Canada's Nuclear Regulator

Tritium Releases and Dose Consequences in Canada in 2006

Part of the Tritium Studies Project

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Tritium Releases and Dose Consequences in Canada in 2006

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This document can be viewed on the CNSC Web site at nuclearsafety.gc.ca. To order a printed copy of the document in English or French, please contact:

Canadian Nuclear Safety Commission
280 Slater Street
P.O. Box 1046, Station B
Ottawa, Ontario K1P 5S9
CANADA

Tel.: 613-995-5894 or 1-800-668-5284 (in Canada only)
Facsimile: 613-995-5086
E-mail: info@cnsc-ccsn.gc.ca
Web site: nuclearsafety.gc.ca

Cover images (from left to right)
1. Tritium occurs as a byproduct of the operation of nuclear and research reactors. Pictured is a stack at Bruce A nuclear generating station.
2. Tritium is used in the production of self-luminescent lights, like Exit signs.
3. Environmental monitoring is a requirement of a CNSC licence.
4. Protecting the environment is an important part of our work at the CNSC.

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EXTENDED EXECUTIVE SUMMARY

Tritium is a radioactive form of hydrogen that occurs both naturally and as a byproduct of the operation of nuclear and research reactors. Tritium can pose a health risk if it is ingested through drinking water or food, or if it is inhaled or absorbed through the skin.

In Canada, the control of tritium releases to the environment is particularly important. Canadian-designed CANDU (CANada Deuterium Uranium) reactors produce more tritium than most other types of reactors because they use heavy water in their moderator and heat transport systems. Commercially, tritium is used in Canada in the production of self-luminescent lights and paints used in many products, including exit signs, airport runway lights, watch dials and gun sights. Hospitals use tritium in diagnostic tests, pharmaceuticals and radio therapeutics. It is also used in research laboratories and as a tracer in oil and gas exploration.

Releases of man-made tritium into the environment are regulated and carefully monitored by the Canadian Nuclear Safety Commission (CNSC) in order to protect the health, safety and security of Canadians and the environment. In 2007, the CNSC initiated a series of research studies on tritium releases in Canada to expand the body of knowledge on the subject and to further enhance regulatory oversight of tritium-related activities. This report, *Tritium Releases and Dose Consequences in Canada in 2006*, is one of this series. It presents an overview of the tritium releases in 2006 from CANDU nuclear reactors, research reactors, nuclear waste management facilities, tritium processing facilities, research facilities, and chemical laboratories. Hospitals and universities with nuclear research facilities are not presented in this report since they release trivial amounts of tritium.

Sources of tritium

Tritium forms naturally in the Earth's upper atmosphere, due to the interaction of gases and cosmic rays. As a form of hydrogen, it readily forms water molecules, which explains why natural background levels of tritium can be found everywhere in the environment where water is present — including precipitation, surface water, groundwater, ice, soil moisture, animals and plants.

Tritium is also produced as a byproduct of the operation of nuclear and research reactors. Canadian-designed CANDU reactors use heavy water (known as deuterium), which produces tritium as a result of nuclear reactions. There are currently 18 operating CANDU reactors in Canada: 16 in Ontario, 1 in New Brunswick and 1 in Quebec. Non-power reactors at Chalk River Laboratories (Ontario) and Whiteshell Laboratories (Manitoba) do not produce significant amounts of tritium.

Study Results

All licensed nuclear facilities release, in a controlled manner, small quantities of radioactive substances into the atmosphere and bodies of water. Releases are measured in becquerels (Bq) and reported over time (for example, on a weekly or monthly basis).

In 2006, all the tritium releases — both gaseous and liquid — from each facility were only a small fraction of Derived Release Limits (DRLs). These limits restrict the amount of tritium that can be released from a licensed nuclear facility. DRLs are based on the estimated release that could result in a dose of 1 millisievert (mSv) to a member of the public through exposure to tritium in the environment in air, water or vegetables.

Tritium concentrations in the environment (in air, water, vegetation, animals and milk) are monitored to estimate the annual dose to members of the public living around nuclear facilities. This information is used to confirm that the impact of the releases is below the public dose limit of 1 mSv, as established in the CNSC's *Radiation Protection Regulations*. In 2006, tritium concentrations in the vicinity of nuclear facilities varied between 0.38 Bq/m^3 and 35.66 Bq/m^3. The corresponding radiation doses due to exposure to tritium for people living near nuclear generating stations varied from 0.00045 to 0.00236 mSv/year. Tritium doses to members of the public around processing facilities were also very low (0.00001 to 0.0145 mSv/year). All these doses are well below the regulatory dose limit for a member of the public.

Tritium doses to workers are compared with the regulatory dose limit of 50 mSv/year and 100 mSv over five years (cumulatively) for nuclear energy workers. In 2006, occupational doses from tritium exposures ranged from 0.07 to 0.26 mSv for workers in nuclear generating stations, and from 0.30 to 0.90 mSv for workers in processing and research facilities. In all cases, doses received by workers were far less than the CNSC annual occupational regulatory dose limits.

This study reports elevated tritium concentrations in groundwater at nuclear reactors, research facilities and tritium processing facilities. As required by the CNSC, licensees have addressed, or are addressing the contamination issues, which were due to historical practices, malfunctions and the washout of emissions from stacks. The tritium plumes identified are generally within the fenced and protected boundaries of the licensed facilities, and do not contribute to radiation doses to workers or the public. Also, since the groundwater near these plumes is not used for drinking water or other purposes, they do not pose health risks to workers or the public.

Concentrations of tritium in municipal drinking water sources around nuclear facilities vary from 7 Bq/L to 18 Bq/L. These values are below both the current Canadian drinking water quality guideline of 7,000 Bq/L and the proposed limit of 20 Bq/L by the Ontario Drinking Water Advisory Council. Levels in private wells ranged to a maximum of 1,875 Bq/L, which is still below the current guideline of 7,000 Bq/L.

Conclusions

Data on tritium releases and dose calculations for 2006 indicate that releases of tritium from nuclear facilities were only a small fraction of DRLs, and that doses to workers or the public living near nuclear facilities were at only a fraction of CNSC dose limits. Any elevated levels of tritium in groundwater were due to historical practices or malfunctions, and they are being addressed appropriately by licensees and do not contribute to radiation doses to workers or the public. Concentrations of tritium in drinking water sources around nuclear facilities were all below the Canadian drinking water quality guideline of 7,000 Bq/L.

In summary, the CNSC concludes that tritium releases in 2006 from CANDU nuclear reactors, research reactors, nuclear waste management facilities, tritium processing facilities, research facilities, and chemical laboratories were effectively controlled to prevent risk from tritium exposure to the health of nuclear workers, the public and the environment. The CNSC continues its regulatory oversight of these licensed facilities to ensure the health of Canadians and protection of the environment.

1. INTRODUCTION

1.1 Tritium in the Environment

Tritium is a radioactive form of hydrogen, with a physical decay half-life of 12.3 years. It emits very low energy beta radiation, which is completely absorbed by common materials such as sheets of plastic, paper, glass or metal, and it cannot penetrate the top dead layer of skin in humans or animals. Nevertheless, tritium exposure can pose a health risk if it is ingested in drinking water or food, or inhaled or absorbed through the skin or other biological tissue. In Canada, the control of tritium releases to the environment is particularly important, since CANDU reactors produce significantly more tritium than most other types of reactors due to the use of heavy water (deuterium) in their moderators and heat transport systems. A few industries also use tritium in large quantities to produce gaseous tritium light sources. Much smaller quantities are used in research applications, and as tracers in oil and gas exploration. Tritium also forms naturally in the Earth's upper atmosphere due to the continuous bombardment of atmospheric gases by high energy cosmic rays. As a form of hydrogen, tritium is readily incorporated into water and enters the natural hydrological cycle. Hence, natural background levels of tritium can be found everywhere in the environment where water is present — including precipitation, surface water, groundwater, ice, soil moisture, animals and plants. Additional information on the presence and use of tritium in Canada can be found in a recent document produced by the Canadian Nuclear Safety Commission (CNSC) [Ref. 1].

1.2 Regulation of Tritium Releases in Canada

Under the *Nuclear Safety and Control Act* (NSCA), the CNSC's mandate includes the dissemination of scientific, technical and regulatory information concerning the activities of the CNSC, and the effects on the environment and the health and safety of persons, of the development, production, possession, transport and use of nuclear substances. Under the NSCA, the CNSC licenses facilities that possess more than one gigabecquerel (1 GBq, 1×10^9 Bq) of tritium. The CNSC regulates potential releases of tritium to the environment through several licensing requirements, including absolute limits on how much tritium can be released on a licence-specific basis. This is typically accomplished by imposing quantitative Derived Release Limits (DRLs) on the amounts of tritium entering air or water. The DRL represents a calculated estimate of what a licensee would have to release to the environment in order to deliver to a critical member of the public a dose equal to the public dose limit of 1 mSv prescribed in the CNSC *Radiation Protection Regulations*. As discussed below, other CNSC regulatory requirements for the control of emissions at licensed facilities and sites ensure that the actual releases remain at only a small fraction of the DRLs or the public dose limit.

General requirements for the major nuclear facilities licensed by the CNSC include environmental protection policies, along with programs and procedures that make adequate provision for protection of the environment. These are typically referred to collectively as an environmental management system and include two key provisions for the control of releases of radioactivity to the environment: ALARA and Action Levels. ALARA is the paramount requirement for all licensed activities under the *Radiation Protection Regulations;* according to it, releases must be kept "As Low As Reasonably Achievable", with social and economic factors being taken into account. Action Levels are also required and are set below the DRLs at values that may indicate a loss of control on the operation. The approach or exceedance of an Action Level allows corrective action to be taken well before a DRL or dose limit is approached or exceeded. Action Levels are typically set for gaseous or liquid effluent concentrations and/or for activity levels found in the receiving environment. The response procedure to reaching or exceeding an Action Level includes a thorough investigation of the cause, remedial actions and reporting to the CNSC. In addition, many licensees also establish administrative levels. Administrative levels are normally set well below the regulatory Action Levels, in order to trigger a licensee's own internal investigation into potentially unusual operating conditions and their root causes.

The CNSC requires reporting of the results of monitoring of routinely discharged radioactive effluents (including the total activity or total amount released) and, at minimum, annual reports of environmental monitoring results. Furthermore, the CNSC requires the reporting of any release of a nuclear substance into the environment at a quantity not authorized by the NSCA, regulation or the licence, and any unmeasured release.

Further details on the regulatory control of tritium in Canada are found in section 3.

1.3 Document Scope

In January 2007, the Commission directed CNSC staff to initiate research studies on tritium releases in Canada, and to study and evaluate those tritium processing facilities in the world that exercise the best practices. In response, CNSC staff initiated a "*Tritium Studies*" project with several planned information gathering and research activities extending to 2010 (a fact sheet is available at www.nuclearsafety.gc.ca). The objective of this project is to enhance the currently available information, so as to guide regulatory oversight of tritium processing and tritium releases in Canada. The present report on tritium releases and dose consequences in Canada is one of a series of public information documents being produced through the auspices of this "*Tritium Studies*" project.

