Tritium Behaviour in the Vicinity of SRB Technologies (Canada) Inc., Pembroke, Ontario

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Prepared by:

Ole Hendrickson, Ph.D.
Ottawa, Ontario
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1.0 Introduction
For the past 25 years, the Canadian Nuclear Safety Commission (CNSC) and its predecessor, the Atomic Energy Control Board, have licenced SRB Technologies (Canada) Ltd. (SRBT) of Pembroke, Ontario to produce glow-in-the-dark products made of heat-sealed glass filled with tritium (a radioactive form of hydrogen). SRBT has applied to the CNSC for a 10-year licence to continue its tritium processing activities. CNSC's hearing on SRBT's licence application will be held May 13-14, 2015, in Pembroke.

1.1 Purpose
This report provides information relevant to the SRBT licencing hearing. I review Commission Member Documents (CMDs) produced by CNSC staff and SRBT, other relevant documents prepared by CNSC and SRBT, SRBT's environmental monitoring data, and relevant studies from the scientific literature.

1.2 Scope
This report focuses on the environmental fate of tritium emitted from SRBT's stacks. I examine the forms of tritium that occur in the Pembroke environment; how tritium changes from one form to another; how tritium moves through or is retained in air, water, soil, vegetation and other biota; and whether current limits on SRBT's tritium emissions are adequate to protect the health and property of Pembroke area residents.

1.3 Background
Licences issued over a 25-year period by CNSC (and its predecessor, the Atomic Energy Control Board) permitted SRBT to emit immense amounts of tritium (Appendices 1 and 2). Pre-2006 tritium emissions were far higher than currently allowed under SRBT's licence release limits. As tritium has a 12.3-year half-life, roughly a quarter of the tritium emitted during SRBT's 25 years of operations remains in the environment, much of it likely in the Pembroke area.

2.0 Commission Member Documents (CMDs) and other Relevant Documentation

2.1 CNSC documents
The CNSC has produced three major sources of information that are relevant to my report on the behaviour of tritium in the Pembroke environment:

- Tritium Studies Project documents, particularly the *Tritium Studies Project Synthesis Report* (CNSC 2011);
- The section entitled *Environmental Assessment Information Report* in the CNSC staff Commission Member Document CMD 15-H5 (CNSC 2015a); and
- CNSC's *Independent Environmental Monitoring Program: SRB Technologies Nuclear Processing Facility* (CNSC 2015b).

CNSC is to be commended for its efforts to develop an in-house scientific capacity. The development of an *Independent Environmental Monitoring Program* is a positive step that addresses the object of the Commission "to disseminate objective scientific, technical and regulatory information to the public" concerning the effects on the environment and on the health and safety of persons of nuclear energy and nuclear substances (section 9b, *Nuclear Safety and Control Act*). The word "objective" is key – in disseminating information, CNSC staff must avoid errors, bias and subjectivity.

In this context, it is disappointing that the *Independent Environmental Monitoring Program* presents the following statements as "results" for SRBT:

- "results confirm that the public and the environment in the vicinity of the SRBT facility site are protected from the releases from the facility;" and
- "radioactivity measured in water, air, soil, vegetation, milk, wine, fruits and vegetables samples… are within natural background levels" (CNSC 2015b).

The first statement is not a "result" but a subjective interpretation of the data. The second statement is clearly <u>not</u> supported by the data. Although no background levels are provided for most of the samples, Thompson et al. (2015) measured 0.8 to 2.6 Becquerels per liter (Bq/L) of tritium in samples from two background locations in Saskatchewan (a Becquerel (Bq) is the amount of a radioactive substance that produces one radioactive disintegration every second). Tritium radiation levels in the vicinity of SRBT greatly exceed these background levels.

Other problems with the information in (CNSC 2015b) include the lack of information on methodology employed for sample analysis, use of non-standard units (Bq/kg fresh weight), lack of clarity as to whether tritium concentrations in vegetation include organically-bound tritium, and the failure to provide a source for the "Guideline/Reference Levels" in the table.

