



Oral Presentation

Submission from the Ian Fairlie

In the Matter of

Ontario Power Generation Inc., Pickering Nuclear Generating Station

Request for a ten-year renewal of its Nuclear Power Reactor Operating Licence for the Pickering Nuclear Generating Station

Commission Public Hearing – Part 2

June 2018

Exposé oral

Mémoire de Ian Fairlie

À l'égard de

Ontario Power Generation Inc., centrale nucléaire de Pickering

Demande de renouvellement, pour une période de dix ans, de son permis d'exploitation d'un réacteur nucléaire de puissance à la centrale nucléaire de Pickering

**Audience publique de la Commission –
Partie 2**

Juin 2018

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Submission: Tritium Hazards at Pickering NPP

Re: Pickering Nuclear Generating Station Licence Renewal

May 7 2018

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Executive Summary

Ontario Power Generation (OPG) has applied for a 10 year extension of its license at the Pickering NGS near Toronto from 2018 to 2028. OPG plans to operate its 6 remaining Pickering reactors until the end of December 2023. Annual tritium emissions to air from Pickering NGS are the largest from any civil nuclear facility in the world. The station lies within the boundary of Greater Toronto with a population of 6 million people with 2.2 million people living within 30 kilometres of the plant.

Environmental measurements of tritium in air, soils, foodstuffs, and water near the Pickering NGS facility indicate pervasive, widespread, long-term tritium contamination.

Major international agencies recognise that tritium, the radioactive isotope of hydrogen, has unusual properties marking it as an unusually hazardous nuclide. It is extremely mobile in the environment, contaminates all biota including humans in nearby areas and binds with organic matter to form organically bound tritium (OBT) with long residence times in the body making it more radiotoxic than tritiated water.

This report estimates that annual tritium intakes for local residents amount to about 120,000 Bq. This is mainly from inhalation and skin absorption of tritiated water vapour. This estimate is conservative as it assumes residents neither consume their own garden produce nor drink from their own wells. These annual amounts are 20 times greater than the natural background intake of 6,000 Bq/a. More hazardous OBT intakes will also occur.

These radioactive intakes increase the probability of cancer and other radiogenic diseases in nearby exposed people. Embryos, fetuses, babies, infants and children are more radiosensitive than adults and females more than males. Due to long latency periods, these cancers and diseases will arise in the future. These probabilistic effects mean all exposed people in and near Toronto will have been handed “negative” lottery tickets, and that at random some will get cancer in future. However it is not possible to ascertain in advance who will be affected.

Considerable evidence from cell and animal studies, and radiation biology theory indicates that radiogenic effects will occur. Indicative (‘ecological’) epidemiology studies of Canadian facilities emitting tritium reveal increases in cancer and congenital malformations. This is backed by strong evidence from recent, large-scale, statistically powerful epidemiology studies from other countries.

The Canadian studies should have been confirmed with case-control or cohort studies. The absence of such studies over the past few decades is a notable lapse in the duties of public health bodies in the Toronto area, especially Toronto’s public health officials and its Board of Health, to protect the health of Toronto citizens.

According to the Nuclear Safety and Control Act, the aims of the CNSC include “To regulate the development, production and use of nuclear energy....to (i) prevent unreasonable risk.... to the health and safety of persons....” This written submission concludes that tritium and other releases from Pickering NPP constitute a serious continuing health risk to the residents of Greater Toronto. The massive scale of the tritium releases – the highest in the world from a civil facility - their longevity, and their hazardous nature mean that their risks are “unreasonable” under any definition of the word.

OPG’s application should be declined and the station closed as soon as technically feasible.

A. Overview

1. OPG has applied for a 10 year extension of its license at Pickering NGS, currently thought to be the largest source of tritium in the world¹. Tritium is the radioactive isotope of hydrogen with a half-life of 12.3 years. This independent report summarises current understandings of the biological and health effects of exposures to tritium and comments on the risks faced by local citizens near Pickering NGS.

2. I am a Canadian citizen currently resident in the United Kingdom. I am an independent consultant 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. My area 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 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 the hearing, I have written numerous scientific articles discussing the hazards of tritium emissions, including the following:

- 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.
<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 from Pickering NGS

4. For many years, Pickering NGS has been emitting very large quantities of tritium – the radioactive isotope of hydrogen. See Table 1. In recent years these emissions have been increasing. These emissions are of the order of hundreds of terabecquerels per year (TBq/a)². One terabecquerel is 10^{12} , or one trillion becquerels - a very large amount of radioactivity. This tritium is released mainly in two forms – tritiated hydrogen gas (HT) and tritiated water vapour (HTO) however for regulatory purposes the two source terms are

¹ Although tritium is created in the upper atmosphere by cosmic ray bombardment, annual tritium releases from Canadian heavy water reactors comfortably exceed the amounts created naturally.

² A becquerel is the unit for radioactivity and means one nuclear disintegration per second.

combined. Both are invisible gases, both are odourless, mainly tasteless and the emissions are silent. They are not detectable by any of our senses, but they are nevertheless still very hazardous³.

