E-03
	HTO[2]	1.23E-01	0.00E+00	3.80E-03	3.48E-03	0.00E+00	0.00E+00	1.33E-04	9.98E-02	2.26E-02	2.53E-01
	I(mfp)	1.33E-05	3.99E-07	0.00E+00	0.00E+00	7.81E-07	0.00E+00	0.00E+00	7.97E-05	2.03E-04	2.97E-04
	Noble Gases	0.00E+00	7.44E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.44E-02

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Total		1.23E-01	7.44E-02	3.80E-03	9.59E-03	8.43E-04	3.55E-03	4.07E-03	3.27E-01	1.66E-01	**7.13E-01**
Infant (0-5 yrs)	C-14	1.81E-04	2.13E-07	0.00E+00	1.03E-11	0.00E+00	6.55E-07	1.32E-03	1.89E-01	1.70E-01	3.60E-01
	Co-60	3.19E-07	1.50E-08	0.00E+00	0.00E+00	1.09E-03	6.84E-04	6.18E-04	9.76E-06	1.49E-06	2.41E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.45E-04	4.39E-04	0.00E+00	0.00E+00	1.08E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-03	5.49E-05	0.00E+00	0.00E+00	3.34E-03
	HTO[2]	8.49E-02	0.00E+00	0.00E+00	7.97E-05	0.00E+00	0.00E+00	9.54E-05	1.06E-01	2.67E-02	2.18E-01
	I(mfp)	1.59E-05	5.18E-07	0.00E+00	0.00E+00	1.02E-06	0.00E+00	0.00E+00	1.17E-04	6.79E-04	8.13E-04
	Noble Gases	0.00E+00	9.64E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.64E-02
Total		8.51E-02	9.64E-02	0.00E+00	7.97E-05	1.10E-03	4.62E-03	2.52E-03	2.95E-01	1.97E-01	**6.82E-01**

Note: All doses reported in units of µSv/a.

[1] includes dose due to external exposure to progeny of Cs-137 in air, water, soil, and sediment

[2] includes dose incurred via ingestion of OBT in fish, plant produce and animal products.

Table 86
Dose to Representative Persons Located at BHF1

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Adult (16-70 yrs)	C-14	4.18E-05	4.80E-08	4.38E-05	9.36E-10	2.78E-10	5.36E-09	8.61E-03	7.99E-02	6.14E-02	1.50E-01
	Co-60	9.64E-08	3.65E-09	2.03E-04	6.59E-05	6.49E-03	5.19E-04	1.40E-03	6.30E-05	1.50E-05	8.75E-03
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.91E-04	9.41E-03	0.00E+00	0.00E+00	9.90E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E-03	1.07E-03	0.00E+00	0.00E+00	3.54E-03
	HTO[2]	2.86E-02	0.00E+00	7.61E-02	2.58E-03	0.00E+00	0.00E+00	6.37E-04	1.25E-01	4.89E-02	2.82E-01
	I(mfp)	1.88E-06	1.27E-07	0.00E+00	0.00E+00	2.43E-07	0.00E+00	0.00E+00	2.86E-05	2.76E-05	5.84E-05
	Noble Gases	0.00E+00	2.36E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.36E-02
Total		2.86E-02	2.36E-02	7.63E-02	2.65E-03	6.49E-03	3.48E-03	2.11E-02	2.05E-01	1.10E-01	**4.77E-01**
Child (6-15 yrs)	C-14	5.96E-05	4.80E-08	2.40E-05	9.36E-10	6.04E-10	6.64E-08	7.73E-03	8.84E-02	6.05E-02	1.57E-01
	Co-60	1.38E-07	3.65E-09	2.61E-04	6.59E-05	6.49E-03	5.22E-04	2.95E-03	1.56E-04	2.80E-05	1.05E-02
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.97E-04	4.51E-03	0.00E+00	0.00E+00	5.01E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.53E-03	5.37E-04	0.00E+00	0.00E+00	3.07E-03
	HTO[2]	3.40E-02	0.00E+00	3.79E-02	2.15E-03	0.00E+00	0.00E+00	5.33E-04	1.15E-01	6.06E-02	2.50E-01
	I(mfp)	4.21E-06	1.27E-07	0.00E+00	0.00E+00	2.43E-07	0.00E+00	0.00E+00	5.21E-05	8.05E-05	1.37E-04
	Noble Gases	0.00E+00	2.36E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.36E-02

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Total		3.40E-02	2.36E-02	3.81E-02	2.22E-03	6.49E-03	3.55E-03	1.63E-02	2.03E-01	1.21E-01	**4.49E-01**
Infant (0-5 yrs)	C-14	4.07E-05	4.80E-08	0.00E+00	1.77E-10	1.03E-09	1.46E-07	5.27E-03	7.09E-02	8.09E-02	1.57E-01
	Co-60	1.01E-07	4.75E-09	0.00E+00	1.62E-05	8.43E-03	6.84E-04	2.47E-03	1.62E-04	2.90E-05	1.18E-02
	Cs-134	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.45E-04	1.76E-03	0.00E+00	0.00E+00	2.40E-03
	Cs-137[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.29E-03	2.20E-04	0.00E+00	0.00E+00	3.51E-03
	HTO[2]	2.34E-02	0.00E+00	0.00E+00	5.62E-04	0.00E+00	0.00E+00	3.82E-04	1.05E-01	1.08E-01	2.37E-01
	I(mfp)	5.04E-06	1.65E-07	0.00E+00	0.00E+00	3.18E-07	0.00E+00	0.00E+00	7.68E-05	2.59E-04	3.41E-04
	Noble Gases	0.00E+00	3.05E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.05E-02
Total		2.35E-02	3.05E-02	0.00E+00	5.78E-04	8.43E-03	4.62E-03	1.01E-02	1.76E-01	1.89E-01	**4.43E-01**

Note: All doses reported in units of µSv/a.

