Tritium Hazards:
Report Prepared on behalf of Passamaquoddy Recognition Group Inc.

Dr Ian Fairlie PhD, MSc, BSc
Consultant on Radioactivity in the Environment
115 Riversdale Road
LONDON N5 2SU
United Kingdom

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Executive Summary

I prepared this expert report on behalf of the Passamaquoddy Recognition Group Inc to review New Brunswick Power's application for a further licence to operate its reactor at Point Lepreau, New Brunswick.

Tritium (^{3}H) is the radioactive isotope of hydrogen. Reports from several international agencies recognise that tritium is an unusually hazardous radionuclide.

Annual tritium releases from the Point Lepreau reactor are very large in comparison with other nuclear reactors and have been increasing in recent years. According to New Brunswick Power's EIA, local residents receive radiation exposures from tritium. This is from ingested tritium, inhaled tritium, and tritium absorbed through skin. These intakes increase the probability of cancer and other radiogenic diseases. No measurements are made of HTO and OBT levels in people living near Point Lepreau.

Epidemiology studies at other Canadian facilities emitting tritium have indicated increases in cancer and congenital malformations. However no epidemiological studies near Point Lepreau have been commissioned or carried out to ascertain levels of adverse health effects in the local population. In addition, evidence from cell and animal studies, and radiation biology theory, indicates that radiogenic effects 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. The evidence from these studies is applicable to tritium's radiation exposures at Point Lepreau NPS.

These high emissions, high levels of radioactive contamination, and increased estimates of cancer risks together mean that tritium poses worrying health risks to workers and to people near St John NB.

Under the Precautionary Principle, I recommended no further license be issued for the Point Lepreau NPS. In more detail, I also recommend

i. **CNSC should apply the Ontario Government's ODWAC recommended maximum of 20 becquerels per litre (Bq/L) for drinking water**
ii. **CNSC should recommend its own design guide[1] for ground water of 100 Bq/L for tritium.**
iii. **Urine tests and non-invasive bioassay tests should be carried out on volunteers from the community to ascertain local HTO and OBT levels.**
iv. **Residents within 10 km of the plant should be advised to avoid consuming locally-grown foods including honey from hives, wild foods such as mushrooms and berries, and produce from their gardens.**

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[1] Canadian Nuclear Safety Commission. An Update on Tritium Contamination in Groundwater at SRBT. March 2010 (e-doc 3523400)

v. **In view of the discussion in Appendix C, 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 remain ignorant of them.**

vi. **NB Power employees, especially young workers and women workers, should be informed about the hazards of tritium.**

Tritium Hazards

A. Introduction

1. I prepared this report on behalf of the Passamaquoddy Recognition Group Inc to review New Brunswick Power's application[2] for a further licence to operate its reactor at Point Lepreau, New Brunswick. This report is focussed on tritium - the radioactive isotope of hydrogen – because the extremely large releases of tritium from Point Lepreau are a cause of concern. This report summarizes current understandings of the biological and health effects of exposures to tritium and comments upon the risks faced by local citizens. In particular, new evidence on increased radiation risks is discussed.

2. I am a Canadian citizen resident in the United Kingdom. I am an independent scientist who has specialised on radioactivity in the environment with degrees in chemistry and radiation biology. My doctoral studies at Imperial College, UK and Princeton University, US examined nuclear waste technologies. One of my areas of expertise is the dosimetric impacts of nuclear reactor emissions. I have authored many articles in peer-reviewed journals on epidemiology studies of child leukemias near radiation facilities and on the hazards of radionuclides. I have been an employee of, and advisor to, UK Government departments, the European Parliament, the World Health Organisation, environmental NGOs, and UK local authorities. Between 2000 and 2004, I was head of the Secretariat to the UK Government's Committee Examining the Radiation Risks of Internal Emitters (CERRIE). Of particular relevance to these CNSC hearings, I have authored numerous scientific articles on the hazards of tritium which have been published in peer-reviewed journals, as follows

