Canada's Nuclear Regulator

Tritium Activity in Garden Produce from Pembroke in 2007 and Dose to the Public

Part of the Tritium Studies Project

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Tritium Activity in Garden Produce from Pembroke in 2007 and Dose to the Public

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Background

Tritium is a radioactive isotope 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 important, as Canadian-designed CANDU (CANada Deuterium Uranium) reactors produce more tritium than most other types of reactors. Some of the tritium generated in power reactors is recovered and is used to produce self-luminescent lights and paints by companies such as SRB Technologies and Shield Source Incorporated in Ontario. Commercial applications of tritium processing are evident in products such as exit signs, airport runway lights, watch dials and gun sights.

The Canadian Nuclear Safety Commission (CNSC) regulates and carefully monitors environmental releases of man-made tritium in order to protect the health and safety 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 describes the results from one such study, which aimed to characterize public exposure to tritium in Pembroke garden produce as a result of tritium emissions from the SRB Technologies tritium processing facility.

Objective

SRB Technologies (SRBT) has been producing tritium light sources since 1991. As a result of CNSC compliance enforcement actions, it temporarily ceased processing in 2007. This resulted in a large reduction in atmospheric releases relative to past operations and created a unique opportunity to study the environment's response to this reduction.

This report provides results of CNSC-funded research at the University of Ottawa on tritium activity in garden vegetables and fruits, and a few matching soils collected in late summer 2007. The objective was to document how the local environment recovered when a long-term source of tritium was removed. In 2005, CNSC staff had collected similar produce data, which provided a suitable point of comparison for this investigation.

Dose estimates for people consuming local produce are also provided for interpretation.

Main findings

Garden produce and soils

- Tritium activity in the water (HTO) in produce grown close to SRBT in 2007 was about 20 times natural tritium background levels. Altogether, activity levels were about 100 times lower than during normal operations in 2005.
- Total tritium activity in produce and soils declined considerably as distance from SRBT's stacks increased. Activity approached natural tritium background at about 3 km from the stacks.
- First-time measurements of organically bound tritium (OBT) in produce and surface soils from Pembroke in 2007 did not reveal significant accumulation of tritium from past releases, but did reveal some high ratios of OBT relative to HTO.
- HTO results from the CNSC and the University of Ottawa were in general agreement with compliance monitoring data reported by SRBT.
- On the whole, tritium activity in produce and soils agreed with expectations based on reported releases from SRBT and on models of tritium in the environment.

Public dose

- The annual doses from tritium in produce, calculated from the background tritium samples, is 0.0002 mSv.
- Based on measurements of HTO and OBT in garden produce, dose to Pembroke residents from the consumption of local produce was less than 0.004 mSv per year, a small fraction of the public dose limit of 1 mSv and only slightly higher than dose background tritium levels.

Health risks in people exposed chronically to radiation doses of approximately 100 mSv or less cannot be distinguished from similar health risks in the general Canadian population. Hence the dose of 0.004 mSv from consumption of local produce in Pembroke is not considered an additional risk.

Conclusions

CNSC-funded research found expected levels of tritium in local garden vegetables and fruits grown in Pembroke in 2005 and 2007. There was no evidence of significant accumulation of tritium in surface soils after 16 years of tritium releases from the SRBT facility. First-time measurements of OBT from fruits in Pembroke, and from several items at background locations, revealed much greater diversity in OBT/HTO ratios than expected.

The dose resulting from the consumption of tritium in fruits and vegetables grown in Pembroke declines considerably with distance of the garden from the SRBT facility. The highest annual dose in 2007 was about 0.004 mSv. This is well below the public dose limit of 1 mSv per year and orders of magnitude below doses known to cause health effects.

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. Tritium 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 addition to nuclear reactors, a few industries in Canada — such as those that produce gaseous tritium light sources — release tritium to the environment through routine operations. Tritium is readily incorporated into water as a form of hydrogen and enters the natural hydrological cycle. Hence, trace amounts of tritium can be found everywhere that water is present — including precipitation, surface water, groundwater, ice, soil moisture, animals and plants. Detailed information on the presence and use of tritium in Canada can be found in *Tritium Releases and Dose Consequences in Canada in 2006*, which was published by the Canadian Nuclear Safety Commission (CNSC) (Ref. 1).

1.2 Scope

In January 2007, the Commission directed CNSC staff to initiate research studies on tritium releases in Canada, and to study and evaluate tritium processing facilities around the world that exercise best practices. In response, CNSC staff initiated the Tritium Studies Project with several information gathering and research activities extending to 2010. The project aimed to enhance available information in order to guide regulatory oversight of tritium processing and tritium releases in Canada. A fact sheet, along with outputs from completed studies, can be found at nuclearsafety.gc.ca.

This report provides a synopsis of research and compliance monitoring information for tritium in vegetation (mostly home garden produce and a few wild fruits, and some soils) near SRB Technologies (SRBT) in Pembroke, Ontario, during late summer of 2005 and 2007. In 2005, the SRBT facility was in full operation while tritium processing ceased temporarily from 1 February, 2007, through 31 July, 2008. Dose estimates for people consuming local produce in 2007 during the time when tritium was not being processed, along with interpretation of the results, are also provided.

SRBT is one of the few facilities in the world that produces gaseous tritium light sources for safety signs and similar applications (Ref. 2). Located at 320 Boundary Road in Pembroke, Ontario, it is a CNSC-licensed facility that has released tritium to the atmosphere through two adjacent stacks since operations began in 1991. As a result of CNSC compliance enforcement actions, SRBT temporarily ceased processing on February 1, 2007, resuming only after being granted a new processing licence on August 1, 2008. This resulted in a large reduction in atmospheric releases relative to past operations. This created a unique opportunity to document tritium levels during the growing season following a major reduction in long-term, steady releases for comparison with normal operations.

1.3 Context

At the time of environmental sampling in August 2007, stack emissions resulting from materials stored at SRBT were 49.8 GBq HTO (hydrogen-tritium-oxygen vapour) and 3.2 GBq HT (hydrogen-tritium gas) per week, with only minor variation in emissions prior to that time throughout the growing season. For comparison, stack emissions resulting from processing operations at SRBT in August and September 2005 were much greater, averaging 3,618 GBq HTO and 9,332 GBq HT per week.

When tritium was being processed in August and September 2005, monthly air concentrations in Pembroke were as high as 252 Bq/m^3 at 60 m, and as high as 25.5 Bq/m^3 at 1,050 m from the stacks (Ref. 3)[1]. SRBT laboratory procedures at that time were not sensitive enough to measure the very low concentrations of tritium in air at sites distant from SRBT. However, typical tritium concentrations in air at six background locations in Ontario were measured by several organizations such as Bruce Power (BP), Ontario Power Generation (OPG), and others. BP and OPG background results were near or just below limits of detection (0.11–0.15 Bq/m^3 [Ref. 4]; <0.2 Bq/m^3 [Ref. 5]).

In August 2007, air concentrations in Pembroke were being measured at SRBT with much better sensitivity in an expanded monitoring program at 31 locations between 50 m and 2,200 m from the stacks. Tritium in air results ranged from 0.14 to 1.76 Bq/m^3. Four locations 7 to 16 km from Pembroke were also monitored and averaged 0.14 Bq/m^3. Similar background measurements by BP and OPG in 2007 (Refs. 4 and 5) recorded tritium levels in air below analytical limits of detection (<0.38 Bq/m^3 and <0.2 Bq/m^3, respectively).

1.4 Methods

Vegetation and soil samples were collected by CNSC staff on August 14, 2007, and analyses were conducted at the University of Ottawa. In 2005, only vegetation samples were collected and were analyzed at the CNSC laboratory. Two collections were made on August 9 and September 13. In 2005 and 2007, SRBT also independently collected and analyzed garden produce at similar times from mostly similar locations (Ref. 6).

Produce samples were obtained from Pembroke residents at several distances from SRBT. At each site, an attempt was made to get at least one sample of above- and below-ground garden produce as well as fruit such as apples or berries. The largest number of samples came from several homes along Boundary Road about 400 m from the stacks. Data summarized for other distances came from just one home garden/site. This area of Boundary Road at about 400 m from SRBT roughly corresponds to the *critical group* that is maximally exposed to tritium released from SRBT. The critical group is defined as a fairly homogenous group of people receiving the highest dose from facility releases due to location, lifestyle, etc. Natural

1 All measurements for tritium in air from various references are for HTO concentrations; HT in air is not routinely measured in monitoring programs. The HTO in air is the main form of tritium that contributes to public dose.

background samples were from the same home garden in Russell, Ontario in both years; a few garden fruits were also collected at two other background sites in 2007 (Golden Lake, Ontario; Hay River, Northwest Territories).