The CNSC staff *Environmental Assessment Information Report* (CNSC 2015a) is also noteworthy for its errors, omissions, and subjective statements:

- On page 5 of 18 it is stated "CNSC staff verify SRBT's environmental performance by reviewing monitoring results on effluent releases (air and liquid) and levels of radioactivity in <u>soils</u> and vegetation which are provided in the licensee's quarterly and annual reports and other submissions [emphasis added]." SRBT does not monitor radioactivity in soils.
- Section 4.2, entitled *Tritium in Groundwater,* contains serious errors, omissions, and misleading statements (section 3.4.1, below).
- Other serious deficiencies in the *Environmental Assessment Information Report* are the absence of a rationale for CNSC's proposed licence release limits (section 3.1, below), and the lack of any discussion of organically bound tritium (sections 3.2 and 3.3, below).

2.2 SRBT CMD 15-H5.1 and licence application

Section 3.11 ("*Environmental Protection*") of CMD 15-H5.1 (SRBT 2015b) provides a general overview of SRBT's environmental monitoring program, and SRBT's *Annual Compliance Reports* provide monitoring results. Similarly, the main body of SRBT's licence application provides general information about environmental monitoring, while some of its 40+ appendices provide more details on SRBT's approach to environmental protection and are cited in this report.

2.3 Tritium Studies Project

In its *Record of Proceedings, Including Reasons for Decision* issued after the 2006 licencing hearings on SRBT, the Commission provided reasons for its decision to suspend SRBT's tritium processing licence (CNSC 2006). The Commission asked CNSC staff to conduct "research studies on tritium with the objective to enhance information available to guide regulatory oversight of tritium processing and tritium releases in Canada." The *Tritium Studies Project Synthesis Report* summarizes CNSC staff findings through 2010 (CNSC 2011).

Perhaps the most important statement in the *Synthesis Report* is the following:

> "Groundwater is a critical drinking water resource for future generations; it is difficult if not impossible to remediate after it becomes contaminated. Groundwater therefore warrants special considerations in terms of protection from degradation over the long term. Staff is recommending a tritium level in groundwater of 100 Bq/L for this specific purpose. A value of 100 Bq/L of tritium for the protection of a potential drinking water resource represents a balanced consideration of science, public health policy, achievability/practicality and societal expectations. In particular, society has an expectation that drinking water will be not just safe, but also "clean"" (CNSC 2011).

The *Synthesis Report* goes on to explain that this 100 Bq/L target is an achievable one:

> "On the basis of a detailed analysis of levels of tritium in groundwater around existing Class 1 nuclear facilities discharging tritium, and of the circumstances that led to contamination of groundwater by tritium, an objective of 100 Bq/L for groundwater protection was determined to be practical and achievable. Much of industry has also already adopted this level of tritium as a voluntary target for the protection of drinking water" (CNSC 2011).

In addition to this recommended 100 Bq/L objective, the *Synthesis Report* recommends "a controlled zone within the licensee's control of sufficient size to ensure that the design objective of 100 Bq/L would be achieved at the perimeter given discharges of tritium to the atmosphere under normal operations" (CNSC 2011).

This exclusion zone and the 100 Bq/L objective for tritium in groundwater are proposed for new facilities, but not necessarily existing ones. With regard to "existing facilities emitting tritium where historical practices or malfunctions/accidents have resulted in groundwater contamination," the *Synthesis Report* recommends that groundwater protection issues "should be addressed by the CNSC at the policy level in consultation with the provinces, which have legal jurisdiction over these resources" (CNSC 2011). CNSC documents prepared for the May 13th hearing do not indicate if consultations regarding groundwater contamination in Pembroke have taken place with the Province of Ontario.

One of the individual documents from the Tritium Studies Project, *Evaluation of Facilities Handling Tritium: Part of the Tritium Studies Project* is helpful for understanding SRBT's "historical practices" that have contributed to the high levels of tritium contamination currently found in the Pembroke environment:

> "A tritium recycle rig was used [by SRBT] for crushing old tritium light source tubes and extracting the tritium for reuse. It consisted of a vacuum system, containing a mechanical crusher built into a fume hood. This equipment was not very efficient and, having contributed to high releases of tritium to the environment in the past, is no longer in operation" (CNSC 2010a).

3.0 Environmental Monitoring – Results and Discussion

3.1 Stack emissions of tritium

Appendix 1 shows SRBT's stack emissions on a yearly basis from 1996 to 2014. Prior to 2006, SRBT emitted thousands of TeraBecquerels per year of tritium. A TeraBecquerel is an amount of a radioactive substance that produces one trillion radioactive disintegration every second. CNSC suspended SRBT's tritium processing operations between February 2007 and August 2008. Since 2006 SRBT's tritium emissions have been on the order of tens of TeraBecquerels per year.

