Radionuclides pose a current and sustained threat to the Great Lakes' environment and its inhabitants

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Brief Biography

Cindy Folkers has a Master of Science in Environmental Sciences from Johns Hopkins University and has researched radiation and health issues since 1994. She has written extensively, including essays in two anthologies, and has given numerous presentations focused on radiation's disproportionate impact on women, children and pregnancy.

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[1]Prepared for Canadian Environmental Law Association, and Toxics Free Great Lakes Binational Network

In March 2016, 110 advocacy groups submitted an application under the binational Great Lakes Water Quality Agreement to designate radionuclides as "Chemicals of Mutual Concern" (CMCs) under Annex 3 of that Agreement.[2] Environment and Climate Change Canada and the U.S. Environmental Protection Agency sent that application to each country's nuclear regulatory agency (U.S. Nuclear Regulatory Commission and the Canadian Nuclear Safety Commission) for comment.

Both countries' nuclear regulatory agencies reported back to the environment agencies for their country in 2017. Both nuclear regulatory agencies recommended that radionuclides not be designated as CMC's under the GLWQA.

We are disturbed that the USEPA and ECCC have not also commented on consideration of radionuclides as CMCs. EPA and ECCC have a much better understanding of the GLWQA and the prime responsibility for implementing that Agreement. They also have the most promising frameworks for meeting the GLWQA goals and have significant responsibility environmental contamination from these persistent pollutants - not only for their release, but also their remediation. Yet they appear to have ceded the comment responsibility to NRC and CNSC.

One of the reasons the nuclear agencies gave for rejecting a CMC designation for radionuclides is that radionuclides are not a threat to human health and the environment in the Great Lakes. The groups who nominated radionuclides to become CMC's asked Cindy Folkers[+] to assess the adequacy of the CNSC and NRC's assertion on health impacts. The following are her findings on this topic.

Radionuclide impacts on the Great Lakes: U.S. Nuclear Regulatory Commission and Canadian Nuclear Safety Commission claims of safety are unwarranted

Summary

The U.S. Nuclear Regulatory Commission (NRC) and the Canadian Nuclear Safety Commission (CNSC) cannot know whether radionuclides have harmed or "are potentially harmful"[3] to the health or environment of the Great Lakes because they do not have the research that would allow them to make such a claim. These agencies have permitted releases to the Great Lakes environment of persistent radioisotopes such as tritium, carbon 14, and uranium that decays into radium 226.

Both CNSC and NRC rely on health assessment models that leave out crucial impacts on sensitive life stages. This could lead to understated health risks, contradicting studies indicating that there is threat of harm. It is imperative that radioisotopes be listed as CMCs so that a more robust accounting of their impacts on the Great Lakes, now and in the future, is undertaken.

NRC's and CNSC's contention that science shows that there is a safe dose of radiation

[2] See application at [http://www.cela.ca/publications/radionuclides-chemical-mutual-concern-great-lakes-basin]

[+] Cindy Folkers has a Master of Science in Environmental Sciences from Johns Hopkins University and has researched radiation and health issues since 1994. She has written extensively, including essays in two anthologies, and has given numerous presentations focused on radiation's disproportionate impact on women, children and pregnancy.

[3] Annex 3, Section 3 of the GLWQA uses the phrase "potentially harmful" to determine whether a substance should be named as a CMC.

is incorrect. The 2006 U.S. National Academy of Sciences report concludes "…the preponderance of information indicates that there will be some risk, even at low doses."[4] More recent research continues to show low doses can have negative health outcomes.

Both NRC and CNSC claim that releases of radionuclides are low enough that there will be no *discernable* impact to people, non-human animals or the environment. However, neither has conducted the public health or biological research needed to determine what the impact might actually be. Studies that are done have routinely suffered from improper hypothesis formation and research design by presupposing a conclusion of no impact. This predetermined conclusion, a scientific method no-no, is based first on error-ridden dose reconstruction, rather than an examination of public health, which is usually the second research question examined. Although data around normally operating nuclear facilities show increases in childhood leukemia, associating it with radiation exposure becomes impossible, not because radiation isn't the cause, but because it was falsely exonerated from the beginning.