This report provides information on:

- tritium production/generation and use
- tritium releases to the environment in the calendar year 2006 from licensed facilities with significant releases (higher than one terabecquerel, 1 TBq)
- levels of tritium measured in environmental media around facilities releasing tritium to the environment
- estimated tritium doses to workers and members of the public due to releases in 2006

The information presented in this report was obtained from annual compliance and environmental monitoring reports from the year 2006 that major licensees submitted to the CNSC. These data sets provide a snapshot of tritium releases and doses to workers and members of the public in Canada throughout 2006. Detailed facility-specific data are also available on licensee Web sites and can be requested from licensees or the CNSC. In all cases, the data represent annual totals or averages of measured releases to the environment. This information is used to estimate doses to either actual or hypothetical members of the public living in the vicinity of nuclear facilities.

2. TRITIUM PRODUCTION AND USE IN CANADA

Nuclear power and research reactors are the source of most of the tritium produced in Canada. The CANDU reactor (CANada Deuterium Uranium), a Canadian design, uses heavy water (deuterium) as a coolant and moderator to slow neutrons. When a neutron is captured by a deuterium atom, tritium - in the form of tritiated water (HTO) - is formed. The majority (i.e., 97 percent of tritium) is formed in the moderator system. The reason for this is that 90 percent of the moderator volume in the calandria is exposed to a large thermal neutron flux. In contrast, only about 5 percent of the total heat transport volume is subject to high flux. The average production rate of tritium in the moderator of a CANDU power reactor is about 7.5×10^{10} Bq per kg of heavy water per year. A representative moderator volume is 281 cubic meters; the density of heavy water is 1.1 grams/cubic centimetres [Ref. 2]. This equates to 309,100 kg of deuterium per reactor. Therefore, a CANDU power reactor produces approximately 2.3×10^{16} Bq/year of tritium in the moderator system. Adding the heat transport system to this, the total tritium yield is approximately equal to 2.4×10^{16} Bq/yr per reactor unit. A representative total release from a CANDU power reactor is about 3.3×10^{14} Bq/yr through gaseous and liquid pathways which represents about 1.5% of the total tritium produced in a year. In all cases, tritium releases are strictly controlled and represent a small fraction of regulatory limits and, therefore, do not represent a risk to people's health or the environment. Tritium levels in the environment and doses to members of the public are presented in sections 5 and 6 of the report, respectively. There are currently 20 operational CANDU reactor units in Canada and two are in a permanent shutdown state.

Non-power reactors such as the NRU at Chalk River Laboratories do not produce significant amounts of tritium and releases through stacks and the waste treatment center are consistently below regulatory limits [Ref. 3].

Commercially, tritium is used in Canada for the production of self-luminescent lights and paints, including exit signs, airport runway lights, watch dials and gun sights. Other facilities that use tritium include hospitals and research laboratories. The substance is also used as a tracer in oil and gas exploration.

3. REGULATORY CONTROLS AND COMPLIANCE

3.1 Regulatory Controls

The *Nuclear Safety and Control Act* (NSCA) and associated regulations require each licensee to take all reasonable precautions to protect the environment and the health and safety of persons, including controlling the release of radioactive and hazardous substances to the environment. CNSC staff verifies that licensees have programs in place to protect workers and the public, and to identify, control and monitor all releases of nuclear and hazardous substances from their facilities. CNSC staff reviews of licensee performance include: occupational doses, public doses, emission data, effluent and environmental monitoring and unplanned releases. The CNSC requires that licensees establish environmental protection policies, programs, and procedures that make adequate provision for protection of the environment. Together, these policies, programs and procedures are usually referred to as an Environmental Management System (EMS) [Ref. 4]. One of the key objectives of an EMS is continual improvement in order to control releases in a more efficient and effective manner.

3.2 Reporting Requirements

The CNSC requires, among other things, quarterly reporting of the monitoring results for routinely-discharged radioactive effluents (including the total activity or total amount released) for all nuclear generating stations; annual reports on the results of the environmental monitoring program are also required [Ref. 5]. The CNSC also requires reporting of any release of a nuclear substance into the environment at a quantity not authorized by the NSCA, regulations or the licence, or any unmeasured release of a nuclear substance into the environment. The reporting requirements of other licensees are commensurate with the likelihood and significance of adverse environmental effects of operations; they are specific to each licensee and are commonly set to an annual basis.

3.3 Regulation of Environmental Releases

Section 13 of the *Radiation Protection Regulations* limits effective doses to 1 mSv per year for members of the public and paragraph 4(a) requires that exposure be ALARA. Licensees with significant releases of radionuclides - such as tritium - typically calculate upper limits on releases, called Derived Release Limits, or DRLs. These DRLs are typically incorporated into licences as secondary regulatory limits, as a means of demonstrating compliance with the 1 mSv public dose limit. Licensees are also required to establish and implement Action Levels for releases of nuclear substances that are indicative of a loss of control of any part of the environmental protection program. These Action Levels are developed according to guidance provided by the CNSC in G-228 "Preparing and Using Action Levels" [Ref. 6]. As a result of ALARA initiatives regarding public exposure, Action Levels are typically a small fraction (about 10%) of the DRL. They are often based on the upper limits of normal operations as defined by previous operating performance. Lastly, many licensees establish internal investigation or administrative levels for early warning of any failures in the control system. Paragraph 12(f) of the *General Nuclear Safety and Control Regulations* also requires licensees to take all reasonable precautions to control the release of hazardous or radioactive nuclear substances, both within the site of the licensed activity and into the environment as a result of the licensed activity.

The CNSC staff reviews in detail the methodology, adequacy, accuracy and applicability of DRL calculations for prospective licensees and, where appropriate, includes them as a licence condition. CNSC staff also reviews for acceptability the means identified by licensees to comply with paragraph 12(f) of the *General Nuclear Safety and Control Regulations*.

3.3.1 Calculation of Derived Release Limits

DRL methodology has evolved through time, but continues to incorporate many of the features of methodology defined in CSA standard N288.1-08 [Ref. 7]. The calculation of DRLs involves the specification of environmental characteristics, the fate and transfer of the contaminant (in this case, tritium) through environmental pathways (e.g., air, water, soils, vegetation), and the ultimate impact of the contaminant on representative persons belonging to a “critical group”. DRLs are unique to each facility, and depend on several factors (e.g., critical group, lifestyle, exposure pathways etc.).

Licensees use site-specific studies and surveys to obtain data on the surrounding environment, land use, water use, demographics, plants and animals in the human food chain, meteorological data and other relevant information to establish the characteristics of potential critical group(s) and pathways. In the absence of site-specific data, licensees use hypothetical scenarios (e.g., conservative scenarios and parameters such as an individual member of the public living at the boundary of the facility) to estimate doses to potential critical groups. The DRLs based largely on hypothetical scenarios tend to be more conservative (lower more stringent release limits) than the ones based on site-specific or realistic data. The absence or inclusion of a significant exposure pathway (i.e., route by which the contaminant – tritium – reaches the critical group) also affects the resulting DRL. For example, the absence of a drinking water exposure pathway and the distant location of a critical group, as in the case of New Brunswick Power’s Point Lepreau station, leads to a relatively high DRL (Figures 3 and 4). Where most of the human exposure estimates are conservative and/or hypothetical (e.g., SSI, Figure 3), lower values are found. DRLs cannot be compared directly, but in all cases they represent a dose of 1 mSv to the critical group. Public dose comparisons among facilities require knowledge of the many assumptions and differences in critical group characteristics underlying such calculations.

It is important to note that, while a DRL for one facility may be higher than for another facility of similar design (i.e., as a result of a different environmental setting), this does not automatically imply that a licensee with a higher DRL would release more of a contaminant to the environment than other licensees. As shown earlier, the CNSC regulatory regime is based on the ALARA principle which systematically drives emissions towards the lowest achievable levels.

3.4 Estimating Dose to Members of the Public

Tritium may be released as HT gas and as HTO (tritiated water) – liquid or vapour. However, tritium may be incorporated into an organic compound like proteins, carbohydrates or fats. This form of tritium is called Organically Bound Tritium (OBT) and may be ingested through food. In the environment, HTO is normally the main contributor to the public dose. HTO behaves like water in the human body and is eliminated with a biological half life of about 10 days, whereas OBT remains present for a longer period. One may also be exposed to tritium through intake of OBT by ingestion of foods produced, grown or raised close to a source of environmental tritium. About half of the tritium taken in as OBT is quickly converted to water (HTO) and leaves the body in that form. The tritium that stays as OBT is excreted according to a nominal 40-day biological half-life. A small fraction of the OBT leaves the body through urine; some of it may concentrate in specific tissues or organs, depending on its chemical form.

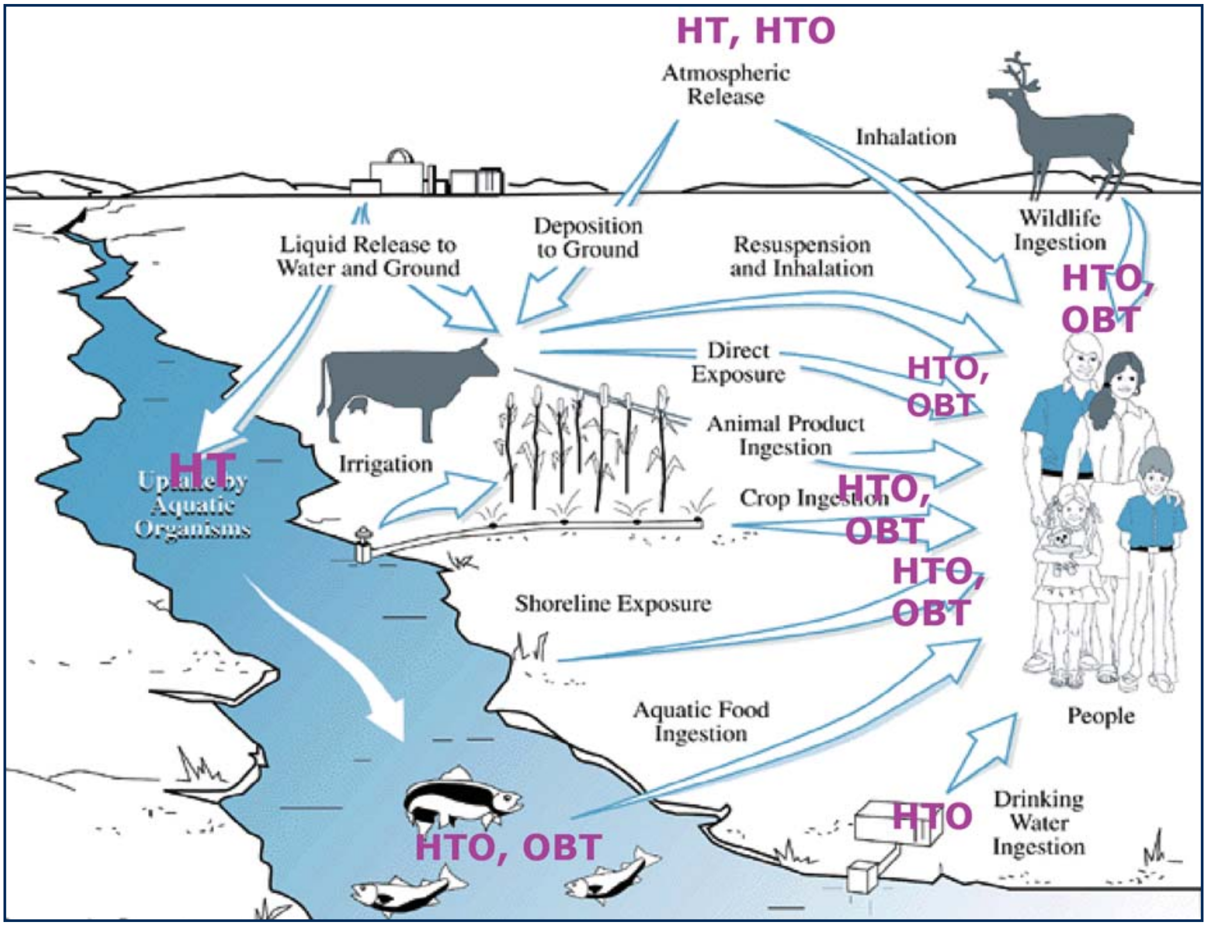
Due to the very low exposures, direct dose measurements are not practical for members of the public. The radiological dose to members of the public, for measuring actual exposures and for calculating theoretical DRLs (as discussed in the upcoming section) is estimated by using environmental transfer models and relevant site-specific data. Typically, dose estimates include considerable realism, through the use of measured concentrations of tritium (e.g., HT, HTO and OBT) in air, food and water, and through the incorporation of data on the activities and dietary habits of people living in the vicinity of the tritium source.