Table 1
Annual Tritium Emissions to Air and to Lake Ontario from Pickering: TBq per year

Year	HTO emissions to Air	HTO discharges to Lake Ontario	Total
2016	680	320	1,000
2015	540	370	910
2014	530	340	870
2013	430	310	740
2012	530	290	820
2011	550	310	860

Source: OPG: Results of Environmental Monitoring Programs
https://www.opg.com/news-and-media/Reports/2016_EMP_Report.pdf

5. These annual emissions to air are significantly higher than other reactor types, as shown in table 2.

Table 2
Annual Tritium air emissions from various NPP sources

Facility	Year	TBq/a
Pickering	2016	680
Dungeness B (AGR) UK	2013	12
Sizewell B (PWR) UK	2013	3
Dungeness A (Magnox) UK	2013	2.6
German NPPs (BWRs, PWRs)	2003	0.5 average

6. In their risk assessments, many people and some environmental groups often consider waterborne risks to be more important than airborne ones. But we are deceived by the domination of our visual sense: because we can SEE water and not air we often assume waterborne risks are more important.

7. But, in fact, aerial nuclide emissions are considerably more dangerous than liquid nuclide discharges to Lake Ontario. This is for several reasons. First, air emissions are usually greater than water discharges – see table 1. Second, individual radiation doses and collective radiation doses from air emissions are both generally much larger than from discharges to water.

8. Third, the vital factor in estimating radiation doses to local people is the nuclide concentration in environmental materials. Again, contrary to what many people – including environmentalists - think, air emissions result in much higher environmental concentrations than water discharges.

9. The reason is lake dilution. A cubic metre of lake water contains about a million grams of water which dilutes radioactive contaminants far more effectively than a cubic metre of air with a mass of ~5 grams: i.e., >200,000 times more effectively. This is not to

³ An analogy here is bacteria. Everyone knows that they exist even though they are invisible to the naked eye, and not detectable to any of our senses.

accept that dilution is the solution to pollution. It isn't: it merely reflects the fact of existing (ill-advised) methods of disposing nuclear wastes.

10. A fourth reason is that air concentrations are often presented in numerically small units of Bq per cubic metre of air. But to assess the hazard of an air concentration of tritium we need to know how much nuclide there is in the air's water vapour rather than the air itself. If we assume a reasonable value of 5 ml of water per cubic metre of dry air (Davis et al, 1996), then an observed concentration of, say, 5 Bq per m³ in air (which appears innocuous) actually means a concentration of 1,000 Bq per litre of water vapour (which is not innocuous).

11. Accordingly this report deals mainly with air emissions. This is not to suggest that water releases can be disregarded: they certainly must be considered as well and have been discussed by others elsewhere.

C. Tritium levels in environmental samples

12. The CNSC carries out an annual sampling program of environmental materials (air, soil, grass, vegetation, food) near Pickering. Illustrative values for 2017 are noted below in table 3. The reported concentration values for tritium vary considerably from very low levels of a few Bq to hundreds of Bq per litre or per kg. In order to comply with the Precautionary Principle, we have reported in table 3 the highest observed values as these are the values we should be most concerned about. These tritium concentrations clearly indicate that some areas near Pickering are highly contaminated with tritium. However much larger tritium concentrations were observed in the past, as seen in table 4.

13. The source of these levels of tritium is the air emissions⁴ from the six remaining reactors at Pickering NGS. These reactors continuously emit to air both forms of tritium (elemental tritium and tritiated water vapour) 365 days a year. As a general rule, the closer residents live to the station, the higher the HTO concentrations, but this is not a hard and fast rule, as much depends on the strength and direction of the winds and the weather conditions during emissions. Sometimes radioactive plumes can travel for dozens of kilometres. After the Chernobyl accident in 1986, its radioactive plumes circumnavigated the world.

Table 3. Illustrative tritium concentrations near Pickering from CNSC measurements in 2017

Sample	Concentration	Sample Number
grass/vegetation	178.7 Bq/kg	PP01-V01
grass/vegetation	12.2 Bq/kg (OBT)	PP01-V01
grass/vegetation	520.4 Bq/kg	PP07-V05
air	4.9 Bq per m ³	PP07-A03
water vapour in dry air	approx. 1,000 Bq/litre	PP07-A03
Lake Ontario water	30.4 Bq per litre	PP05-W02
Lake Ontario water	14.8 Bq per litre	PP02-W01

source: <http://nuclearsafety.gc.ca/eng/resources/maps-of-nuclear-facilities/iemp/pickering.cfm#table>

Table 4. Tritium (HTO) concentrations near (<5 km) Pickering from Osborne (2002) study – read from figures 1 and 2 below

Sample	Concentration
air	1 – 30 Bq per m ³

⁴ Tritium discharged as liquid water to Lake Ontario only contributes negligible amounts to land-based contamination away from Pickering NPP. A problem remains with frequent leaks and spills of highly tritiated water to the ground in the immediate vicinity of Pickering NPP. This problem is the subject of other submissions to the CNSC.

water vapour in dry air (assuming 5 ml of water vapour per m ³)	approx. 200 - 6,000 Bq per litre
⁵ moisture in vegetables, fruits, cereals	80 – 6,000 Bq per litre
⁵ moisture in vegetation	200 – 3,000 Bq per litre
⁵ moisture in meats, milk, eggs	20 - 90 Bq per litre

source: Tritium in the Canadian Environment: Levels and Health Effects. Report RSP-0153-1.
Prepared for the Canadian Nuclear Safety Commission under CNSC contract no. 87055-01-0184 by
Ranasara Consultants and Richard Osborne.