All vegetation samples were free of adhering dirt but were not washed. The content of free water tritium (HTO or tritiated water) in tissue was measured by liquid scintillation counting at independent laboratories, for comparison with SRBT's compliance monitoring data (2005: CNSC; 2007: University of Ottawa). Free water tritium is the tritium incorporated in the water that can be extracted through techniques such as evaporation or freeze drying. Analytical limits of detection for HTO in 2005 at the CNSC laboratory were not low enough to quantify background levels in produce from Russell, but were sufficiently low to do so at the University of Ottawa laboratory in 2007 (1 Bq/L).

In 2007, an additional form of tritium in produce was also measured by helium ingrowth mass spectroscopy. Analyses were performed at the MAPL Noble Gas Laboratory in the University of Ottawa's Earth Sciences Department. This advanced technique is based on capturing the helium gas produced during the decay of tritium in an encapsulated sample. In organic materials such as vegetation, the form of tritium measured using this technique is referred to as organically bound tritium (OBT). It represents tritium in compounds such as carbohydrates, fats and proteins. Samples for OBT determination were washed with tritium-free water, and results therefore represent "non-exchangeable" OBT; that is, tritium strongly bound to carbon atoms. Based on levels of tritium measured in representative wash water, the total OBT present in samples would have included an additional 5% "exchangeable" OBT (tritium bound to atoms such as nitrogen, oxygen or sulphur).

In 2007, CNSC staff obtained six matching soil samples from gardens where produce was collected, and a few representative samples of wild fruits from natural areas in Pembroke. Helium ingrowth mass spectroscopy was used to measure the tritium activity remaining in dry soils after all water was extracted. This measurement may represent tritium incorporated in both the organic and mineral components of soil and is therefore not exactly equivalent to OBT in produce.

Tritium results from different laboratories have been summarized for comparison by type of produce (above- and below-ground vegetables, fruits) and by distance from the stacks. Results at this level of detail are for only a few items by location or type of material (See Appendix for full raw data, organized by location to facilitate further data analysis; original laboratory reports are available from the CNSC on request.)

Additional natural background data collected by BP and OPG in Ontario in 2005 and 2007 (Refs. 4 and 5) are also summarized for interpretation of results. More detailed information on tritium levels in many items in the environment near nuclear facilities in Canada is available in a recent CNSC summary, *Tritium Releases and Dose Consequences in Canada in 2006* (Ref. 1).

2. RESULTS

2.1 Free Water Tritium (HTO) in Vegetation

Garden produce and fruits contain large amounts of water; therefore, HTO is the most commonly monitored component of tritium. HTO activity in produce from Russell, Ontario, and other background locations averaged 2 Bq/L (range 1–5 Bq/L). The lowest value was for choke-cherries from the Northwest Territories. Similar natural background levels of HTO for vegetable composites and some fruits were obtained by BP and OPG at five locations far from tritium sources in Ontario (Lakefield, Bancroft, Sarnia, Barrie, Picton) in 2005 and 2007. Levels ranged from 2 to 6 Bq/L, with no clear pattern among years or locations (Refs. 4 and 5).

Results for HTO in produce in relation to distance from SRBT are presented in Figure 1A (2005, total sample size N=37) and Figure 1B (2007, N=42). When SRBT was not processing tritium in 2007, HTO activity in produce near the facility was roughly 100 times lower than during processing in 2005. HTO activity declined considerably with distance from SRBT in both years. HTO activity in produce approached natural background levels at the furthest site, where samples were taken at a distance of 2.7 km from SRBT in 2007 (13 Bq/L). This site was located in one of the major downwind sectors SE from SRBT (Ref. 3). HTO at this location was about 10 times higher in 2005 (123 Bq/L, N=6). HTO activities measured by the CNSC, SRBT and the University of Ottawa across years and sites were consistent in magnitude and in overall pattern (see Figures 1A and 1B). HTO activities were also similar in above and below ground vegetables. Only fruits (mainly apples) stood out in terms of occasionally having higher levels of HTO than other items.

Figure 1A: Free water tritium activity (HTO: Bq/L water) in above- and below-ground garden produce and various fruits collected at several distances from an atmospheric source of tritium at SRBT in 2005 at Pembroke. Analyses were done on different samples from similar areas by SRBT and the CNSC. Background samples are not shown as analytical limits of detection were not sufficient to quantify tritium activity at the background location in 2005.

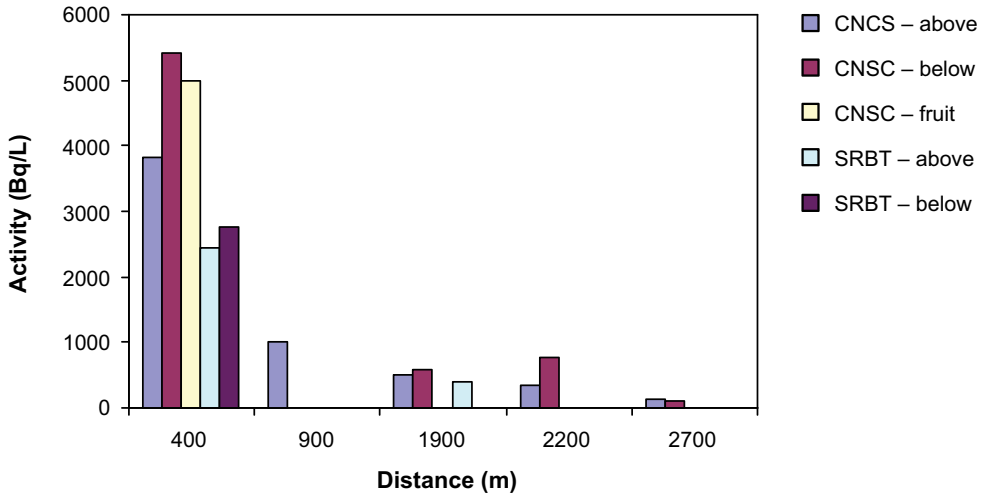
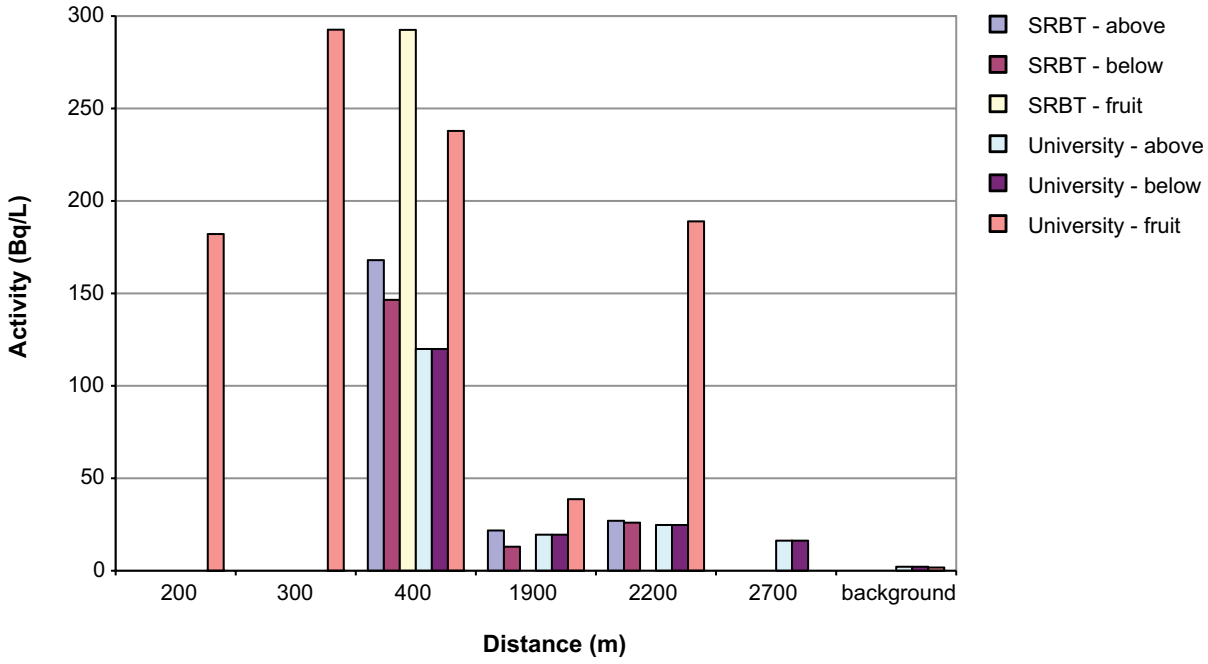


Figure 1B: Free water tritium activity (HTO: Bq/L water) in above- and below-ground garden produce and various fruits collected at several distances from an atmospheric source of tritium in 2007 at SRBT in Pembroke, and at a few background locations. Analyses were done on different samples from similar areas by SRBT and the University of Ottawa.