[1] includes dose due to external exposure to progeny of Cs-137 in air, water, soil, and sediment

[2] includes dose incurred via ingestion of OBT in fish, plant produce and animal products.

Table 87
Dose to Representative Persons Located at BEC

Age Class	Radionuclide	Air Inhalation	Air Immersion	Water Ingestion	Water Immersion	Soil (ingestion and external)	Sediment (ingestion and external)	Fish Ingestion	Plant Ingestion	Animal Ingestion	Total
Adult (16-70 yrs)	C-14	5.06E-05	5.82E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.06E-05
	Co-60	1.17E-07	4.43E-09	0.00E+00	0.00E+00	5.75E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.75E-04
	Cs-134	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
	Cs-137[1]	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
	HTO[2]	4.06E-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	4.06E-02
	I(mfp)	2.27E-06	1.53E-07	0.00E+00	0.00E+00	3.31E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.75E-06
	Noble Gases	0.00E+00	2.86E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.86E-02
Total		4.07E-02	2.86E-02	0.00E+00	0.00E+00	5.75E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**6.99E-02**

Note: All doses reported in units of μSv/a.
[1] includes dose due to external exposure to progeny of Cs-137 in air, water, soil, and sediment
[2] includes dose incurred via ingestion of OBT in fish, plant produce and animal products.

APPENDIX D: SAMPLING SITE LOCATIONS

Figure 63
Environmental Monitoring Sample Points -1

Appendix D (Continued)

Figure 64
Environmental Monitoring Sample Points - 2

Appendix D (Continued)

