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Exposé oral

Written submission from the Concerned Citizens of Renfrew County and Area

Mémoire des Concerned Citizens of Renfrew County and Area

In the Matter of the

À l'égard de

SRB Technologies (Canada) Inc.

SRB Technologies (Canada) Inc.

Application for the renewal of the licence for SRBT Facility

Demande de renouvellement de permis pour l'installation de SRBT

Commission Public Hearing

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Tritium Hazards at SRBT Pembroke:
Submission from Concerned Citizens of Renfrew County and Area

CNSC Hearing Dates: April 27/28 2022

Table of Contents

Executive Summary

SRB Technologies (Canada) Inc (SRBT) operates a tritium light manufacturing plant at Pembroke, Ontario. It has applied to CNSC for a 15-year extension of its current 7-year license allowing operations to continue through 2037.

Annual tritium emissions to air and to water from SRBT's factory continue at high levels. Environmental measurements of soils, foodstuffs, wells and sewage near the SRBT facility show continuing tritium contamination. SRBT workers and local residents will ingest tritium, inhale tritium, and absorb tritium through their skin, and these intakes will increase their probability of getting cancer and other radiogenic diseases. However no measurements are made of HTO and OBT levels in people living in Pembroke.

Tritium, ^{3}H, is the radioactive isotope of hydrogen. Major international agencies recognise that tritium is an unusually hazardous radionuclide.

No epidemiological studies in the Pembroke area have been commissioned or carried out to ascertain levels of adverse health effects. However epidemiology studies at other Canadian facilities emitting tritium indicate increases in cancer and congenital malformations. In addition, evidence from cell and animal studies, and radiation biology theory, indicates that radiogenic effects will occur from exposures to tritium.

Recent, large-scale, statistically powerful, epidemiology studies of nuclear workers in UK, US and France have resulted in perceived increases in the radiation risks of low-LET radiation, including tritium. The new studies show a 47% increase in solid cancers and a 580% increase in leukemias. These new studies are applicable to tritium's radiation exposures at the SRBT plant at Pembroke.

The high emissions, high levels of contamination, and raised estimates of cancer risks together mean that tritium poses increased health risks to SRBT workers and the people of Pembroke. Using the Precautionary Principle, it is recommended that any license should be contingent on relocation of the SRB factory to an unpopulated area outside the city limits of Pembroke.

Tritium Hazards at SRBT Pembroke

A. Introduction

1. Concerned Citizens of Renfrew County and Valley, a NGO based in the Ottawa area, has requested Dr Ian Fairlie to review SRBT's proposals for the CNSC hearing, and to prepare an independent report summarizing current understandings of the biological and health effects of exposures to tritium and commenting on the risks faced by local citizens. In particular, new evidence since 2015, when SRBT last applied for an extension to its operating licence, will be discussed.

2. Dr Ian Fairlie is a Canadian citizen resident in the United Kingdom. He is an independent consultant on radioactivity in the environment with degrees in chemistry and radiation biology. His doctoral studies at Imperial College, UK and Princeton University, US examined nuclear waste technologies. One of his areas of expertise is the dosimetric impacts of nuclear reactor emissions. He has authored many articles in peer-reviewed journals on epidemiology studies of child leukemias near radiation facilities and on the hazards of radionuclides. He has been a consultant to UK Government Departments, the European Parliament, the World Health Organisation, environment NGOs, and UK local authorities. Between 2000 and 2004, he was head of the Secretariat to the UK Government's Committee Examining the Radiation Risks of Internal Emitters (CERRIE).

3. Of particular relevance to these hearings, Dr Fairlie has written numerous scientific articles on the hazards of tritium emissions which have been published in peer-reviewed journals.

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- Fairlie I. Tritium: The Overlooked Nuclear Hazard. The Ecologist. 22 No 5. 228-232 (1992)

B. Tritium Releases from SRBT

4. In recent years, SRBT has continued to release large quantities of tritium to air. See Table 1. These are of the order of tens of terabecquerels per year (TBq/a – see radioactivity units at Annex B). One terabecquerel is 10^{12} Bq, or one trillion Bq, i.e. 1,000,000,000,000 Bq - a very large amount or radioactivity.

5. Tritium is released mainly in two forms – tritium gas (HT) and tritiated water or water vapour (HTO), in other words radioactive water or /water vapour. As a result of molecular exchange - explained in BOX 1 below - these two types of releases are added together and treated as HTO. This is an important matter as the ICRP (in its Annual Limits of Intake - https://www.icrp.org/docs/Occupational_Intakes_P1_for_consultation.pdf) considers HTO, radioactive water, to be 25,000 times more radiotoxic than HT, radioactive hydrogen gas.

6. It is also important because official regulatory models for atmospheric releases of tritium do not deal with doses from emissions of tritiated hydrogen gas (HT) and conversion of HT to HTO in the environment, nor do they address the dose from ingesting tritium incorporated into organic compounds (Peterson and Davis, 2002).

7. Although SRB's Safety Analysis Report http://srbt.com/SRBT%20Safety%20Analysis%20Report,%20Rev.%204%20(November%202017).pdf includes a voluntary commitment not to process tritium when it is raining, this is not a licence requirement. It should be as, rather worryingly, SRB's commitment re rainfall apparently does not recognize the risks of HTO uptakes via inhalation. Instead it states "Tritium processing is not permitted during times where precipitation is occurring. This restriction is in place in order to provide protection of groundwater resources."

BOX 1. Molecular Exchange

In the environment, tritium atoms in HT rapidly exchange with stable H atoms in water through the phenomenon of molecular exchange. Therefore here all tritium releases are treated as HTO. This is common practice in OPG and AECL reports (Davis et al, 1997).

In more detail, in matter, all atoms engage in exchange reactions with like atoms in other molecules to varying degrees. This means that tritium atoms in HT swap positions with stable H atoms in the environment in the hydrosphere and in biota, including humans. H and T, the smallest atoms (apart from deuterium) are prominent as regards exchange reactions. These exchange reactions are very quick, taking about 10^{-15} seconds on average.

As the most common hydrogenous material in the environment is water in liquid or vapour forms, this means that tritium released as HT relatively quickly transfers to HTO. In practical terms, open water surfaces and biota downwind, including food growing in the area, plants, animals and humans, would become contaminated with tritium up to the tritium concentration in the atmosphere. For example, it would include vegetables and fruit in exposed market stalls and shops (Inoue, 1993).