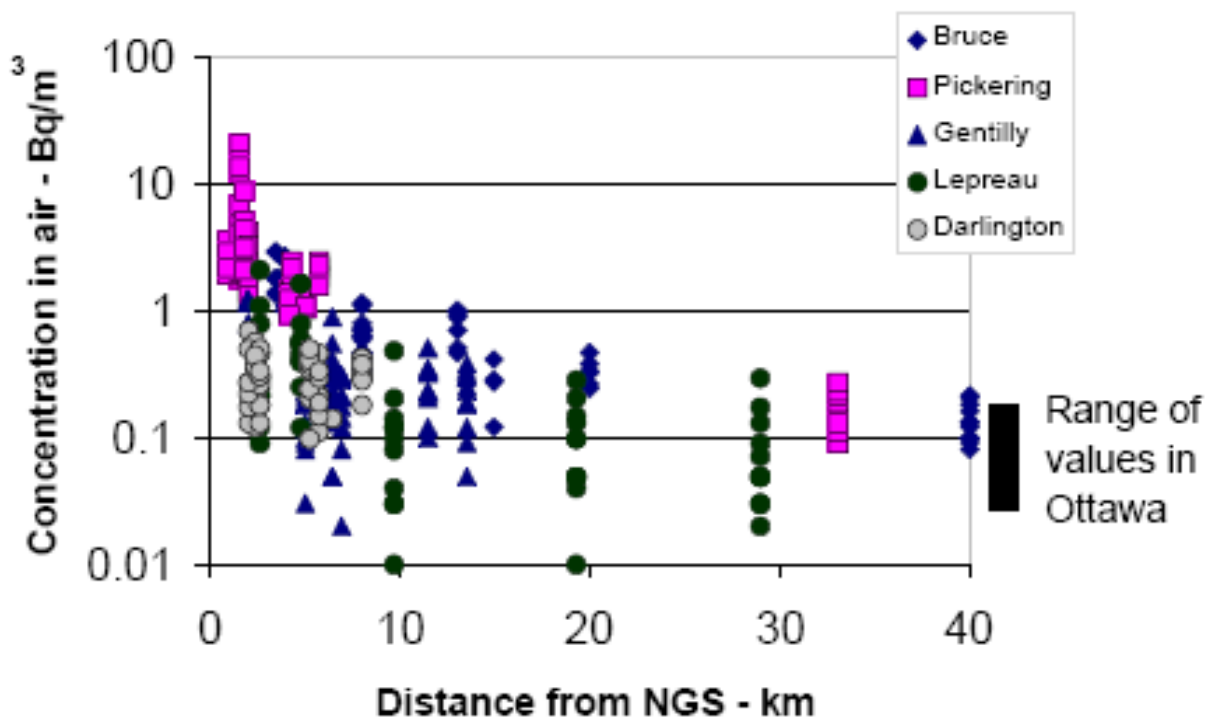
D. Are these Tritium Levels Safe?

14. To assess risks to local people, the official approach is to estimate tritium’s radiation doses in mSv units, but major difficulties exist with tritium’s dosimetry (Fairlie, 2007). The result is that – as the UK Government’s CERRIE Report (2004) concluded - estimates of internal doses and risks from tritium are unreliable.

15. Instead of radiation doses in mSv, this report uses amounts of radioactivity in Bq: in other words it will estimate tritium’s Bq annual intakes and concentrations in local people and assess the resulting likely levels of risks. This approach has been used by other scientists (Osborne, 2002). It consists of four steps as follows. In order to measure tritium’s Bq annual intakes and concentrations in local people, four steps need to be carried out.

16. **STEP 1.** Tritium emissions will result in raised tritium air concentrations near Pickering as indicated in Figure 1 which shows tritium concentrations near Canadian nuclear power stations. We use the following graphs to see what actually occurs and what the trends are.

Figure 1. Tritium air concentrations near nuclear facilities



⁵ It is understood (from personal communications) that most of the values in figure 2 were measured near Pickering NPP

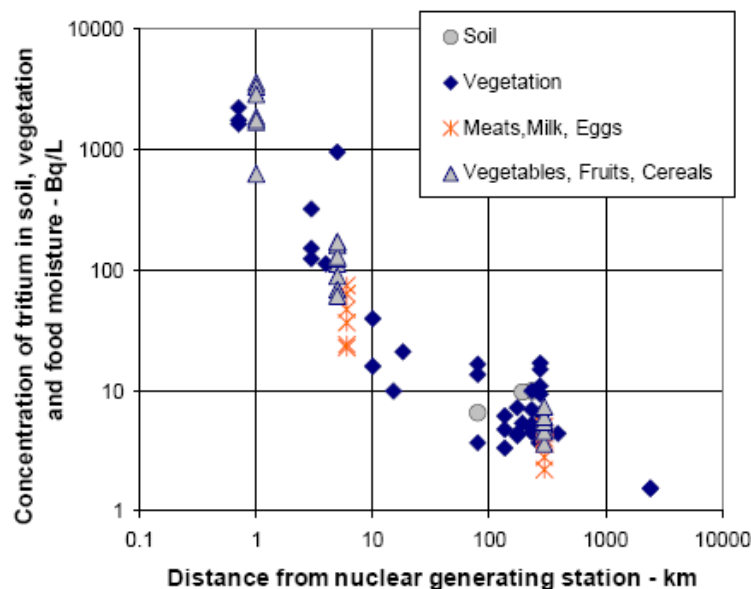
17. The above graph indicates that the closer people live to a NGS, the higher the air concentrations of tritium. The range of air concentrations is very large⁶. The highest air concentration (30 Bq per cubic metre) is 3,000 times greater than the lowest air concentration (0.01 Bq per cubic metre).