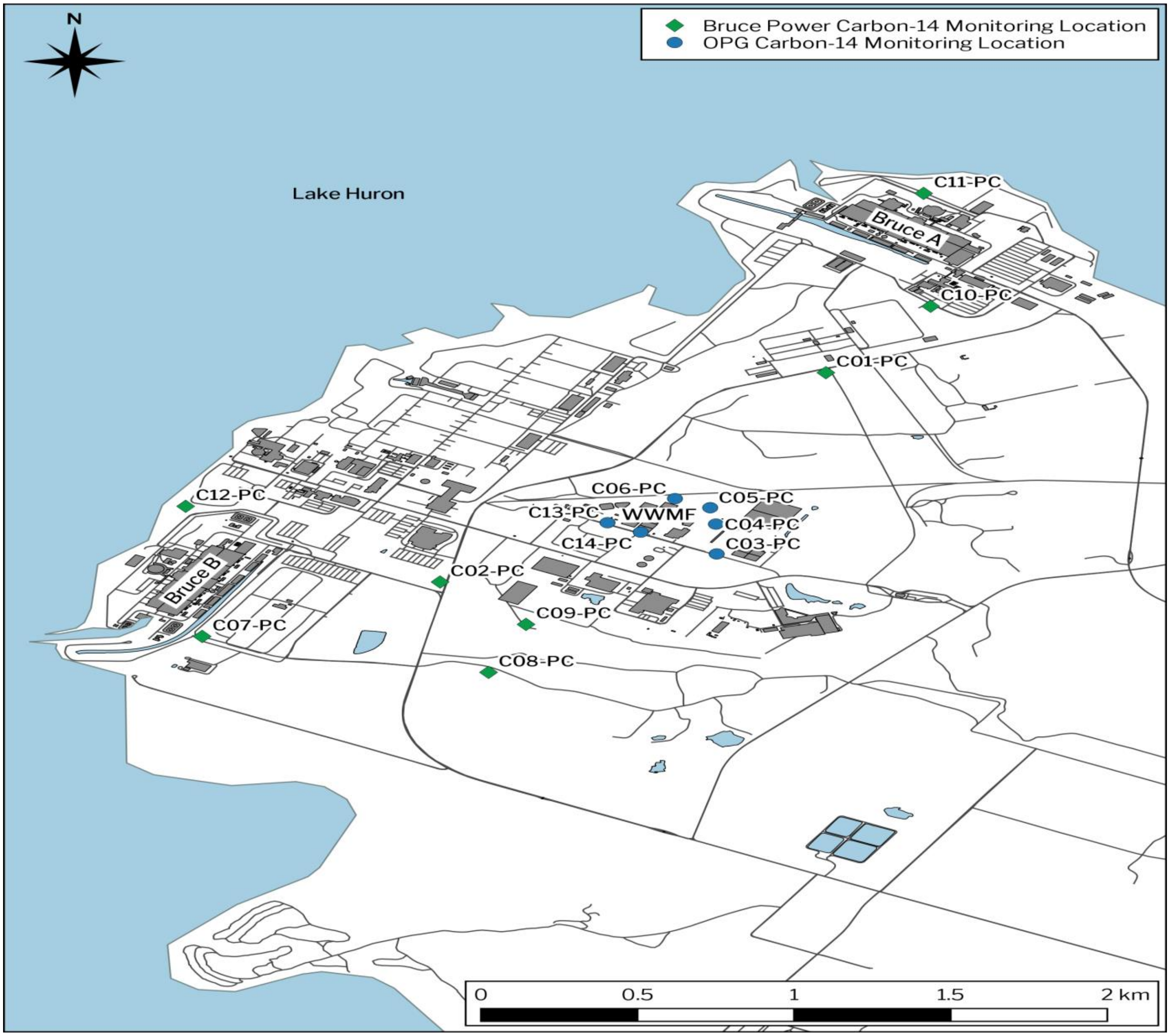

Figure 65
On-Site ^{14}C Sampling Locations

Appendix D (Continued)

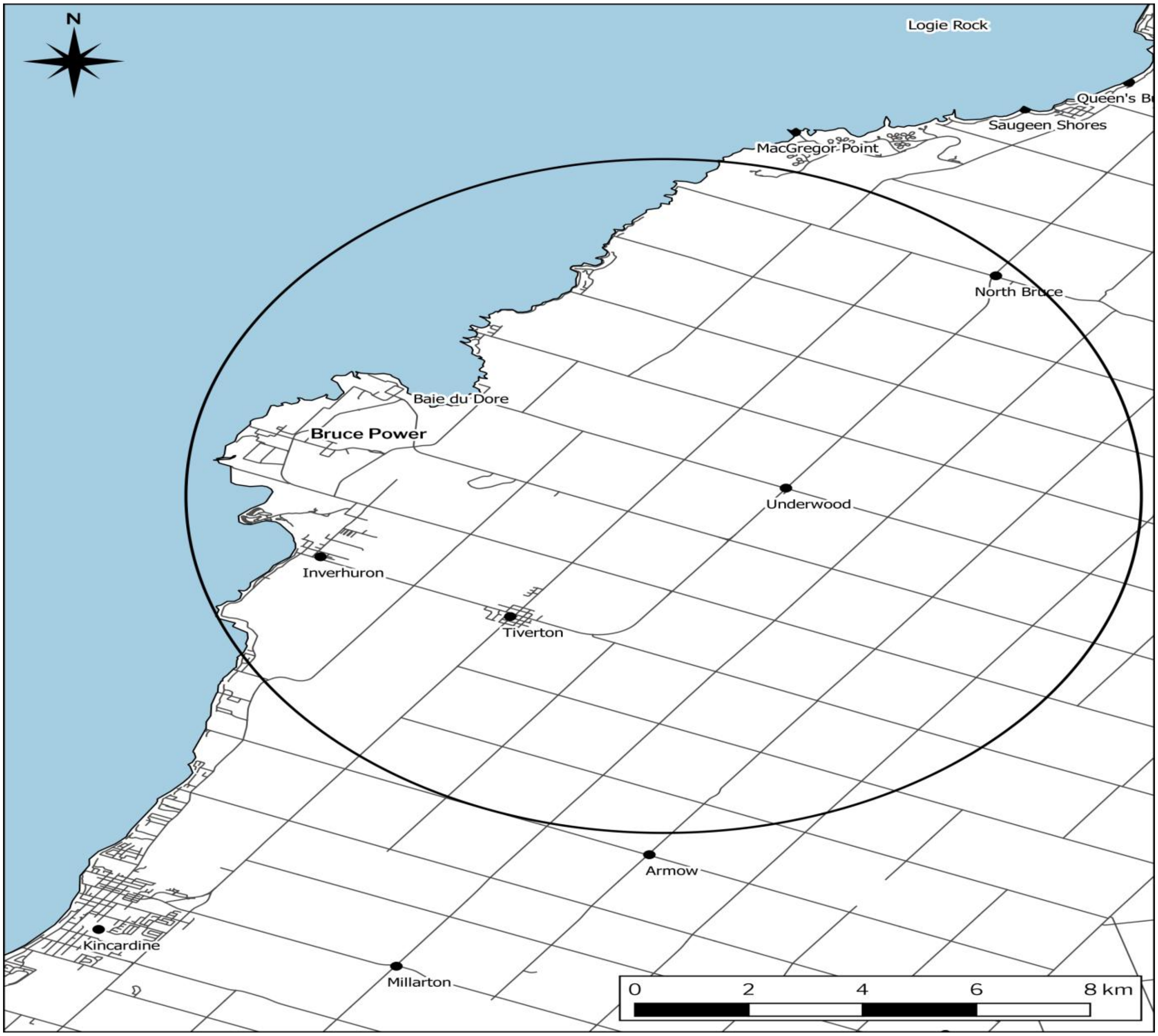

Figure 66
Milk Sampling Locations within Circumference

Appendix D (Continued)