2.2 Organically Bound Tritium (OBT) in Vegetation

Organically bound tritium (OBT) accounts for a variable amount of tritium present in different biological materials, depending on the composition of the material (Ref. 7-9). OBT is measured in dried samples and is most easily interpreted in terms of the activity in *water equivalents* (*we*) for comparison with data for HTO. For dose calculations, it is necessary to know the results in terms of fresh weight (wet weight before the sample is dried for analysis). The Appendix presents both values for reference. OBT in Bq/L *we* represents the activity captured in the water (H_2O + HTO) formed after conversion of all organic matter into simple components (typically done by combustion at very high temperatures). Examples of other products of combustion that do not contain tritium or hydrogen are carbon dioxide, nitrogen oxide, trace minerals, etc.

On a theoretical basis, and from laboratory studies of HTO conversion to OBT in plants, the amount of OBT in *we* units in plants is expected to be about 0.8 times the amount of HTO if both values are expressed on a similar basis (Ref. 7). This is mainly because the heavier tritium atom reacts more slowly than hydrogen in metabolic processes. However, the range of observed ratios is large, with common occurrences of OBT/HTO ratios much greater than 0.8. For example, the OBT/HTO ratio was 1.7 in six produce

samples from Perth, Ontario, in a previous CNSC study (8.2 Bq/ L *we* versus 4.9 Bq/L, Ref. 8). Ratios near 1 were also typical of supermarket items purchased from Ajax and Pickering.

The compliance monitoring programs of a few CNSC licensees have only recently incorporated OBT measurements. In 2005 and 2007, OPG analyzed composite produce samples at background locations in Ontario and observed levels of 19–37 Bq/L *we*; these levels were much higher than expected, relative to HTO values of 2–5 Bq/L (Ref. 5). The reason for high OBT levels in natural background areas is not yet fully understood (Ref. 9). This phenomenon is the subject of continuing research by the CANDU Owners Group. Further insights into OBT/HTO ratios will be available in a forthcoming CNSC report on soils and vegetation sampled near four nuclear sites in Ontario in 2008 and 2009.

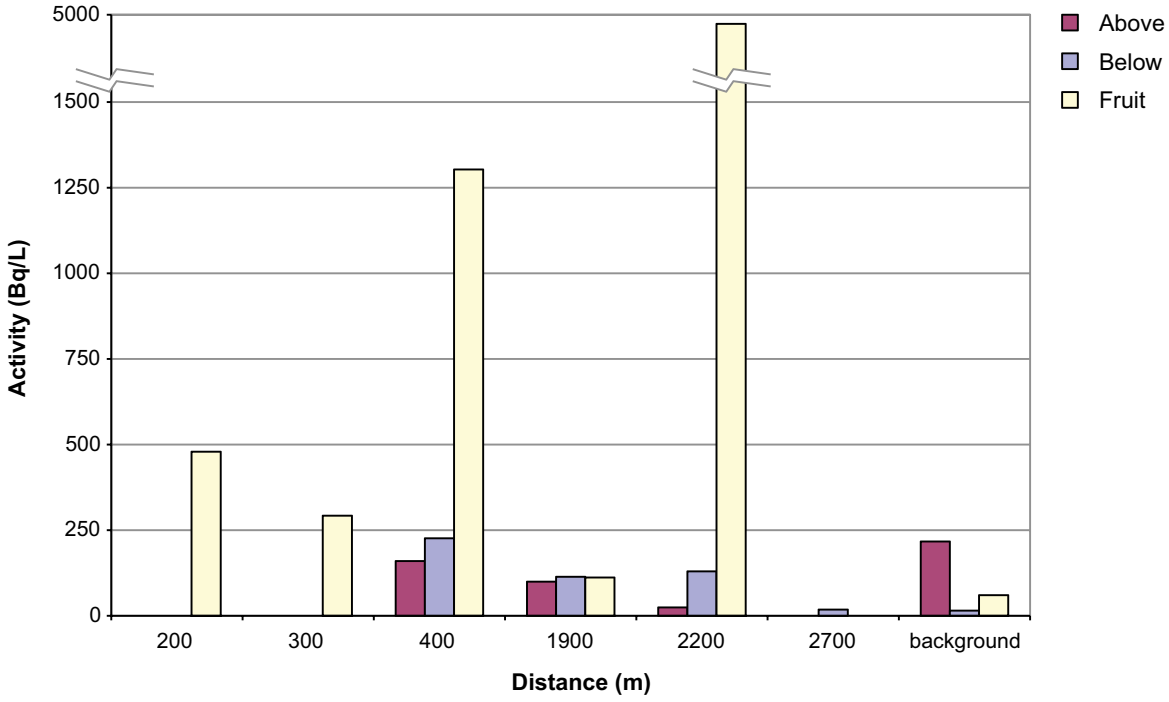
Figure 2 presents OBT results for 25 vegetation samples collected in 2007. The pattern of activity by distance was reasonably consistent with results for HTO in Figures 1A and 1B, but with some important exceptions. For example, unusually high OBT activity was found in apples collected from a wild tree growing in a field near a home at 2,200 m WNW from SRBT (4,920 Bq/L *we*). There is no self-evident explanation for this result relative to results for produce from a nearby garden. OBT in other apples varied greatly for trees in home gardens at four sites about 300–400 m from SRBT (51, 343, 524, 3,320 Bq/L *we*). The lowest value was for apples from a young tree growing in a new subdivision in relatively new soil; the other apples were all from old trees in native soils. Levels of tritium in groundwater in certain areas near SRBT are much higher than those in surface soils. Hence, fruits collected from old trees with deep roots may reflect past conditions in shallow groundwater rather than current conditions in surface soils. High OBT activity was also found in apples from Golden Lake (144 Bq/L *we*, young tree in relatively new soil), but not in apples from Russell (1.5 Bq/L *we*, old tree in native soil).

Overall, OBT activity was within a factor of 2 of HTO activity in about half of all the samples. OBT activity in many fruits, and in produce collected at background locations was noticeably higher than HTO activity in many instances. Particularly high OBT/HTO ratios (>10) were found in all three of the above ground vegetables collected in Russell, and for chokecherries from the Northwest Territories (old tree in a home garden).

In a previous CNSC study by Brown (1995) (Ref. 8), the OBT/HTO ratio observed in produce grown or purchased in Ontario was 1.25 ± 0.75 for concentrations expressed in units of Bq/L *we*. This equated to about 0.4 ± 0.9 for concentrations expressed as Bq/kg fresh weight. Brown's (1995) study included several sites near sources of tritium as well as produce grown or purchased in a few sites far from nuclear facilities.

For all above- and below-ground produce collected in Pembroke, the OBT/HTO ratios were 2.82 ± 2.67 (N=10, ratio in Bq/L *we*), or 0.41 ± 0.31 (ratio in Bq/kg fresh weight). Although the Bq/L *we* ratio for produce appears high, the range of values observed was similar to that observed by Brown (1995) (0.4 to 9.2 versus 0.3 to 4.2). Ratios in fruits from Pembroke (mostly apples) were higher than in other produce at 6.23 ± 9.05 (N=8, ratio in Bq/L *we*), or 1.38 ± 2.11 (ratio in Bq/kg fresh weight). At background locations the corresponding ratios for all items were very high, but extremely variable at 48 ± 69 (N=7, ratio in Bq/L *we*), or 1.69 ± 3.01 (ratio in Bq/kg fresh weight). Although some OBT/HTO ratios were higher than expected, the OBT activity in produce samples was generally low (see Figure 2). OBT data are included in dose calculations in Section 4, and in the integrated summary of the total tritium in produce provided later in the document (see Figure 4).