8. Annual tritium emissions to air from SRBT are set out in table 1. These emissions have been declining in general terms, but still remain unacceptably high.

TABLE 1. Tritium Emissions to air from SRBT

Year	(HT and HTO) TBq/a
2020	25
2019	32
2018	33
2017	25
2016	29
2015	56
2014	66
2013	79
2012	30
2011	56
2010	36
2009	42
2008	40
2007	42
2006	285
2005	1224
2004	4315
2003	676
2002	834

correct to two significant figures

9. SRBT's annual emissions are lower than those from CANDU nuclear reactors - widely known as prolific sources of tritium - but significantly higher than other reactor types around the world – see Table 2.

TABLE 2. Annual Tritium air emissions from various sources

Facility	**TBq/a**
Pickering NPP (2019) Ontario	560
Bruce NPP(2019) Ontario	793
Darlington NPP (2019) Ontario	223
SRBT Ontario	25
Dungeness B (AGR) UK	12
Sizewell B (PWR) UK	3
Dungeness A (Magnox)UK	2.6
German NPPs	0.5 average

Ontario NPP data from http://nuclearsafety.gc.ca/eng/resources/publications/reports/regulatory-oversight-reports/npgs-report-2019.cfm

10. According to its most recent Annual Compliance Report (SRBT, 2020) SRBT emitted 25 TBq of tritium in 2020. Although this is a welcome decrease from some previous years, it still remains a large annual amount of tritium, i.e. 25,000,000,000,000 Bq.

11. Canada's only other tritium light factory (SSI in Peterborough, Ontario) was abandoned by its operating company in 2012, partly as a result of local opposition arising from health concerns about its large tritium releases. http://www.nuclearsafety.gc.ca/eng/the-commission/pdf/2015-03-27-Report-on-the-Clean-up-and-Abandonment-of-Shield-Source-Inc-eng.pdf

12. In risk assessments, aerial emissions are more important than liquid discharges for two reasons. First, the key parameter in estimating radiation exposures to local people is the nuclide concentration in environmental materials. Contrary to what many people think, air emissions[1] result in higher environmental concentrations than water discharges. The reason is dilution. A cubic metre of water contains a million grams of water which dilutes radioactive contaminants far more effectively than a cubic metre of air which only has ~10 grams of water: i.e., >100,000 times more effectively. This is not to accept that dilution is the solution to pollution - it isn't - it merely reflects the fact of existing (ill-advised) methods of disposing of gaseous nuclear wastes. Second, individual exposures and collective exposures from air emissions are much larger than from discharges to water. Accordingly this report deals mainly with air emissions.

C. The Hazards of Tritium

13. In order to understand and appreciate tritium risks to local people, we need to discuss tritium's properties in some detail. In the past, nuclear scientists had tended to minimise the risks from tritium and to regard it as being only weakly radiotoxic. This is changing: in the last decade, 10 major reports on tritium have been published by radiation safety agencies in the UK (AGIR, 2008), Canada (CNSC, 2010a; 2010b) and France. In France, the French Nuclear Safety Authority (ASN, 2010) published a comprehensive White Paper on tritium and the French Institute de Radioprotection and Nuclear Safety published six major reports on tritium (IRSN, 2010a; 2010b; 2010c; 2010d; 2010e; 2010f). In particular, these reports all noted that tritium exposures resulted in internal radiation doses whose estimation contained uncertainties which could render them unreliable.

[1] Hence the importance of the rapid conversion of HT to HTO in air and the subsequent conversion of a portion of HTO into OBT in the human body

14. The most comprehensive report on tritium remains the report by UK Government's senior Advisory Group on Ionising Radiation (AGIR, 2008). This strongly recommended that tritium's hazard (ie, its radiation weighting factor, w_R) should be doubled from 1 to 2. Other scientists (Fairlie, 2008; Fairlie, 2007a; Fairlie, 2007b; Melintescu et al, 2007; Makhijani et al, 2006) have presented evidence for even larger increases in tritium's radiotoxicity, including the US EPA (2006) which recommended a 2.5 fold increase.

15. These reports drew attention to tritium's properties which mark it out as an unusually hazardous radionuclide. These include

a. its relatively long half-life of 12.3 years
b. its mobility and cycling (as H_2O) in the biosphere,
c. its multiple pathways to man,
d. its ability to swap instantaneously with H atoms in adjacent materials,
e. its relatively high relative biological effectiveness (RBE) of 2 to 3,
f. its ability to bind with cell constituents to form organically-bound tritium (OBT) which is heterogeneously distributed in humans,
g. its long residence time in bodies as OBT, and
h. its short-range beta particle, meaning that its damage depends on location within cellular molecules, e.g. DNA

16. It is necessary to take into full account the long biological half-lives of OBT. Recently Matsumoto, Hideki et al. (2021) stated "*To understand the effects of internal exposures by tritium … it is important to realize that a part of tritium atoms (5–6% of HTO absorbed into the body) exists as a component of the body due to exchange with hydrogen atoms in organic compounds such as proteins and carbohydrates in the body, the so-called OBT. OBT, especially tritium bound to carbon atoms in organic compounds remains longer in the body, because such OBT is difficult to exchange for other atoms in organic compounds. Thus, the biological half-life of OBT is about 40 days for a short-term component and about one year for a long-term component*."

17. For these reasons, tritium presents severe challenges to conventional dosimetry and health-risk assessments. Also, tritium in its elemental form diffuses through most containers, including those made of steel, aluminium, concrete and plastic. Furthermore, in either form, tritium is not detected by commonly-used survey instruments (Okada et al, 1993). Normally swabs have to be taken which are then sent to specialist laboratories to determine their tritium concentrations.

18. When tritium is emitted from SRBT (whether as water vapour or elemental tritium), it travels via multiple environmental pathways to humans. It cycles in the environment, because tritium atoms swap quickly with stable hydrogen atoms in the biosphere and hydrosphere. This means that open water surfaces, rivers, streams and all biota, local crops and foods in open-air markets (Inoue, 1993) animals and humans will become contaminated by tritiated moisture up to ambient levels – that is, up to the air concentrations of the emitted tritium.