NRC and CNSC allowable exposure levels fail to account for pregnancy development, including impacts on the placenta, which performs organ functions during pregnancy; impacts on certain blood forming cells during embryo and fetal development; impacts on fetal and embryo organs which are forming from single cells. They fail to account for estrogenic impacts, increased impacts on women, or genetic impacts past the second generation. Cumulative damage of repeated radiation exposure is also ignored, despite population studies among animals, humans and plants indicating "significant negative effects on immunology, mutation and disease frequency" beginning at very low annual doses.[5,6]

Introduction

Protection measures for the Great Lakes environment require special consideration of its unique ecosystem. The International Joint Commission (IJC) in its 1997 report[7] recognizes the Great Lakes as a large, freshwater environment, which is a closed ecosystem, retaining contaminants often in a non-uniform way. Specifically, The IJC states that the Great Lakes exhibit considerable irregularity and non-uniformity in geographical distribution of radionuclides due to "many different sources of radioactivity to the Great Lakes, their patterns of release and the actions of various environmental processes…"[8] For instance, not all radionuclides are distributed evenly among different lakes, or even within the water column of the same lake, nor do lake sediments retain radionuclides in the same way as do the lake waters above.

The IJC concludes that use of radionuclide monitoring systems by regulatory bodies is primarily to demonstrate compliance with discharge licenses. These systems are not capable of assessing cycling of radionuclides through the environment. This IJC report begins to describe the cycling of radionuclides through biota in a systematic but limited

[4] Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2. 2006. p 10.

[5] Møller, et al. Strong effects of ionizing radiation from Chernobyl on mutation rates. Scientific Report. Nature. 10 February 2015.

[6] Møller, A. et al. The effects of natural variation in background radioactivity on humans, animals and other organisms. Biol Rev Camb Philos Soc. 2013 Feb;88(1):226-54.

[7] Inventory of Radionuclides for the Great Lakes. Nuclear Task Force. International Joint Commission United States and Canada. December 1997

[8] *Ibid*. p 52.

way, using a material balance approach. IJC recognizes a number of radionuclides as posing long-term concern, including tritium and carbon 14. Both tritium and carbon 14 are basic building blocks of the human body and retention of them in the environment means increased exposure of humans, with potentially stark consequences (see part 2 section b). Tritium and carbon 14 are not the only radionuclides of concern.

Radionuclides can decay to other radionuclides. This means that the chemical composition of the radionuclide can change, a phenomenon that must be taken into account for the Great Lakes and long-term contamination concerns. For instance, radioactive xenon can decay to cesium (chemically a potassium mimic in our bodies, replacing stable potassium) and radioactive krypton can decay to strontium (chemically a calcium mimic). The gases xenon and krypton can be released during power reactor normal operations or catastrophes and can give a huge quick dose to people in the pathways, but decay relatively quickly. But because these gases decay to chemicals our bodies use regularly, their exposure profile alters. Interactive chemicals (gases xenon and krypton) that had little implication for future contamination concerns, have now become an issue for health over the long term.[9] As an additional example, uranium decays to lead-214, a toxic chemical that is also radioactive; and radon, a gas. The *quality* of the nuclides changes and so does the threat.

Additionally, what was released 70 years ago can still be exposing the public, wildlife, etc.[10] Certain chemical properties of radionuclides can cause them to build up in systems in non-uniform ways and become more or less bioavailable depending on where they are in the environment. For instance, uptake of cesium by aquatic life is higher in fresh water compared to ocean water.[11] Also, radionuclides don't always spread evenly in the environment, so "dilution is the solution to pollution" doesn't really apply over time. The radionuclide may start out more dispersed, but the natural system can collect and recycle whatever nutrient the radiation is mimicking, concentrating it (bioaccumulation).[12]

The DNA damage radiation causes to an individual, and across generations, compounds. Radiation exposure causes germline mutations in DNA that can be passed down to offspring (see studies section). Such mutations are responsible for more than just the obvious, well-researched diseases like cancer. These more subtle diseases can be very devastating as well.