Figure 2: Organically bound tritium activity (OBT, Bq/L water equivalents) in above- and below-ground garden produce and various fruits collected at several distances from an atmospheric source of tritium in 2007 at SRBT in Pembroke, and at a few background locations. Analyses were done by the University of Ottawa.



3. RELATIONSHIPS AMONG HTO IN ENVIRONMENTAL COMPARTMENTS

3.1 HTO in Air Compared With Vegetation and Soils

In Canadian Standards Association (CSA) methods for modeling the fate of tritium in the environment (Ref. 7), HTO in plants and soils is assumed to be in equilibrium with the HTO in water vapour in the air. After adjusting for absolute humidity for the Pembroke area (0.0108 L/m^3, Ref. 3), field measurements of tritium would be expected to reflect the following relationships:

- Concentration in plant water = 0.63 × concentration in air vapour
- Concentration in soil water = 0.28 × concentration in air vapour

Data from 37 samples of produce were available at 200–400 m from SRBT to test the validity of the CSA model relative to air concentrations recorded nearby in SRBT's compliance monitoring program. Vegetation data came from three laboratories analyzing independently-collected samples from mostly the same gardens in 2005 and 2007.

Within 100–150 m of the relevant sampling sites, SRBT maintained passive diffusion air samplers for monitoring HTO in air on a monthly basis as part of a larger monitoring program in Pembroke (Appendix C, Refs. 3 and 10). Annual average air concentrations from these samplers agree well (within a factor of 2 for 60% of the values) for predictions based on the CSA model (Ref. 10). The model predicts HTO concentrations in air based on distance and direction from SRBT, taking into account the environmental pathways and atmospheric dispersion pattern of both the HTO and HT released (Ref. 7).

August air concentrations corresponded best to the times of plant sampling and were therefore used to predict concentrations in vegetation and soils. Measured HTO activities were as follows:

- 1.24 times higher than predicted values for above-ground produce (N=15)
- 1.45 times higher than predicted values for below-ground produce (N=10)
- 2.29 times higher than predicted values for fruit (N=12)

These are the main items collected in compliance programs to monitor tritium levels in terrestrial vegetation. All laboratories obtained high measured values for fruits relative to predicted values (1.81–2.73 times higher than predicted).

Only three matching soil samples from 2007 were available to test model predictions. Measured values were 1.71 times higher than predicted values.

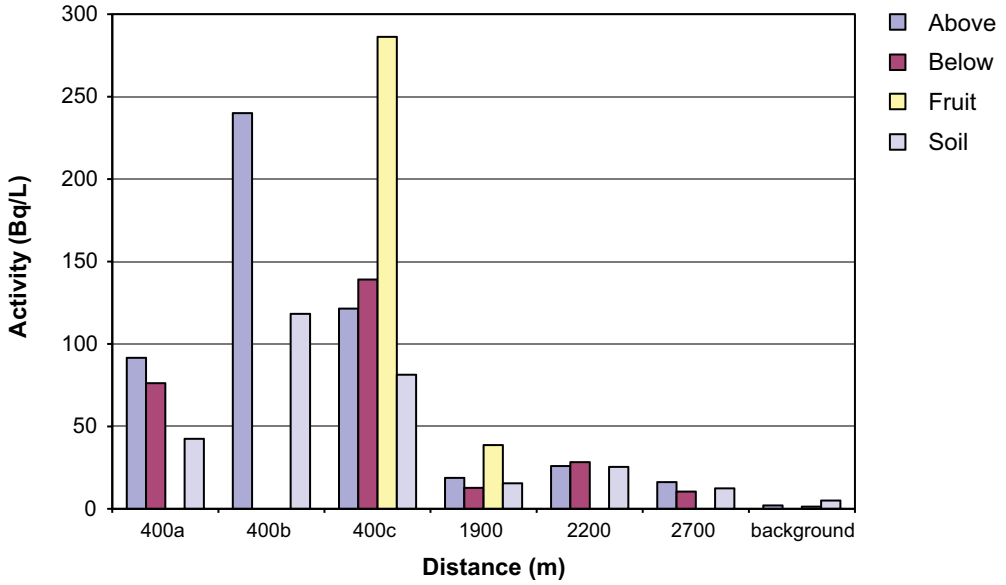
3.2 HTO in Vegetation Compared With Soils

At six home gardens in Pembroke (native soils) and at one home in Russell (local soil, but with many amendments), 31 produce samples were collected in parallel with soils. At each site, a soil composite (N=15) was obtained from the same garden plot. Soils were all silty or sandy loam or loam types with 4.0% to 8.8% organic matter and a pH of 6.5 to 7.6. The

recent history of each plot included minor amendments of manure or compost; all were essentially rain fed.

HTO levels for garden produce and matching soils are presented in Figure 3A, with each cluster of bars representing a single property. Overall, there was a similar pattern of lower tritium activity at greater distances from SRBT's stacks in both soils and produce. HTO activity in produce was typically higher than in matching soils, as predicted by the CSA model.

Figure 3A: Free water tritium activity (HTO: Bq/L water) in above- and below-ground garden produce and matching soils collected at several distances from an atmospheric source of tritium in 2007 at SRBT in Pembroke, and at a background location (Russell). Data are from produce and matching soils at each property (independent samples analyzed by SRBT or the University of Ottawa).

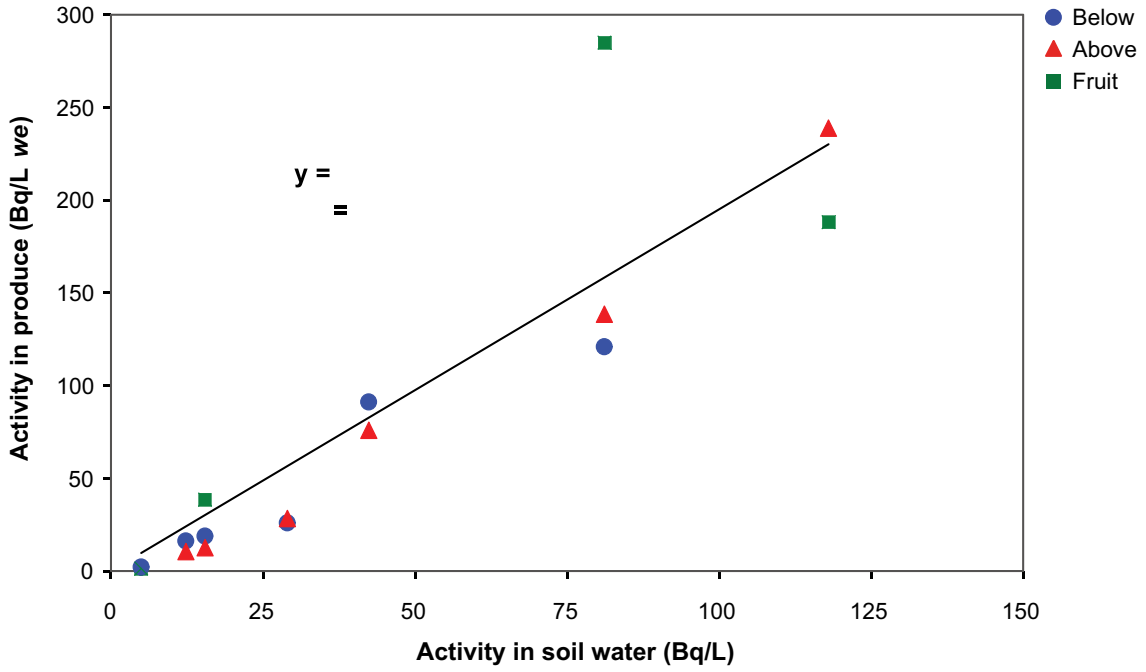


From the CSA model parameters given in the previous section, field measurements of tritium in plants and soils would be expected to reflect the following relationship:

- Concentration in plant water = 2.3 concentration in soil water

Figure 3B presents the observed relationship between tritium activity in produce and soil water for matching data (averaged by type of produce) from Figure 3A. The fit of observed to predicted values was good, with 90% of the variance in produce HTO activity explained through a linear regression against soil HTO activity. The observed ratio for HTO activity in plants to soils was 1.95 (95% confidence interval 1.6–2.3), relative to the model prediction of 2.3.

Figure 3B: Relationship between free water tritium activity (HTO: Bq/L water) in above- and below-ground garden produce and matching soils.