3.4.1 Environmental Pathways

When tritium is released to the environment, it will be dispersed and deposited in air, surface water, soil and vegetation. Tritium is highly mobile, and will become incorporated into key components of the environment (e.g., drinking water, fish, vegetables, grass, grazing animals, milk, meat and humans). Members of the public living near release points may be exposed to tritium through many environmental transfer pathways. A typical set of pathways is shown in Figure 1. An overview of the concentrations of tritium in these environmental media in proximity to Canadian nuclear facilities is also presented in section 5.

Tritium can enter the body by inhalation, ingestion or through the skin by direct contact (swimming, bathing etc.). The number of pathways included in public dose estimates varies depending on site-specific environmental and critical group characteristics, and may range up to ten. All the major CNSC licensees handling tritium have to monitor the levels of tritium in the environment, and use some of these data in dose calculation models to estimate dose to members of the public. Concentrations of tritium in the environment are provided in section 5 of the report and doses to members of the public in section 6.

Figure 1 A Typical Environmental Pathway Diagram



Courtesy of Pacific Northwest National Laboratory, United States Department of Energy, Hanford Site.

3.4.2 Critical Groups

A critical group is a fairly homogenous group of members of the public identified as being those individuals most likely to receive the highest doses from exposure to radioactive materials. CSA N288.1-08 (7) defines a “representative person” (formerly known as a “member of the critical group”) as an individual with characteristics that reflect those of the group (known as the critical group) who receives the highest doses from a particular source for the radionuclide in question. As noted above, licensees use site-specific studies and surveys to identify potential critical groups. In some cases, the critical group is hypothetical, because no one is living under the same conditions as the critical group. The location and distance from the licensed facility are also very important relative to the dispersion pattern of tritium releases. Similarly, nuclear sites consist of far larger licensed/controlled areas than those at tritium processing facilities. As a result, members of critical groups are living much closer to tritium releases at tritium processing facilities. This can result in apparently higher public doses for some facilities, when compared to nuclear generating stations (e.g., the largely hypothetical control group at SSI, Table 12).

These assumptions about the location and behaviours of the critical group result in a conservatively high estimate of exposure, which contributes to higher margins of safety in the licensing of the facilities. Hence, actual members of the public residing in communities neighboring nuclear facilities would be less exposed to tritium than the critical groups.

Some of the key characteristics of the critical group affecting the dose estimation are age, diet, food and drinking water sources, and any dominant cultural habits (e.g., use of country foods, home gardens, recreational fishing, hunting etc.). Water and food ingestion are often the predominant environmental pathways. As such, realistic information is required on drinking water sources (such as water supply plants or wells), food (grown at home or purchased from a local market), and the consumption of contaminated fish, animal meat and milk. Consumption rates and sources of drinking water, food and inhalation rates are key parameters. For example, a nursing infant raised on a dairy farm near a facility releasing tritium may drink local milk, whereas another infant may drink formula prepared with local well water. Where local site specific data are not available, model parameters are required for dose calculation. Parameter values are taken from credible and internationally recognized international and national sources. Some information on the critical groups selected by the licensees is presented in Table 12.

4. TRITIUM RELEASES TO THE ENVIRONMENT

The nuclear fuel cycle regulated by the CNSC consists of uranium mines, uranium refining and conversion facilities, fuel fabrication facilities, nuclear power and research stations, and waste management facilities. Mines and uranium processing (refining, conversion and fuel fabrication) facilities do not generate or use any tritium.

As described earlier, all CANDU reactors release radioactive materials in a controlled manner, including tritium. Tritium is also released from some nuclear waste management facilities, tritium processing facilities, research facilities and some chemical laboratories. Trivial amounts of tritium are released from some hospitals and universities; these are not presented in this report.

Tritium is generally released in a controlled manner in the form of gaseous emissions to the atmosphere, and as liquid effluents to adjoining water bodies. Small amounts are released to municipal sewage systems that ultimately discharge to natural water bodies. The gaseous emissions usually are tritium oxide - in the form of water vapour (HTO) - and elemental tritium (HT) as gas. Liquid effluents contain only the HTO form (tritiated form) of water. As discussed in section 3.4.1, tritium released to the atmosphere may find its way through various mechanisms into surface waters and other environmental media, such as soils, groundwater, sediments and vegetation. Similarly, waterborne releases may disperse through various other media after being released from a facility.

Licensees implement effluent monitoring programs to sample, measure and analyze the releases of tritium, and the results are reported quarterly and/or annually to the CNSC. Tritium release information is also presented in conjunction with environmental monitoring results reported to the CNSC annually. The amounts of tritium released from major facilities in Canada throughout 2006 are presented in sections 4.1 to 4.6. These releases are presented in units of becquerels or tera becquerels (one million million becquerels) per year.

Tritium releases are measured in units of becquerel (Bq) which is the activity of radiation whereas radiation dose to workers and members of the public is measured in units of sievert (Sv) or millisievert (mSv) which is 1,000 times smaller. The *Radiation Protection Regulations* of the *Nuclear Safety and Control Act* set a statutory radiation dose limit of 1 mSv per year for members of the public, and 50 mSv per year and 100 mSv over a 5-year period for workers. The doses received by members of the public from routine releases of tritium from nuclear generating stations are too low to measure directly. Therefore, the licensees calculate an equivalent value of radioactivity that if released into the environment will result in a regulatory dose limit of 1 mSv/year. These numbers are called Derived Release Limits or DRLs and are in the same units of becquerels (Bq) as the releases. Thus the DRL is a limit on the release of a radioactive substance from a licensed nuclear facility such that compliance with the DRL gives reasonable assurance that the regulatory public dose limit of 1 mSv/year is not exceeded. In the following sections, the annual tritium releases from the licensed facilities and their compliance with regulatory limit, as a percent of DRL, are shown. Where DRLs are not required to be calculated (due to potentially very small releases or situations require more stringent limits) CNSC stipulates the release limits in the license as a condition. As can be seen in the following Tables 2-5, the releases from the licensed facilities in 2006 are a very small percentage of the DRLs and thus, are far below the dose limit to the members of the public.

More details of CNSC regulatory controls including the use and methodology of DRLs calculation are given in Sections 1.2 and 3.0.

4.1 Nuclear Generating Stations

4.1.1. Background

Canada currently has seven nuclear generating stations located in three provinces: Ontario, Quebec and New Brunswick (Figure 2). There is only one operating nuclear reactor in New Brunswick and one in Quebec. Twenty nuclear reactors are located in Ontario. A brief description and relevant data for each nuclear generating station is provided below, as well as in Table 1.

The **Pickering-A** nuclear generating station (PNGS-A) consists of four nuclear reactors (units 1-4). It began operation in 1971. It is located on the shore of Lake Ontario near the Town of Pickering. In 1997, as part of its extensive recovery program, Ontario Hydro (now Ontario Power Generation) shut down all four Pickering-A reactors, and the reactors were maintained in a guaranteed shutdown state. Recently, units 1 and 4 were restarted after an extensive environmental assessment and refurbishment. Units 2 and 3 are in a permanent safe shutdown state and will not be restarted. The **Pickering-B** nuclear generating station (PNGS-B), immediately adjacent to Pickering-A, consists of four nuclear reactors (units 5-8). These began operation in 1982.

The **Bruce-A** nuclear generating station (BNGS-A) consists of four nuclear reactors (units 1-4) which began operation in 1976. The **Bruce-B** nuclear generating station (BNGS-B) consists of four nuclear reactors (units 5-8) which began operation in 1984. Bruce-A and Bruce-B are located in Ontario on the shores of Lake Huron near the Town of Kincardine. The Bruce nuclear generating stations are currently operated by Bruce Power Inc. In 1997, as part of its extensive recovery program, Ontario Hydro (now Ontario Power Generation) temporarily shut down all Bruce-A reactors and all units were maintained in a guaranteed shutdown state. Units 3 and 4 were recently returned to service; unit 4 was restarted in October 2003, while unit 3 was restarted in January 2004. Refurbishment for the return to service and life extension of Bruce-A (units 1 and 2) is underway. Bruce-B units (5-8) are currently operating.

The **Gentilly-2** nuclear generating station (G-2), operated by Hydro-Québec (HQ), consists of one nuclear reactor which began operation in 1982. It is located in Quebec on the southern shore of the Saint Lawrence River near the city of Trois-Rivières. Hydro-Québec is also considering refurbishing this unit to extend its operating life.

The **Point Lepreau** nuclear generating station (PLGS), operated by New Brunswick Power (NB Power), consists of one nuclear reactor which began operation in 1982. It is located in New Brunswick on Point Lepreau, which extends into the Bay of Fundy. The reactor is being refurbished.

The **Darlington** nuclear generating station (DNGS) consists of four nuclear reactors, the first of which started up in 1989, and a tritium removal facility which started operation in 1990. The tritium removal facility is designed to extract tritium from used heavy water prior to its reuse, thus controlling the build-up of tritium in the moderator. Both facilities are located on the shore of Lake Ontario near the Town of Bowmanville.