19. With the tritium emitted by SRBT in the atmosphere, Pembroke people and SRBT workers can become tritiated by skin absorption, and by inhalation of contaminated water vapour. Because tritium is quickly transferred to food and water (Inoue, 1993), workers and the public will also get tritium by eating contaminated food and drinking liquids. When tritium enters the body, it is readily taken up by exchange mechanisms, by metabolic reactions and by cellular growth. Over 60 per cent of the body's atoms are hydrogen atoms and every day about five per cent of them are engaged in metabolic reactions and cell proliferation. The

result is that a proportion of the tritium taken in is fixed to proteins, lipids and carbohydrates, including nucleo-proteins such as DNA in our cells.

20. This is termed organically bound tritium (OBT) which is non-uniformly distributed and is retained in our bodies for longer periods than tritiated water. Exposures from OBT are therefore higher than from HTO. The longer people are exposed to tritiated water emissions (i.e. in terms of the numbers of days), the higher their levels of OBT become until, in the case of repetitive exposures lasting years, equilibrium is established between HTO and OBT levels. Unfortunately, the dosimetric models used by the International Commission on Radiological Protection (ICRP) assume the opposite – that tritium is homogenously distributed in the body/tissue/ organ of interest and is quickly excreted. And ICRP dosimetric models only consider single exposures not chronic ones so that their model estimates of OBT levels are unreliable.

21. It can be seen that tritium has unusual properties which suggest that it should be regarded as hazardous in radiation protection advice. Unfortunately, tritium's properties are not recognised by the ICRP and authorities which take their lead from the ICRP. This bad situation is made worse by the ICRP's incorrect dose model for tritium which results in the underestimation of tritium 'doses' and its risks. For example, the ICRP's dose conversion factor for tritium intakes is 1.8×10^{-11} Sv per Bq, the lowest of any common nuclide by some margin. It is about 1000 times smaller than that for Cs-137.

22. One major controversy, which has lasted for about 60 years, is the ICRP's continued recommendation of the radiation weighting factor (w_R) for tritium of 1. See Fairlie (2007a). This value is simply wrong and should be at least doubled. It should be borne in mind that the ICRP is not an official body, but a voluntary one. It operates rather like a trade association, as it is principally concerned with protecting the interests of its members rather than those of the general public. It appears that non-scientific considerations may have played a part in the ICRP's decisions on tritium, as regards nuclear weapons production plants in the past, nuclear reactors at present, and proposed fusion facilities in the future.

D. New Evidence on Radiation Risks

23. In 2015, during SRBT's previous application for a License renewal, extensive evidence on tritium's hazards was submitted to the CNSC by the NGO "First 5 Years". Since then, to our knowledge, no new tritium studies have been commissioned although it can be argued that these should have been conducted.

24. Nevertheless important new epidemiological evidence has been published indicating that **all low-LET radiation risks have increased**. Low-LET radiation means low linear energy transfer and includes beta particles like tritium's, gamma rays and most X-rays.

25. The new evidence is from the International Nuclear Workers' Study (INWORKS) meta-studies of nuclear workers in the US, UK and France. The meta-studies are very large (>300,000 participants) which lends considerable authority to their findings. The new studies do not estimate tritium risks directly but do so indirectly. Since tritium is emitted from all nuclear facilities, all nuclear workers in these studies were exposed to tritium as well as to gamma rays which were measured in their film badge dosimeters, of which records had been kept for many years.

26. In late 2015 and in subsequent years, the INWORKS studies of nuclear workers in France, United Kingdom, and United States (Hamra et al, 2016) examined associations between low dose-rate radiation and **leukemia/lymphoma** (Leuraud et al, 2015, 2021), **solid cancers** (Richardson et al, 2018), and **circulatory disease** (Gillies et al, 2017).

27. The main findings from the first two were that radiation risk estimates were broadly similar to, but higher than, the risk estimates derived previously from the Japanese bomb survivors' studies. For example, in the solid cancer study, the authors stated "*Our estimated association between radiation and solid cancer (ERR = 0.47 per Gy; 90% confidence interval 0.18 to 0.79) is larger than but statistically compatible with the estimate from a mortality analysis of male survivors of the Japanese atomic bomb exposed at ages 20-60 years (ERR = 0.32 per Sv; 95% confidence interval 0.01 to 0.50).*"

28. The phrase "statistically compatible" in this quote is a jargon definition used in statistics. It does not mean 'the same or similar'. It means that the confidence intervals in the two studies overlapped which is a different matter. Therefore it is necessary to compare the main point estimates of risk. The actual observed increase between the two studies was 0.47/0.32 = 1.47, i.e. a 47% increase - a significant amount.

29. Similarly for leukemias. The more recent study in leukemia risks (Leurad et al, 2021) stated "i*n the dose range … 0–500 mGy, the linear estimated ERR/Gy …..derived from LSS (0.59; 90% CI − 0.43; 2.03) is substantially smaller than that derived from INWORKS (3.46; 90% CI 1.29; 6.19)".*

30. The actual increase in point estimates is 5.8 fold or 580%. This very large increase is driven mainly by the 11-fold increase in chronic myelogenous leukemia (CML) in older workers. In myeloid leukemia, the cancers occur in cells that form red blood cells, some other types of white cells, and platelets.

31. The third study on cardiovascular risks somewhat surprisingly reported brand new risks of heart disease and strokes. These are not taken into account in official risk estimates by regulatory agencies but they should be.

32. A main assumption of this report is that the recorded external gamma doses in the new occupational studies may be used to comment upon tritium risks. **This is reasonable because when tritium risks are calculated the risk from external gammas is used as a factor. Therefore when external gamma risks are increased so are tritium's risks**. It is also reasonable because both forms of radiation i.e. gamma rays and the beta particles from tritium are low-LET forms of radiation and, at least in official reports, both use the same radiation weighting factor, i.e. 1.

33. It is important to note this report does NOT take the absolute numerical risks from gamma ray exposures cited in the published studies and apply them to tritium. Instead it uses the risk **increases** (i.e. the ratios of the INWORKS risks compared to the LSS risks). This safeguard allows us to extract useful information from gamma risks and apply it to tritium risks, i.e. the observed risk increases (i.e in ERRs per Sv) from external gamma rays can be applied as well to tritium.