3.3 Total Tritium in Vegetation Compared With Soils

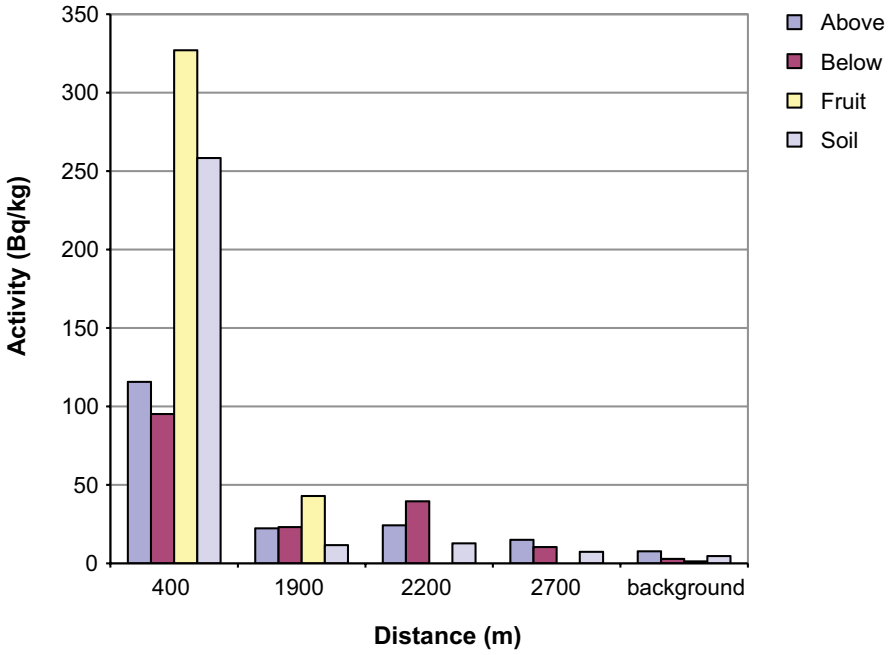
The nature of the tritium in soils, after all water has been removed, has rarely been studied. The tritium counted in dry soils by helium ingrowth mass spectroscopy may represent tritium in organic materials such as humic acids (OBT), and an unknown amount bound to mineral components. Clays in particular have a large potential to accumulate tritium. Soils contained from 4% to 22% clay in Pembroke, and 2% clay in Russell.

Figure 4 shows the pattern of total tritium activity in soils versus vegetation for matching samples, as in the previous section. Results are presented on a per-kilogram fresh weight basis (the sum of HTO measured by liquid scintillation counting, and the additional tritium counted by helium ingrowth mass spectroscopy), for comparison with Figure 3A, which shows only the pattern of the HTO activity in extracted water.

As for HTO, the pattern of decreasing total tritium activity with increasing distance from SRBT remains clear, as well as higher levels of tritium in vegetation versus soils. The only significant pattern difference versus HTO is the high level of total tritium in soils at 400 m when compared to produce, but not relative to fruits. An important feature of this graph is that there is no evidence of any unusual reservoir of tritium in soils after 16 years of SRBT's operations. The amounts and trends of total tritium in soils and vegetation are grossly similar to that of HTO using these two different indicators of tritium in the environment. This is also reflected in

gross statistics for each sample type. Vegetation contained 75% HTO on a fresh weight basis (range 66–94% by sites); a value similar to the mean water content (86%). Soils contained 32% HTO on a fresh-weight basis (range 11–76% by sites); a value also similar to their mean water content (27%).

Figure 4: Total tritium activity (Bq/kg fresh weight) in above- and below-ground garden produce and matching soils collected at several distances from an atmospheric source of tritium at SRBT in 2007 at Pembroke, and at a background location (Russell, Ontario). All data are from matching samples collected on the same day and analyzed by the University of Ottawa.



4. DOSE TO MEMBERS OF THE PUBLIC

4.1 Estimation and Interpretation of Public Dose

Exposure to high levels of ionizing radiation, such as X-rays, alpha or beta particles emitted by radioactive materials, increases the probability of developing health effects that include cancer and hereditary effects. The *dose* that results from being exposed to radiation is a measure of the probability of developing health effects because of that exposure. As a conservative assumption, no dose threshold of effect is assumed. Dose is expressed in units of sieverts or, more commonly, as thousandths of sieverts (millisieverts, or mSv). Effects due to exposure to tritium beta particles are similar to those of other sources of radiation exposures and have been extensively reviewed and discussed in a recent CNSC publication, *Health Effects, Dosimetry and Radiological Protection of Tritium Beta Radiation* (Ref. 11).

Natural radioactivity causes us to receive on average about 2 mSv every year from exposure to radon, cosmic radiation, and naturally occurring radioactive materials in the earth's crust and in our bodies (for example, Carbon-14 and Potassium-40). The dose from natural radioactivity varies by location and can be as high as several mSv per year. CNSC regulations limit the dose that any member of the public can receive from a licensed facility or activity to 1 mSv per year (in addition to the dose from natural sources).

The public dose resulting from airborne emissions from nuclear facilities is only an estimate, as it is too low to measure directly. Estimates are based primarily on environmental monitoring conducted by licensees to demonstrate compliance with the CNSC public dose limit. Monitoring programs include representative measurements of radionuclides and/or radioactivity in air and water, and in the foods grown near nuclear facilities. By combining these data with information on the activities and dietary habits of people living in the area, one can estimate public doses with confidence.

CNSC licensees calculate public dose for a *critical group*, and not for any actual person. The critical group is defined as a fairly homogenous group of people receiving the highest dose from facility releases due to location, lifestyle, etc. To calculate the dose to a member of the group, a *representative person* is defined as a type of individual who would likely receive the highest dose. CNSC licensees use site-specific studies and surveys to identify potential critical groups near their facilities for detailed analysis. In some cases, the critical group is hypothetical, because no one lives under the specified conditions. The assumptions about the location and lifestyle of the critical group are chosen to give conservatively high estimates of dose. This contributes to higher margins of safety in facility licensing. Hence, members of the public living near nuclear facilities are often less exposed than any "critical group". These many features of regulatory oversight of the public dose limit need to be considered when comparing dose estimates across many types of facilities in different settings (Ref. 1). For example, radionuclide processing facilities, including SRBT which processes tritium, do not have the same large licensed land areas as those required at nuclear power generating stations. People who live near facilities like SRBT can therefore be more readily compared to the representative person in a modeled critical group.

The key characteristics of the critical group that affect dose estimation are age and diet, and sources of food and drinking water. Exposure can be greatly affected by both prevailing wind directions and distance from a release point. Cultural habits are also important in accurately reflecting exposure; for example, use of country foods, home gardens, recreational fishing, hunting, etc. Water and food ingestion are often the main environmental pathways that determine dose, with distance from the source often the main factor determining the dose to the critical group. Realistic information is therefore 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 that may need to be specified in different ways to capture maximum exposures. For example, an 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 used to calculate dose in different ways to identify potential critical groups. Parameter values are taken from credible and recognized international and national sources, such as the International Commission on Radiological Protection (ICRP) and the CSA.

4.2 Public Dose Near SRBT in Pembroke in 2007

The many site-specific and theoretical parameters (for example a site-specific dietary survey) needed to calculate a suitably conservative dose to representative persons in Pembroke as a result of the operations of SRBT were updated in September 2006 (Ref. 3). This update followed the environmental pathways model subsequently adopted by the CSA (Ref. 7). Hence, the 2006 analysis was used as a basis for estimating dose to members of the public.

From the survey results presented in previous sections, measured activity levels in food items were available for estimating tritium intakes for members of the public in terms of both HTO and OBT for above- and below-ground vegetables, and fruits. The data were for items grown at homes at different distances from SRBT and at a background location far from Pembroke. The doses presented in this report are based on the assumption that all above- and below-ground vegetables as well as fruits consumed are homegrown. A recent site-specific survey found that 29% of consumed fruits and vegetables are actually homegrown, with the remainder obtained from uncontaminated market sources (Ref. 3). Annual consumption rates were derived as per the CSA model for an average or 95% upper limit daily caloric intake, (for example, 186.9 kg of fruit per year for an adult male, conservatively representing an “adult”; 97.1 kg of fruit per year for an infant). Dose was calculated assuming that the August results were representative of tritium concentrations in locally grown fruits and vegetables throughout 2007. A large market garden in Pembroke is located 1.9 km from SRBT and is not far from the home at the same distance where produce was collected.