Figure 2 Locations of Nuclear Generating Stations in Canada

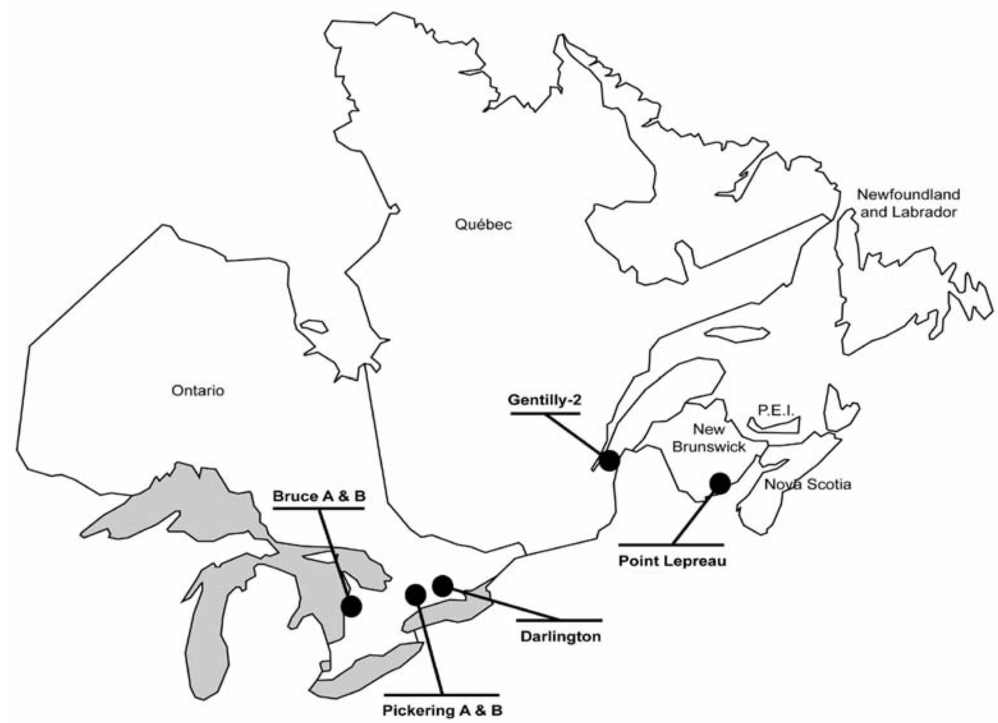


Table 1 Nuclear Generating Stations in Canada in 2006

	Ontario					Quebec	New Brunswick
Plant	Bruce A	Bruce B	Pickering-A	Pickering B	Darlington	Gentilly-2	Point Lepreau
Licensee	Bruce Power	Bruce Power	Ontario Power Generation	Ontario Power Generation	Ontario Power Generation	Hydro-Québec	New Brunswick Power Nuclear
Reactor Units	4*	4	4*	4	4	1	1
Gross Electrical Capacity/Reactor (MW)	904	915	542	540	935	675	680
Start-up	1976	1984	1971	1982	1989	1982	1982

* Two of the Pickering A reactors are permanently shut down. Only two reactors are operating at Bruce A.

4.1.2 Tritium Releases from Nuclear Generation Stations

All nuclear generating stations (including the reactors, waste management and tritium recovery facilities that form component parts of those stations) release small quantities of radioactive materials, in a controlled manner, into both the atmosphere (as gaseous effluents) and adjoining water bodies (as liquid effluents). Data for HTO and HT releases to the atmosphere and HTO to surface water in 2006 from currently operating nuclear generating stations in Canada are presented in Table 2.

For comparison, the releases are also presented as a percentage of a DRL which is an indirect estimation equivalent to a 1 mSv dose limit to members of the public. (See Sections 1.2 and 3.0 for more details on regulatory controls and DRLs).

Elemental tritium gas HT is released only from the tritium removal facility of the Darlington Nuclear Generating Station and there are no releases to water bodies. The release of HT in 2006 was 9.5×10^{13} Bq/yr, which is 0.01 % of the DRL.

The levels of tritium releases in the environment from all the nuclear power plants are far below the DRLs and thus, below the regulatory dose limit to members of the public (see also Section 6).

Table 2 Tritium Releases from Nuclear Generating Stations in Canada for 2006

Locations	Facilities	Gaseous Emissions Bq/yr*		Liquid Effluents Bq/yr*	
		Tritium Oxide (HTO)	% DRL	Tritium Oxide (HTO)	% DRL
Ontario	Darlington Nuclear Generating Station	1.3×10^{14}	0.3	1.9×10^{14}	0.004
	Pickering Nuclear Generating Station**	5.7×10^{14}	0.8	3.3×10^{14}	0.194
	Bruce Nuclear Generating Station	9.0×10^{14}	1.0	7.3×10^{14}	0.226
Québec	Gentilly-2 Nuclear Generating Station**	1.8×10^{14}	0.04	2.3×10^{14}	0.019
New Brunswick	Point Lepreau Nuclear Generating Station**	1.7×10^{14}	0.04	1.6×10^{14}	0.001

* Based on 2006 Annual Reports (Refs. 8, 9, 10 and 11).

** Includes waste management facilities; statistics for the Western Waste Management Facility at Bruce are in Table 11.

4.2 Nuclear Reactor Waste Management Facilities

Nuclear Waste Management Facilities (NWMF) store low and intermediate level (L&IL) wastes which are a by-product from the operation of nuclear reactors. These wastes may contain low levels of tritium as HTO in various materials. Some of these facilities also store dry spent fuel above ground. Tritium is present, in small amounts, in the inventory of radionuclides in used nuclear fuel wastes.

The L&IL waste management facilities are located on site at the nuclear generating stations in Quebec and New Brunswick. Therefore, their emissions are accounted for in the nuclear generating station's total emissions (as in Table 2 above). In Ontario, the L&IL wastes produced at all the nuclear reactors, Pickering A and B, Darlington, Bruce A and B, are transferred to the Western Waste Management Facility (WWMF) which is located on the Bruce Power site. The WWMF is operated by Ontario Power Generation. The accounting of emissions for the WWMF is separate from the Bruce A and B nuclear generating stations. In 2006, the WWMF reported 5.5×10^{13} Bq/yr of HTO in gaseous emissions and 4.4×10^{10} Bq/yr of HTO of liquid emissions [Ref. 9]. These are 0.04% and 0.002% of the DRLs for gaseous and liquid releases respectively and do not represent a health risk to members of the public.

4.3 Tritium Processing Facilities

Two companies that are involved in the processing of tritium are SRB Technologies (Pembroke, Ontario) and Shield Source Incorporated (Peterborough, Ontario). They manufacture gaseous tritium light sources for domestic and international customers. As a result of elevated levels of tritium in the groundwater in the vicinity of the stack, the CNSC has imposed a more stringent tritium release limit for SRB Technologies as a licence condition. Tritium releases in Bq/yr for 2006 are compared with the DRL for Shield Source Inc. and the operating licence limit for SRB Technologies in Table 3. Tritium releases from these two facilities were below the applicable CNSC regulatory limits in 2006.

Table 3 Tritium Releases from Tritium Processing Facilities in Canada for 2006

Facilities*	Gaseous Emissions Bq/yr				Liquid Effluents Bq/yr	
	Tritium Oxide (HTO)	%DRL OLC	Tritium Gas (HT)	%DRL	Tritium Oxide (HTO)	%OLC
SRB Technologies**	7.2×10^{13}	4.8 (OLC)	2.1×10^{14}	0.23 (OLC)	4.3×10^{10}	21.6
Shield Source Incorporated	1.3×10^{13}	13.0 (LOD)	9.8×10^{13}	0.0003 (LOD)	2.4×10^{9}	***

* Based on 2006 Annual Reports [Refs. 12, 13].

** SRB Technologies Inc. operated only for a period of 11 months and did not operate during the occurrence of any type of precipitation late in 2006. SRB Technologies has a more stringent operating licence condition (OLC) for tritium release limits in lieu of DRLs.

*** Liquid releases from Shield Source Inc. are so small that it is not required to calculate DRLs for liquid releases.

4.4 Research Facilities

Two research facilities in Canada are currently releasing tritium. The Chalk River Laboratories located in Chalk River, Ontario is a large nuclear research and test establishment with nuclear and non-nuclear facilities and activities. The Whiteshell Laboratories facility located in Pinawa, Manitoba is currently being decommissioned. The releases in Bq/yr are presented in Table 4. For comparison, the releases are also presented as a percentage of DRLs which is an indirect estimation equivalent to a 1 mSv dose limit to members of the public (see Sections 1.2 and 3.0 for more details on regulatory controls and DRLs). Tritium releases from the research facilities are below 1% of the DRLs, and thus do not result in undue risk to members of the public.

Table 4 Tritium Releases from Research Facilities in Canada for 2006

Facilities*	Gaseous Emissions Bq/yr				Liquid Effluents Bq/yr	
	Tritium Oxide (HTO)	%DRL	Tritium (HT)	%DRL	Tritium Oxide (HTO)	%DRL
Chalk River Laboratories	3.2×10^{14}	0.10	9.6×10^{11}	6.4×10^{-6}	9.5×10^{13}	0.006
Whiteshell Laboratories	7.3×10^{9}	1.84×10^{-5}	0	0	0	0

* Based on 2006 Annual Reports [Ref. 14, 15].

4.5 Chemical Laboratories

Chemical laboratories handle tritium for analysis and for other uses. Kinectrics Incorporated located in Toronto, Ontario uses tritium in an enclosed laboratory. Monserco Limited is a radioactive waste management company located in Brampton, Ontario. The reported releases from those two facilities in Bq/yr are presented in Table 5. Monserco is not required to calculate DRLs since it has been determined that their releases are very small; however, Monserco does have to comply with the licence condition. Tritium releases from these licensed chemical laboratories are well below the allowable limits.

Table 5 Tritium Releases from Chemical Laboratories in Canada for 2006

Facilities*	Gaseous Emissions Bq/yr				Liquid Effluents Bq/yr	
	Tritium Oxide (HTO)	%DRL/OLC	Tritium (HT)	%DRL	Tritium Oxide (HTO)	%DRL
Kinectrics Incorporated	7.6×10^{11}	0.3 (LOD)	1.7×10^{11}	0.004	6.6×10^{10}	6.6
Monserco Limited	1.7×10^{10}	15.5 (OLC)**	0		0	

* Based on 2006 Annual Reports [Ref. 16, 17].

** Monserco is not required to calculate DRLs since it has been determined that their releases are very small; however, Monserco does have to comply with the operating licence condition (OLC).

4.6 Summary of Tritium Releases from all Licensed Facilities in Canada

Comparisons of the annual tritium releases with regulatory limits are presented in Section 7.1, and Figures 3 and 4. All tritium releases were a small fraction of regulatory limits. Releases are strictly controlled and do not result in undue risk to the health of members of the public.

The next section provides an overview of tritium levels in various environmental compartments as a result of operational tritium releases to the environment.

5. TRITIUM LEVELS IN ENVIRONMENTAL MEDIA AROUND FACILITIES RELEASING TRITIUM

All the CNSC licensees implement environmental monitoring programs (EMPs) with an objective to sample, measure and analyze various media, and physical and biological parameters in the environment for the presence of radionuclides such as tritium. The results of every EMP are reviewed to confirm that adequate measures have been taken to protect the environment and to keep radiation doses to members of the public ALARA, social and economic factors taken into consideration. The results of the EMP may be used in estimation of tritium dose to the public. These data are also used to confirm and verify the accuracy and appropriateness of the parameter values used in the environmental pathway models to estimate tritium doses and calculate DRLs.