- Fairlie I. (2014) A hypothesis to explain childhood cancers near nuclear power plants J Environ Radioact. 133 (2014) pp 10- 17
- Fairlie I. Hypothesis to Explain Childhood Cancer near Nuclear Power Plants. Int J Occup Environ Health 2010;16:341–350.
- Fairlie I. The hazards of tritium – revisited. Medicine, Conflict and Survival. Vol 24:4. October 2008. pp 306 -319. http://www.informaworld.com/smpp/content~content=a904743144~db=all~order=page
- Fairlie I. RBE and w_R values of Auger emitters and low-range beta emitters with particular reference to tritium. Journal of Radiological Protection. 2007; 27:157-168. http://www.iop.org/EJ/abstract/0952-4746/27/2/003/
- Fairlie I. Tritium Hazard Report: Pollution and Radiation Risk from Canadian Nuclear Facilities. Published by Greenpeace Canada. June 2007. http://www.greenpeace.org/raw/content/canada/en/documents-and-links/publications/tritium-hazard-report-pollu.pdf
- Fairlie I**.** Tritium Hazard Report on Cernavoda 3/4: Environment Impact Analysis: Report for Greenpeace Romania. Published by Greenpeace Central Europe. November 2007.

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[2] https://www.nuclearsafety.gc.ca/eng/the-commission/hearings/cmd/pdf/CMD22/CMD22-H2-1.pdf

http://www.greenpeace.ro/uploads/articole/Cernavoda%20Report%20for%20GP%20Central%20Europe.pdf

- Fairlie I. Uncertainties in Doses and Risks from Internal Radiation. Medicine, Conflict and Survival, Vol 21:2. pp 111 – 126. (2005) http://www.informaworld.com/smpp/content~content=a714004320~db=all~order=page
- Fairlie I. Tritium: The Overlooked Nuclear Hazard. The Ecologist. 22 No 5. 228-232 (1992)

B. Tritium Releases

3. In recent years, Point Lepreau has continued to release large quantities of tritium - see Table 1. These are of the order of hundreds of terabecquerels per year (TBq/a – see radioactivity units at Annex B). One terabecquerel is 10^{12} Bq, or one trillion Bq, ie 1,000,000,000,000 Bq - a very large amount or radioactivity. The Point Lepreau reactor releases more tritium than any other single nuclear reactor in Canada. This is a matter of some concern. It is also worrisome that, in recent years, tritium releases at Point Lepreau have been steadily increasing.

4. Tritium is released mainly in two forms – tritium gas (HT) and tritiated water or water vapour (HTO), in other words radioactive water or radioactive water vapour. As a result of molecular exchange - explained in the BOX 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, i.e., radioactive water, to be 25,000 times more radiotoxic than HT, radioactive hydrogen gas. 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.

BOX. 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).

5. A third form of tritium exists - organically bound tritium (OBT). Official models for tritium do not address exposures from ingesting tritium incorporated into organic compounds (Peterson and Davis, 2002).

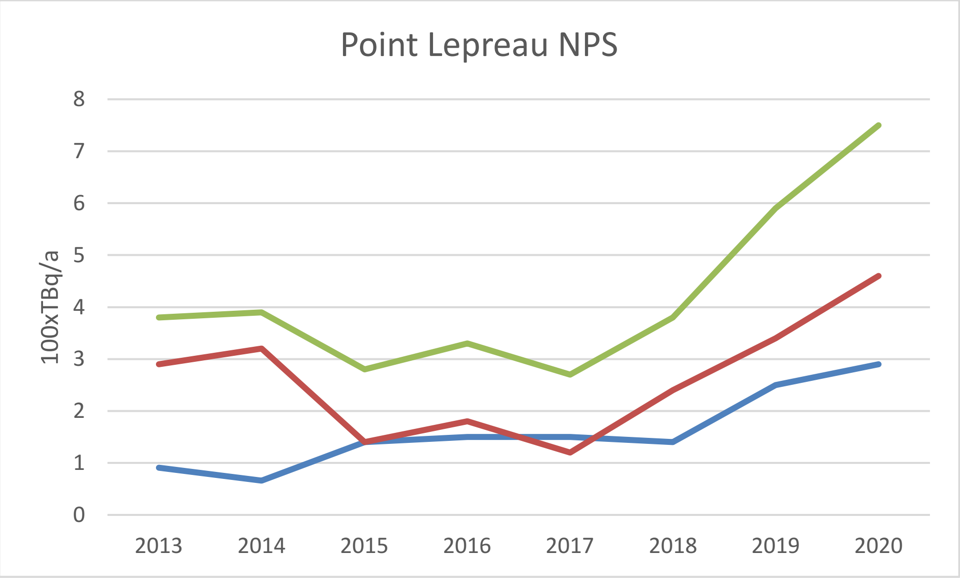
6. Annual tritium releases from Point Lepreau are set out in table 1 – 100 x TBq/a - correct to two figures. No data have been published for 2021 releases.

