APPENDIX I: HEALTH BASE REGULATION, ABSORDED DOSE AND EFFECTIVE DOSE

1: Health Based Regulation:

Tritium (^3H) is the radioactive isotope of hydrogen. It is a beta emitter with a maximum decay energy of 18 keV (average 5.7 keV), and a physical half-life of 12.3 years. Tritium is formed naturally through cosmic ray interaction with H in the upper atmosphere and transfers to the troposphere. However emissions from civil and military nuclear facilities considerably exceed natural sources, and in this paper I will consider only man-made tritium. Tritium most commonly occurs as tritiated water (HTO), organically bound tritium (OBT) and elemental tritium gas.

Tritium may be considered a very effective distributor of radioactivity in the environment since it is exceedingly mobile as tritiated water, and can travel everywhere that water can travel. The human body, all tissues and cells, are composed of about 70% water. About 80% of the atoms in the human body are hydrogen atoms, which can be replaced by tritium. Tritium has multiple pathways to humans: via inhalation and drinking water, through ingestion of food, and absorbed through the skin.

The International Atomic Energy Agency, depending on ICRP, ranks tritium based only on its disintegration energy, which is low in comparison with other known radionuclides. However, the very large emissions of tritium both from hydrogen bomb explosions and from the CANDU nuclear reactors, makes this dose calculation important for humans and their environment. The potential for binding with important molecules in living organisms adds to concerns. A major error in the ICRP estimation implies major health and environmental problems!

No one doubts either tritium's ubiquitousness or its radioactivity. Tritium is classified as radioactive, carcinogenic and mutagenic to humans. **The Health Based Goal (HBG) of regulation of tritium is zero.** Permission to pollute with tritium, must be regulated by the ALARA policy: as low as reasonably achievable. Permissible exposure to Tritium must be as close to zero as possible, and must carry a benefit which outweighs the risk.

2: Calculation of Dose from Tritium:

a. Absorbed Dose Depends on Biological Half-life:

Radiation dose depends on the strength of the source and the length of time the person is exposed to the source. It is well know that one's sun exposure results from both the sun's energy reaching the earth (time of day) and the length of time spent exposed to this energy. Therefore, although the physical half-life of tritium in known to be 12 years, it is important when calculating dose to consider its biological half-life, i.e. the time needed for one half of the tritium to be emitted from the body in urine, feces or sweat.

ICRP considers that most of the tritium formed when tritium gas is released into the

environment will be in the form of tritiated water. It assumes that it will be taken up by plants, animals and humans as tritiated water (HTO), and distributed homogeneously with a biological half life of between 6 and 12 days [Ref. 1, 2].

ICRP recognizes an exchange component which binds with organic molecules, (called here OBT 1) with a biological half life between 21 and 76 days, generally accepted as 40 days. In the Exchangeable OBT's (OBT 1), tritium is bound to oxygen, sulfur, phosphorus or nitrogen atoms, to form hydroxides, phosphides and amines.

With chronic environmental HTO exposure, with food web involvement, the two fractions: HTO and OBT 1, become about equal in size. All organic molecules downwind of a tritium (HTO) plume which come in contact with the HTO become tritiated very quickly. This includes all plant and animal species, all water bearing materials and soil, including vegetables and fruit in market places or backyard gardens.

The fixed binding of tritium to a carbon atom of the DNA, called here OBT 2, has a longer biological half life between 280 and 550 days [Ref. 3, 4].

ICRP appears to base OBT half-life calculation on either the cycling time of the carbon, 40 days (which is difficult to document) or a misapplication of research on OBT 1.

The estimate of energy deposited in tissue from tritium, incorporated into the body as tritiated water, according to ICRP, would be as HTO with a 12 day biological half-life for 97% and OBT with biological half-life of 40 days for 3%. The alternative, based on published research, proposed by ECRR [Ref. 5] for chronic exposure is: 43.5% HTO with half-life 12 days; 43.5%; OBT 1, with half-life 40 days and 3% OBT 2 with half-life 550 days. This will increase the ICRP estimate by about a factor of three.

The U.S. EPA in 2001 settled this dispute with the ruling:

> "(EPA) currently takes the view that the more cautious, wider definition of OBT to include any organic matter which contains tritium either exchangeably bound or fixed more firmly to the carbon chain, should be used. This will ensure that any dose assessments will take account of both forms of OBT while uncertainty remains. Indeed, this definition more closely describes the OBT fraction which is measured by current laboratory methods." [Ref. 6]

The OBT 1 includes amino acids, proteins, sugars, starches, lipids, and cell structural material.

In summary, due to longer half-life of tritium in the human body, and the proportion of each of three components (HTO, OBT 1, and OBT 2) the energy deposit of HTO ingested, inhaled or absorbed would be three times higher than that estimated by ICRP methodology.

b. Absorbed Dose with Non-homogeneous Distribution

There is another factor, important for the calculation of the energy deposited in tissue from HTO. Contrary to the ICRP assumption OBT is not uniformly distributed in the tissues of the body. Homogeneity is clearly not true of either OBT 1 or OBT 2, each delivering highly localized doses. The cells at most risk of tritium would be those dividing at the time of exposure and which afterwards were long-lived, replicating the resultant damage, namely: oocytes, embryos and embryonic nerve cells.