Licensees submit annual reports on the results of their environmental monitoring programs. The sampled environmental media surrounding each tritium releasing facility depends on the nature and size of the licensed operations and the main pathways through which the receptor, a member of the public, is assumed to be receiving the highest potential exposure and the consequent tritium dose. Thus, the EMPs vary among facilities as the main pathways of exposure vary. The CNSC verifies that the monitoring data confirm that doses to members of the public are well below the limit of 1mSv/year. In this section, tritium concentration in various environmental media, (e.g., ambient air, water, vegetation, terrestrial and aquatic animals) are presented. These data are taken from the annual environmental monitoring program reports of the licensees which contain detailed descriptions of the programs and the monitoring results. Only a brief compilation of the information contained in the licensees' annual compliance reports [Refs. 8-14] is presented in the tables of this section. The referenced source documents contain additional details. An effort is made to provide an overview of the tritium levels in various environmental media reflecting potential effects of tritium releases from the licensed facilities. In general, tritium concentration in various environmental media in the vicinity of all tritium releasing facilities showed a decreasing trend, to almost background levels, as the distance from the facility increases. The data are presented in Tables 6 to 9.

The Canadian Radiological Monitoring Network (CRMN) operated by Health Canada monitors levels of radioactivity from a national perspective. The CRMN monitors levels of tritium in atmospheric water vapour in the vicinity of Canadian nuclear power plants. These data are available on the Health Canada website with a link to CRMN. In addition, CRMN established in 1991 a sampling station located on the roof of Health Canada's Radiation Protection Bureau building in Ottawa, Ontario to act as a test-bed site and to monitor background levels of tritium. The 2006 data from this Ottawa site are included in Table 6 to serve as a comparison between background levels of tritium in atmospheric water and tritium concentrations measured in the air around nuclear facilities.

For all other environmental media, the licensees' measurements of tritium levels and where available provincial background, control or reasonably remote sites are presented in Tables 6 through 9 and may be considered as comparable to background levels.

The following tables provide a comparison of tritium levels around nuclear facilities in comparison to relevant background data and form the basis for the estimates of radiation doses to members of the public living in the vicinity of nuclear facilities. Radiation doses to members of the public are discussed in section 6 of this report.

Table 6 Tritium Concentrations in Air near Nuclear Reactors, Research Facilities and Tritium Processing Facilities

Facility	Distance/Location	Tritium Concentration in Air Bq/m³ (Annual Averages) *(a)*	Range Bq/m³
Bruce Power Site	Bruce Power Main Gate Exit	2.29	1.3 - 3.4*(b)*
	Close Residence Baie du Doré	2.66	2.3 - 3.25*(b)*
	Bruce Power Site Average	2.75	0.08 - 3.6*(b)*
Pickering Nuclear Site	Boundary Sites	6.2	1.3 - 31.2 *(d)*
	Area Sites: Ajax Hospital	1.1	*(c)*
	OPG Health Physics Laboratory	1.4	*(c)*
Darlington Nuclear Site	Boundary Sites	0.7	0.3 - 3.3 *(d)*
	Area Sites: Oshawa	0.2	*(c)*
	Bowmanville	0.5	*(c)*
	Ontario Provincial Average	**0.08**	**0.05 - 0.10**
Gentilly-2 Nuclear Site	Regional Site	*(b)*	0.05 - 1.8
	Reference Site	Less than detection level (0.10)	
Point Lepreau Nuclear Site	All Air Monitoring Stations 45 km from Station	0.8 Below Detection Level: 0.096	0.05 - 4.8
AECL Chalk River Laboratories	On Site	19.0	2.6 - 50.0
	Site Boundary	1.7	0.17 - 3.9
	Off Site	0.5	0.4 - 0.6
SRB Technologies Inc.	62 Meters	35.66	1.6 - 139.0
	220 Meters	19.05	3.9 - 56.4
	1050 Meters	3.42	1.3 - 7.2
	9480 Meters (Petawawa)	0.38	0.2 - 1.7
Shield Source Inc.	74 Meters	4.94	Less than 0.05 to 0.32
	210 Meters	2.21	0.34 - 3.75
	870 Meters	0.76	Less than 0.05 to 2.5
	1600 Meters	0.61	Less than 0.05 to 1.0
Background*	Ottawa, Ontario	0.04	0.01 - 0.08

(a) Where two methods - active and passive sampling - are used, only the highest value of the two methods is shown.
(b) Numbers extracted from graphs in the source reports.
(c) Missing entries represent data not given in the report.
(d) Range at sampling sites for combined active and passive sampling data values.
* CRMN, Health Canada, Monitoring Nuclear Power Plants, 2006 data average of six positive measurements.

Table 7 Tritium Concentrations in Water and Milk near Nuclear Reactors

	Precipitation		Municipal Water Supply		Off-Site Wells		Surface Water		Milk	
Facility	Location	Bq/L[1]	Location	Bq/L[1]	Location	Bq/L[1]	Location	Bq/L[1]	Location	Bq/L[1]
Bruce Power Site	Bruce Power Main Gate (B2)	258.0	Kincardine (15 km)	6.4	Deep Wells (Highest Avg., Bruce Site	19.0	Baie du Dore - Highest	143	Highest Avg. at Indicator Dairy Farm	8.7
	Background Value	Less than 3.7 - 6.8	Port Elgin (17 km)	17.4	Shallow Wells (Highest Avg., Bruce Site)	58.2	On-site Creek	101	Provincial Sites	Less than 3.7
			Southampton (22 km)	12.0			Provincial Background (Burlington)	Range: 3.7 to 6		
			Provincial Background in Drinking Water	4.7						
Pickering Nuclear Site	Indicator Sites++	240	Annual Highest Avg. (Whitby WSP - 12 km)	6.4	Annual Highest Avg. in Well Water Samples Critical Group Locations	115	Annual Highest Avg. in Frenchman's Bay	29.8	Average for all Farms	24.4
	Range	121 - 493							Range for all Farms	18 - 28
Darlington Nuclear Site	Indicator Sites – Avg.	28	Annual Highest Avg. (Oshawa WSP – 8 km)	7.1	Annual Highest Avg. in Well Water Samples Critical Group Locations	21.6	Annual Highest Avg. McLaughlin Bay	24.2	Average for all Farms	5.8
	Range	14 - 45							Range	4.0-7.4
	Background (Calgary, Saskatoon and Fredericton)	Less than 1.9	Provincial Background – Drinking Water (including Lakes Superior, Huron and Ontario)	Less than 1.9 to 4.8			Provincial Background – Drinking Water (including Lakes Superior, Huron and Ontario)	Less than 1.9 to 4.8	Provincial Background	Less than 1.9
Gentilly-2 Nuclear Site	Nearest to Site	910	Drummondville Gentilly Champlain Trois-Rivières	All Samples Below Detection Level: 18	4 km south Sector	Below Detection Limit: 18	Spent Fuel waste Disposal Area	Range: 50-892	4 Farms (2-8 km)	Range: 21-48
	Drummondville	Below Detection Limit: 18					St. Lawrence River; operation	Below Detection Limit: 18	K.D. Farm (8 km)	Below Detection Limit: 18
Point Lepreau Nuclear Site	On Site	1.5 - 4.6			11 Locations[2] Average and Range: 45 km away from Station	28 11-61 Below Detection Limit of 24	All Surface Water Samples	77.0 Range: 17-160	All Farms and Fredericton	At or below detection level of 24

(1) Annual Averages unless noted.
(2) On site, outside the exclusion boundary and belongs to the local residents.
(3) This category includes ponds, lakes, streams and runoff and most of them are from on site locations and two off site locations (freshwater supply reservoirs for Saint John and PLGS, at Spruce Lake and Hanson Stream).
** Blanks denote data not available.
++ Indicator locations are used to assess the potential dose to the public. These locations are outside the facility perimeter, at points where the most significant public exposure (direct or indirect) occurs or is "predicted to occur".

Table 8 Tritium Concentrations in Vegetation and Other Terrestrial Media Samples near Nuclear Reactors

Facility	Vegetables and Fruits (1)		Terrestrial Animals*		Aquatic Samples*		Honey*	
	Type	Bq/L(2)	Location	Bq/L(2)	Location/Type	Bq/L(2)	Location	Bq/L
Bruce Power Site	Bruce Power Sites: Fruits and Vegetables	62	Deer Meat on site	810	Baie du Dore – White Sucker	44.6-HTO** 16.8-OBT***	Surrounding Areas	43.7
	Background: Provincial Sites	2.7	No background data available		White Fish	16.1-HTO 10.7-OBT	No other data available	
					Background: Lake Huron –White Sucker	7.7-HTO 7.3-OBT		
					Background: Lake Huron White Fish	8.2-HTO 12.9-OBT		
Pickering Nuclear Site	Fruits, Vegetables and Silage	91 HTO Range: 13-1194 77 OBT Range: 37-144			Pickering Outfall Fish Samples (White Sucker and Round Whitefish)	10.2 HTO Range: less that 1.9-26 31.0 OBT Range: 25-36	Surrounding Areas	68 Range: 31-86
Darlington Nuclear Site	Fruits, Vegetables and Silage	22.5 Range: 4.6-61			Darlington Outfall Fish Samples (White Sucker and Round Whitefish)	8.1 HTO Range: 4-19 33 OBT Range: 22-44	Surrounding Areas	48 Range: 27-81
					McLaughlin Bay, Assorted Pan Fish Samples	23.0 HTO Range: 21-25 26.0 OBT		
	Provincial Background (Vegetables)	2.7 HTO Range: 1.9-3.8			Lake Ontario Fish Samples (White Sucker and White Fish)	5.0 HTO Range: 2.7-7.4 18.0 OBT Range: 16-20		
		29 OBT Range: 25-36			Far field: Lake Huron Fish Samples (White Sucker and Lake Whitefish)	4.2 HTO Range: 1.8-7.8 16.0 OBT Range: 14-17		
Gentilly-2	Vegetables (at 20 km)	Below Detection Limit of 18					Bécancour (Maple Syrup)	Below Detection Limit of 18
Point Lepreau	Garden Vegetables Dipper Harbour	Below Detection Limit			Sea Food and Sea Plants	Below Detection Limit		

Notes:

(1) Vegetables and fruits are sampled during the growing season. Values are averages for all vegetables and/or all fruit samples from all farms.

(2) Annual Vegetables unless noted otherwise.

* Blanks denote data not available.

** HTO: Tritiated Water or Vapour. Tritium Oxide: Tritium incorporated into water.

*** OBT: Organically Bound Tritium – Tritium incorporated into organic compounds such as proteins, in nature (fruits and vegetables, organisms, humans, etc.).