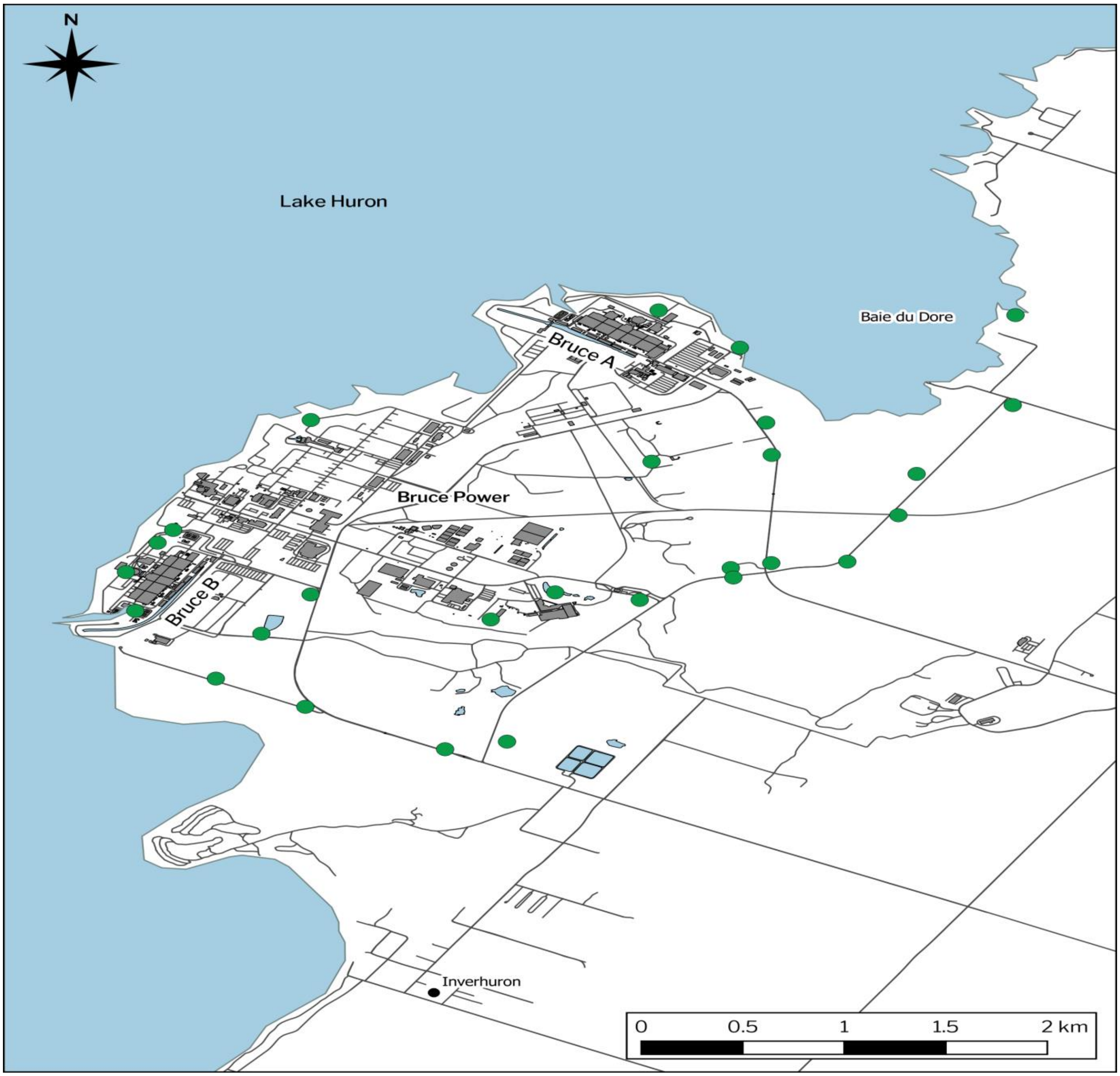

Figure 67
On-Site Soil Sample (2016)