18. However, as stated above, we need to know tritium concentrations in the air's water vapour rather than the air itself. If we assume a reasonable value of 5 grams of water per cubic metre of dry air (Davis et al, 1996) then observed tritium water vapour concentrations in air a few km from Pickering in the graph vary between 1 and 6,000 Bq per litre.

19. These data are point measurements. Air concentrations vary considerably and large spikes of tritium emissions may occur during outages for repairs and occasionally for refuelling. Pulsed tritium emissions could result in heavy labelling of cells being formed in the embryos and fetuses of nearby pregnant women at that particular moment. This fear was expressed decades ago by Professor Edward Radford in his 1979 testimony to the Ontario Government's Select Committee on Ontario Hydro Affairs: Hearings on The Safety of Ontario's Nuclear Reactors, July 10 1979. [See http://www.ccnr.org/tritium_2.html#scoha]. This provides the basic mechanism for the hypothesis explaining the large observed increases in leukemias in subsequent children born near nuclear reactors (Fairlie, 2014). Radionuclide spikes are discussed further in Appendix D of this report.

20. **STEP 2.** The second step is that high tritium air concentrations result in raised tritium concentrations in foodstuffs, as seen in figure 2.

Figure 2. Tritium concentrations in foodstuffs near Canadian nuclear facilities



⁶ The logarithmic scale used on the Y-axis compresses the data range.

21. **STEP 3.** The next step is to estimate tritium intakes in local people living near (within a few km of) the Pickering facility. Local people will be exposed by:

- ingesting foodstuffs contaminated with tritiated water vapour, including from local markets and fruit stalls, and
- inhaling tritium gas and tritiated water vapour, and
- drinking tritiated water and milk, and
- skin absorption of tritiated water vapour

22. This report uses the method adopted by Osborne et al (2002), and estimates annual HTO and OBT uptakes in people living close (within 5 km) to Pickering plant. The calculations are set out in BOX 1 and BOX 2.

23. This analysis indicates that local people living near the Pickering plant will have high annual intakes of tritium. Therefore tritium concentrations in local people should be measured using urine analyses for HTO and non-invasive bioassays such as nail clippings and hair clippings for OBT. As far as is known, this sampling does not occur.

24. Using the Osborne et al (2002) method, this report estimates annual HTO uptakes in people living close (within 5 km) to Pickering plant to be 120,000 **Bq/year** to two significant figures. Note this estimate assumes that people do not consume their own garden produce nor drink water from their own wells. If it did, the intakes would be greater. However it assumes people obtain one third of their food from locally-sourced foods.

BOX 1 – Estimate of Annual HTO Intakes by residents near Pickering NPP

To calculate annual tritium intakes by residents near Pickering, we multiply together two parameters. First, average annual dietary, breathing and eating rates for adult Canadians (see table 4). And second, recent HTO concentrations in these media as measured by CNSC (2017) <http://nuclearsafety.gc.ca/eng/resources/maps-of-nuclear-facilities/iemp/pickering.cfm>

For the first parameter, average breathing and eating rates for adult Canadians have been compiled by Health Canada (1994) from a national habit and diet survey. These values, together with values for drinking water intakes from Health Canada (2001) are shown in table 4.

25. Some uncertainty exists about the estimated tritium concentrations in food and water, but these amounts are the smallest of the four intake categories listed below. Even if incorrect, they would not significantly affect the overall estimate.

Table 4. Annual food, water and air intakes by adult Canadians

Water Source	Average Intake
Total foods	490 kg per year
Drinking water, made-up drinks	550 litres per year
Air	8,400 cubic metres per year

Source; Health Canada (1994).
Daily rates are multiplied by 365 days per year [from Health Canada (2001) guide]

Table 5. Estimate of annual HTO intakes in people near Pickering NPP (<5 km)

Source of HTO	Intake per year	HTO Concentration	HTO Bq/year
Air Inhalation	8,400 m ³	5.9 Bq/m ³ *	50,000
Skin absorpt'n	60%** of inhalation intake	5.9 Bq/m ³ *	30,000
Food	33% of 490 kg = 160 kg	180 Bq/kg ***	29,000
Water in drinks	550 litres	14.8 Bq/L ****	8,000

* Sample code PP07-A03

** from Osborne, 1966.

***Assumptions: 1/3 of food from local market; no home-grown food. Sample code PP01-V01

****Sample code PP02-W01

TOTAL ~117,000

BOX 3 – Estimation of annual OBT Intake

To calculate annual OBT intake by residents near Pickering NGS, we multiply together three parameters.