Table 9 Tritium Concentrations in Water, Milk, Meat and Vegetables near Research Facilities and Tritium Processing Facilities

Facility*	Well Water		Surface Water		Milk and Meat		Vegetables and Fruits (Averages)	
	Location	Bq/L	Location	Bq/L	Location	Bq/L	Location	Bq/Kg (fresh weight)
AECL Chalk River Laboratories			#Onsite, east side stream discharging to Ottawa River	207.0	Milk Deep River	26.0	Garden Produce Deep River	28.0 (25-32)++
			Ottawa River – Deep River (9 km upstream)	3.1	Milk Pembroke	16.0	Chalk River	16.5 HTO (11-21) 0.6 OBT (0.3-0.7)
			Ottawa River Water at the boundary	14.0	CRL Site Area animals	28-1447 HTO** 4.0-322 OBT***	Pembroke	141 HTO (126-169)++
			CRL Downstream 9 km	114.0	Meat deer buck within 25km radius	15.0 HTO 9.0 OBT	Balmer Bay	76.0 HTO (21-126) 1.5 OBT (0.6-2.2)
			Petawawa Downstream 18 km	6.0	(50 km) Meat deer, buck outside 50km radius	3.0 HTO 2.2 OBT	Killaloe (Background location)	32 HTO 0.4 OBT
					Local Farms Beef (Chapeau, Que)	13.0 HTO 13.0 OBT		
SRB Technologies Inc.	Residential well 465 m	1,875	Ottawa River at Westmeath	5.0	Average, Locally Produced Milk from a Market	13.0	Nearest Local Garden Produce	738 Range: 500-949
	Residential well 650 m	455	Madawaska River at Arnprior	4.0			Background: Local Grown Vegetable Samples (from Market)	141 Range: 113-163
	Residential well 1,100 m	406						
	Residential well 2,200 m	3						
							Fruits: Apples	1,257
Shield Source Inc.	Well water - house opposite to SSI	302+++	Highest in Pond Water at 220 m	1,490	Nearest Dairy Farm (2,860 m)	Less than Detection Limit	250 m from stack (grapes)	1,529 Bq/l
			Water Sample at 870 m	106			220 m from stack (apples)	3,091 Bq/l
			Water Sample at 1,600 m	51,0+++			1,000 and 2,500 m from stack (grapes and berries)	Below detection level
			Provincial Background: Drinking Water (including Lakes Superior, Huron and Ontario)	Less than 1.9 to 4.8			Provincial Background: Vegetables	2.7 HTO Range: 1.9-3.8

NOTES:

* Tritium was not measured in the environmental media around Whiteshell Laboratories.

** HTO: Tritiated Water or Vapour. Tritium Oxide: Tritium incorporated into water.

*** OBT: Organically Bound Tritium – Tritium incorporated into organic compounds in nature (fruits and vegetables, organisms, humans, etc.).

++ OBT Not Monitored.

+++ One monthly sample above the detection limit of 50 Bq/l. All other monthly samples were less than detection limit in 2006.

\# AECL onsite surface water at waste management are presented in Table 10.

Table 10 Tritium Concentrations in Surface Waters within the Chalk River Laboratories Waste Management Areas

Waste Management Area	Location	Average (Bq/L)
Liquid Waste Management Area	East Swamp (ESW)	547
Waste Management Area A	South Swamp (SSW) Main Stream (MSC) Perch Lake (PL2)	1,560 689 6,530
Waste Management Area B	Spring Disposal B (SDB) Perch Lake (PL1)	2,310 3,130
Waste Management Area C	Duke Stream Weir (DSW) Maskinonge Lake Outlet (MLO) Chalk Lake	20,400 1,220 127
Perch Lake System	Perch Creek Weir (PCW)	6,670
	Provincial Background in surface waters including Lakes Superior, Huron and Ontario	Less than 1.9 to 4.8

5.1 Tritium in Groundwaters within the Licensed Site Boundaries

Tritium in groundwater can arise from both natural and man-made sources. Data on background levels of tritium in Canadian groundwaters are not readily available at this time. However, it can be inferred that the background levels of tritium in groundwater are very low and similar to that of the surface water bodies.

Table 11 summarizes levels of tritium in groundwater across Canada, at nuclear reactors, research facilities and tritium processing facilities that are licensed by the CNSC. The maximum tritium concentration in the table represents the highest detected value among all the groundwater monitoring wells near a facility, during the latest sampling period for data submitted to the CNSC as of January 2008. Table 11 also identifies the source of the contamination at each site.

It should be noted that there is no currently authorized direct discharge of tritium to groundwater. The elevated tritium concentrations found in groundwater at nuclear reactors, research facilities and tritium processing facilities represent tritium contamination due to malfunctions, historical practices or washout of stack emissions. Contamination resulting from historical practices and malfunctions are all in the process of being addressed by the licensees, as required by the CNSC.

The tritium plumes identified are generally within the fenced and protected boundaries of the licensed facilities and do not contribute to the radiation dose of workers or the public. Also, because groundwater near these plumes is not used for drinking water or other purposes, there is no dose or health risk to workers or members of the public.

Based on the assessment of licensee monitoring and investigation programs, this summary is the latest representative snapshot of groundwater tritium plumes at facilities licensed by the CNSC. There is no associated radiation dose or health risk to workers and the public. The CNSC continues its regulatory oversight of this issue.

Table 11 Tritium Concentrations in Groundwater at Nuclear Reactors, Research Facilities and Tritium Processing Facilities

Facility	Number of Monitoring Wells	Maximum Concentration (Bq/L)	Comments on the Contamination Sources	Data Year	Ref.
SRB Technologies	15	108,879	Stack emission washout by precipitation	2007	[17]
Shield Source Inc.	4	6,996	Stack emission washout by precipitation	2007	[18]
Darlington Nuclear Site	8	Below detection limit		2005	[19]
Bruce A	12	667	Airborne emission washout by precipitation	2005	[20, 21]
Bruce B	14	1,593	Airborne emission washout by precipitation	2005	[20, 21]
Bruce Western Waste Management Facility	18	41,000	Foundation and subsurface drainage	2005	[22]
Point Lepreau Plant and Waste Management Facility Area	11	1,100	Emission washout by precipitation	2006	[11]
Point Lepreau Solid Radioactive Waste Management Facility	34	400	Airborne emission washout by precipitation	2006	[11]
Gentilly-2	7	20,553	Emission washout by precipitation	2006	[10]
Pickering Nuclear (PN)	Most tritium in groundwater at the site is captured by the foundation drains that are the lowest points acting as a hydraulic sink			2006	[23]
PN Unit 1-4 Area	30	128,800,000	Sources: (1) Leaking concrete pit in the Moderator Purification room. The pit gets tritium from spills on the floor; (2) Leaking RAB sumps receiving tritium from spent resin storage tank. Problem fixed. Tritium concentration is decreasing.		
PN UPP (Upgrading Plant Pickering Area)	32	888,000	Past practice of discharging tritiated water onto the ground. Practice stopped. No new releases. Tritium concentration in ground is decreasing.		
PN Irradiated Fuel Bay A&B (Wells and Sumps)	13	21,100,000	Due to tritium migration from Unit 1 area and sump leaking. Repairs underway in 2007.		
PN Vacuum Building Area	11	1,200,000	Due to tritium migration from Unit 1 area and sump leaking. Repairs underway in 2007.		
PN Catchbasin-97	6	108,410	Historical sources in 70's and 80's from Moderator Upgrader (Sulzer).		
PN "B" Reactor Auxiliary Bay (Sumps)	4	10,200,000	Leaking sump pipes. Repaired at Units 5 and 7. Repairs at Unit 6 were completed in 2007. Sump tritium concentration is decreasing. Unit 8 is normal.		
Chalk River Laboratories – NRU Reactor Site	8 monitoring wells are around the fuel rod bay room and 21 monitoring well between the NRU building and Ottawa River	Between the NRU Building and Ottawa River: 3,240,000	AECL identified the Rod Bay leakage as the source. AECL is in the process of addressing the leakage issue.	2006	[24]
Chalk River Laboratories – NRX Fuel Bay Area		3,000,000	Due to Fuel Rod Bay leaking. The Bay water was emptied in June 2006.	2005	[25]

6. DOSE TO MEMBERS OF THE PUBLIC

The foregoing section provides an overview of the concentrations of tritium in the environment in which people live and work. The resulting public dose around nuclear facilities, generating stations, including the waste management facilities, is estimated and presented in the facilities' annual reports.

Estimated public doses for 2006, for each facility, are presented in Table 12 along with the characteristics of their respective critical group. Multiple facilities at one site typically calculate only one value for all tritium releases from the site (e.g., the Bruce site). These values are estimates, but they are largely based on measured levels of tritium in the environment and characteristics of the critical group in terms of occupancy factor, local meat and produce consumption, etc.

The environmental monitoring data that are used to estimate the radiation dose are summarized in section 5, Tables 6 to 9 of this report.

Members of the public living in the vicinity of nuclear facilities licensed by the CNSC received very low doses of radiation from tritium exposures. Doses are typically less than 3 µSv per year for nuclear power stations and the AECL CRL site, and less than 67 µSv per year for tritium processing facilities. These doses are well below the public dose limit of 1000 µSv per year (1 mSv per year).

Table 12 Some Features of Critical Groups and Tritium Doses for 2006 by Facility

FACILITY	CRITICAL GROUP			TOTAL TRITIUM DOSE	TRITIUM DOSE BY PATHWAY			COMMENTS
	Receptor	Location Distance (km)	Characteristics	(µSv/a)	Pathway*	Tritium Form**	Percent of total %	
Bruce Power	Infant (BR1-Critical group)	North of the Bruce Power site. Closest to Bruce A.	Northerly wind and lake currents more frequent. Number of shallow wells impacted by tritium in precipitation. Critical group infant drinking water source. Dose assigned to the resident closest to Bruce A.	1.55	Water Ingestion Air Inhalation Terrestrial Plants Terrestrial Animals	HTO	73 19 6 5	Estimation based on the environmental monitoring program.
Pickering (PN)	C2 Correctional Institution (15 years old)	Approxi-mately 3 km NNE of the PN site	C2 resident uses municipal drinking water, does not eat local produce and lives at this location continuously.	2.36	Air Inhalation Water Ingestion	HTO	98 2	Measurements and modeling with the program IMPACT version 4.03.
Darlington (DN)	Farm Resident-Nursing Infant	1.5 to 10 km WNW wind sector	This group obtains their water mostly from wells. Diet from locally grown products.	0.92	Terrestrial Animals Air Inhalation Terrestrial Plants Terrestrial Animals Terrestrial Plants	HTO OBT	58 17 8 14 1	Measurements and modeling with the program IMPACT version 4.03.
Gentilly-2	Farm Resident (Adult)	2.0 km SSW	Dominant wind in the SSW sector. Critical group members assumed to consume 50% of diet obtained locally.	0.6	Air Inhalation, Skin Absorption, food and water ingestion.	HTO	100	IAEA-specific activity method. (IAEA, 2001).This does not consider explicitly the critical pathways.
Point Lepreau	Infant	1.0 to 1.5	Members live at 1 km from the stack. Some or all vegetables, meat and milk are produced at 1.5 km from the stack, which is the nearest distance to pasture.	0.45	Air Inhalation and food and milk ingestion	HTO	100	Measurements and modeling.
Chalk River Laboratories	Sheenboro (Infant)	N/A	Milk originates from dairy herds within Renfrew County and is therefore applicable to the critical group at Sheenboro. (There is no dairy farming in Sheenboro.)	1.2	Milk Ingestion Inhalation & immersion		19 11	
	Ft. William (Adult)		Members of the downstream critical group consume drinking water from the Ottawa River.	1.2	Animal meat ingestion		63	
SRB Technologies	Adult worker	Resides within 500 m, works at or near the SRBT Inc	Hypothetical worker: uptake of tritium from inhalation and immersion at or near home, and workplace; drinks well water, eats local produce and drinks locally produced milk.	14.5	Drinking well water Inhalation at workplace and home Skin absorption at workplace and home Eating local produce	HTO	*39 28 28 4	Estimation is based on the environmental monitoring program.
Shield Source Inc.	One-year old Infant	220 m	Hypothetical, living in nearest residence. Drinking water source assumed to be from a near by contaminated pond.	67.0	Total Water Total Animal Ingestion Total Vegetation Ingestion Total Air dose	HTO HTO OBT HTO OBT HTO	49 12 28 4 6 0.8	At no time vegetable garden or livestock been observed at critical group residence Highly conservative methodology.