34. The new INWORKS radiation studies remain pertinent to whether a further license extension should be given to SRBT for a number of other reasons as follows. The INWORKS studies

a. provide ***strong evidence*** of a dose-response relationship between cumulative, chronic, low-dose, exposures to radiation and leukemia.
b. confirm that radiation risks exist even **at very low dose rates** (average = 1·1 mGy per year).
c. **observe** risks at low dose rates rather than extrapolating them from high dose rates. (e.g. as in the LSS study of Japanese bomb survivors)

d. found that risks **do not depend on dose rate** thus contradicting the ICRP's use of a Dose and Dose Rate Effectiveness Factor (DDREF) (which acts to reduce by half its published radiation risks).
e. found radiogenic leukemia risks decline **linearly** with dose, contradicting earlier studies suggesting a lower, linear-quadratic relationship for leukemia.
f. **strengthen** the Linear No-Threshold (LNT) model of radiogenic risks, as it now applies to leukemias as well as solid cancers.
g. found **no evidence of a threshold** below which no effects are seen.
h. found a trend of **increasing risk of solid cancer by attained age.**

35. Because these findings are far-reaching in their implications, it is necessary to double check the INWORKS findings. A recent exhaustive review (Hauptmann et al, 2020) of the INWORKS studies examined possible sources of bias[2] and confounding[3]. It concluded that the new epidemiological studies directly support the conclusion of excess cancer risks from low doses of ionising radiation, with little evidence of bias and confounding. Furthermore, the magnitude of the cancer risks from these low exposures was statistically compatible with the dose-related cancer risks of the atomic bomb survivors. This is similar to the findings of another study (Berrington et al, 2020) which reviewed the INWORKS studies using specialist statistical and epidemiological methods to look for evidence of bias and found none.

E. Questionable Conclusions from Environmental Data

36. In addition to SRBT's own surveys, in some years, the CNSC carries out an Independent Environmental Monitoring Program (IEMP) at Pembroke. The most recent report http://nuclearsafety.gc.ca/eng/resources/maps-of-nuclear-facilities/iemp/srb-tech.cfm states

> *"the results for 2013, 2014, 2015 and 2018 confirm that the public and the environment in the vicinity of the SRB facility are protected and that there are no expected health impacts."*

37. However this statement is unsatisfactory for several reasons. The first is that the SRBT and CNSC environmental data are patchy, i.e. not comprehensive, and are highly variable. These variations are unexplained and are therefore unreliable for deriving any health conclusions.

38. The second is that the steps (i.e. computer models) needed to go from environmental data to health risks are large in size and number: none of these steps is explained either by CNSC or SRBT (see Appendix B). The reality is that these steps contain many assumptions and uncertainties: to assert that there are no expected health impacts from the environmental data is hubristic and unjustified.

39. The third reason is that no monitoring exists of any health outcomes among Pembroke residents. For example, no epidemiological studies have been carried out in the area. In addition, no monitoring of HTO and OBT levels in Pembroke residents is carried out.

40. Fourth, the guideline/reference levels in the IEMP are extremely high and non-conservative. For example, the reference level for elemental tritium in air is cited as 5,100,000 Bq/m^3, for tritium in air 340 Bq/m^3, and for tritium in (e.g.) kale 104,000 Bq/kg fresh weight. These unsafe limits are all derived from the unacceptably high level of tritium in

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[2] statistical bias occurs when a model or statistic is unrepresentative of the population being studied: several sources of bias can occur, e.g. selection bias

[3] Confounding occurs when an extraneous factor causes inaccuracy in the estimated measure of an association, e.g. smoking in a lung cancer study

drinking water - 7,000 Bq per litre - currently used by Health Canada. This is extremely lax given the current recommendation of the Ontario Drinking Water Advisory Council (ODWAC) of 20 Bq per litre.[4] CCRCA considers that the safer recommended tritium limit of 20 Bq per litre should be used throughout these documents.

See table 1 on the various drinking water limits in use.

Table 1. Tritium (HTO) limits in drinking water

Agency	**Tritium limit** (Bq per litre)
SRBT (citing Health Canada)	7,000
European Union	100
Recommended by Ontario Government's ACES in 1994	20
Recommended by Ontario Government's ODWAC in 2009	20
US State of Colorado	18
US State of California	15

41. Fifth, the latest IEMP report incorrectly states "The radioactivity measured in water, soil, vegetation, air and food samples (are) …within natural background levels." Natural levels of HTO in Canada vary between 2 to 5 Bq per litre in biota, soils and water (i.e. in areas remote from nuclear facilities) however a perusal of the tritium levels published in the IEMP report are considerably higher than 2 to 5 Bq per litre.

42. Finally, to conclude from the presented patchy environmental data that the public and the environment near the SRBT facility are thereby "*protected*" is unwarranted. To state "*there are no expected health impacts*" is simply a guess, or an aspiration, as no studies have been carried out on any health impacts in the area.

43. My overall conclusion is that it is unknown whether or not "*the licensee's environmental protection program protects the health and safety of people and the environment*" as claimed by CNSC. A precautionary approach should be used here instead of hubristic assumptions.

F. Tritium Concentrations in Pembroke Sewage

44. In 2013 and 2014, HTO and OBT concentrations is Pembroke's sewage sludge were published by the CNSC (2015a) as set out below in table 2 These concentrations have not been published in more recent years.