SRBT has two stacks. A *Systematic and Quantitative Analysis of Tritium Sources and Their Potential Contribution to Groundwater Contamination* indicates that the primary sources of tritium released from its "bulk stack" are the laser cutting system and the bulk splitter, and the primary sources of tritium released from its "rig stack" are the filling rig and the reclaim rig (SRBT 2007a). In 2010 CNSC included a clause in SRBT's Licence Condition Handbook which says that "SRBT shall not operate the reclamation unit that is currently found in the facility."

The main gases released through the two stacks are elemental tritium (HT) and tritiated water (HTO). The document *Evaluation of Facilities Handling Tritium* explains that:

> "Pure tritium gas (T_2) is only seen inside processing equipment. As soon as it comes into contact with atmospheric air, it rapidly combines with small quantities of free hydrogen in the air and forms the more stable form of tritium gas HT. This is the type of tritium gas released into the air from tritium handling facilities.
>
> Tritium gas will also oxidize in air – over a period of hours or days – to form tritiated water (HTO). HTO can also be produced rapidly when tritium gas comes into contact with metal surfaces in air. The metal surface will act as a catalyst in the presence of air (oxygen) and form HTO" (CNSC 2010a).

A significant percentage of the tritium gas processed by SRBT is oxidized to HTO before it leaves the stacks (owing in part to contact with metal surfaces within the facility). This percentage has varied from 6.2% to 35.3% on an annual basis (Appendix 2) and has been higher since the 2007-2008 shutdown. In the form of radioactive water (HTO) tritium poses much greater immediate hazards to humans than in the form of hydrogen gas (HT). HTO is rapidly incorporated into all the cells and tissues of living organisms (plants, humans, other animals, etc.).

CNSC's current licence provides SRBT with separate release limits for HTO (67.2 TBq) and for total tritium as (HT + HTO) (448 TBq). CNSC staff's proposed new licence retains these release limits, but CMD 15-H5 provides no rationale for having separate release limits for HTO and (HT + HTO), and only a cursory explanation as to how the licence release limits (LRLs) were set:

> "SRB's LRLs for airborne and liquid releases are even lower than the DRLs, and are based on an environmental protection target for groundwater of 5,250 Bq/L (25% less than the Canadian Drinking Water Quality Guideline of 7,000 Bq/L)" (CNSC 2015a).

The *Tritium Study Project Synthesis Report* recommends "a value of 100 Bq/L of tritium for the protection of a potential drinking water resource" (CNSC 2011). Why then does CNSC (2015a) choose an environmental protection target for Pembroke of 5250 Bq/L of tritium? And how did CNSC staff translate the 5250 Bq/L target into limits on tritium emissions from SRBT's stacks? The absence of a clear justification for the proposed licence release limits is a major deficiency. CNSC has made many changes to SRBT's licence release limits over the years (Appendix 2), but has provided very limited information to explain or justify these changes.

CNSC staff may wish to consider advice in the *Guide for Applicants and Intervenors Writing CNSC Commission Member Documents* (CNSC 2010c). This *Guide* says that "The CMD should contain material that allows the Tribunal to render an informed decision, and that all readers (the Tribunal, the public or others) **can be reasonably expected to understand** [emphasis added]. The *Guide* goes on to say,

> "It is therefore important to step back regularly when preparing a CMD and to keep the following principles in mind:
>
> - Communicate clearly, logically, and consistently, and
> - convey information in plain language—where you must use specialized, technical language in order to be technically accurate, explain any unusual terms clearly within the text or define them in a glossary" (CNSC 2010c).

3.2 Tritium in soil

Until recently it was thought that elemental tritium – the main form emitted by SRBT – can largely be ignored as an environmental risk. The Tritium Studies Project document entitled *Investigation of the Environmental Fate of Tritium in the Atmosphere* includes a section on SRBT starting on page 57. It states that SRBT:

> "…releases HT; however, this is primarily of interest due to the small portion that converts to HTO. The HT itself has a much small dose coefficient and does not transfer to the human food chain" (EcoMetrix 2010).

In a footnote on page 57, Ecometrix (2010) states that "2% of HT emissions… are expected to be converted to HTO in ground-level air." SRBT's *Release Limit Rationale* (SRBT 2007b) also assumes that the "small portion" of elemental tritium (HT) that converts to HTO is equal to 2%.