APPENDIX E: SUMMARY OF BRUCE A AND BRUCE B MONITORING WELLS

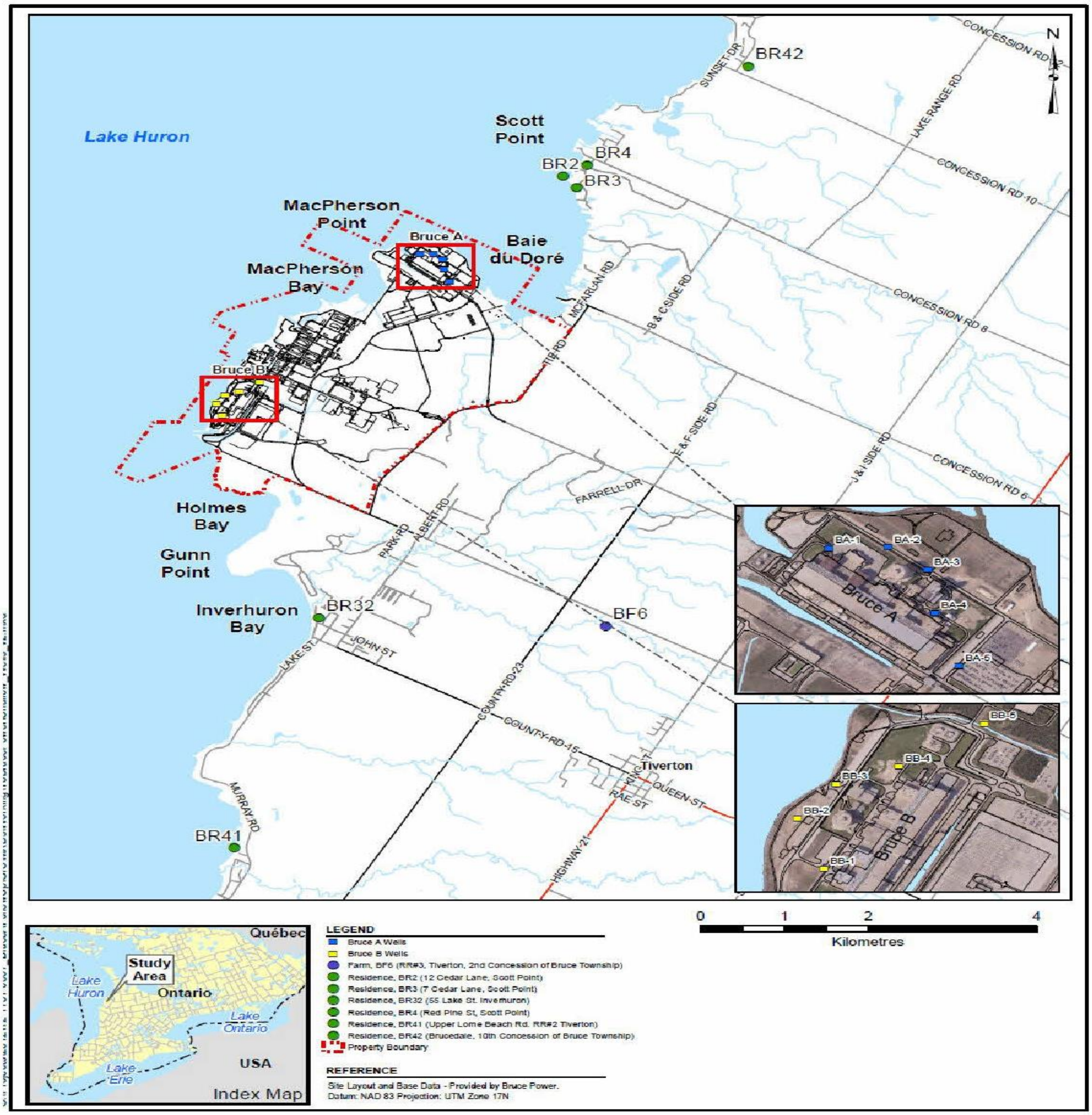

Figure 68
Bruce A and Bruce B Monitoring Wells

Appendix E (Continued)