* Pathways contributing significant dose.

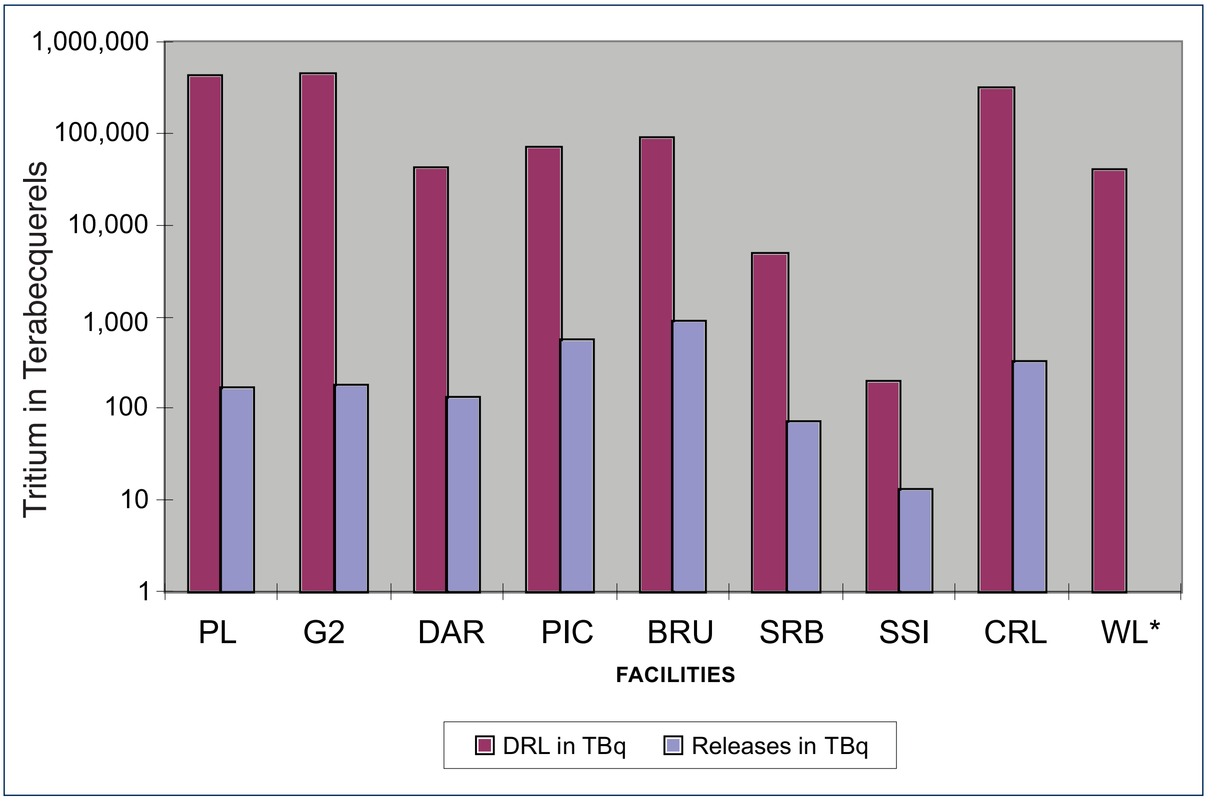
** HTO: tritiated water or vapour. OBT: Organically bound tritium – Tritium incorporated into organic compounds such as proteins, in nature (fruits and vegetables, organisms, humans, etc.)

7. REGULATORY COMPLIANCE

7.1 Status of Tritium Releases

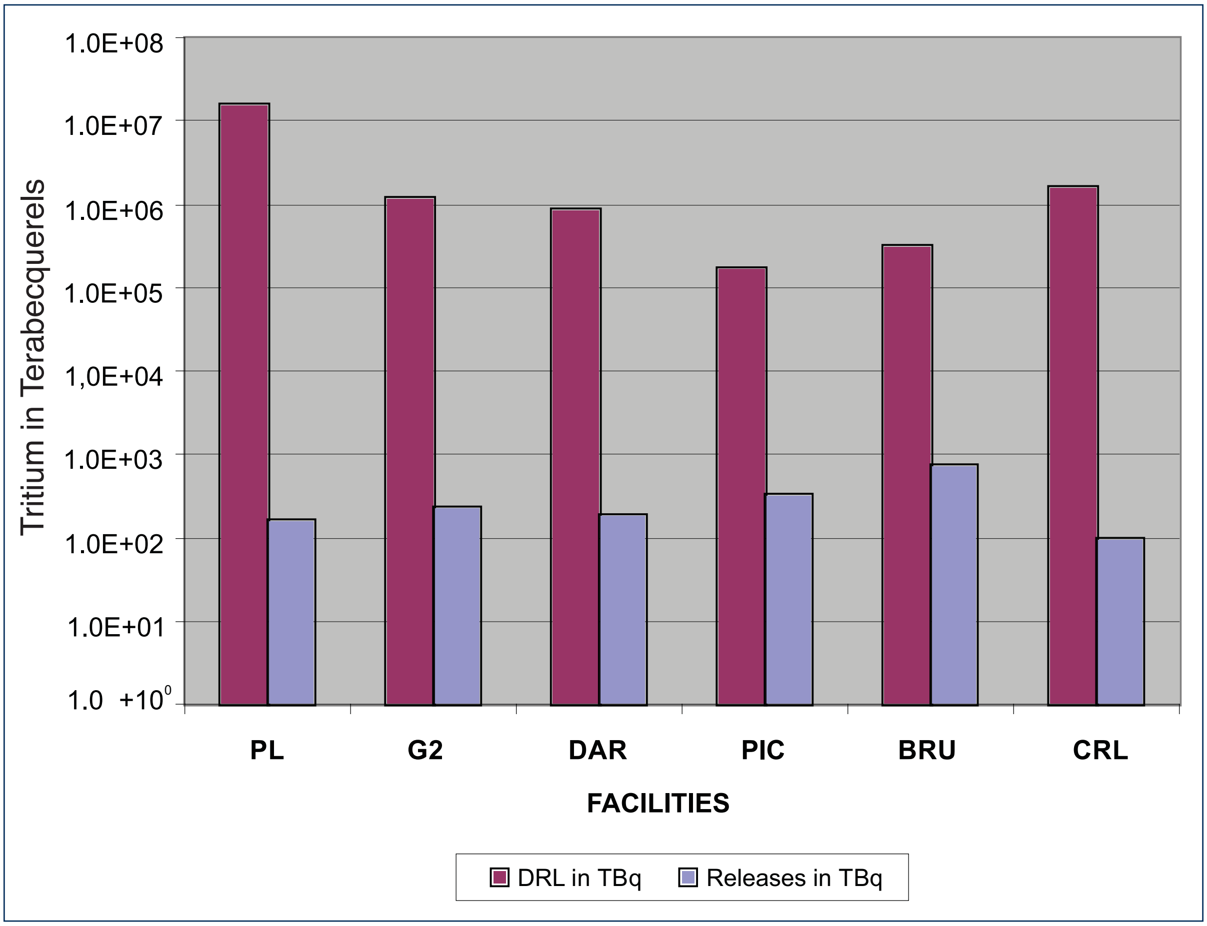
The performance of licensees, related to the release of tritium, can be judged relative to each facility's DRLs. Representative data for emissions to air and water are shown in Figures 3 and 4, on a logarithmic scale. In 2006, all these releases were only a small fraction of the regulatory limits.

Figure 3 Tritium Emissions to Air in 2006 Compared with Derived Release Limits



* Whiteshell released 0.0076 Tbq in 2006 (far below the scale).

Figure 4 Tritium Liquid Emissions in 2006 Compared with Derived Release Limits

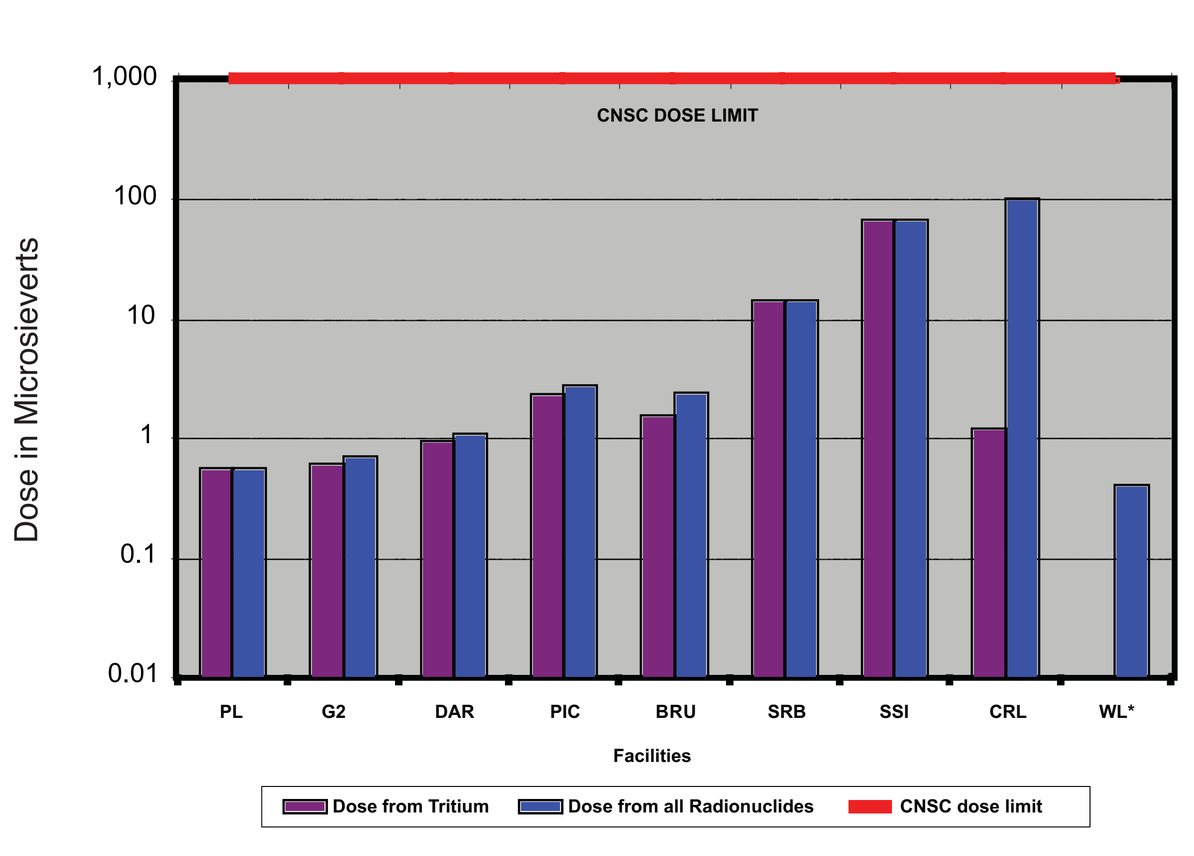


* SRBT, SSI, WL, Kinectrics and Monserco release only very small amounts of tritium in liquid form to the environment (less than 1 TBq; below the scale).