Assumptions that HT is of interest primarily due to its conversion to HTO, that only 2% of HT converts to HTO, and that HT does not transfer to the food chain, are incorrect. These assumptions greatly understate the hazards of HT releases.

Many published studies in the microbiology literature indicate that a significant pathway for molecular hydrogen in ground-level air is to be taken up, split into protons and electrons (via the hydrogenase enzyme), and retained as organically bound tritium (OBT):

> "The capacity of certain microorganisms to metabolize molecular hydrogen was discovered at the end of the 19th century and later identified to be catalyzed by a hydrogenase. Since then hydrogenases have been observed and characterized in many microorganisms, including some algae, trichomonads, anaerobic ciliates, and chytrid fungi. The enzyme catalyzes the simplest of chemical reactions, the reversible reductive formation of hydrogen from protons and electrons: $2H^+ + 2e^- \leftrightarrow H_2$" (Tamagnini et al. 2002).

Many common bacteria use hydrogen gas as a source of energy when organic substrates are in short supply (Andersen et al. 1981). As of the late 1970's, gram-negative bacteria capable of using hydrogen gas as an energy source were assigned to a variety of common genera, including *Pseudomonas*, *Alcaligenes*, *Paracoccus*, *Corynebacterium*, and *Aquaspirillum* (Palleroni and Palleroni (1978). Special proteins in these bacteria possess sense the presence of hydrogen gas and trigger rapid production of hydrogenase enzymes that cleave it (Lenz and Friedrich 1998). Given that the supply of energy-containing organic compounds is often limited in soil and competition is intense among soil bacteria, when hydrogen gas is available on a regular basis (as in the vicinity of a tritium-emitting facility), bacterial hydrogenase enzymes will be correspondingly abundant, rates of hydrogen gas uptake will likely be high, and significant amounts of organically bound tritium (OBT) are likely to form.

When hydrogen gas is split into protons and electrons by the hydrogenase enzyme, this is called an "oxidation" reaction because it involves loss of electrons. However, this enzymatic reaction does not involve formation and release of water. Use of the term "oxidation" in connection with the hydrogenase reaction may have confused tritium researchers, who assumed that soil bacteria converted hydrogen gas (in the form of HT) into water (in the form of HTO).

Confusion on this point remains widespread in scientific literature on the environmental fate of tritium. For example, the authors of *Environmental Fate of Tritium in Soil and Vegetation* concluded that their experimental approach "did not provide insight into whether OBT was derived from atmospheric HTO or from tritiated hydrogen gas converted to HTO in soils" (CNSC 2013). These authors did not consider that tritiated hydrogen gas might be converted directly to OBT. There is a "disconnect" between papers on microbial uptake of hydrogen gas and papers on environmental fate of tritium. Tritium researchers appear to be unaware of the importance of the hydrogenase enzyme in nature. This lack of knowledge of the microbiology of hydrogen may have led them to greatly underestimate the potential for OBT to accumulate in the environment (as OBT) near major point sources of HT emissions (such as SRBT).

This lack of knowledge may also help explain the surprise among tritium researchers that emissions of elemental tritium can lead to long-tritium retention in soil in the immediate vicinity of the point of release. When Kim et al. (2012) re-examined soil at the site of the 1994 international HT release at Chalk River Laboratories, they found negligible amounts of tritiated water (HTO), but significant amounts of OBT, many years later: "OBT activity concentrations retained the signature of the historical tritium releases."

Thompson et al. (2015) have confirmed these findings, showing that OBT is present at high levels where tritium in the form of hydrogen gas is emitted, and that OBT levels generally exceed HTO levels in the environment. Samples they collected near SRBT had the highest ratios of OBT to HTO in soil of any sites they studied, with a mean of 5.6. This indicates that significant portions of SRBT's "historical" tritium emissions have accumulated in the Pembroke environment, and that the models on which tritium emission limits are based are flawed:

> "The accumulated data also suggest that some of the parameters used in environmental transfer models approved for regulatory assessments need to be re-visited to better account for data obtained both at background locations and near nuclear facilities and to ensure that modelled estimates are appropriately conservative" (Thompson et al. 2015).