Tritiated food is quicker and more effective than HTO in delivering tritium to cells and to the DNA [Ref. 7, 8] Proteins (amino acids) are efficiently incorporated into nucleoproteins and localized doses from tritiated proteins to DNA are four times greater than from HTO.

Because the dose from OBT 1, and OBT 2 is not uniformly distributed and the localized dose can be four times the dose from homogeneously distributed HTO, the effective dose estimate is increased by another factor of three. This means that the current scientific calculation of tritium energy deposited in tissue is nine times greater than that estimated using ICRP methodology.

c. **Effective Dose Equivalent:**

The energy deposited in tissue determines the dose in mGy, and must be converted into mSv, with a relative biological effectiveness (RBE) factor, reflecting its equivalence for cell killing with a comparable dose of 200 kVp X-Ray (the usual reference dose for radiation comparison) or 137 cesium.

In 1980, the Oak Ridge National Nuclear Laboratory in the U.S. mounted a campaign, based on copious evidence, to recognize the RBE of tritium as two. [Ref. 9, 10]. In 1986, a joint committee of ICRP and ICRU (International Commission on Radiation Units) recommended an increase in the quality factor for tritium from one to two for microdosimetric reasons [Ref. 11]. This recommendation was not implemented by ICRP, which insisted on keeping an RBE of one for tritium [Ref. 12]. In 1991 and 1993 [Ref. 13, 14] a comprehensive review of tritium data was developed. Researchers concluded that a radiation weighting factor of three was appropriate for tritiated water (HTO), and that higher RBE's were appropriate for exposure to tritiated nucleotides such as human lymphocytes (a kind of white blood cell).

Combining the effects of chemical change (OBT ! and OBT 2) and biological half-life with the weighting factor of two or three RBE, for the energy deposited in tissue by tritium, one can argue effectively that current ICRP dose calculation, used by CNSC and the Canadian nuclear industries, should actually be about 18 to 27 time higher.

Damage wrought will also be increased by a transmutation effect currently not well understood. A transmutation effect by which the atom formed when tritium has a nuclear disintegration, namely helium, recoils from the emission of the beta particle and has an associated excitation of energy ruptures the bond to the compound to which the former tritium atom had been attached. This process is of special concern when the tritium atom

has been bound to the DNA or DNA precursors, giving it significant mutagenic force. More research is needed to understand this mechanism which enhances the radiation effect especially for OBT 2. Not allowing for this effect makes the present evaluation of dose conservative.

ICRP methodology significantly ignores these contradictory research findings in favor of its minimizing assumptions. This may be due to its protection of the military nuclear program. When the first large hydrogen bomb was exploded over Bikini Atoll in the Pacific, in March 1954, the Great Lakes, 6000 miles away, registered tritium levels of several hundred tritium units. Prior to that explosion tritium was undetectable in the Great Lakes. This reluctance to deal realistically with tritium has proven fortunate for the Canadian nuclear industry since the CANDU reactor releases much more tritium that do American light-water reactors. The faulty (or biased) calculations of ICRP are now benefiting the SRBT facility in Pembroke, at the cost of the health and common good of citizens of Pembroke and the Ottawa Valley.

I would point out for the record, that prevalence of Down's Syndrome was found to be increased by 80% in Pickering (observed 24; expected 12.9 cases) and by 46% at Ajak (observed 14, expected 9.6), a town further from the Pickering Nuclear Station (PNS). This report by the AECB (Atomic Energy Control Board) also found an association between the high tritium releases from PNS and central nervous system anomalies in births at Pickering.

Moreover, It is apparent from the IARC study of Nuclear Workers that radiation related cancers among Canadian workers is higher than that of other nuclear workers receiving the same radiation dose. The study on which this was based, done by Lydia Zablotska, J.P. Ashmore and the Radiation Protection Bureau of Health Canada [Ref. 15] was tested with and without tritium exposure (with ICRP calculations). Researchers were unable to account for the difference. They failed to consider a significant underestimation of the effects of tritium exposure as the cause. The IARC study was a summary of the experience of 400,000 workers at 531 nuclear reactors internationally.

There is evidence that with long term chronic exposure, OBT 1 makes up 50%. In long term mice studies, it was shown that the OBT/HTO ratio after 15 months of HTO feeding was between 0.73 and 1.07 [Ref. 16]. Other animal studies found the long term ratio between 0.85 and 1.5 [Ref. 17, 18, 19], although these animals may have consumed OBT as well as HTO in the natural environment.

A human who died after eight months chronic exposure to tritiated water had tritium constituents of fat and hair (OBT) higher than that in body water at time of autopsy. [Ref. 20] Eight workers at a CANDU reactor station in India were found to have a much larger fraction of OBT than was predicted by ICRP, and the committed dose equivalent was 3.4 times higher than that based on HTO [Ref. 21].

Background tritium levels in humans and plants with long term chronic doses of tritiated water have been found to be about 50% OBT and 50% HTO. [Ref. 22, 23, 24, 25, 26]

In conclusion, two or three are reasonable quality factors for the RBE of tritium. This implies that doses estimated to be 1 mGy and 1 mSv using ICRP methodology, would actually be 9 mGy and 18 to 27 mSv according to well documented research. It would seem conservative to use the factor 20 to represent the true conversion from ICRP calculated doses to more realistic research based effective doses. This would imply the need for reducing the 7,000 Bq/litre water permitted by CNSC to about 350 Bq/litre water.

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