Given all of the above, the public dose from consuming local produce in Pembroke was estimated to be less than 0.004 mSv per year for all age groups in 2007. This estimate took into account the measured HTO and OBT concentrations in various foods as weighted by dose conversion factors specific to each type of tritium. The highest dose occurred closest to the facility, at a location 400 m from SRBT. This dose represents the dose from all tritium

(background and man-made) in fruits and vegetables grown at 400 m from the SRBT facility, assuming all fruits and vegetables consumed annually were from this location.

The estimated dose from consuming homegrown foods in 2007 is only a small fraction of the 1 mSv public dose limit and can also be compared to the annual dose calculated from background samples. The background annual dose from tritium was 0.0002 mSv. This dose represents the dose from tritium in fruits and vegetables grown at a background location, assuming all fruits and vegetables consumed annually are from this location.

The site-specific survey (Ref. 3) indicated that not more than 29% of the fruits and vegetables consumed in Pembroke are homegrown; therefore, the potential dose for a more typical diet for a person consuming produce grown at 400m from SRBT could be derived:

- dose from tritium in produce grown at 400m from SRBT (equal to 29% of 0.004 mSv), plus
- contribution of background tritium in the produce from other sources (equal to 71% of 0.0002 mSv)

This would be calculated as follows:

$$(0.29 \times 0.004) + (0.71 \times 0.0002)$$
$$= 0.001 \text{ mSv} + 0.00014 \text{ mSv}$$
$$= 0.0011 \text{ mSv}$$

It should be noted that the total dose (man-made and natural) from consuming fruits and vegetables — whether from near the SRBT facility or at a background location will be more than this value as background radionuclides other than tritium, such as uranium, radium and polonium also contribute to dose. In addition, the doses calculated here may be compared to the average Canadian annual dose from natural background radiation, which is about 2 mSv. Another point of comparison is that health risks in people exposed chronically to radiation doses of approximately 100 mSv or less cannot be distinguished from similar health risks (such as cancer) in the general Canadian population.

Figure 5 summarizes the relative contributions of HTO and OBT to total dose for various distances from the source of tritium emissions. Figure 6 shows the breakdown of dose by food type. As expected from trends in OBT/HTO activity, ratios among food items at different locations, certain food items and forms of tritium sometimes influenced the general pattern by distance in total dose. In particular, some of the high OBT/HTO ratios in fruits and in background samples had a measurable effect on the overall pattern.[2]

2 Data for the wild apples collected at 2.2 km at 4,920 Bq/L we *OBT were not included in the total dose calculation for this location, as they were taken from a tree in a nearby field and not from the home garden. The highest value for garden vegetables grown at this location was used instead. If the tritium concentration in these wild apples represented the concentration of tritium in all fruits and vegetables consumed by a person in one year (about 550 kg for adults and 200 kg for infants), the annual dose at this location would be about 0.005 mSv (adults) and 0.007 mSv (infants). Consuming 1 kg of such apples would result in a dose of about 0.00003 mSv (dose to infants).*

Figure 5: Adult ingestion dose (consumption of local fruits and vegetables) by the type of tritium (HTO or OBT) at several distances from an atmospheric source of tritium at SRBT in 2007 at Pembroke, compared to dose at a background location. Tritium data are from home garden samples at each distance collected on the same day in August 2007 and analyzed at the University of Ottawa.

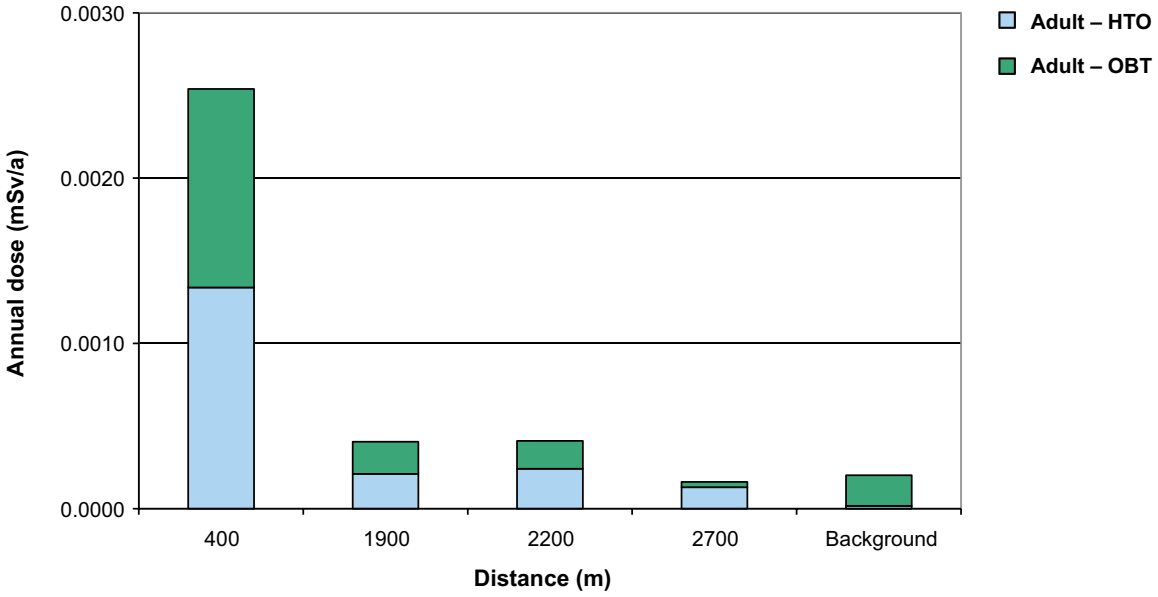
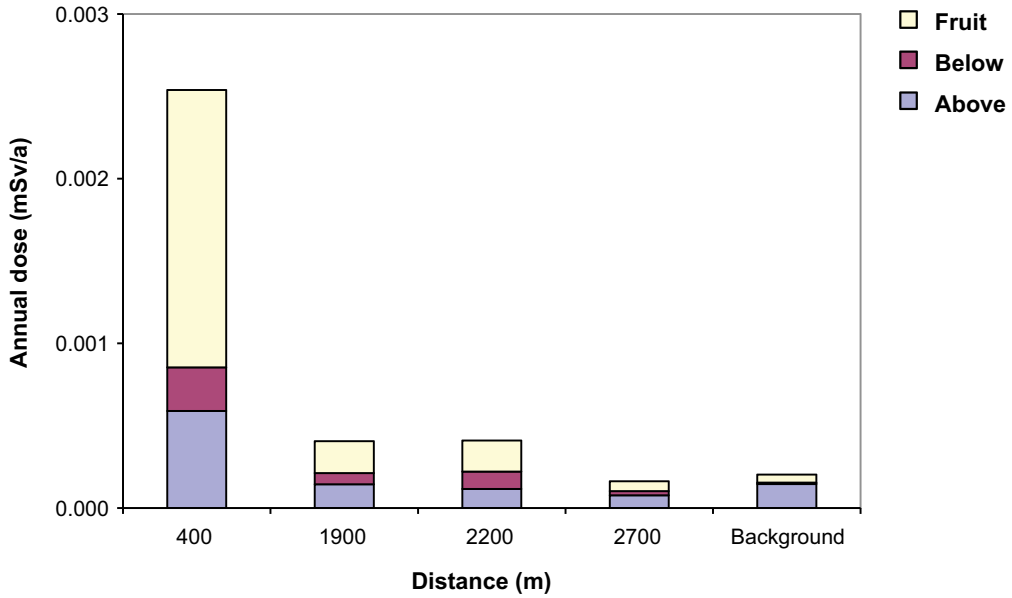
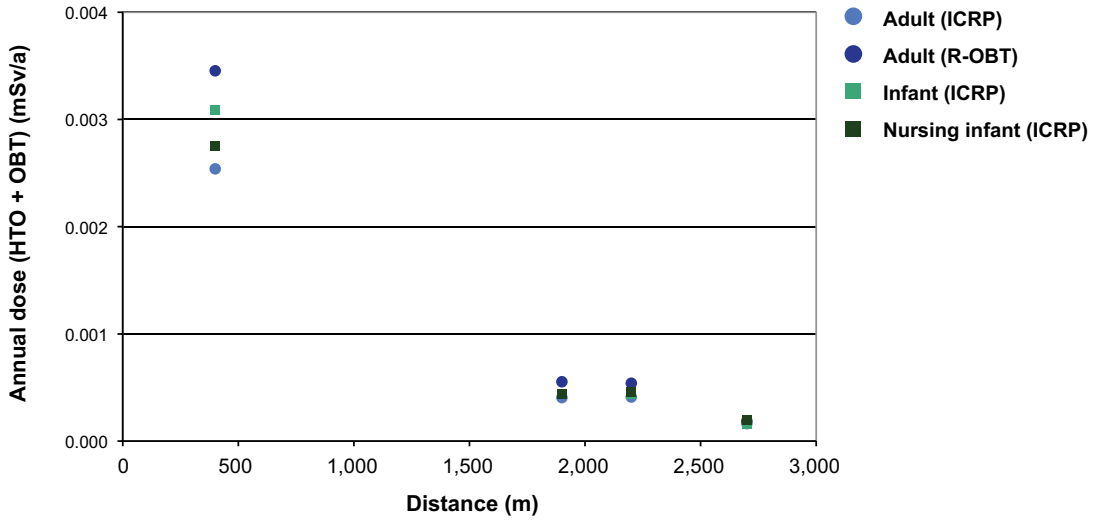