TABLE 1

Year	Tritium emissions to air 100xTBq/a	Tritium discharges to sea 100xTBq/a	Total Tritium releases 100xTBq/a
2021	-	-	-
2020	2.9	4.6	7.5
2019	2.5	3.4	5.9
2018	1.4	2.4	3.8
2017	1.5	1.2	2.7
2016	1.5	1.8	3.3
2015	1.4	1.4	2.8
2014	0.66	3.2	3.9
2013	0.91	2.9	3.8

7. These data are presented in chart form in figure 1 below. It can be seen that tritium total releases have been increasing each year since 2017.

Figure 1. Tritium releases at Point Lepreau



Legend
Red = tritium discharges to sea.
Blue = tritium releases to air.
Green = combined tritium releases to sea and air

8. Point Lepreau's annual air emissions are higher than those from other CANDU nuclear reactors and significantly higher than other reactor types around the world – see Table 2.

TABLE 2. Annual tritium air emissions per reactor from various nuclear power facilities

Facility	**Number of operating reactors**	**TBq/a per reactor** (average)
Point Lepreau -New Brunswick (2020)	1	290
Bruce -Ontario (2019)	8	100
Pickering -Ontario (2019)	6	80
Darlington- Ontario (2019)	3	75

Dungeness B (AGR) UK in 2016	2	6
Sizewell B (PWR) UK in 2018	1	3
Dungeness A (Magnox) UK in 2010	1	1.3
German NPPs in 2015 (average)	16	0.5

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

9. Air 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 result in higher environmental concentrations than water discharges do. 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: ie >100,000 times more effectively. This is not to accept that dilution is the solution to pollution - it isn't - it merely reflects existing (unsatisfactory) 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.

10. It is correct that emissions of noble radioactive gases including Kr-85 and xenon isotopes from Point Lepreau NPS are also relatively high. However these nuclides are chemically inert and are not thought to be particularly toxic to humans. For example, when they are inhaled, they are exhaled straight back out without interacting significantly with the body – unlike tritium. Skin doses will also occur but these are estimated to be very low, in comparison with tritium doses.

11. The EIA published[3] by NB Power has admitted that local populations would be exposed to radiation as a result of the tritiated water vapour in the air, drinking water in local wells, diving for sea urchins, harvesting clams and dulse, and eating local seafood. The EIA could also have added exposures from the harvesting of local wild foodstuffs such as mushrooms, berries and other fruits, gardening vegetables, and the harvesting of seaweeds for fertiliser. These are all important matters for indigenous peoples who take pride in living close to their lands and seas. The radioactive poisoning of their lands and seas is deeply offensive.

12. The above data on the high, and annually increasing, tritium releases from Point Lepreau NPP are worrisome. It is well understood that the older a reactor becomes the higher its tritium inventories in the moderator and cooling circuits. And ergo- the higher its annual tritium releases. Without a means of removing tritium, its inventory and releases will continue to increase.

13. These worries are exacerbated by NB Power's proposed 25 plant life extension from 2022 to 2047. The reactor started operations in 1982 with retubing between 2008 and 2012. CNSC is apparently minded to allow NB Power to operate its reactor for another 20 years to 2042, see the CNSC's response. However this would mean that the reactor would have operated for 60 years which is unacceptably long as it was originally designed with an approximately 30 year lifespan.

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C. The Hazards of Tritium

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[3] https://www.nbpower.com/media/1490873/2021-06-30-application-by-new-brunswick-power-for-the-renewal-of-170-1-2022.pdf

15. In order to understand and appreciate tritium risks to local people, we need to discuss tritium's properties in 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 incorrect and perceptions are slowly 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.

16. 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.

17. These reports all 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 its location within cellular molecules, e.g. DNA

18. 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*."