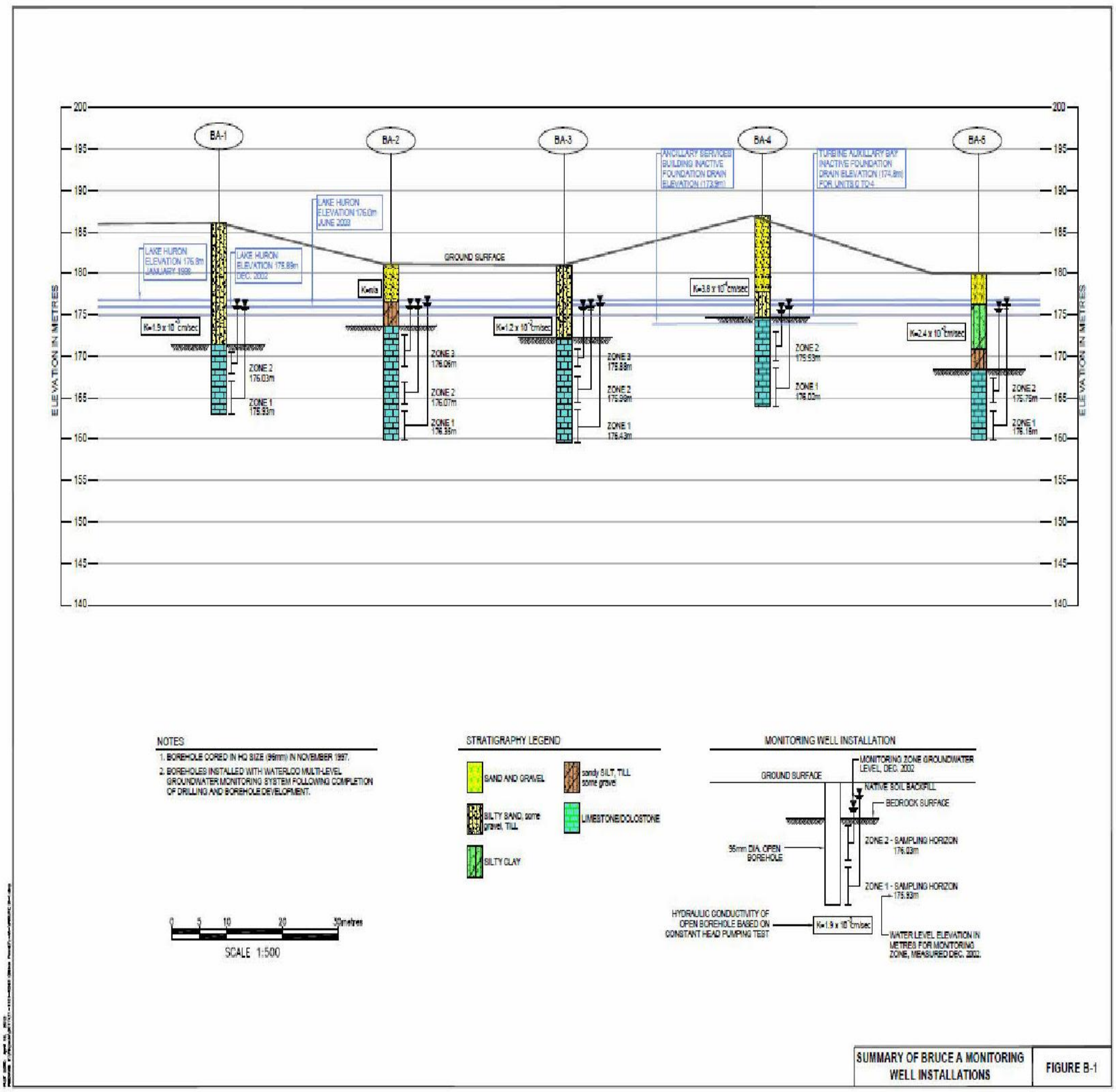

Figure 69
Summary of Bruce A Monitoring Well Installation

Appendix E (Continued)

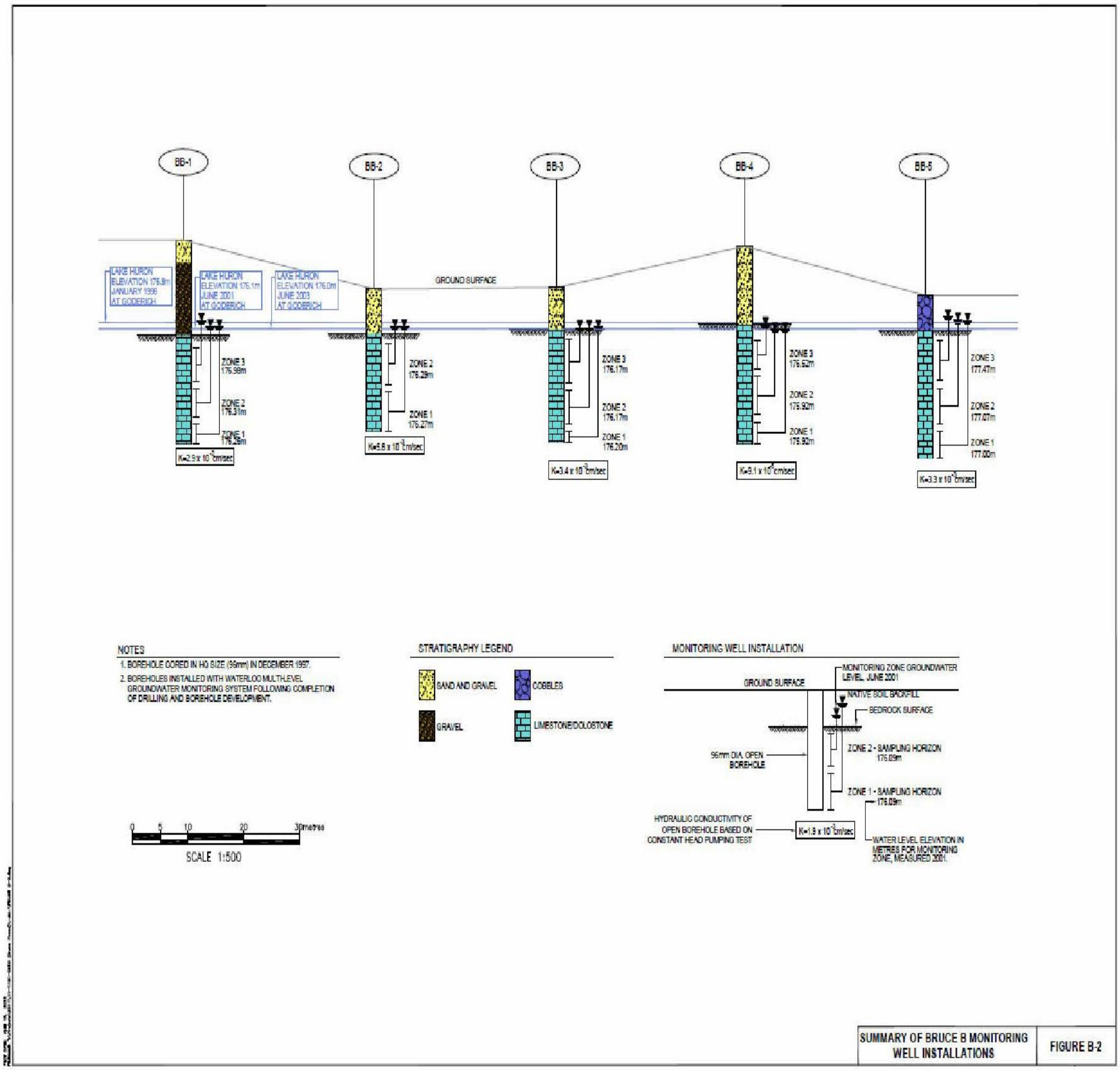

Figure 70
Summary of Bruce B Monitoring Well Installations

Table 88
Annual Average TJF (Surrogate) for Bruce Power Site for Year 2019 50m Meteorological Tower at 10m Height