First, average annual dietary intake for adult Canadians (490 kg/a). Second, the parameter of 1/3 the fraction of food from local markets. Third, the average OBT concentration in foods as measured by CNSC (2017) of 12.2 Bq per kg (sample PP01-V01) to arrive at 1200 Bq/a.

26. Our 120,000 Bq/a estimate is higher than but reasonably consistent with estimates near other tritium-contaminated sites. For example, Osborne et al (2002) estimated an annual HTO uptake of 67,000 Bq in people within 5 - 10 km of nuclear reactors. Trivedi et al (1997) calculated annual HTO uptakes of 20,000 Bq in adults living in Deep River, Ontario (10 km from the AECL Chalk River reactor).

27. For OBT, our calculation in Box 3 above using tritium in food data from Thompson et al (2015) indicates that people within 2 km of Pickering would also annually ingest approximately 1,200 Bq of OBT in their food. This compares with the Osborne et al (2002) OBT estimate of 7,000 Bq/a in people living within 5 - 10 km from nuclear reactors, and the Trivedi et al (1997) estimate of 800 Bq/a OBT in people living 10 km from the AECL Chalk River reactor. The OBT level is also larger than annual intake of 350 Bq OBT from background (Osborne et al, 2002), about 4 times higher. Table 6 sets out the comparisons for HTO and OBT annual intakes. It shows that the Bq uptake estimates are reasonable as they are commensurate with other Canadian scientific estimates.

TABLE 6. Annual Tritium Intakes near various sites- Bq/a

SOURCE	EXPOSED PEOPLE	HTO	OBT
This report	>5 km from Pickering NGS	120,000	1,200
Trivedi et al, 1997	10 km from Chalk River reactor	20,000	800
Osborne et al, 2002	5-10 km of Canadian NPPs	67,000	7,000

28. **STEP 4.** The last step is to address the original question in this section, i.e., are these annual tritium levels hazardous? To answer this we need a yardstick, which we construct in the next paragraph.

29. It is widely accepted that an annual risk of one in a million (10^{-6}) of fatal cancer from an exposure to a toxic agent is acceptable. Using this acceptable risk level, the Ontario Government's Ontario Drinking Water Advisory Council (ODWAC, 2009) http://www.odwac.gov.on.ca/reports/minister_reports.htm recommended a maximum concentration for tritium in drinking water of 20 Bq/L. If we multiply this concentration by Health Canada's average annual water intake (see table 4) of 550 litres for adult Canadians, we get **~10,000 Bq** of tritiated water per year, correct to one significant figure. This may be used as an approximate limit for an annual intake of tritium. This should not be quoted as "safe" or "acceptable" but it does give an indication of a limit for an annual intake of tritium.

30. It is true the yardstick depends on the value chosen for the drinking water limit, and different views exist on this - table 7 shows the various limits in play. In our view, it is reasonable to use the authoritative limit recommended twice by Ontario Government agencies, ACES and ODWAC –ie 20 Bq/L.

Table 7. Tritium Limits in drinking water - Bq per litre

AGENCY	DATE	TRITIUM LIMIT BQ PER LITRE
Ontario Government (Advisory Committee on Environmental Standards)	1994	20
EC (European Commission,1998)	1998	100
US State of Colorado target	2008	18
US State of California target	2008	15
Ontario Government (ODWAC,2009)	2009	20
CNSC design guide for groundwater (CNSC,2011)	2011	100

31. The 120,000 Bq per year uptake we estimate for nearby people is 12 times higher than our estimated annual limit of 10,000 Bq/a.

32. It is concluded from this analysis that people living within 5 km of the Pickering NGS are being exposed annually to hazardous levels of tritium. We estimate that each year they will take up much more tritium than they would normally take in from background exposures. This will result in added radiation exposures which will inevitably increase their cancer risks.

D. The Hazards of Tritium

33. So, we've got our rough limit for an acceptable annual intake of tritium of 10,000 Bq of tritiated water per year, but because of tritium's unusual properties, the situation is much more complicated. In order to assess the risks to local people from tritium uptakes and exposures, we need to discuss tritium's properties in some depth. In the past, nuclear scientists had tended to minimise the risks from tritium and to regard it as being only 'weakly' radiotoxic.

34. This view is now changing: in the past decade, 10 major reports on tritium have been published by radiation safety agencies including in the UK (AGIR, 2008), Canada (CNSC, 2010a; 2010b) and France. In the latter country, the Autorité de Sûreté Nucléaire published a comprehensive White Paper on tritium (ASN, 2010) and the Institut de Radioprotection et Sûreté Nucléaire published six major reports on tritium (IRSN, 2010a; 2010b; 2010c; 2010d; 2010e; 2010f). In particular, the reports all noted that tritium exposures resulted in internal

radiation doses whose estimation contained uncertainties which could render them unreliable.

35. The most comprehensive of all these reports on tritium was published by the UK Government's senior Advisory Group on Ionising Radiation (AGIR, 2008). This report strongly recommended that tritium's hazard (ie, its radiation weighting factor) should be doubled from 1 to 2. However 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.