19. For these reasons, tritium presents severe challenges to conventional dosimetry and health-risk assessments. The unfortunate reality is that official models for tritium DO NOT take the above properties of tritium into account.

20. Also, tritium in its elemental form diffuses through most containers with relative ease, 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 liquid swabs have to be taken which are then sent to specialist laboratories to determine their tritium concentrations.

21. When tritium is emitted from Point Lepreau NPS, it travels via multiple environmental pathways to humans including through air. It cycles in the environment, because tritium atoms swap quickly with stable hydrogen atoms in the biosphere and hydrosphere. This means that all 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.

22. When tritium is emitted into the atmosphere, local residents and nuclear workers can become tritiated by skin absorption, and by breathing in contaminated water vapour. Because tritium is quickly transferred to food and water, workers and the public will also get tritium by eating contaminated food and drinking liquids (Inoue,1993). 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.

23. This is termed organically bound tritium (OBT) which is non-uniformly distributed and is retained in our bodies for longer periods than tritiated water. Radiation exposures from OBT are therefore higher than from HTO. The longer people are exposed to tritiated water emissions (ie in terms of the numbers of days), the higher their levels of OBT become until, in the case of repetitive exposures lasting years, equilibria is established between HTO and OBT levels.

24. Unfortunately, the dose 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's models only consider single not chronic exposures so that their model estimates of OBT levels become very unreliable.

25. It can be seen that tritium has unusual properties which suggest that it should be regarded as hazardous in radiation protection advice. Unfortunately, these properties are not recognised by the ICRP and authorities, such as CNSC, 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 1,000 times smaller than that for Cs-137. 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 or trebled.

26. The major problem, in a nutshell. Is that CNSC and NB Power exclusively use unreliable ICRP dosimetry models for tritium. 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

27. In recent years, 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.

28. 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.

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

30. 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).*"

31. The phrase "*statistically compatible*" in the above quote is a jargon phrase used in statistics. It does not mean 'the same or similar'. It means that the confidence intervals in the two studies overlapped – quite 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 fold, or a 47% increase - a significant amount.

32. Similarly for leukemias. The more recent study in the INWORKS 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)".*

33. The actual increase in point estimates here was 5.8 fold or 580%. This very large increase was 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.

34. 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 which only consider cancer risks - but they should be.

35. 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.

36. 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.

37. The new INWORKS radiation studies remain pertinent to whether a further license extension should be given to NB Power 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.**

38. Because these findings are far-reaching in their implications, it is necessary to double-check the INWORKS studies. A recent exhaustive review (Hauptmann et al, 2020) of these studies examined possible sources of bias[4] and confounding[5]. 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. 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. CNSC's Initial Response

39. In January 2022, the CNSC published its initial comments[6] on NB Power's application. CNSC staff agreed with NB Power's conclusions that the overall risk to the environment and human health from Point Lepreau NGS was acceptably low, and they concluded that NB Power maintained an adequate licensing basis for continued safe operations.

40. However the CNSC's views are fundamentally based on the low doses estimated to local people from the radioactive discharges at Point Lepreau and these estimates are flawed and unreliable as explained next.

F. Unreliable Dose Estimates

41. NB Power's EIA estimates of very low radiation doses to local residents from the plant's discharges and emissions are unreliable as they contain very large uncertainties. The

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

[5] Confounding occurs when an extraneous factor causes inaccuracy in the estimated measure of an association, eg smoking in a lung cancer study

[6] https://www.nuclearsafety.gc.ca/eng/the-commission/hearings/cmd/pdf/CMD22/CMD22-H2.pdf

EIA dose estimates should not be used to justify further licenses to operate the Point Lepreau reactor. There are several reasons for this statement.

42. The first is that NB Power's EIA does not explain how its dose estimates are derived. This process is complex and poorly understood by many people: the process is explained in Appendix B below. Another reason is that no monitoring exists of any health outcomes among local residents. For example, no epidemiological health studies have been carried out in the area. In addition, no monitoring of HTO and OBT levels in local residents is carried out.

43. Third, unsafe limits including DRLs are derived from the unacceptably high level of tritium in drinking water - 7,000 Bq per litre - currently used by Health Canada. This is extremely lax given the current recommendation[7] of the Ontario Drinking Water Advisory Council (ODWAC) of 20 Bq per litre. It is recommended that this safer recommended tritium limit should be used throughout these documents. See table 3 on official drinking water limits in use.