Stability Class	Wind Direction (wind blowing from)	Wind Speed, u (m/s)						
		u ≤ 2	2 < u ≤ 3	3 < u ≤ 4	4 < u ≤ 5	5 < u ≤ 6	u > 6	Total
		Frequency (%) at 10 m Height						
A	N	0.53	0.30	0.25	0.05	0.03	0.03	**1.19**
	NNE	0.52	0.36	0.34	0.11	0.03	0.01	**1.37**
	NE	0.29	0.17	0.09	0.02	0.01	0.01	**0.58**
	ENE	0.33	0.15	0.10	0.01	0.00	0.00	**0.59**
	E	0.46	0.20	0.07	0.01	0.01	0.00	**0.76**
	ESE	0.43	0.12	0.05	0.02	0.01	0.00	**0.63**
	SE	0.36	0.18	0.05	0.02	0.00	0.00	**0.60**
	SSE	0.35	0.13	0.11	0.03	0.00	0.00	**0.62**
	S	0.34	0.16	0.13	0.03	0.01	0.00	**0.68**
	SSW	0.37	0.14	0.13	0.07	0.03	0.00	**0.74**
	SW	0.37	0.27	0.19	0.08	0.01	0.01	**0.93**
	WSW	0.36	0.28	0.20	0.03	0.01	0.02	**0.89**
	W	0.29	0.37	0.16	0.02	0.02	0.02	**0.88**
	WNW	0.35	0.39	0.16	0.02	0.01	0.00	**0.94**
	NW	0.49	0.43	0.14	0.05	0.03	0.00	**1.14**
	NNW	0.90	0.54	0.19	0.07	0.03	0.00	**1.72**
	Total	**6.72**	**4.19**	**2.37**	**0.64**	**0.23**	**0.11**	**14.26**
B	N	0.21	0.10	0.32	0.32	0.12	0.05	**1.12**
	NNE	0.35	0.37	0.55	0.42	0.15	0.05	**1.89**
	NE	0.13	0.09	0.14	0.12	0.03	0.02	**0.54**
	ENE	0.26	0.10	0.14	0.11	0.03	0.00	**0.65**
	E	0.11	0.11	0.08	0.03	0.00	0.00	**0.32**
	ESE	0.07	0.05	0.07	0.05	0.03	0.02	**0.29**
	SE	0.24	0.16	0.12	0.05	0.03	0.02	**0.63**
	SSE	0.37	0.28	0.26	0.15	0.08	0.06	**1.20**
	S	0.40	0.21	0.27	0.26	0.12	0.10	**1.36**
	SSW	0.38	0.27	0.37	0.41	0.36	0.40	**2.19**
	SW	0.77	0.38	0.94	0.90	0.42	0.15	**3.56**
	WSW	0.26	0.18	0.28	0.12	0.08	0.06	**0.98**
	W	0.15	0.14	0.25	0.11	0.08	0.09	**0.81**
	WNW	0.22	0.15	0.22	0.21	0.13	0.10	**1.03**
	NW	0.23	0.14	0.22	0.27	0.12	0.10	**1.09**

Stability Class	Wind Direction (wind blowing from)	Wind Speed, u (m/s)						
		u ≤ 2	2 < u ≤ 3	3 < u ≤ 4	4 < u ≤ 5	5 < u ≤ 6	u > 6	Total
		Frequency (%) at 10 m Height						
	NNW	0.34	0.35	0.47	0.39	0.20	0.14	**1.89**
	Total	**4.49**	**3.09**	**4.71**	**3.90**	**1.98**	**1.36**	**19.54**
C	N	0.00	0.01	0.03	0.03	0.02	0.01	**0.10**
	NNE	0.03	0.03	0.02	0.01	0.00	0.00	**0.08**
	NE	0.01	0.01	0.01	0.01	0.00	0.00	**0.05**
	ENE	0.09	0.05	0.03	0.02	0.00	0.00	**0.20**
	E	0.02	0.02	0.00	0.00	0.00	0.00	**0.03**
	ESE	0.01	0.00	0.00	0.00	0.00	0.00	**0.03**
	SE	0.08	0.01	0.00	0.00	0.00	0.00	**0.10**
	SSE	0.14	0.12	0.10	0.04	0.01	0.01	**0.42**
	S	0.19	0.16	0.14	0.08	0.05	0.01	**0.64**
	SSW	0.17	0.11	0.13	0.06	0.08	0.07	**0.62**
	SW	0.18	0.14	0.39	0.47	0.19	0.24	**1.60**
	WSW	0.21	0.13	0.19	0.18	0.19	0.54	**1.43**
	W	0.07	0.11	0.09	0.11	0.11	0.23	**0.73**
	WNW	0.06	0.04	0.06	0.09	0.07	0.13	**0.45**
	NW	0.01	0.01	0.04	0.06	0.07	0.11	**0.30**
	NNW	0.04	0.05	0.12	0.16	0.08	0.16	**0.61**
	Total	**1.33**	**1.00**	**1.34**	**1.33**	**0.88**	**1.51**	**7.39**
D	N	0.00	0.03	0.43	0.33	0.22	0.24	**1.26**
	NNE	0.00	0.00	0.24	0.27	0.14	0.11	**0.76**
	NE	0.07	0.03	0.26	0.21	0.10	0.05	**0.73**
	ENE	0.22	0.17	0.29	0.11	0.04	0.04	**0.87**
	E	0.11	0.02	0.11	0.04	0.01	0.00	**0.29**
	ESE	0.05	0.02	0.12	0.07	0.04	0.03	**0.33**
	SE	0.15	0.09	0.27	0.17	0.08	0.04	**0.80**
	SSE	0.57	0.69	0.76	0.25	0.12	0.04	**2.43**
	S	0.52	0.38	0.92	0.63	0.25	0.11	**2.81**
	SSW	0.25	0.45	0.86	0.72	0.64	0.68	**3.60**
	SW	0.02	0.19	0.50	0.51	0.42	0.51	**2.15**
	WSW	0.01	0.12	0.31	0.51	0.42	0.91	**2.28**
	W	0.00	0.07	0.30	0.35	0.34	0.72	**1.80**
	WNW	0.00	0.08	0.37	0.44	0.51	0.66	**2.06**
	NW	0.00	0.06	0.37	0.48	0.45	0.43	**1.79**