Figure 6: Adult ingestion dose by food type for above- and below-ground vegetables and fruits at several distances from an atmospheric source of tritium in 2007 at SRBT in Pembroke, versus a background location. Tritium data are from home garden samples at each distance collected on the same day in August 2007 and analyzed at the University of Ottawa.



After the ICRP dose models were adopted, other models were developed to provide a more accurate determination of the dose from tritium (Ref. 11). Some of these take into account the fact that tritium bound to nutrients is retained for varying amounts of time in certain organs and tissues. These models are available to determine the dose to adults only. Figure 7 compares dose estimates from the use of such a model (Ref. 12.) for adults (R-OBT) relative to standard ICRP models for adults, infants, and nursing infants. Use of this improved model for adults increased the dose estimate by about 30% to 70% depending on the proportion of OBT in food consumed. However, the dose remained low.

Figure 7: Total ingestion dose estimated for adults and infants by different methods at several distances from an atmospheric source of tritium in 2007 at SRBT in Pembroke, versus a background location. Tritium data are from home garden samples at each distance collected on the same day in August 2007 and analyzed at the University of Ottawa.



5. MAIN FINDINGS

Garden produce and soils

- Tritium activity in the water (HTO) in produce grown close to SRB Technologies (SRBT) in 2007 was about 20 times natural tritium background levels; altogether, activity levels were about 100 times lower after SRBT operations ceased than during full operations in 2005.
- Total tritium activity in produce and soils declined considerably with distance from SRBT's stacks and approached natural tritium background at about 3 km away.
- First-time measurements of organically bound tritium (OBT) in produce and surface soils from Pembroke in 2007 did not reveal significant accumulation of tritium from past releases, but did reveal some high ratios of OBT relative to HTO.
- HTO results from the CNSC and the University of Ottawa generally agreed with compliance monitoring data reported by SRBT.
- On the whole, tritium activity in produce and soils agreed with expectations, based on reported releases from SRBT and on models of tritium in the environment.

Public dose

- Based on measurements of HTO and OBT in garden produce, dose to the public from the consumption of local produce was less than 0.004 mSv per year — a small fraction of the 1xmSv annual public dose limit.
- This dose can be compared to the annual doses from tritium in produce (0.0002 mSv), calculated from the background tritium samples.

6. CONCLUSIONS

CNSC-funded research found expected levels of tritium in local garden vegetables and fruits grown in Pembroke in 2005 and 2007. There was no evidence of significant accumulation of tritium in surface soils after 16 years of tritium releases from the SRBT facility. First-time measurements of OBT from fruits in Pembroke and from several items at background locations revealed much greater diversity in OBT/HTO ratios than expected.

The dose resulting from the consumption of tritium in fruits and vegetables grown in Pembroke declines considerably with distance of the garden from the SRBT facility. The highest annual dose in 2007 was about 0.004 mSv. This is well below the annual public dose limit of 1 mSv per year and orders of magnitude below doses known to cause health effects.

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ACRONYMS

ALARA	As Low As Reasonably Achievable
BP	Bruce Power
CNSC	Canadian Nuclear Safety Commission
CSA	Canadian Standards Association
HTO	tritiated water
ICRP	International Commission on Radiological Protection
OBT	organically bound tritium
OPG	Ontario Power Generation
SRBT	SRB Technologies (Canada) Inc.

GLOSSARY

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

becquerel — Unit of activity that is a measure of the rate at which transformations occur in a radioactive substance. 1 Bq = 1 transformation or disintegration per second. 1 GBq = 10^9 Bq transformation or disintegration per second.

critical group — A homogeneous group of members of the public identified as 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, with some more conservative than others. It is based on analysis of site-specific radionuclide releases and exposure pathways and on site-specific land use information.

dose limit — An upper limit on radiation dose specified in the CNSC *Radiation Protection Regulations*.

ionizing radiation — Any atomic or subatomic particle or electromagnetic wave with sufficient energy to produce ions (atoms that have become charged due to the loss or gain of electrons) in the material that absorbs it. Ionizing radiation includes alpha and beta particles and gamma radiation, as well as neutrons and some other particles.

tritium — A radioactive form of hydrogen produced both naturally and by human activities. Tritium is produced during normal operation of Canadian nuclear reactors. The ionizing radiation from tritium is a beta particle.

APPENDIX

This table presents data on tritium activity in garden produce and some wild fruits, and in garden soils. The data sources are research conducted by the Canadian Nuclear Safety Commission (CNSC) in late summer 2005 and 2007, and compliance monitoring data from SRB Technologies (SRBT) relevant to SRBT's tritium processing operations in Pembroke, Ontario. Grouped entries represent the same site within and between years. Data are sorted with soils first, followed by below- and above-ground vegetables and fruits, in sequence by year.

Abbreviations

HTO	tissue free water tritium in produce versus total water in soils
OBT	non-exchangeable organically bound tritium in produce versus total tritium after extraction of HTO in soils
we	water equivalent
wet	fresh weight before sample is dried

Note:

There are no entries for OBT in Bq/L we for soils, as the tritium measured by helium ingrowth mass spectroscopy appears to reflect tritium in both organic and mineral components of soil. The amount of tritium present in dried soil is therefore listed in terms of the fresh weight of the sample. Soil samples contained the following percentages of organic matter:

001A	8.8 %
006A	5.9%
009A	6.9 %
013A	4.5%
024A	6.4 %
025A	4.0 %
027A	4.3 %

Data Source	Sample ID	Collection Date	Item	Location	Distance From SRBT (m)	HTO Bq/L	HTO Bq/g wet	OBT we Bq/L	OBT Bq/g wet
University	001A	14-Aug-07	Soil	Russell, ON	Background	5.0	0.00131	See note	<0.0034
University	003A	14-Aug-07	Zucchini	Russell, ON	Background	2.4	0.00222	460	0.0130
University	004B	14-Aug-07	Cucumber	Russell, ON	Background	2.9	0.00274	160	0.0037
University	005A	14-Aug-07	Tomato	Russell, ON	Background	1.2	0.00115	13.2	0.0004
University	002A	14-Aug-07	Apple	Russell, ON	Background	1.3	0.00121	1.5	0.0001
University	000A	14-Aug-07	Potato[1]	Russell, ON	Background	2.2	0.00178	9.3	0.0011
University	035D	14-Aug-07	Apple[2]	Golden Lake, ON	Background	3.0	0.00260	144	0.0215
University	NWT	5-Oct-07	Domestic chokecherry	Hay River, NWT	Background	1.0	0.00049	19.0	0.0057
University	026A	14-Aug-07	Wild chokecherry	Pembroke, ON	200	182	0.10564	475	0.1158
University	030A	14-Aug-07	Wild plum	Pembroke, ON	300	322	0.23413	233	0.0351
University	031	14-Aug-07	Wild apple	Pembroke, ON	300	264	0.14605	343	0.0887