Table 3. Official Tritium (HTO) limits in drinking water

Agency	**Tritium limit** (Bq per litre)
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

44. The current Canadian limit for tritium in drinking water of 7,000 Bq//L is unsafe compared with the limits set by all other agencies. Even the current US limit[8] is 740 Bq/l, and is based on a maximum dose to the public of 40 μSv per year from drinking water. The European Commission's limit is 100 Bq per litre. The US State of Colorado has set a standard[9] for tritium in surface water, of 18.5 Bq/l, and the US Department of Energy specified the Colorado state action level for tritium in surface water in its clean-up program at the Rocky Flats plutonium plant in Colorado. The US State of California recommends a limit[10] of 15 Bq/L. Both limits are based on a 10^{-6} lifetime risk of a fatal cancer, which is the clean-up goal under the US Comprehensive Environmental Response Compensation and Liability Act (CERCLA), commonly known as the Superfund Act.

45. Health Canada's limit for tritium corresponds to a risk of 350 excess fatal cancers per million people which is considerably more lax than the 1 to 10 excess fatal cancers per million normally used in toxicity limits. For example, Health Canada's drinking water objectives for **chemicals** only allow a lifetime risk of 1 to10 fatal cancers per million people. The primary reason for the difference is that the predicted radiogenic cancers are calculated using ICRP dosimetry, which assumes only *one year's* consumption of drinking water. With chemicals, it is assumed that people consume drinking water for their whole lifetime—commonly set at 70 years.

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[7] 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

[8] 20,000 picocuries per litre.

[9] 500 picocuries per litre.

[10] 400 picocuries per litre.

46. In 2009, the Ontario Government's Ontario Drinking Water Advisory Council (ODWAC) published a comprehensive report[11] which recommended that the tritium limit in drinking water should be tightened to 20 Bq per litre. The difference between 7,000 and 20 Bq/l was partly due to ODWAC's choice of a stricter fatal cancer risk factor of 10^{-6} and partly due to its use of a lifetime instead of a first year risk. Interestingly, the 2009 ODWAC report's recommendations were identical to a 1994 report by the Ontario Government's Advisory Council on Environmental Standards on tritium. In other words, two separate Governmental committees with different scientific memberships over 15 years apart came to very similar conclusions. However the Federal Health Canada department remains in denial of these reports. This report also recommends that the ODWAC/ACES limit should be used.

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

47. It is an obvious step to look for evidence of ill health at other areas where people are exposed to radiation. However many epidemiology studies are ecologic studies (Wakefield, 2008), that is, quick studies which look at health or population statistics and not at 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.

48. Below are some ecologic studies near Canadian nuclear facilities.

Leukaemia in children near Candu nuclear facilities

49. 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.

50. 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

51. 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.

52. 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

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[11] http://www.odwac.gov.on.ca/reports/minister%20reports/minister_reports.htm

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.

53. 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

54. 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

55. 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)

56. 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)

57. 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)

58. 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”.

59. All of the above studies 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, in particular the small sizes of some of these studies mean they were simply unable to detect effects with statistical

certainty. But lack of statistical significance should NOT be used as a reason for dismissing these studies. See https://www.ianfairlie.org/news/uk-and-us-scientists-call-for-statistical-significance-tests-to-be-dropped-in-health-studies/

60. Despite the positive numerical findings in all these studies, their published conclusions were invariably negative, often on flimsy or untenable grounds such as inconsistent results, too many comparisons, lack of an overall pattern, etc. In the case of the Lane et al study, it was because the observed increases in cancer incidence were greater than predicted by 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. This is poor science,

61. Instead the above studies, taken together, provide indicative evidence for increased health effects from exposure to tritium. This could be confirmed with larger, case-control or cohort studies, or by meta-studies, but the CNSC has refrained from commissioning such studies or meta-studies.

H. CONCLUSION

62. Several reports by 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. Epidemiology studies at 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 above.