In the 20 years since the IJC's report, little to no action has been taken to address its concerns. The fundamental lack of understanding of radionuclide cycling and accumulation highlights the need to list radionuclides as CMCs as soon as possible.

There are an abundant and growing number of studies that demonstrate the harm to health and environment from low dose, long-term exposure to radiation. That the CNSC

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[9] International Joint Commission. Nuclear Task Force (1998). Report on Bioaccumulation of Elements to Accompany the Inventory of Radionuclides in the Great Lakes Basin. *International Joint Commission (IJC) Digital Archive*. https://scholar.uwindsor.ca/ijcarchive/143

[10] USEPA Cesium. http://www.fuji-water.com/radiation/Cesium_RadiationProtection_USEPA.pdf

[11] Rowan DJ, Rasmussen JB. Bioaccumulation of radiocesium by fish: the influence of physicochemical factors and trophic structure. Canadian Journal of Fisheries and Aquatic Sciences. 1994;51:2388–2410

[12] Ophel, et al. Strontium-calcium relationships in aquatic food chains. Atomic Energy of Canada, Limited. 1969. pp 221-222

and NRC refuse to acknowledge this, speaks to the need for an independent assessment afforded by a CMC designation under the GLWQA.

Part 1. NRC and CNSC cannot know whether radionuclides have harmed the health or environment of the Great Lakes. These agencies have failed to bring forward the research that would allow them to claim "no harm"; yet they persist in assuming low doses are "safe enough".

a. NRC's and CNSC's contention that science shows a safe dose of radiation is incorrect.

The U.S. National Academy of Sciences expert panel, commonly referred to as the BEIR (Biological Effects of Ionizing Radiation) VII panel, was established to explore impacts of low dose radiation. In its 2006/7 report, it rejected a threshold, concluding "…the preponderance of information indicates that there will be some risk, even at low doses" and "there is no compelling evidence to indicate a dose threshold below which the risk of tumor induction is zero."[13] Despite NRC and CNSC attempts to dissemble the truth of this statement, research since the BEIR VII report *also* shows low doses, even within background range, can have negative health outcomes (see summary of studies below).

For genetic impacts, this report also recognizes that "…there is a vast amount of evidence for radiation-induced mutations in diverse biological systems…"[14] For protection of the Great Lakes ecosystem, this revelation is key. Since the GL ecosystem is extremely diverse and unique, the ecosystem as a whole must be protected from radiation-induced mutations that could permanently alter it in unpredictable ways. Partial protection is not protective enough.

CNSC states; "While the probability of occurrence of stochastic effects (e.g., cancer) within a population has been shown to be dependent on the dose, the severity of the effect is not dose dependent." [15] In essence, they are counting on a severe impact at low doses being rare enough so it will not be noticed among the diseases already existing in a population. CNSC also recognizes that "there is generally a significant lag time or latency in the order of months to years between exposure and discernable health effects." [16] They are banking on long disease latency to help them hide radiation as a cause of any disease. They are sowing doubt and establishing plausible deniability. CNSC's logic is flawed. If the severity of the effect is not based on dose, even low doses can result in severe consequences. A single radiation hit can cause a single cell death; a whole body, or even organ dose, will not account for this damage. Since all parts of the human body develop from single cells during pregnancy, the severity of a radiation hit during pregnancy can be devastating for mother and child, yet never registered as an official radiation impact. Therefore, a safe dose CANNOT exist. CNSC's claim that low doses can be safe is based on probability (gambling), not biology. But biology is reality.

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[13] Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2. 2006. p 10.

[14] Ibid. p 92.

[15] CNSC. Assessment of the Relevance of the Inclusion of Radionuclides as a Chemical of Mutual Concern under Annex 3 of the Canada-United States Great Lakes Water Quality Agreement. September 2017. e-Doc: 5207535 (Word) e-Doc: 5309178 (PDF). p 8.