Stability Class	Wind Direction (wind blowing from)	Wind Speed, u (m/s)						Total
		u ≤ 2	2 < u ≤ 3	3 < u ≤ 4	4 < u ≤ 5	5 < u ≤ 6	u > 6	Total
		Frequency (%) at 10 m Height						
	NNW	0.00	0.07	0.54	0.54	0.44	0.45	**2.05**
	Total	**1.99**	**2.48**	**6.63**	**5.63**	**4.24**	**5.03**	**26.00**
E	N	0.03	0.23	0.06	0.00	0.00	0.00	**0.32**
	NNE	0.06	0.15	0.10	0.00	0.00	0.00	**0.32**
	NE	0.22	0.18	0.05	0.00	0.00	0.00	**0.45**
	ENE	0.68	0.22	0.02	0.00	0.00	0.00	**0.91**
	E	0.38	0.10	0.02	0.00	0.00	0.00	**0.51**
	ESE	0.20	0.08	0.00	0.00	0.00	0.00	**0.29**
	SE	0.60	0.30	0.01	0.00	0.00	0.00	**0.92**
	SSE	1.17	0.60	0.02	0.00	0.00	0.00	**1.78**
	S	1.20	0.55	0.03	0.00	0.00	0.00	**1.78**
	SSW	0.93	0.48	0.04	0.00	0.00	0.00	**1.44**
	SW	0.40	0.24	0.05	0.00	0.00	0.00	**0.69**
	WSW	0.34	0.17	0.03	0.00	0.00	0.00	**0.54**
	W	0.17	0.11	0.03	0.00	0.00	0.00	**0.30**
	WNW	0.21	0.13	0.05	0.00	0.00	0.00	**0.39**
	NW	0.06	0.18	0.05	0.00	0.00	0.00	**0.29**
	NNW	0.06	0.27	0.07	0.00	0.00	0.00	**0.41**
	Total	**6.72**	**4.00**	**0.63**	**0.00**	**0.00**	**0.00**	**11.35**
F	N	0.94	0.27	0.00	0.00	0.00	0.00	**1.21**
	NNE	0.97	0.30	0.00	0.00	0.00	0.00	**1.27**
	NE	1.05	0.25	0.00	0.00	0.00	0.00	**1.31**
	ENE	1.37	0.22	0.00	0.00	0.00	0.00	**1.59**
	E	1.42	0.17	0.00	0.00	0.00	0.00	**1.59**
	ESE	1.08	0.12	0.00	0.00	0.00	0.00	**1.20**
	SE	1.43	0.17	0.00	0.00	0.00	0.00	**1.60**
	SSE	1.95	0.22	0.00	0.00	0.00	0.00	**2.17**
	S	2.14	0.34	0.00	0.00	0.00	0.00	**2.49**
	SSW	1.47	0.25	0.00	0.00	0.00	0.00	**1.72**
	SW	1.01	0.18	0.00	0.00	0.00	0.00	**1.20**
	WSW	0.37	0.12	0.00	0.00	0.00	0.00	**0.49**
	W	0.42	0.14	0.00	0.00	0.00	0.00	**0.55**
	WNW	0.57	0.15	0.00	0.00	0.00	0.00	**0.73**
	NW	0.86	0.19	0.00	0.00	0.00	0.00	**1.05**
	NNW	1.03	0.27	0.00	0.00	0.00	0.00	**1.31**
	Total	**18.09**	**3.38**	**0.00**	**0.00**	**0.00**	**0.00**	**21.46**

Stability Class	Wind Direction (wind blowing from)	Wind Speed, u (m/s)						
		u ≤ 2	2 < u ≤ 3	3 < u ≤ 4	4 < u ≤ 5	5 < u ≤ 6	u > 6	Total
		Frequency (%) at 10 m Height						
Grand Total		**39.33**	**18.15**	**15.69**	**11.49**	**7.33**	**8.01**	**100.00**