Uptake and retention of radiation as OBT in the local environment near HT-emitting facilities such as SRBT suggests that radiation levels will persist or increase through time if emissions are allowed to continue. Furthermore, because some OBT is incorporated within soil organic matter compounds with long persistence times in soil (Thompson et al. 2015), remediation of tritium-contaminated properties is likely to be a slow process, perhaps taking decades, and mainly dependent on radioactive decay. This strongly indicates that facilities that emit elemental tritium should only operate in locations where there is a sufficiently large exclusion zone so that neighbouring private properties do not become permanently radioactive.

3.3 Tritium in fruits, vegetables and trees

The unexpected discovery of high levels of OBT in soil, discussed in the previous section, has implications for levels of tritium contamination in vegetation as well. Once tritium has been converted into OBT in microorganisms and soil, it can readily enter the food chain. OBT has a significantly longer retention time in biological organisms and systems than HTO, and the longer retention time leads to higher dose consequences of OBT relative to HTO (CNSC 2013).

Similar to their findings for soils, Thompson et al. (2015) observed that the highest OBT/HTO ratios in vegetation in their study were found near SRBT, with a mean of 3.3. The highest OBT/HTO ratio of any plant sample in their study (15.4) was in a cucumber grown 4.8 kilometers from SRBT. These high ratios are not merely of academic interest. OBT is seldom measured in food samples because the analysis is relatively difficult and expensive. Instead, OBT is estimated by multiplying measured HTO by 0.7. This is unacceptable given that OBT/HTO ratios are generally much greater than 0.7 (Thompson et al. 2015).

Until this problem is addressed, tritium in fruits and vegetables will be underestimated by an unknown but potentially very large amount (for SRBT, by an average of 3-fold, and by as much as 15-fold for individual samples). This introduces a high degree of uncertainty in calculation of radiation hazards to Pembroke area residents, who grow and consume significant amounts of fruits and vegetables in their own gardens, and/or purchase food grown by local businesses such as Boudens Gardens, located 2 km downwind from SRBT.

SRBT's 2014 *Annual Compliance Report* (SRBT 2014) reports relatively high tritium concentrations in locally grown food sampled in 2014 compared to 2010-2013. The highest values were for carrots from Boudens Gardens, at 410 Bq/L of tritium, and for rhubarb from a home garden at 408 Boundary Road, at 402 Bq/L of tritium. Do these values include OBT? If OBT was estimated from HTO, what OBT/HTO ratio was used? These issues should be clarified.

Table 1. Tritium in fruits and vegetables grown at Boudens Gardens

Type of produce	CNSC 2013 (Bq/kg fresh weight)	SRBT 2013 (Bq/L)	SRBT 2014 (Bq/L)
Carrots	19.3	23	410
Cucumbers	18.9	24	15
Onions		78	123
Strawberries	35.8		
Tomatoes	89.6	157	48
Zucchinis	25.3	32	289

The *Independent Environmental Monitoring Program* CNSC (2015b) also provides 2013 data on tritium in vegetables sampled from Boudens Gardens. Table 1 suggest that these values may be similar to those in SRBT's 2013 *Annual Compliance Report* (SRBT 2013), but the reported units differ, and (as noted in section 2.1 above) it is not clear if these measurements include OBT.

Trees (including food crops such as fruit and nut trees) can sequester tritium as OBT in their annual growth rings. The potential for OBT to reach high levels in trees is shown in CNSC (2013). OBT levels in the annual rings of an aspen growing about 20 meters from SRBT peaked at 27,500 Bq/L in 2004, and declined in following years. The authors of CNSC (2013) noted that their measurements of tritium in annual growth rings were "partially consistent with the emissions trend at SRBT," meaning that the annual growth rings with the highest tritium were from years with high tritium emissions. When trees with high OBT levels die and decay they will contribute additional OBT to what is already present in soils near the SRBT facility.

3.4 Tritium in groundwater and surface water

After the 2005 CNSC hearings on SRBT's licence renewal, the Commission gave SRBT a 1-year licence with four "actions and measures to take regarding groundwater":

- "Define the extent and magnitude of groundwater contamination on and around the property where the licensed activity is carried out;
- Characterize and confirm all sources and causes of groundwater contamination by tritium;
- Identify any continuing sources of contamination; and
- Assess the potential adverse impacts of the contaminated groundwater on human health, the environment and land use" (CNSC 2005).