[16] Ibid. 2017 p 9.

CNSC claims that cancer incidence at low doses is not statistically different from zero, relying on the Health Physics Society (HPS) for this conclusion. But the HPS is a 501c6 in the U.S., which means it promotes the interests of the businesses it represents.[17] Therefore, HPS has no interest in protecting public and environmental health if this runs counter to these interests. This represents a clear conflict. The HPS position paper[18] on which this statement is based talks in generalities, providing no specific primary references for any of its claims. Further, many of these reports are not readily available to the public. Evaluation of the studies HPS is relying on is, therefore, impossible. Further, HPS makes these claims in the context of estimating health risks of low doses, which it claims are full of uncertainties. In this sea of supposed uncertainty, one certainty exists about the radiation risk numbers: they are often averaged between men, women and children, meaning that the most sensitive are not fully protected. Pregnancy is discounted almost completely. Genetic impacts are basically ignored. Cumulative damage of repeated doses over time (such as those that come from continually consuming contaminated food, or breathing contaminated air) are not included in the formula that converts radioactivity to health damage (see part 2 below)

b. Nuclear agencies cannot claim effluent flowing out of their facilities has produced no health impacts because there has never been an adequate investigation of the question.

NRC claims, in its 2017 letter on CMCs, that there is no need to list radionuclides as chemicals of mutual concern since NRC licensees do not release enough radioactivity to harm public health. In truth, there has never been independent analysis in the U.S. examining cancer and non-cancer health impacts particularly in children. Estimating risk alone is not enough. Independent assessment of actual public health status is essential. The one recent attempt[19] to investigate this issue in the U.S. was scuttled when the NRC cut its funding. This study was going to examine Big Rock Point in Charlevoix, MI on the coast of Lake Michigan, among other sites.

CNSC conducted a 2013 study[20] around Ontario nuclear facilities, but their assessment bases its conclusions on doses reconstructed from inadequate models, not on actual disease data from the area or biological testing. This study, dubbed RADICON, suffers[21] from the same well-known deficits as NRC's basis for claiming its exposure standards are safe: assumptions that its pollution measurements are reliable and robust and that its dose calculations are correct.

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[17] According IRS legal code the 501(c)(6) is specifically reserved to Chamber of Commerce organizations, economic development corporations, real estate boards, trade boards, professional football leagues (*e.g.*, the NFL), and other types of business leagues. They are characterized by a common business interest, which the organization typically promotes. Organizations under this category are exempt from most federal income taxes. Donations to a 501(c)(6) are not tax deductible as charitable contributions, as is the case in the 501(c)(3) category.

[18] RADIATION RISK IN PERSPECTIVE POSITION STATEMENT OF THE HEALTH PHYSICS SOCIETY. Adopted: January 1996 Revised: July 2010 Further revised: May 2016 and February 2019. Accessed 3/12/2021.

[19] Analysis of Cancer Risks in Populations Near Nuclear Facilities. Phase 1. National Academy of Sciences. National Research Council of the National Academies, Nuclear Radiation and Studies Board. 2012.

[20] Canadian Nuclear Safety Commission. Radiation and Incidence of Cancer Around Ontario Nuclear Power Plants From 1990 to 2008 (The RADICON Study). Journal of Environmental Protection. Volume 9, 2013.

[21] Greening, F.R. A Critique of the RADICON Study.

Despite this, studies performed around reactors often observe increases (small but persistent across studies) in disease, which then becomes attributable to no cause. During the NAS study committee investigation in the U.S., Dr. Steve Wing, an epidemiologist with experience in radiation exposure who taught at the University of North Carolina, Chapel Hill, recommended conducting a health assessment decoupled from any dose assumptions to first determine if there were increases, particularly in childhood leukemia, a sentinel indicator for radiation exposure in a community. To do otherwise, Wing argues[22], biases study conclusions before the study even begins. Improper hypothesis formation and research design, the author continues, plagues studies on radiation's impact on health.