7.2 Status of Tritium Doses to Members of the Public

The performance of licensees, related to tritium dose to members of the public from their operations, can also be compared directly to the CNSC public dose limit of 1 mSv (Figure 5). In 2006, all doses resulting from the operation of these facilities were only a small fraction of the regulatory limit.

Figure 5 Tritium Doses to Members of the Public Compared to the Dose Limit



* Dose to public from tritium at Whiteshell is 0.01 μSv/y and therefore does not show on the figure.

8. OCCUPATIONAL DOSES

8.1 Regulation of Occupational Exposures under the NSCA

In addition to the regulatory requirements mentioned in Section 1.3, licensees must comply with the dose limits in Section 13 of the *Radiation Protection Regulations*, which limit effective doses to 50 mSv per year and 100 mSv in 5 years for Nuclear Energy Workers. In addition, licensees must ensure that the doses are ALARA.

8.2 Tritium Doses to Workers

Most worker exposures to tritium at CANDU plants are linked to the heat transport system water, since it is more accessible, more prone to leaks, and requires more maintenance than the moderator water system. Similarly, workers in other industries which use tritium are exposed directly or indirectly via leaks, contaminated equipment, work areas, work surfaces and material (e.g., oils, grease) or failure of controls. As with the public, workers are mostly exposed to tritium through inhalation and skin absorption. HTO is readily soluble in body fluids and is uniformly distributed throughout the body. Tritium is eliminated with a nominal biological half life of 10 days, but the rate of elimination varies from individual to individual.

Tritium doses to workers are estimated by analysis of the tritium concentration in urine. The average dose rate to soft tissues is directly proportional to the concentration of tritium in urine. Altogether, the metabolism of HTO in the body is well enough understood for radiation protection purposes that the absorbed doses from HTO exposures can be calculated reliably from tritium concentrations in urine [Ref. 26].

Only the nuclear generating stations, the tritium processing facilities and AECL (Chalk River and Whiteshell research facilities) handle sufficient tritium to require dose monitoring for occupational exposures to this element. The 2006 statistics for radiation dose due to tritium and effective dose from all radiation exposure are shown in Table 13 [Ref. 27]. The effective dose is a measure of the total detriment, or risk, due to an exposure of ionizing radiation and it has been corrected for the type of radiation (equivalent dose) and the radiosensitivity of the irradiated organ or tissue. When there is more than one tissue or organ being irradiated, then the weighted dose for each tissue is summed. Effective dose is measured in millisieverts (mSv).

The percentage of the effective dose from tritium is given by each facility in Table 13. This percentage will also vary greatly between different work groups within a given facility e.g., maintenance worker groups.

Exposure to tritiated water (HTO) vapour is the main contribution to the dose at the nuclear generating stations and at AECL. Tritium gas (HT) is used for the manufacture of self illuminating lights at SRBT and SSI; therefore both HT and HTO may be present in the workplace. The dose resulting from tritium gas HT is very small per unit of radiation exposure. Consequently, most of the radiation dose to workers is due to exposure to HTO.

Current occupational exposures are presented in Figure 6 on a logarithmic scale, with the regulatory limit for reference. In all cases, doses are well below regulatory limits.

Table 13 Average Annual Occupational Dose for 2006

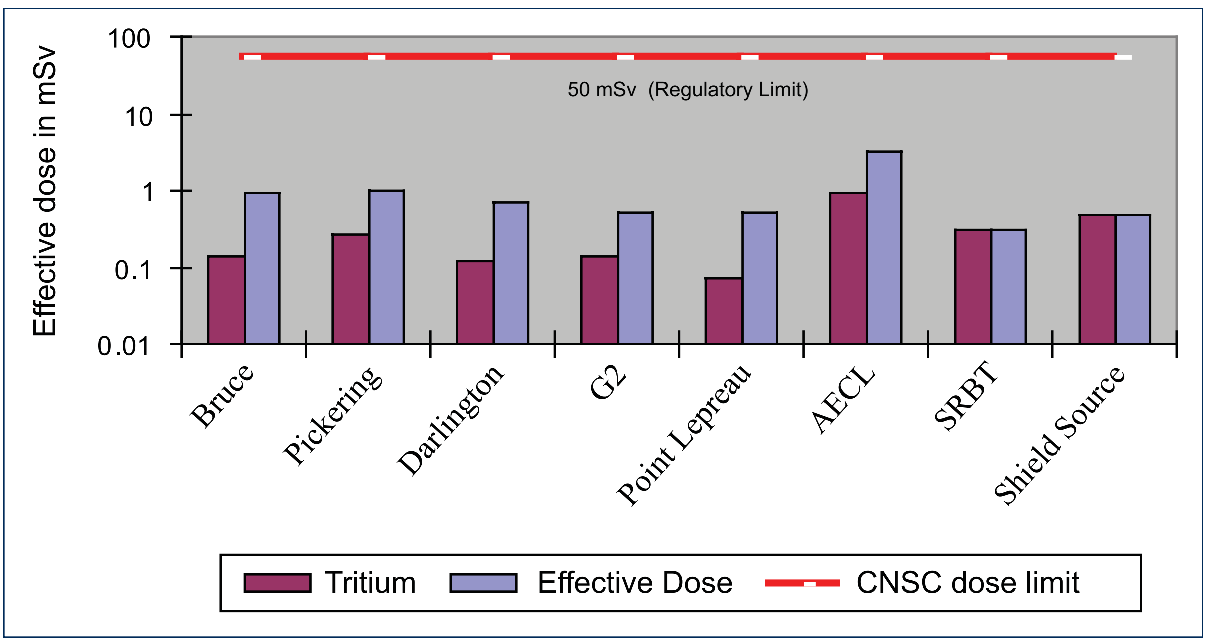
++	Bruce	Pickering	Darlington	G2	Point Lepreau	AECL*	SRBT**	SSI**
Tritium (mSv)	0.14	0.26	0.12	0.14	0.07	0.90	0.30	0.19
Effective Dose Comprend (mSv) (includes all radiation exposures)	0.90	0.97	0.67	0.49	0.51	3.15	0.30	0.19
% of Effective Dose from Tritium	15.6	26.8	17.9	28.6	13.7	28.5	100	100

* Doses appear higher due to AECL group being a smaller, more specific work group.

** Tritium is the only radioactive material handled.

++ Kinectrics and Monserco do not have data for tritium-specific dose. Average occupational doses are lower than 1mSv. [Refs. 12, 13].

Figure 6 Average Tritium Doses and Total Effective Doses to Workers Compared with Regulatory Limits



ACRONYMS

ALARA	As Low As Reasonably Achievable
BNGS	Bruce Nuclear Generating Station
CANDU	CANada Deuterium Uranium
CRL	Chalk River Laboratories
DNGS	Darlington Nuclear Generating Station
DRL	Derived Released Limit
DWL	Drinking Water Limit
EMS	Environmental Management System
G2	Gentilly-2
HQ	Hydro-Québec
NSCA	Nuclear Safety and Control Act
NWMF	Nuclear Waste Management Facility
OBT	Organically Bound Tritium
OPG	Ontario Power Generation
PLGS	Point Lepreau Generating Station
PNGS	Pickering Nuclear Generating Station
SRBT	SRB Technologies
SSI	Shield Source Incorporated
WWMF	Western Waste Management Facility
WL	Whiteshell Laboratories

GLOSSARY

For simplicity, some terms are defined in plain language and may differ from definitions in standard references.

ALARA	Principle for radiation protection, according to which exposures are kept as low as reasonably achievable below regulatory limits, social and economic factors being taken into account.
becquerel	Unit of activity, the rate at which transformations occur in a radioactive substance. 1 Bq = 1 transformation or disintegration per second.
bioassay	The measurement of radioactive substances in the body, either by analysis of excreta (usually urine) or by measurement of radiation from the substances, by means of radiation detectors outside the body.
biological half-life	The time required for the biological elimination in a natural way, of half of the amount of a substance, such as tritium, from an organ or the body. The biological half-life is determined by the metabolic behaviour of the substance inside the body.
critical group	A homogeneous group of members of the public identified as being those individuals most likely to receive the highest doses from exposure to radioactive materials. Whereas the concept of critical group is the same for all CNSC licensees in Canada, the description of each critical group is unique, some being more conservative than others. It is based on analysis of site-specific radionuclide releases and exposure pathways and on site-specific land use information.
derived release limit (DRL)	A limit on the release of a radioactive substance from a licensed nuclear facility, calculated so that compliance with the DRL gives reasonable assurance that the regulatory dose limit is not exceeded. It represents a release that would result in a dose of 1 mSv per year to the critical group.
dose limit	An upper limit on radiation dose specified in the CNSC *Radiation Protection Regulations*.
effective dose	A measure of the total detriment, or risk, due to an exposure to ionizing radiation. If the exposure to different organs or tissues is not uniform (as is the case when radionuclides are deposited in the body), the concept of effective dose is used. The basic idea is to express the risk from the exposure of a single organ or tissue in terms of the equivalent risk from an exposure of the whole body. The unit of effective dose is sieverts (Sv).

hydrogen isotopes	Nuclides of an element that have the same number of protons, but different numbers of neutrons, are called isotopes of that element. Hydrogen has three isotopes: hydrogen-1 (common hydrogen with a nucleus of only one proton), hydrogen-2, also called deuterium (one proton and one neutron), and hydrogen-3, also called tritium (one proton and two neutrons).
ionizing radiation	Any atomic or subatomic particle or electromagnetic wave having sufficient energy to produce ions (atoms which have become charged due to the loss or gain of electrons) in the material which absorbs it. Ionizing radiation includes alpha and beta particles and gamma radiation, as well as neutrons and some other particles.
logarithmic scale	An exponential scale in which the distances that numbers are at from a reference point are proportional to their exponents rather than their linear relationship to each other. These scales are more useful than linear scales for creating graphic representations of large numbers.
representative person	an individual with characteristics that reflect those of the group (known as the critical group) who receives the highest doses from a particular source for the radionuclide in question.
tritium	A radioactive form of hydrogen which is produced both naturally and by human activities. The ionizing radiation from tritium is a beta particle. Tritium is produced during normal operation of Canadian nuclear reactors

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