Table 2. Pembroke Sewage Sludge tritium levels

Year	HTO	OBT
2013	33 Bq/l	290 Bq/kg
2014	34 Bq/L	400 Bq/kg

45. The HTO levels in table 2 are raised compared with normal background HTO levels in Canada of about 2-5 Bq/L as stated above. The OBT data are more worrying, assuming the laboratory measurements are correct. They are a cause for concern because one must recognise that "sewage sludge" is mainly human feces. So the question arises how did such

[4] Ontario Drinking Water Advisory Council, *Report and Advice on the Ontario Drinking Water Quality Standard for Tritium* (2009), available online: http://meteopolitique.com/Fiches/nucleaire/documentation/01/Nucleaire_eau-potable-Ontario-Tritium.pdf

high OBT levels arise in human feces? The two main sources of OBT in feces are (a) from the human digestion of OBT-contaminated foods and (b) from the discharge of live and dead tritiated bacteria, dead tritiated blood cells, i.e. the detritus of the human metabolism of tritiated body cells. The latter indicates that the body cells of Pembroke residents have OBT levels similar to those indicated in table 2. In other words, Pembroke residents themselves would appear to be tritiated to levels of 300 to 400 Bq/kg

46. Some thought has gone into the question of whether the sludge at sewage treatment plants in Pembroke could have been contaminated by non-fecal matter, but this is now considered unlikely. Therefore the data in table 2 probably indicate raised levels of OBT in the bodies of Pembroke citizens. This would mean that the people's bodies may be contaminated to such levels – a worrisome finding. It is difficult to explain such high levels otherwise as recent measured OBT levels in locally-grown foodstuffs are about a factor of 10 lower than the levels in feces. See http://srbt.com/PRODUCE.pdf

47. To explore this matter, HTO and OBT concentrations in people near the SRBT facility should be measured. Urine samples for HTO and non-intrusive bioassays (e.g. hair, nail clippings) of OBT levels should be undertaken in order that the risks of radiation exposures from OBT can be estimated. The overall conclusion from the data in table 2 is that all biota in the local area around SRBT and Pembroke people remain contaminated with tritium.

G. Epidemiological evidence of risks at other tritium-emitting sites

48. It is an obvious step to look for evidence of ill health at other areas where people are exposed to radiation. However, due to methodological limitations, epidemiology studies are often a blunt tool for discovering whether adverse effects result from radiation exposures. These limitations include:

- under-ascertainment, i.e., people move away, or cases are not found or reported.
- strict data requirements: ideally, epidemiology data is required with good case identification, uniform registration, clear diagnostic criteria and uniformity of data collation. These data requirements are often difficult to fulfil and make large demands on time and resources.
- confounding factors: the true causes of morbidity or mortality can be uncertain due to confounding factors such as socio-economic status and competing causes of death.
- bias: smoking and alcohol cause major increases in overall mortality and morbidity, and in cancer and cardiovascular disease. These require careful handling of the raw data to avoid bias.
- poor signal to noise: only large, expensive and lengthy epidemiology studies are able to reveal effects where the signal (added cancers) is weak, and the noise (large numbers of spontaneous cancers) is strong.
- uncertain doses: establishing causality often requires estimating doses in order to show a dose-effect relationship. However, large uncertainties often exist in estimating doses - especially from internal radiation, e.g. from tritium.
- wide confidence intervals: usually findings (e.g. risks or odds ratios) are expressed with 95% confidence intervals- that is, the range of values within which the true value lies within 95% of the time. But often this range can be very wide - simply because of low numbers of cases. This can severely limit what we can conclude from the findings.

49. Many epidemiology studies are ecologic studies (Wakefield, 2008), that is, quick studies which look at health or population statistics and not individual data. Their findings are usually regarded as indicative and not conclusive. If their findings suggest an adverse effect then these should be investigated further by more detailed cohort or case-control studies.

The latter match "cases" (i.e. those which have an adverse effect) with randomly-selected similar individuals, in order to minimise under-ascertainment. However fewer of these are carried out because of their expense and long timespans.

Leukaemia in children near Candu nuclear facilities

50. Clarke et al (1991) studied mortality and incidence of childhood leukaemia near nuclear facilities in Ontario. Its first report considered leukaemia deaths and cases at ages 0-4, and the second (Clarke et al*.* 1991) considered cases and deaths at ages 0-14. Data for areas "nearby" (<25 km) the 16 reactors at Bruce and Pickering over the period 1971-1987 were pooled together to increase statistical significance. The findings were 36 leukemia deaths aged 0-14 vs. 25.7 expected (SMR = 1.40, 95% CI 0.98 - 1.9) indicating excess leukemia mortality with borderline statistical significance. However the confidence intervals were wide: the data were consistent with there being no increase and with there being a 90% increase in leukemia.

51. However there were indications which warranted further investigation: higher leukemia death rates after the reactors had started than before; more deaths when counted at place of birth than at place of death; and the size of the higher confidence interval. It is notable that different levels of statistical significance were adopted by the two reports. The first was 10%, and the second 5%. If the 10% level had been used in the second study as it had been in the first, the leukemia increase would have been considered "statistically significant". The authors recommended further case-control research which was not carried out.

Birth defects and infant mortality in the vicinity of the Pickering nuclear facility, Ontario

52. Johnson and Rouleau (1991) studied birth defects, stillbirths, perinatal, neonatal and infant mortality within 25 km of the Pickering nuclear station. They also studied these endpoints in relation to airborne and waterborne discharges of tritium from Pickering, concentrating on the Pickering and Ajax townships closest to the Pickering plant.

53. The incidence of central nervous system defects was significantly elevated in Pickering township for the highest level of airborne tritium emissions (odds ratio in highest group = 4.01 (95% CI; 1.25, 14.04)), based on 6 cases)) but no statistically significant trends with tritium emissions (p=0.197) or ground monitoring data (p=0.24) were observed.

54. Births with Down Syndrome in Pickering township were significantly increased (24 observed *vs.* 12.9 expected (relative risk = 1.85, 95% CI = 1.19, 2.76)). But 23 other birth defect endpoints did not show such an excess. The raised incidence of Down Syndrome cases was notable, as many Chernobyl studies also indicate excesses in areas exposed to radioactive fallout. However the authors of the study queried why the incidence of Down Syndrome alone should be increased and not other forms of congenital malformation. This does not provide a reason to discount the observed association between tritium exposures and Down Syndrome.

Offspring of Canadian nuclear workers

55. Green et al (1997) assessed cases of congenital abnormalities and matched controls in the offspring of Canadian nuclear workers. (763 case-control pairs of fathers and 165 case-control pairs of mothers). Tritium doses were assessed for those cases/controls having a recorded tritium dose 60 days before conception vs. those with no dose. The study revealed increased chromosomal disorders with tritium exposure, but the number of cases (two) is small and confidence intervals wide.