36. These reports all draw 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 H₂O) 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 binding with cell constituents to form organically-bound tritium (OBT) with heterogeneous distribution in humans, and
- g. its short-range beta particle, meaning that its damage depends on location within cellular molecules, e.g. DNA

37. For these reasons, tritium presents multiple challenges to conventional dosimetry and health risk assessment. Also, in its elemental form, tritium diffuses through most containers, including those made of steel, aluminium, concrete and plastic. In the oxide form, tritium is generally not detected by commonly-used survey instruments (Okada et al, 1993).

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

Molecular Exchange

CNSC reports commonly distinguish between elemental tritium (HT) and tritiated water vapour (HTO) emissions. However 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 the former AECL (Davis et al, 1997).

In more detail, 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 on average about 10^{-15} seconds to swap.

As the most common hydrogenous material in the environment is water in liquid or vapour forms, this means that tritium in 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 includes vegetables and fruit in exposed market stalls and shops (Inoue, 1993)

39. Humans can become tritiated by skin absorption, by inhalation of contaminated water vapour, and by ingestion of contaminated food and water. When tritium enters the body, it is readily taken up through exchange mechanisms and used in metabolic reactions and in cellular growth. Over 60 per cent of the body's atoms are hydrogen atoms and every day about five per cent of these 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 nucleoproteins such as DNA and RNA.

40. This is termed organically bound tritium (OBT) which is non-uniformly distributed and is retained for longer periods than tritiated water. ICRP dosimetric models assume the opposite – that tritium is homogeneously distributed in the body/tissue/ organ of interest and is relatively quickly excreted. Exposures from OBT are therefore higher than from HTO. The longer people are exposed to tritiated water emissions, the higher their levels of OBT become until, in the case of exposures lasting years, equilibria is established between HTO and OBT levels. Again ICRP dosimetric models assume the opposite: only single exposures are considered so that OBT levels remain low.

41. Tritium's unusual properties suggest that it should be regarded as hazardous in radiation protection advice. Unfortunately these properties are not recognised by the ICRP and authorities which take their lead from the ICRP. This is discussed further in Appendix F.

42. The main controversy is over the ICRP's radiation weighting factor (w_R) for tritium of 1. See Fairlie (2007a). The debate has lasted for decades. 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, 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 power plants, nuclear weapons production plants in the past and proposed fusion facilities more recently.

E. Organically Bound Tritium

43. The form of organically bound tritium (OBT) which is bound to carbon atoms is produced through photosynthesis in plants and by metabolic processes in animals. It is detected in most organic materials such as plants, animals and soils. A second form of OBT which is more loosely bound to P, N and S atoms is called exchangeable OBT.

44. The behaviour of OBT (both forms) in the environment is not well understood, e.g. it is very heterogeneously distributed in natural ecosystems. 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).

45. 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 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 HTO⁷. However much evidence suggests it should be at least 5 times greater (Fairlie, 2008).

⁷ ICRP dose coefficients for adults are 1.8×10^{-11} Sv/Bq for tritiated water and 4.2×10^{-11} Sv/Bq for OBT.

46. 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 more slowly than HTO. Commerford et al (1982) found, after a transient HTO exposure, tritium remained bound to DNA and histone 8 weeks later. They concluded that the OBT doses from them would exceed HTO doses overall.

47. 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. 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 PICKERING NGS emissions should be multiplied by 1.2.

Longevity of OBT in the environment

48. Eyrolle-Boyer et al (2014) have suggested 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.

49. A 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.”

F. Tritium Concentrations in Food and Environment

50. The overall conclusion from the CNSC environmental data is that the local area around Pickering NGS remains highly contaminated with tritium. 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.

G. Epidemiological Evidence of Risks

51. Because of methodological limitations, epidemiology studies are often a blunt tool for discovering whether adverse effects result from radiation exposures. These limitations include:

- under-ascertainment: ie 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.

52. Many epidemiology studies are ecologic studies, that is, quick studies which look at health or population stats and not individual data. Their findings are usually regarded as indicative 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 time-spans.

53. We need to be aware of the many factors to be taken into account when considering epidemiology studies, and we need to interpret their findings with care. Readers are advised to lower their expectations when considering the following studies - which are all ecologic.

Leukaemia in children near Candu nuclear facilities

54. Clarke et al. (1989, 1991) studied mortality and incidence of childhood leukaemia near nuclear facilities in Ontario. The first report (Clarke et al. 1989) 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.

55. 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

56. 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.

57. 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.

58. 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

59. 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

60. 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)

61. This study showed statistically significant elevated rates of several radiogenic cancers near the NPPs east of Toronto. Leukemia incidences in males were 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 was at pains to conclude that the overall findings did not indicate a pattern.

Lane Study (Lane et al, 2013)

62. 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 no overall pattern could be seen.

Wanigaratne et al Study (2013)

63. 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”.

64. The above studies mostly show increased ill effects, some statistically significant and others with borderline statistical significance. Some studies showed no increases for specific illnesses, but 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.