One year later, after the 2006 hearings on SRBT's licence renewal, the Commission issued a decision not to renew SRBT's tritium processing licence. It cited evidence that "the operation of the SRBT facility has resulted in an unreasonable risk to the environment", which included serious groundwater contamination:

> "CNSC staff reported that SRBT's environmental protection has been unacceptable (rated "E") mainly due to the groundwater contamination at levels that would be detrimental to its use by humans... data obtained over the last year from the groundwater monitoring have demonstrated that emissions are not being properly controlled to protect the environment close to the facility" (CNSC 2006).

The Commission noted that causes of this contamination were still not well understood:

> "…the Commission is of the opinion that the contributing sources to contamination are not well understood, nor identified by the licensee. In this regard, the Commission can only conclude that there are unexplained and uncontrolled events occurring during the operation of the facility, resulting in contaminated wells in the area external to the licensee's site perimeter" (CNSC 2006).

Three years later, the *Tritium Studies Project Synthesis Report* indicated (page 9) that groundwater contamination in the Pembroke environment was caused by "precipitation washout" of tritium emitted from SRBT's stacks:

> "At the two tritium processing facilities (SRBT and SSI), groundwater contamination has resulted from precipitation washout of tritium in the plume in the immediate vicinity of atmospheric release points (stacks). Historically, the low stacks and ventilation rates used at these facilities were less than optimal for the quantities of tritium being released. Current atmospheric dispersion capabilities at these facilities are now adequate, as a direct result of CNSC compliance enforcement actions" (CNSC 2011).

Page 31 of the *Synthesis Report* provides further details on tritium washout:

> "Similar tritium washout also occurs at power reactors as shown by high tritium activity levels in on-site precipitation samples. However, impacts on surrounding public lands at power reactors have been minimal due to the large exclusion zones surrounding these facilities. During the Tritium Studies project, limits on releases in the licences of SRBT and SSI have been greatly reduced to take into account impacts to groundwater and the absence of an exclusion zone" (CNSC 2011).

An important overarching question is, "Are the current tritium emission limits in SRBT's licence sufficient to protect groundwater on "public lands", i.e., private property?" This raises a number of additional questions:

- What is the appropriate level of groundwater protection?
- Is the relationship between SRBT's tritium gas emissions and groundwater tritium contamination in the vicinity of the SRBT facility well understood?
- Can groundwater tritium concentrations near SRBT be accurately modelled and predicted?

3.4.1 Groundwater trends, modeling and predictions

On 17 February 2010, at the Day 1 Hearing for SRBT's licence renewal application, the Commission requested additional information on the groundwater at SRBT, including "a modelling exercise to project the tritium concentrations in the groundwater monitoring wells in the next five years of the proposed license renewal period." One reason for this request was that tritium concentrations in the monitoring well at the base of SRBT's stacks (MW06-10) were increasing, even though SRBT's reported tritium emissions had decreased.

In response, CNSC staff produced a March 2010 *Update on Tritium Contamination in Groundwater at SRBT.* In this document CNSC staff "project the tritium concentrations in MW06-10 as well as other groundwater monitoring wells in the next five years." Specifically,

> "CNSC Staff predicts that tritium concentration at MW06-10 is likely going to continue to increase for a while but it will soon (in a few months) start to come down and will reach a steady state of about 31000 Bq/L 2 years later…" (CNSC 2010b).

Now, four years later, it is possible to compare the CNSC staff predictions made in 2010 with actual measurements taken since then. Section 4.2 of the *Environmental Assessment Information Report* in CMD 15-H5 attempts to do this in Figures 4 and 5. On page 10 of 18 of this *Report* CNSC staff make the following claims about these Figures:

> "The monitoring data collected by SRBT since the last licence renewal continue to be within the range predicted from CNSC staff's modeling assessment conducted in 2010, as shown in figures 4 and 5, using the two monitoring wells in close proximity to SRBT as

an example. The relatively good match between the modeling results and measurements provides validation to CNSC staff's 2010 prediction on the behaviors of tritium in the groundwater system. It also demonstrates that releases of tritium resulting from SRB's operation are under control and the tritium movement in groundwater around the SRB facility is well understood" (CNSC 2015b).

In fact, Figure 5 indicates a poor match between the modeling results and actual tritium measurements in monitoring MW07-13. None of the results for the 15 most recent samples taken from this monitoring well are within the range predicted by CNSC staff's modeling assessment. All had consistently higher tritium contamination than predicted by CNSC staff.