Childhood leukemia incidence is rising[23] in Canada, while deaths from leukemia are decreasing. For each child that is treated for a cancer, their risk of getting a secondary cancer[24] later in life is increased from the cancer treatment that initially saved their life. So while children in Canada are surviving their cancers with the help of treatment, this population is at higher risk for future cancers. It would be prudent to know why childhood leukemias are increasing in the first place.

While it may be reasonable to conclude that not all childhood leukemias are due to radiation exposure, it is also reasonable to ask what percentage are due in whole or in part to radiation exposure and if living around a nuclear facility increases the risk. Studies on child health have shown increases of childhood leukemia surrounding similar facilities. Studies of background radiation, natural and manmade, also showed increased risk of childhood leukemia and central nervous system cancers (see study list below)

c. NRC clings to old health assumptions, eschewing new, careful, insightful examination methods. CNSC's 2017 CMC statement indicates that they are also clinging to old health assumptions.

Radiation exposure can change our bodies in microscopic ways. These microscopic formations (biomarkers or bioindicators) can be malformations of cell components, proteins, etc. and often occur in both humans and animals. Health studies have incorporated biomarkers to help determine radiation exposure but U.S. and Canadian agencies appear to have never incorporated biological or genetic monitoring to assess radiation damage. This flaw needs to be corrected.

Case study 1. Fifteen years after a Three Mile Island (TMI) nuclear power reactor melted down and released radiation into the surrounding environment, 29 people who experienced erythema (skin reddening), vomiting and diarrhea had their blood drawn and examined for a type of chromosome malformation called a dicentric. These tests determined that these people, who were in the pathways of the passing radioactive plumes, had sustained doses between 600-900 milligray (60-90 rad). Lung cancer and

[22] Wing, et al. Cancer Risks near Nuclear Facilities: The Importance of Research Design and Explicit Study Hypotheses. Environ Health Perspect 119:417-421 (2011).

[23] CTVNews.ca Staff. Childhood cancer mortality decreasing, incidence increasing: StatsCan. September 22, 2015. Accessed 3/12/2021.

[24] Children's Oncology Group. Secondary Cancers.

leukemia also increased in these plume pathways.[25]

Case study 2. Between 1992 and 1995, 21 people who resided within 5 km downwind of the Krümmel boiling water reactor in Germany had blood draws examined for dicentrics. The rate of dicentrics in all 21 people near the reactor was "significantly elevated and indicated ongoing exposures over the years of its operation. These findings led to the hypothesis that chronic reactor leakages had occurred."[26] A cascade of studies in Europe followed, showing increases in childhood leukemia around nuclear facilities.

Case study 3. Eighty people who were 100-200 km from the Chernobyl explosion in 1986, had their blood drawn and examined using a micronucleus assay.[27] The presence of a cell malformation called micronuclei was significantly and positively associated with the internal contamination of radiocesium, which ranged from 0.6 mGy (60 millirad) to 9.2 mGy, The internal radiocesium activity ranged from 12.7 Bq/kg to 56.8 Bq/kg. Both the internal contamination level and the doses are well below the level claimed safe by CNSC, NRC and HPS.

Part 2. Both CNSC and NRC rely on health assessment models that do not account for crucial impacts on sensitive life stages. This could lead to understated health risks, in the face of studies indicating that there is threat of harm.

a. Both CNSC and NRC rely on International Commission on Radiological Protection (ICRP) for recommendations on radiation exposure, but ICRP's science fails to account for some very important damage from radiation.

ICRP fails to account for radiation damage past the second generation because it feels it doesn't have enough information to calculate this impact. This is regrettable, because for the two generations of exposure damage they do calculate, the genetic disease per million people increases from the first generation to the next, even while each generation receives the same dose.[28] This trajectory of increasing vulnerability across generations should make humanity very skeptical of allowing ever increasing exposure to radioactivity, including low dose chronic exposure. Even if, as regulators claim, releases of radionuclides have decreased, exposures have not. For example, even decades later, the cesium-137 that has been released from atomic bomb explosions, nuclear power routine releases and catastrophes, is "impossible to avoid."[29] Total human exposure is not decreasing.