Offspring of Ontario radiation workers

56. McLaughlin et al (1992, 1993) considered cases of childhood leukaemia in the offspring (aged 0-14) of Ontario radiation workers and matched cases. Tritium workers were those employed at the AECL laboratories at Chalk River, and 5 power stations (Rolphton, Pickering (A, B), Bruce (A, B); 112 cases and 896 controls). Preconceptional tritium doses were assessed for this group. There was some evidence of raised risks with internal tritium + external radiation exposures but with wide confidence intervals.

Durham Region Health Department (2007)

57. This study showed statistically significant elevated rates of several radiogenic cancers near the NPPs east of Toronto. Leukemia incidence was significantly increased in Ajax-Pickering and Clarington males in 1993-2004. This study was based on municipal borders, about 10 km from the reactors. The authors admitted some findings were of concern and recommended further more accurate studies, but none have been done. However the report incorrectly concluded that the overall findings did not indicate a pattern.

Lane Study (Lane et al, 2013)

58. This study purportedly sought to determine whether radiation doses to members of the public living within 25 km of the Pickering, Darlington and Bruce nuclear power plants (NPPs) were causing an increase in cancer rates from 1990-2008. It reported that some types of cancers were statistically higher than expected but radiation exposures were dismissed as a cause of these cancers “on the basis of current radiation risk estimates."

Wanigaratne et al Study (2013)

59. This study examined cancer incidences (1985–2005) among Pickering and north Oshawa residents including all cancers, leukemia, lung, thyroid and childhood cancers (6–19 years). Person-years analysis showed female childhood cancer cases to be significantly higher than expected (SIR = 1.99, 95% CI: 1.08–3.38). It concluded that “multiple comparisons were the most likely explanation for this finding”.

60. The above studies all show increased ill effects, some statistically significant and others with borderline statistical significance. Some studies showed increases for some illnesses but not others. However as Altman and Bland (1995) stated “absence of evidence is not evidence of absence”. In addition, the methodological limitations and small sizes of some of these studies mean they were simply unable to detect effects with statistical certainty.

61. Despite their positive numerical findings, the published conclusions of these studies were invariably negative, often on the flimsy grounds of inconsistent results, too many comparisons, lack of an overall pattern. In the case of Lane et al study. It was because the observed increases in cancer incidence were much greater than would be predicted from official estimates of radiation dose. In other words, the authors refused to accept the evidence of their own study, preferring to believe in official dose estimates.

62. Instead the above studies taken together provide suggestive, albeit limited, evidence for increased health effects from exposure to tritium. These could be confirmed with larger, case-control or cohort studies. More important, considerable evidence from cell and animal studies and radiation biology theory indicates that adverse effects will occur. This is backed by evidence from recent, large scale, statistically powerful epidemiology studies – see section D above.

H. CNSC draft recommendation of January 2022

63. In January 2022, the CNSC published its draft recommendations for the requested licence renewal at SRBT at Pembroke. This stated, inter alia, "*CNSC staff have found that the potential risks … from radiological and hazardous releases to the atmospheric, hydrogeological, aquatic, terrestrial and human environments from the SRBT facility are negligible, resulting in no significant adverse effects".* See https://www.nuclearsafety.gc.ca/eng/the-commission/hearings/cmd/pdf/CMD22/CMD22-H8.pdf

64. However this conclusion is highly questionable, as the CNSC has not conducted any health surveys among Pembroke residents to ascertain whether any such effects exist.

CONCLUSIONS

65. Annual tritium emissions to air from SRBT's light factory at Pembroke are large compared to most nuclear power stations in the world.

66. Major international agencies recognise that tritium has unusual properties marking it as a hazardous nuclide. It is extremely mobile in the environment, contaminates all biota including humans in nearby areas to ambient levels, and binds with organic matter to form OBT with long residence times in the body making it more radiotoxic.

67. Environmental measurements of soils, foodstuffs, wells and sewage near the facility indicate pervasive tritium contamination of local areas. Tritium levels in wells are in most cases higher than the CNSC's design guide for groundwater tritium, and higher than the Ontario Government's ODWAC recommended level for tritium in drinking water.

68. It appears that neither CNSC nor SRBT understands the factors responsible for the continuing high groundwater contamination near the SRBT facility. Tritium levels in environmental samples are erratic but do not appear to be declining. In 2013 and 2014 tritium measurements in municipal sewage revealed unexpectedly high levels of OBT. These lead to increased concerns about tritium contamination in the area. These intakes increase the probability of cancer and other diseases in exposed people.

69. Epidemiology studies of other Canadian facilities emitting tritium suggest increases in cancer and congenital malformations: these could be confirmed with case-control or cohort studies. More important, considerable evidence from cell/animal studies and radiation biology theory indicates that adverse effects will occur. This is backed by evidence from recent, large scale, statistically powerful epidemiology studies – see section D.

RECOMMENDATIONS

70. It is recommended that

i. SRBT and CNSC should justify the proposed radiation exposures from SRBT as required by the ICRP's basic principles and by all EU countries. In other words, they should assess their health detriment in relation to any economic or social benefits they may have.
ii. CNSC should ensure the Ontario Government's ODWAC recommendation of 20 becquerels per litre (Bq/L) for drinking water is met for all Pembroke citizens.

iii. CNSC should implement its own design guide for groundwater for tritium of 100 Bq/L for tritium levels in wells near SRBT.

iv. In view of the apparent increases in HTO and OBT levels in the local environment, the CNSC's annual release limits for tritium emissions should be reduced by considerable margins.

v. In view of the unexpectedly high OBT levels, the CNSC should commission an independent report on the findings of OBT levels in sewage sludge near SRBT with a mandate to make recommendations.

vi. Urine tests and non-invasive bioassay tests should be carried out on volunteers from the community to ascertain HTO and OBT levels.

vii. Local residents should continue to avoid consuming locally-grown foods and water from local wells.

viii. In view of the discussion in Appendix E, local women intending to have a family, and families with babies and young children should consider moving elsewhere. It is recognised this recommendation may cause concern but it is better to be aware of the risks to babies and young children than ignorant of them.

ix. SRBT employees, especially workers in their teens, should be informed about the hazards of tritium.