Table 1. Predicted versus measured groundwater tritium contamination in the four monitoring wells modeled in the *Update on Tritium Contamination in Groundwater at SRBT* (CNSC 2010b)

Monitoring well	Well description	CNSC prediction for Dec. 2014, Bq/L, and trend	SRBT (2014) measured average, Bq/L	SRBT (2014) range, Bq/L
MW06-10	Bedrock surface, base of the stacks	31,000, stable	42959	17133-64102
MW07-13	Bedrock surface, 50 m from stacks	~12,000, declining trend	14740	12372-17518
MW07-18	Bedrock surface, 10 m from stacks	2300, stable	7616	5746-11382
MW07-29	Deeper bedrock, 10 m from stacks	460, stable	5019	2799-6423

Even more troubling is that the *Environmental Assessment Information Report* omits data for the other two monitoring wells modeled in the *Update on Tritium Contamination in Groundwater at SRBT*: MW07-18 and MW07-29. In these two wells, the agreement between the CNSC staff model and actual measurements is very poor. Table 1 shows that during 2014, MW07-18 and MW07-29 had average tritium contamination levels 3.3 and 10.9 times higher than CNSC staff predictions, respectively.

One must conclude that the statement on page 11 of 18 of the *Environmental Assessment Information Report* that "SRB's operation has not adversely affected the groundwater quality" is false. The mismatch between predicted and measured groundwater tritium contamination indicates that releases of tritium resulting from SRBT's operations are not under control and the tritium movement in groundwater around the SRBT facility is not well understood.

3.4.2 Liquid discharges

SRBT discharges tritium-contaminated water into Pembroke's sanitary sewer system. Annual discharges during the 2010-2014 period ranged from 7-13 GigaBecquerels (a GigaBecquerel (GBq) is the amount of a radioactive substance that produces one billion radioactive disintegrations every second). CNSC sets a 200 GBq limit for SRBT's liquid discharges.

The City of Pembroke's sewage treatment plant receives SRBT's liquid discharges of tritium. Some of the tritium becomes incorporated in sewage sludge, while the remainder is discharged to the Ottawa River. A recently published study, *Measurements and Dose Consequences of Tritium in Municipal Sewage Sludge*, found that Pembroke had the highest levels of tritium contamination in sewage sludge of any city studied, at 34 Bq/kg of HTO, and 400 Bq/kg of OBT, or 1800 Bq/kg dry weight (CNSC 2015c). According to this study, "A 38 percent increase was observed in the measured OBT concentration of the 2014 sample compared to the one obtained in 2013."

The study does not examine the potential for tritium contamination of soil and crop plants if Pembroke sewage sludge were to be spread as biosolids on agricultural land. It says that sewage sludge from Pembroke's sewage treatment plant "is currently disposed of at the Ottawa Valley Waste Recovery Centre" (CNSC 2015c).

As a follow-up action,

> "CNSC staff will continue to sample and analyze sewage sludge at the Pembroke Pollution Control Plant. Sampling will continue for an additional two years to characterize the tritium levels in sewage sludge over a longer time period. If tritium concentrations in the sewage sludge (and liquid effluent) samples remain stable, the need for future sampling will be re-examined" (CNSC 2015c).

3.5 Tritium in landfills

Tritium-contaminated wastes do not need to be sent to licenced waste storage facilities (such as the one at the Canadian Nuclear Laboratories) if the level of contamination is less than the CNSC's regulatory exclusion and clearance criteria. SRBT contributes tritium-containing wastes that meet these criteria to the City of Pembroke's general waste stream. The City of Pembroke uses the Ottawa Valley Waste Recovery Centre (OVWRC) as its waste management facility.

Given that the OVWRC receives both tritium-contaminated solid wastes from SRBT, and sewage sludge contaminated by SRBT's operations from the City of Pembroke, there is considerable potential for landfill leachate at the OVWRC, and adjacent groundwater resources, to be contaminated with tritium. Neither SRBT's *Annual Compliance Reports* nor CNSC's *Independent Environmental Monitoring Program* results make any mention of tritium measurements of OVWRC landfill leachate.

It should be noted as well that tritium release in landfills through improper disposal of waste tritium lights is globally recognized as a major source of groundwater contamination, with many studies documenting this problem, and numerous recommendations that waste tritium lights only be disposed of in licenced nuclear waste facilities. It is not known if the waste tritium lights have been placed in the OVWRC landfill.