65. Despite the 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 etc.

66. With this in mind, our conclusion is that the above studies taken together provide suggestive evidence for increased health effects from exposure to tritium. These could be confirmed with 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 <http://www.ianfairlie.org/news/recent-evidence-on-the-risks-of-very-low-level-radiation/>

H. CONCLUSIONS AND RECOMMENDATIONS

67. Annual tritium emissions from Pickering NGS are very large compared to most nuclear power stations in the world.

68. 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 in nearby areas including humans to ambient levels, and binds with organic matter to form OBT with long residence times in the body making it more radiotoxic.

69. Environmental measurements of soils, foodstuffs, wells and sewage near the facility indicate pervasive tritium contamination. Tritium levels in environmental samples are erratic but do not appear to be declining.

70. We estimate that annual tritium intakes for local residents (who neither consume their own garden produce nor drink from their own wells) amount to about 120,000 Bq, mainly from inhalation and skin absorption of tritiated water vapour in the vicinity of Pickering. These amounts are higher than the annual limit of 10,000 Bq/a estimated by this report. OBT exposures will also occur.

71. These intakes increase the probability of cancer and other diseases in exposed people. It is not possible to ascertain in advance who will be affected but embryos, fetuses, babies, infants and children are more radiosensitive than adults, and females more than males. These cancers will arise in the future because they have long latency periods in most

cases. Probabilistic effects mean exposed people will have each been handed “negative” lottery tickets, and some tickets will come up in future, ie fatal cancers will occur.

72. Epidemiology studies of 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 <http://www.ianfairlie.org/news/recent-evidence-on-the-risks-of-very-low-level-radiation/>

73. It is recommended that the OPG’s license for Pickering NPP should not be extended past August 31, 2018, and that steps be taken to close the Pickering NGS as soon as possible. In addition the following should be implemented immediately-

- i. CNSC should ensure the recommended limit of the Ontario Government’s ODWAC of 20 becquerels per litre (Bq/L) for drinking water is met for all Toronto citizens.
- ii. CNSC should implement its own design guide for groundwater for tritium of 100 Bq/L for tritium levels in wells near Pickering NGS.
- iii. Urine tests and non-invasive bioassay tests should be carried out on volunteers from the community to ascertain HTO/OBT levels.
- iv. Local residents should be advised to avoid consuming locally-grown foods and water from local wells.
- v. 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 be ignorant of them.
- vi. OPG employees and their spouses should be informed about the hazards of tritium.

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APPENDICES

APPENDIX A. NEW INFORMATION ON RADIATION'S EFFECTS

OPG's application and the CNSC's responses fail to discuss the new information of non-targeted (ie on DNA) effects of radiation. These effects include genomic instability where effects occur many generations later, and bystander effects where adjacent cells not hit by radiation are damaged, and mini-satellite mutations.

The New Effects of Radiation

These "new" effects were in fact discovered about 18 years ago⁸, for example, Khadim et al (1992) discovered genomic instability effects in 1992. However they have not been widely discussed in the popular press. Indeed, there is little public awareness of these effects in Canada. This is partly due to their absence in mainstream reviews such as those published by the former NRPB, USEPA, ICRP and BEIR (and only recently by UNSCEAR in 2009). Nevertheless these new effects have resulted in a "paradigm shift" in scientists' views as evidenced by the articles in the Box A-1 below, and they continue to be intensively discussed among radiation biologists.

BOX A-1: Untargeted effects: a paradigm shift?

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Importance for risk estimation

Non-targeted effects are important in assessing radiation risks for a number of reasons.

First, they do not rely on structural damage to DNA or genetic structures for their effects, the classic explanation for radiation's effects. This is a vital matter because, up to recently, radiation protection authorities had relied on the classic theory to lend support to their estimates for radiation risks derived from epidemiology. That is, the classic theory of

⁸ Some scientists (Baverstock, 2000; Baverstock and Belyakov, 2005) consider that non-targeted effects had in fact been observed in cell/animal studies many years previously but had been unrecognised as they fell outside the then accepted "paradigm" of radiation's effects.

radiation's effects (ionisation-induced DNA strand breaks) buttressed⁹ current estimates of radiation risks. The new effects do not do this.

Second, these effects occur at very low doses of radiation. In fact, some effects occur after the passage of a single alpha particle through a cell (resulting in a less than 10 mGy dose to the cell).

A third reason is that, as many genome instability effects and bystander effects are present in malignant cells, most scientists now think that genomic instability is a precursor to cancer.

Annex C of the UNSCEAR 2009 report stated (paragraph 158) "it would seem prudent to consider the implications of non-targeted and delayed effects of radiation exposure when considering models of radiation carcinogenesis, particularly at low doses." And "...models of radiation-induced carcinogenesis should incorporate both direct and indirect effects when evaluating radiation risks."

When faced with the uncertainties posed by non-targeted effects, it would be wise to apply the Precautionary Principle. One means of doing this would be to recognise publicly that radiation risks are likely to be greater than currently estimated and to add a safety factor – by increasing current official estimates of doses by factor of 10.

APPENDIX B. UNCERTAINTIES IN "DOSE" ESTIMATES

Various CNSC reports contain tables with doses to members of the public: these are invariably very small.[However these reports 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. 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 realistic 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.