J. RECOMMENDATIONS

63. It is recommended that

vii. CNSC should apply the Ontario Government’s ODWAC recommendation of 20 becquerels per litre (Bq/L) for drinking water
viii. CNSC should implement its own design guide[12] for groundwaterfor tritium of 100 Bq/L for tritium levels in wells near Point Lepreau NPS.
ix. Urine tests and non-invasive bioassay tests should be carried out on volunteers from the community to ascertain local HTO and OBT levels.
x. Residents within 10 km of the plant should be advised to avoid consuming locally-grown foods including honey from hives, wild foods such as mushrooms and berries and produce from their gardens.
xi. In view of the discussion in Appendix C, 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 remain ignorant of them.
xii. NB Power employees, especially young workers and women workers, should be informed about the hazards of tritium.

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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 (ie growth) in plants and by metabolic reactions and growth (ie 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[13]. However much evidence suggests it should be at least 5 times or more greater (Fairlie, 2008).

Following a <u>single</u> 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 <u>chronic</u> 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 Point Lepreau NPS 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.

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 behaviour 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.

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

APPENDIX B. UNCERTAINTIES IN “DOSE” ESTIMATES

The EIA and CNSC reports contain 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 of relevance to the Point Lepreau NPS situation as both emit relatively large amounts of tritium.

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 (ie 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.

APPENDIX D. CURRICULUM VITAE FOR Dr IAN FAIRLIE

Address	115 Riversdale Road LONDON N5 2SU United Kingdom
Email:	ianfairlie@gmail.com
Website:	www.ianfairlie.org
Nationality	Canadian

Education

1993 -1997	Imperial College of Science, Technology and Medicine Centre for Environmental Technology London SW7 2PE, UK • PhD (health impacts of radioactive waste technologies)
1996	Princeton University Centre for Energy and Environmental Studies Princeton NJ 08544, USA • Visiting Fellow (health impacts of radioactive waste technologies)
1990-1992	Medical College of St Bartholomew's Hospital Department of Radiation Biology Charterhouse Square London EC1M 6BQ UK • MSc Radiation Biology
1962-1966	University of Western Ontario London, Ontario, Canada • BSc Chemistry
1957-1962	Sarnia Northern Collegiate Institute and Vocational School Sarnia, Ontario, Canada • Honours Graduation Certificate (Grade 13)

Consultancies

Ontario Clean Air Alliance, Toronto, Ontario, Canada
Canadian Environmental Law Association, Toronto, Ontario, Canada
City Government of Vienna, Austria
International Agency on Research on Cancer, Lyon, France
SAGE Peterborough, Ontario, Canada
Greenpeace Canada
Greenpeace Europe
European Parliament
UK Nuclear Free Local Authorities
International Physicians for the Prevention of Nuclear Warfare, Germany
International Society of Doctors for the Environment, Italy and
Physicians for Global Survival, Canada

EMPLOYMENT

2000-2005
UK Government Committee Examining the Radiation Risks of Internal Emitters(CERRIE) www.cerrie.org
Department for the Environment, Food and Rural Affairs
Nobel House, 17 Smith Square
LONDON SW1P 3JR, UK

- Head of Secretariat of Ministerial Committee on internal radiation risks

1996-2000
UK Food Standards Agency
Radiological Safety Unit
Ergon House
17 Smith Square
LONDON SW1P 3JR, UK

- Higher Scientific Officer in the Radiological Safety Unit on regulation of nuclide discharges and nuclear waste management programmes in UK

1992-1996
Imperial College of Science, Technology and Medicine
Centre for Environmental Technology
48 Prince's Gardens
LONDON SW7 2PE, UK

- PhD researcher and lecturer on radiation exposures from radioactive waste technologies

1975 -1989
Trades Union Congress
Great Russell Street
LONDON WC1B 3LS, UK

- Research Officer in occupational health and safety

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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
rad	US unit of absorbed radiation dose
rem	US unit of radiation dose
SI	Systeme Internationale
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}
P = peta = 10^{15}
T = tera (one trillion) = 10^{12}
G = giga (one billion) = 10^{9}
M = mega (one million) = 10^{6}
K = kilo (one thousand) = 10^{3}
d = deci (one tenth) = 10^{-1}
c = centi (one hundredth) = 10^{-2}
m = milli (one thousandth) = 10^{-3}
μ = micro (one millionth) = 10^{-6}
n = nano (one billionth) = 10^{-9}
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.