Data Source	Sample ID	Collection Date	Item	Location	Distance From SRBT (m)	HTO Bq/L	HTO Bq/g wet	OBT we Bq/L	OBT Bq/g wet
SRBT		31-Aug-05	Tomato	Pembroke, ON	400	3143	3.33158		
University	025A	14-Aug-07	Soil	Pembroke, ON	400	118	0.01547	See note	0.4254
SRBT		11-Sep-07	Rhubarb	Pembroke, ON	400	240	0.28080		
University	024A	14-Aug-07	Apple	Pembroke, ON	400	189	0.13506	524	0.0874
CNSC	25	9-Aug-05	Onion	Pembroke, ON	400	7000	7.84000		
SRBT		31-Aug-05	Onion	Pembroke, ON	400	2551	2.85712		
CNSC	29	9-Aug-05	Potato	Pembroke, ON	400	4900	6.22300		
CNSC	24	9-Aug-05	Cucumber	Pembroke, ON	400	2700	2.83500		
CNSC	55	13-Sep-05	Cucumber	Pembroke, ON	400	4400	4.62000		
SRBT		31-Aug-05	Cucumber	Pembroke, ON	400	1087	1.14135		
CNSC	31	9-Aug-05	Zucchini	Pembroke, ON	400	4300	4.51500		
CNSC	23	9-Aug-05	Tomato	Pembroke, ON	400	4800	5.61600		
CNSC	54	13-Sep-05	Tomato	Pembroke, ON	400	4200	4.45200		
SRBT		31-Aug-05	Tomato	Pembroke, ON	400	2434	2.58004		
CNSC	32	9-Aug-05	Apple	Pembroke, ON	400	5500	6.43500		
CNSC	56	13-Sep-05	Apple	Pembroke, ON	400	4200	4.91400		
CNSC	33	9-Aug-05	Grape	Pembroke, ON	400	5400	6.69600		

Data Source	Sample ID	Collection Date	Item	Location	Distance From SRBT (m)	HTO Bq/L	HTO Bq/g wet	OBT we Bq/L	OBT Bq/g wet
University	027A	14-Aug-07	Soil	Pembroke, ON	400	42.5	0.00713	See note	0.0453
University	028A	14-Aug-07	Onion	Pembroke, ON	400	76.2	0.06585		
University	029A	14-Aug-07	Tomato	Pembroke, ON	400	91.6	0.06919	131	0.0171
CNSC	51	13-Sep-05	Potato	Pembroke, ON	400	4900	6.22300		
SRBT		31-Aug-05	Potato	Pembroke, ON	400	2955	3.75285		
CNSC	37	9-Aug-05	Potato	Pembroke, ON	400	4900	6.22300		
CNSC	36	9-Aug-05	Rhubarb	Pembroke, ON	400	3100	3.25500		
CNSC	53	13-Sep-05	Rhubarb	Pembroke, ON	400	3300	3.46500		
CNSC	52	13-Sep-05	Apple	Pembroke, ON	400	4900	5.73300		
University	024A	14-Aug-07	Soil	Pembroke, ON	400	81.3	0.03216	See note	0.2495
University	023A	14-Aug-07	Potato	Pembroke, ON	400	124	0.10539	226	0.0190
SRBT		11-Sep-07	Potato	Pembroke, ON	400	136	0.17272		
SRBT		11-Sep-07	Carrot	Pembroke, ON	400	157	0.18683		
University	020A	14-Aug-07	Zucchini	Pembroke, ON	400	172	0.15460	174	0.0098
University	022A	14-Aug-07	Bean	Pembroke, ON	400	96.3	0.08213	174	0.0142
SRBT		11-Sep-07	Rhubarb	Pembroke, ON	400	96	0.10080		
University	019A	14-Aug-07	Apple	Pembroke, ON	400	247	0.20122	3320	0.3438
SRBT		11-Sep-07	Apple	Pembroke, ON	400	326	0.38142		

Data Source	Sample ID	Collection Date	Item	Location	Distance From SRBT (m)	HTO Bq/L	HTO Bq/g wet	OBT we Bq/L	OBT Bq/g wet
University	018C	14-Aug-07	Apple[3]	Pembroke, ON	400	278	0.20609	50.8	0.0076
SRBT		11-Sep-07	Apple	Pembroke, ON	400	259	0.30303		
CNSC	50	13-Sep-05	Tomato	Pembroke, ON	900	1000	1.06000		
CNSC	42	13-Sep-05	Potato	Pembroke, ON	1900	640	0.81280		
CNSC	43	13-Sep-05	Onion	Pembroke, ON	1900	530	0.59360		
CNSC	48	13-Sep-05	Tomato	Pembroke, ON	1900	620	0.65720		
SRBT		31-Aug-05	Tomato	Pembroke, ON	1900	491	0.52046		
CNSC	49	13-Sep-05	Cucumber	Pembroke, ON	1900	380	0.39900		
SRBT		31-Aug-05	Cucumber	Pembroke, ON	1900	400	0.42000		
SRBT		31-Aug-05	Zucchini	Pembroke, ON	1900	326	0.34230		
University	009A	14-Aug-07	Soil	Pembroke, ON	1900	15.5	0.00315	See note	0.0084
University	010A	14-Aug-07	Potato	Pembroke, ON	1900	12.4	0.00974	114	0.0134
SRBT		11-Sep-07	Beet	Pembroke, ON	1900	13.0	0.01482		
University	011A	14-Aug-07	Tomato	Pembroke, ON	1900	19.5	0.01798	99.3	0.0043
SRBT		11-Sep-07	Tomato	Pembroke, ON	1900	21.0	0.02226		
University	012A	14-Aug-07	Apple	Pembroke, ON	1900	38.7	0.03187	107	0.0111
SRBT		11-Sep-07	Rhubarb	Pembroke, ON	1900	16.0	0.01680		

Data Source	Sample ID	Collection Date	Item	Location	Distance From SRBT (m)	HTO Bq/L	HTO Bq/g wet	OBT we Bq/L	OBT Bq/g wet
CNSC	60	13-Sep-05	Potato	Pembroke, ON	2200	770	0.97790		
CNSC	58	13-Sep-05	Tomato	Pembroke, ON	2200	590	0.62540		
CNSC	59	13-Sep-05	Cucumber	Pembroke, ON	2200	107	0.11235		
University	013A	14-Aug-07	Soil	Pembroke, ON	2200	25.4	0.00970	See note	<0.0031
University	015A	14-Aug-07	Potato	Pembroke, ON	2200	30.7	0.02428	130	0.0153
SRBT		11-Sep-07	Potato	Pembroke, ON	2200	26.0	0.03302		
University	014A	14-Aug-07	Tomato	Pembroke, ON	2200	23.5	0.02236	8.2	0.0002
SRBT		11-Sep-07	Tomato	Pembroke, ON	2200	42.0	0.04452		
University	016A	14-Aug-07	Cucumber	Pembroke, ON	2200	26.0	0.02471	40.3	0.0012
SRBT		11-Sep-07	Spinach	Pembroke, ON	2200	12.0	0.01313		
University	017A	14-Aug-07	Wild apple[4]	Pembroke, ON	2200	189	0.13191	4920	0.8494
CNSC	10	9-Aug-05	Onion	Pembroke, ON	2700	136	0.15232		
CNSC	19	9-Aug-05	Carrot	Pembroke, ON	2700	96.0	0.11424		
CNSC	47	13-Sep-05	Cucumber	Pembroke, ON	2700	86.0	0.09030		
CNSC	5	9-Aug-05	Zucchini	Pembroke, ON	2700	144	0.15120		
CNSC	17	9-Aug-05	Green pepper	Pembroke, ON	2700	138	0.14766		

Data Source	Sample ID	Collection Date	Item	Location	Distance From SRBT (m)	HTO Bq/L	HTO Bq/g wet	OBT we Bq/L	OBT Bq/g wet
CNSC	5	13-Sep-05	Tomato	Pembroke, ON	2700	137	0.14522		
University	008A	14-Aug-07	Potato	Pembroke, ON	2700	10.5	0.00914	17.7	0.0013
University	006A	14-Aug-07	Soil	Pembroke, ON	2700	12.4	0.00247	See note	<0.0049
University	007B	14-Aug-07	Tomato	Pembroke, ON	2700	16.2	0.01500		

[1] *Market garden approximately 1 km from Russell garden, not included in matching soil-vegetation comparisons*

[2] *Young apple tree in relatively new topsoil at a cottage along the lakeshore*

[3] *Young apple tree in relatively new topsoil in a new residential subdivision*

[4] *Old apple tree in a field about 100 m from the garden at 2,200 m from SRBT, not included in matching soil-vegetation comparisons*

Canada's Nuclear Regulator

Canadian Nuclear Safety Commission

Commission canadienne de sûreté nucléaire

Canada