ICRP says that lifetime cancer risk following in utero exposure will be similar to exposure risk in early childhood. For blood cancers, like leukemia, this may not be the case since

[25] Wing, S. A reevaluation of cancer incidence near the Three Mile Island nuclear plant: the collision of evidence and assumptions. Environ Health Perspect. 1997 Jan; 105(1): 52–57.

[26] Schmitz-Feuerhake, I, et al. Leukemia in the Proximity of a German Boiling-water Nuclear Reactor: Evidence of Population Exposure by Chromosome Studies and Environmental Radioactivity. Environmental Health Perspectives - Vol 105, Supplement 6. December 1997

[27] Livingston GK. Radiobiological evaluation of immigrants from the vicinity of Chernobyl. Int J Radiat Biol. 1997 Dec;72(6):703-13.

[28] The 2007 Recommendations of the International Commission on Radiological Protection ICRP Publication 103 Ann. ICRP 37 (2-4), 2007. pp 53-56.

[29] USEPA Cesium. http://www.fuji-water.com/radiation/Cesium_RadiationProtection_USEPA.pdf

hematopoietic (blood-making) tissues appear more radiosensitive in embryos and fetuses than in newborns. ICRP experts admit that its recommendations do not account for developmental changes and damage to all the sites and stem cells responsible for hematopoietic formation.[30,31]

ICRP uses uterine dose to determine embryo dose. However, this does not account for the maternal exchange system, stem cell vulnerability, or any difference between fully formed organ tissues and embryo organ tissues. During embryo development, the heart, spinal cord and brain, major blood vessels and the beginning of bones and muscles, are in process of forming from single cells. ICRP recognizes that averaging of dose over the uterus "hides the fact that the very early embryo, with a small number of cells, might receive doses significantly higher or lower than this average." But ICRP is content to let "future developments" correct for this, not accounting for current health impacts. [32]

ICRP uses models made for postnatal exposures to calculate radiation damage to pre-natal tissues and organs. ICRP mentions the shortcomings of this approach but claims there is a lack of data about damage at these early life stages and that using this method makes it more convenient for comparing dose data over a lifetime.[33]

While ICRP at least admits shortcomings in other areas of pregnancy protection, it seems blind to the unique role of the placenta during pregnancy.[34,35] The placenta is a temporary but immensely important structure that performs organ-like functions. It supplies oxygen, removes metabolic products and provides a limited barrier against some toxins and drugs; it is active endocrinologically to support the ongoing pregnancy. Radiation damages[36] not only fetal cells but also impairs placental development and function by cell killing and cell cycle arrest. Improper placental formation or function can cause a high or low birth weight for babies, which in turn seem to be connected to disease later in adult life.

Radioactivity appears to act along the estrogen pathway. In 2011, a medical hypothesis was published highlighting this interaction: "The impact of estrogen and estrogen receptors on the response of living organisms, including humans, after exposure to ionizing radiation should be included in future in radiation safety regulations..."[37] ICRP has not examined this impact in their recommendations and safety regulations do not account for it either.

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[30] Doses to the Embryo and Fetus from Intakes of Radionuclides by the Mother. ICRP Publication 88. Ann. ICRP 31 (1-3), 2001.

[31] Phipps, A.W. et al. SOME ASPECTS OF THE FETAL DOSES GIVEN IN ICRP PUBLICATION 88. Radiation Protection Dosimetry Vol. 105, Nos 1–4, pp. 279–284 (2003). p. 282.

[32] ICRP 88, pp. 53,60-61.

[33] ICRP 88. p 27.

[34] ICRP 88. Chapter 3.

[35] Basic Anatomical and Physiological Data for Use in Radiological Protection Reference Values. ICRP Publication 89. Ann. ICRP 32 (3-4), 2002. p. 231.