x. In the longer term, it is recommended that any further operating license for SRBT be contingent on relocation of the factory to an unpopulated area outside the city limits of Pembroke. This recommendation may be overtaken by events, as it is likely that the use of radioactive lamps will continue to decline due to increasing market penetration of light emitting diodes (LEDs) lamps, especially in Europe and US https://www.globenewswire.com/en/news-release/2020/11/16/2127168/28124/en/Worldwide-LED-Lighting-Industry-to-2030-Analysis-and-Growth-Forecast.html The recent steep declines in the costs of PV materials and energy storage systems contrast sharply with the very high costs of tritium lamps, currently US$ 30,000 per gram. https://www.reddit.com/r/askscience/comments/abubxw/why_is_tritium_so_ridiculously_expensive

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APPENDICES

APPENDIX A. ORGANICALLY BOUND TRITIUM

Organically bound tritium (OBT) which is bound to carbon atoms is termed non-exchangeable OBT. It is produced through photosynthesis (i.e. growth) in plants and by metabolic reactions and growth (i.e. cell reproduction) in animals. It is detected in most organic materials in plants, animals and soils. A second form of OBT which is more loosely bound to P, N and S atoms is called exchangeable OBT.

The behaviour of OBT (both forms) in the environment is not particularly well understood. For example, its distribution in natural ecosystems is very heterogenous. Nevertheless OBT is increasingly recognized as being more significant than HTO in understanding tritium's behaviour in the environment. (Kim et al, 2013). This is partly because OBT measurements provide a more accurate representation of tritium in the environment due to its longer retention time than HTO. (Kim and Roche, 2012)

OBT can be incorporated into all biochemical compounds, including amino acids, sugars, starches, lipids and cell structural materials: it therefore has longer retention times than tritiated water which only has a biological half-life of about 10 days. Some biomolecules are very long-lived, e.g. phospholipids in nerve cells and the DNA and RNA macromolecules. These longer retention times result in OBT's greater radiotoxicity than tritiated water. The ICRP has recommended an OBT ingestion exposure coefficient 2.3 times greater than that for HTO[5]. However much evidence suggests it should be at least 5 times or more greater (Fairlie, 2008).

Following a single HTO intake, the current ICRP model assumes 3% is bound as OBT and "may be neglected". But Trivedi et al (1997) estimated that up to 9% is bound as OBT. Animal studies also indicate that OBT levels must be considered – essentially because OBT is cleared from the body much more slowly than HTO. Commerford et. al (1982) found, after a transient HTO exposure to mice, tritium remained bound to DNA and histone 8 weeks later. They concluded that the OBT doses from them would exceed HTO doses overall.

The same goes for chronic exposures except more so. Commerford, Carsten and Cronkite (1977) found most of the tritium dose came from OBT 2 to 3 days after stopping chronic HTO administration to mice. Rogers (1992) concluded OBT was the principal determinant in tritium doses to mice following chronic HTO exposure. More recently, Kim et al (2013a) discussed the OBT contribution to tritium exposures from chronic tritium releases to air. They compared 11 studies whose mean OBT contribution to total tritium exposures was 21%. In other words, any estimates of HTO exposures from SRBT emissions should be multiplied by the factor 5/4.

Longevity of OBT in the environment

Eyrolle-Boyer et. al (2014) stated that OBT levels can persist in the environment for several decades. They found that terrestrial biomass pools, contaminated by global atmospheric fallout from nuclear weapons testing in the 1950s and 1960s constituted a significant delayed source of OBT, resulting in an apparent enrichment of OBT levels compared to HTO. This finding helps explain OBT/HTO ratios greater than 1 observed in areas not affected by industrial radioactive wastes. This finding supports the findings by Ichimasa (1995) of long-term raised OBT levels near Chalk River following chronic HT releases.

[5] ICRP dose coefficients for adults are 1.8×10^{-11} Sv/Bq for tritiated water and 4.2×10^{-11} Sv/Bq for OBT.

A more recent study (Thompson et al, 2015) has emphasised the importance of OBT in the environment. It stated that, as soil acts as a repository for decaying organic matter, OBT soil concentrations represents long-term reservoirs of past tritium releases. It added "Our data support the mounting evidence suggesting that some parameters used in environmental transfer models approved for regulatory assessments should be revisited to better account for the behavior of HTO and OBT in the environment and to ensure that modelled estimates (e.g. plant OBT) are appropriately conservative." Unfortunately, these parameters have not been revisited by the CNSC.

APPENDIX B. UNCERTAINTIES IN "DOSE" ESTIMATES

SRBT and CNSC reports contain tables with dose estimates to members of the public: these are invariably very small. However these do not explain that these are estimates not measurements and may contain large uncertainties.

How these dose estimates are derived is not widely understood by scientists, and usually not at all by members of the public. In fact, the method is complicated, as they are derived using many computer models in sequence, with the median value from each model being plugged into the next model and so on. Although there are many smaller sub models, the main models include:

- environmental transport models for radionuclides, including weather models
- human metabolism models for nuclide uptake, retention and excretion
- dose models which estimate doses from internally retained nuclides, and
- risk models

A major source of uncertainty is that we often do not know where radionuclides wind up inside the body after inhalation/ingestion. It is often assumed they are uniformly distributed - but this there is no way of proving this.

Each of the above model results will contain uncertainties which have to be combined to gain an idea of the overall uncertainty in the final dose estimate (Fairlie, 2005). Further uncertainties are introduced by unconservative radiation weighting factors and tissue weighting factors in official models (Fairlie, 2007a). The cumulative uncertainty in dose estimates could be very large as formally accepted by the UK Government's CERRIE Committee in 2004 (www.cerrie.org) particularly for internal emitters.

APPENDIX C: INCREASED INCIDENCES OF CANCER NEAR NPPS

Recent epidemiological studies indicating increases in child leukemias near NPPs in Europe [are] ~~is~~ of relevance to the SRBT situation as both NPPs and SRBT emit relatively large amounts of tritium.(For example, the annual average for tritium emissions from German nuclear power stations in 2003 (a representative year) was 0.53 TBq - much lower than the 79 TBq from SRBT in 2014.)

In the late 1980s and early 1990s, several UK studies revealed increased incidences of childhood leukemia near UK nuclear facilities. Recent epidemiological studies have reopened the child leukemia debate.