⁹ For example, in dose terms, radiation's effects were related to the chances of damaging genes: the smaller the target gene, the larger the dose required to cause damage. Thus, effect and dose were related through radiation damage in irradiated DNA.

APPENDIX C. OTHER PROBLEMS WITH THE CONCEPT OF “DOSE”

Indeed, there are problems with the concept of “dose” itself; including its various definitions and units (Sv and Gy): for example the sievert (Sv) unit has two different definitions. The “dose” concept may give reliable results when **external** radiation (eg X-rays or gamma rays) is physically measured by counting devices such as common Geiger counters, but not with **internal** radiation which cannot be measured except with whole body monitors, that is, very rarely. It is noted that in the parallel field of chemical toxicity, “dose” is not used: concentrations per gram are used instead.

Since almost all of the radioactivity from Pickering emissions results in internal radiation, this report does not rely on radiation “dose” but instead uses concentrations of radionuclides measured in becquerels (Bq) per kg or per litre. When a radionuclide decays inside the body, it gives off radiation (alpha, beta or gamma) which results in body tissues being irradiated. The unit of radioactivity is the becquerel (Bq) defined as one atomic disintegration per second. Bq concentrations have the merit of being measurable: ie, one can make relatively good measurements of how much radioactivity is inside a person (eg, from bioassays). These measurements are considerably more reliable than “dose” estimates particularly for internal emitters.

APPENDIX D. SPIKES IN NUCLIDE RELEASES

Brief exposures to high concentrations are more hazardous to residents near Pickering NGS than chronic exposures to low concentrations. This is partly due to environmental factors (eg wind direction) and partly to metabolic factors: exposures to high concentrations result in higher internal doses due to the labelling of dividing cells and cell proteins at high levels particularly with radioactive tritium inhaled/ingested from Pickering emissions.

In 2011, the UK Government’s National Dose Assessment Working Group published guidance on “Short Term Releases to the Atmosphere” http://www.ndawg.org/documents/NDAWG-2-2011_000.pdf. This states that “...exposures from the assessment of a single realistic short-term release are a factor of about 20 greater than doses from the continuous release assessment.” An older German study (Hinrichsen, 2001) indicated that these exposures could amount to a factor of 100 greater.

The potential for increased harm from short-term releases is partly related to the duration of release. Short-term releases produce narrow plumes, whereas longer durations produce wide plumes. Widths vary non-linearly as a fractional power of duration times with the result that individual doses (per Bq emitted) increase with shorter releases. The reason is also partly due to the fact that spikes result in higher concentrations of OBT in environmental materials and in humans.

APPENDIX E: INCREASED INCIDENCES OF CANCER NEAR NPPs

Recent epidemiological studies indicating increases in child leukemias near NPPs in Europe [are] is of relevance to the Pickering situation as it emits large amounts of tritium.(For example, the annual average for tritium to air emissions from German nuclear power stations in 2003 (a representative year) was 0.53 TBq - much lower than the 680 TBq from Pickering in 2016.)

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 being the KiKK study (*Kinderkrebs in der Umgebung von Kernkraftwerken* - '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 has been the subject of much debate in scientific communities. It is too early to provide a definitive 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 nuclear plant emissions to embryos/foetuses in pregnant women living nearby may be much larger than currently estimated. For example, haematopoietic (ie blood-forming) tissues 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 radiation exposures.

Official organizations have found it difficult to accept that the large cancer increases near nuclear facilities are due to radioactive emissions. This is mainly because their "dose" estimates from NPP emissions are too small by factors of 100 to 1000 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 F: NEED FOR A HAZARD INDEX OF RADIONUCLIDES

The hazards of tritium raise the question of how radiation protection authorities classify dangerous radionuclides: the short answer is that they do not.

There is no comprehensive hazard index for radionuclides as there is for chemicals. Many scientists consider there should be one as the properties of nuclides would be better recognised thus helping regulators to gauge the harmful impact of nuclides on health. Kirchner (1990) has suggested the following characteristics of nuclides should be included in a hazard index:

- large releases to environment;
- widespread use (i.e., industrial/military/research/medical uses);
- rapid nuclide transport, solubility and cycling in biosphere;
- global distribution and resulting large collective doses;
- diverse pathways of exposure (i.e., soil ingestion);
- rapid molecular exchange rates (that is, fast uptake by humans);
- large percentage uptake to blood following intake;
- organic binding in biota;
- long-biological half-life in humans;
- long radiological half-life;
- long nuclide decay chains with radiotoxic daughters;
- high radiotoxicity - the dose coefficient of the nuclide (i.e., the radiation dose imparted from the disintegration of one atom of the nuclide).

Tritium is unique in that it exhibits so many of these characteristics – in fact, ten of the above twelve. Most other nuclides exhibit only three or four traits. This raises a further question – how do radiation authorities currently gauge the relative hazards of nuclides? The answer is by estimating radiation “dose” from the nuclide to an exposed person from one disintegration of that nuclide. As discussed in Appendices B and C, using ‘dose’ alone ignores the first six of the above twelve characteristics. In other words, ‘dose’ is an inadequate indicator of hazard for most radionuclides, and for tritium, it’s a very poor one.