[36] Gude, et al. Growth and function of the normal human placenta. Thromb Res. 2004;114(5-6):397-407.

[37] Fucic A. Interaction between ionizing radiation and estrogen: what we are missing? Med Hypotheses. 2011 Dec;77(6):966-9.

ICRP's math converting radioactivity to damage[38] doesn't completely account for cumulative biological damage from continuing exposure to low doses[39]. Once a biological system has suffered damage, perfect repair is elusive and the same dose given again can result in greater damage than the previous time it was suffered.

b. Tritium, carbon 14 and radium 226 (a uranium decay product): three persistent and present isotopes of concern for GL and all nuclear sites.

ICRP recognizes that both carbon 14 and tritium can collect in fetal tissue at twice the concentration of maternal tissue.[40] Stable carbon and hydrogen are basic building blocks of all biological life. Their radioactive forms, however, are hazardous for future generations, making their assessment in the environment an even more pertinent issue for the Great Lakes region since toxic substances stay for longer periods of time and accumulate. Since most exposure standards are based on an average of impacts on men, women and children (leaving out pregnancy altogether), this effect remains unaccounted for within the ICRP recommendations. Tritium, carbon 14 and radium 226 are recognized among the radionuclides of long-term concern by the 1997 IJC report. Radium 226, a decay product of uranium that is released from a number of fossil fuel processes, is implicated in a number of different health impacts.

The CNSC implies that a level of tritium in Lake Ontario and Lake Huron five times above the naturally occurring level would be acceptable. (figure 8 in CNSC's letter) This increase of persistent tritium includes releases from CANDU reactors and what is left from atomic bombs. While the total amount of tritium contamination may be small, it is still five times what should be present, and this level is for just one radionuclide.

NRC has never required licensees to *measure* the carbon 14 released from nuclear reactors as radioactive carbon dioxide and methane.[41] Consequently, doses are largely unknown – an unfortunate circumstance given that NAS has determined that carbon 14 may represent one of the largest doses to the public.[42] Even after facilities are closed and decommissioned, tritium still oozes[43] from any concrete, cement and metal left. The NRC does not continue monitoring at these dismantled sites. EPA regulations (40 CFR 190) specifically have NOT regulated tritium or carbon 14 from civilian nuclear reactors, claiming that these isotopes can't really be filtered or removed from the environment in any case.[44]

Part 3. There are abundant studies that demonstrate the harm to health and environment from low dose, long-term exposure to radiation. These studies demonstrate negative health impact below 100 mSv, the dose below which CNSC

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[38] ICRP. AGE-DEPENDENT DOSES FROM INTAKE OF RADIONUCLIDES. REPORT OF A TASK GROUP OF COMMITTEE 2. pp 3-5.

[39] Personal communication. Eckerman. November 7, 2016.

[40] ICRP 88. pp 24-25.

[41] Wahl, D. The Impact of Carbon-14 on Limerick's Gaseous Effluent Dose Model. Limerick Generating Station. Exelon Nuclear. 2010. Accessed 3/12/2021.

[42] NAS. 2012. p 5.

[43] McClenaghan et al. Submission to the CNSC on Draft Environmental Impact Statement Re: Nuclear Power Demonstration Closure Project (Ref No. 80121). Canadian Environmental Law Association. February 2018.

[44] https://www.govinfo.gov/content/pkg/FR-2014-02-04/pdf/2014-02307.pdf p. 6519

claims "implications…are currently not known." Some demonstrate effects at doses two orders of magnitude lower than 100 mSv – into the exposure range ICRP maintains as a recommended level even after nuclear catastrophes.

a. Uranium studies

- Uranium in drinking water – at levels allowed by the Environmental Protection Agency – disrupts[45] the estrogen pathway.
- Birth defects[46] and abnormal[47] pregnancy development, including low birth weight, are associated with ingestion of uranium.
- The incidence[48] of reproductive or gonadal cancer in New Mexico Native American children and teenagers is eight-fold greater than that in non-Native Americans of the same ages. New Mexico has been home to hundreds of uranium mines, all of which are now abandoned (although threats of new mines remain). These mines have left behind tailings and other radioactive wastes.