4.0 Summary and Recommendations

CNSC licences allowed SRBT to emit very large amounts of tritium during a 17-year period prior to the temporary shutdown of the facility between February 2007 and July 2008. This has caused long-term radioactive contamination of soil, vegetation and groundwater on private properties in Pembroke and surrounding areas near the facility. Recent studies of organically-bound tritium (OBT) in soils and vegetation near SRBT indicate that levels of tritium contamination in the Pembroke environment are higher than previously reported, and will persist for long time periods. Although SRBT's reported tritium emissions have been considerably lower in the post-shutdown period (2008-present) than the pre-shutdown period, convincing evidence that emissions are under control is lacking. Compared to the year 2013, results of environmental monitoring for 2014 showed increasing levels of tritium contamination in produce from Boudens Gardens, in Pembroke sewage sludge, and in groundwater from monitoring well MW06-10 at the base of SRBT's stacks. Measurements of groundwater tritium contamination in SRBT's monitoring wells greatly exceed levels predicted in a model prepared in 2010 by CNSC staff, suggesting that the causes of this contamination are not understood, and stack emissions are not adequately controlled. CNSC staff provide no clear rationale for the emission limits proposed in their draft licence for SRBT.

I recommend that CNSC:

- require SRBT to investigate options to move to a location with an exclusion zone;
- regulate SRBT's emissions to achieve immediately a level of 100 Bq/L in groundwater, with a further reduction to 20 Bq/L during the period of the licence;
- require SRBT to monitor OBT in produce samples;
- require SRBT to monitor OBT in soil;
- investigate the potential consequences of spreading tritium-contaminated sewage sludge from the Pembroke sewage treatment plant on agricultural lands;
- require SRBT to monitor landfill leachate from the Ottawa Valley Waste Recovery Centre;
- indicate if consultations regarding groundwater contamination in Pembroke have taken place with the Province of Ontario;
- revise its environmental transfer models to account for microbial conversion of HT into OBT, and take this into account in dose calculations and setting of emission limits;
- ensure that *Independent Environmental Monitoring Program* results are communicated in an unbiased and objective manner; and
- provide a clear rationale for the emission limits it proposes for SRBT, and for other licensees, using plain language that is understandable by the public.

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Appendix 1. Annual tritium emissions from SRB Technologies, 1996-2014

Year	HTO (TBq*)	HT (TBq)	Total (TBq)	HTO (% of Total)
1996	572	2319	2891	19.8
1997	1024	8679	9703	10.6
1998	1362	12890	14252	9.6
1999	671	6624	7295	9.2
2000	1388	16598	17986	7.7
2001	993	12875	13868	7.2
2002	868	8398	9266	9.4
2003	420	6338	6758	6.2
2004	342	3973	4315	7.9
2005**	247	935	1224	20.2
2006	72	213	285	25.2
2007	6	36	42	13.7
2008	6	34	40	17.3
2009	14	28	41	35.3
2010	9	27	36	25.2
2011	13	43	56	22.5
2012	8	22	30	27.9
2013	19	61	79	22.6
2014	11	55	66	16.2

Data sources: 1996-2000: Presentation to the Pembroke Municipal Council, November 19, 2002, Dr. Patsy Thompson, CNSC; 2000-2014: SRBT Annual Compliance Reports.

*A TeraBecquerel (TBq) is the amount of a radioactive substance that produces one trillion radioactive disintegrations every second.

**SRBT reported in a letter to CNSC staff dated August 24, 2005 that it had found an error in the calculation of the quantity of gaseous emissions per week, which resulted in a 10-fold underestimation in the reported values of the gaseous emissions from all previous years (Source: CNSC document CMD 05-H26.B.) Data for years prior to 2005 have been corrected for this error.

Appendix 2. Allowable tritium emissions in CNSC licences awarded to SRB Technologies

Time period	HTO (TBq*)	HT (TBq)	HT + HTO {TBq}
1990-1994	2080	562000	(564080)
1994-2005	22800	1400000	(1422800)
2005-2007	1500	93600	(95100)
2007-2008	135	(386)	521
2008-2015	67	(381)	448

Source: CNSC licences for SRB Technologies (Canada) Inc. Values in parentheses were calculated by addition or subtraction from the other two columns.

*A TeraBecquerel (TBq) is the amount of a radioactive substance that produces one trillion radioactive disintegrations every second.