The most important of these is the KiKK study (*Kinderkrebs in der Umgebung von Kernkraftwerken* [translated as: 'Childhood Cancer in the Vicinity of Nuclear Power Plants']. Spix et. al (2007) and Kaatsch et. al (2008) found a 60% increase in solid cancer risk in embryos and a 120% increase in leukemia risk among children under 5 years living within 5 km of all German nuclear reactors. The KiKK findings are important because it was a large well-conducted study, because it was scientifically rigorous, because its evidence was very strong and because the German Government, which had commissioned the study, confirmed the researchers' findings.

The KiKK study is presently the subject of much debate in scientific communities. It is too early to provide an explanation for the increased cancers, although there is evidence to implicate radiation exposures with cancer effects. One hypothesis, (Fairlie, 2014) proposes that infant leukemias are a teratogenic effect of *in utero* exposures to radiation from intakes of radionuclides during fetal development in pregnancies. The German study suggests that exposures from NPP emissions to embryos/foetuses in pregnant women living nearby may be much larger than currently estimated. For example, haematopoietic tissues (i.e. blood-forming cells) are known to be more radiosensitive in embryos and foetuses than in adults. Also, children, particularly in the first six years, undergo rapid development. The combined immaturity of children's nervous systems and blood-forming systems make them particularly vulnerable to chronic radiation exposures.

Official organizations have found it difficult to accept that the large cancer increases near NPPs are due to radioactive emissions. This is mainly because their "dose" estimates from NPP emissions are too small by factors of 100 to 1000 times to explain the observed increases in risks. This of course assumes that official dose estimates and risk models are correct and without uncertainties. Importantly, the UK Government CERRIE Committee in 2004 www.cerrie.org concluded the opposite.

TECHNICAL ANNEXES

ANNEX A. ACRONYMS AND ABBREVIATIONS

AECB	former Atomic Energy Control Board (now CNSC qv)
Bq	becquerel (SI unit of radioactivity)
CERRIE	UK Committee Examining the Radiation Risks of Internal Emitters
Ci	curie (US unit of radioactivity)
COMARE	UK Committee on the Medical Aspects of Radiation in the Environment
CNSC	Canadian Nuclear Safety Commission
DDREF	dose and dose-rate reduction factor
DRL	derived release limit
DNA	deoxyribose nucleic acid
EC	European Commission
EPA	US Environmental Protection Agency
EU	European Union
Gy	gray (unit of absorbed radiation dose)
HTO	tritiated water
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
LET	lineal energy transfer (energy transferred per unit length of track)
LNT	linear no-threshold (model of radiation's dose-effect relationship)
LSS	Life Span Studies of the Japanese bomb survivors
NEA	Nuclear Energy Agency of the OECD
NCI	US National Cancer Institute
NPP	nuclear power plant
NRC	US Nuclear Regulatory Commission
NRPB	former UK National Radiological Protection Board
OBT	organically bound tritium
OPG	Ontario Power Generation Ltd
rad	US unit of absorbed radiation dose
rem	US unit of radiation dose
SI	Systeme Internationale
SRBT	SRB Technologies (Canada) Inc
Sv	sievert (SI unit of equivalent or effective radiation dose)
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WHO	World Health Organisation

ANNEX B. SYSTÈME INTERNATIONALE (SI) UNITS

E = exa	= 10^{18}	d = deci (one tenth)	= 10^{-1}
P = peta	= 10^{15}	c = centi (one hundredth)	= 10^{-2}
T = tera (one trillion)	= 10^{12}	m = milli (one thousandth)	= 10^{-3}
G = giga (one billion)	= 10^{9}	µ = micro (one millionth)	= 10^{-6}
M = mega (one million)	= 10^{6}	n = nano (one billionth)	= 10^{-9}
K = kilo (one thousand)	= 10^{3}	p = pico (one trillionth)	= 10^{-12}

Common examples are:

PBq	= petabecquerel (one million billion becquerels)	= 10^{15} Bq
TBq	= terabecquerel (one trillion becquerels)	= 10^{12} Bq
GBq	= gigabecquerel (one billion becquerels)	= 10^{9} Bq
mSv	= millisievert (one thousandth of a sievert)	= 10^{-3} Sv
µSv	= microsievert (one millionth of a sievert)	= 10^{-6} Sv
nSv	= nanosievert (one billionth of a sievert)	= 10^{-9} Sv

ANNEX C. GLOSSARY OF COMMON RADIATION TERMS

Absorbed dose — Quantity of energy imparted by ionising radiation to unit mass of matter such as tissue. 1 Gy = 1 joule per kilogram.

Activity — rate at which radioactive substances decay. Unit – the becquerel (Bq).
1 Bq = 1 disintegration per second.

Annual limit of intake (ALI) — The amount of material inhaled or ingested in 1 year that would result in a committed effective dose of 20 mSv.

Beta particle — An electron emitted by the nucleus of a radionuclide.

Decay — The process of spontaneous transformation of a radionuclide. The decrease in the activity of a radioactive substance.

Decay product — A nuclide or radionuclide produced by decay. It may be formed directly from a radionuclide or as a result of a series of successive decays through several radionuclides.

Dose — General term for quantity of radiation. See absorbed dose, effective dose, equivalent dose.

Dose factor — committed effective dose resulting from the inhalation or ingestion of 1 Bq of a given radionuclide. Unit - sievert per becquerel, symbol - Sv/Bq.

Effective dose — The quantity obtained by multiplying the equivalent doses to various tissues and organs by the tissue weighting factor appropriate to each and summing the products. Unit sievert, symbol Sv.

Equivalent dose — The quantity obtained by multiplying the absorbed dose by the appropriate radiation weighting factor to allow for the different effectiveness of the various ionizing radiations in causing harm to tissue. Unit sievert, symbol Sv.

Gamma ray — A discrete quantity of electromagnetic energy, without mass or charge.

Half-life — The time taken for the activity of a radionuclide to lose half its value by decay.

Ionisation — The process by which a neutral atom or molecule acquires or loses an electric charge. The production of ions.

Ionising radiation — Radiation that produces ionisation in matter.

Nuclear fission — The process in which a nucleus splits into two or more nuclei and energy is released.

Radionuclide — An unstable nuclide that emits ionizing radiation when it decays.

Risk factor — The probability of fatal cancer or leukaemia per unit effective dose.

Sievert — See effective dose.