b. Operating reactor/fuel facility studies

- The National Academy of Sciences says childhood leukemia is a sentinel indicator[49] for radiation exposure in a community.
- When data around normally operating nuclear facilities is examined worldwide, over 60 studies find increases[50] in childhood leukemia.

c. Studies of background radiation (including natural and man-made)

- All childhood cancers[51] start to increase[52] at exposures not much more than natural annual doses.
- Among childhood cancers, leukemia and central nervous system cancer risks[53] predominate.
- There is a strong impact[54] of radioactive contamination on individual fitness in current and future generations, with potentially significant population-level consequences, even beyond the area contaminated with radioactive material. "[S]ignificant negative effects on immunology, mutation and disease frequency", included reduced levels of antioxidants. The effects were small, but consistent and significant, starting at approximately 1 mSv.[55]

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[45] Williams, F. et al. On Cancer's Trail. May 26, 2008. Accessed 3/12/2021.

[46] ibid.

[47] Mirderikvand, N. Embryo Toxic Effects of Depleted Uranium on the Morphology of the Mouse Fetus. Iranian Journal of Pharmaceutical Research (2014), 13 (1): 199-206

[48] Williams, F 2008.

[49] NAS 2012. p 158.

[50] Fairlie I. Hypothesis to explain childhood cancer near nuclear power plants. Int J Occup Environ Health. 2010 Jul-Sep;16(3):341-50

[51] Background Radiation & Cancer in Children Video, accessed 3/12/2021.

[52] Kendall, GM. A record-based case-control study of natural background radiation and the incidence of childhood leukaemia and other cancers in Great Britain during 1980-2006. Leukemia. 2013 Jan;27(1):3-9.

[53] Spycher, BD. Background ionizing radiation and the risk of childhood cancer: a census-based nationwide cohort study. Environ Health Perspect. 2015 Jun;123(6):622-8.

[54] Møller, 2015.

[55] Møller,.2013.

- Radioactivity is also associated with negative, subclinical health impacts such as impaired[56] neural development and lower I.Q.[57]
- Radiation can increase resistance[58] of bacteria to antibiotics.
- Radioactivity appears to act along the estrogen pathway[59], hinting that, in addition to a carcinogen, radioactivity may be an endocrine disruptor. Estrogen plays key roles in healthy pregnancy and puberty and is greater in women than men.

d. Catastrophe studies

- Children in Chernobyl-contaminated areas have suffered reduced respiratory[60] capacity as recently as 2010. The more radioactive cesium in their body, the greater the effect.
- Exposure to radioactivity is associated with chronic fatigue immune dysfunction syndrome (CFIDS[61]) and related syndromes.
- Cardiovascular defects[62],[63] are still surfacing from radioactivity due to the ongoing Chernobyl catastrophe.
- Birth defects (blastopathies[64]) and other health disturbances are found among not only those who were adults at the time of the Chernobyl disaster, but their children who were in utero at the time and, most disturbingly, their later offspring.
- Thyroid cancers in the TMI area appear to bear a radiation-specific biological marker[65], appear earlier and appear to be more aggressive[66]. Thyroid cancers continued increasing[67] years after Chernobyl began. Thyroid cancers have been observed in children since the Fukushima nuclear disaster in Japan but studies[68] at Fukushima suffer from poor methodology and lack of transparency, putting in serious jeopardy any independent analysis.

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[56] Almond, et al. Chernobyl's Subclinical Legacy: Prenatal Exposure to Radioactive Fallout and School Outcomes in Sweden. The Quarterly Journal of Economics (2009) 124 (4): 1729-1772.

[57] Heiervang, KS. The Chernobyl accident and cognitive functioning: a study of Norwegian adolescents exposed in utero. Dev Neuropsychol. 2010;35(6):643-55.

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- Research[69] indicates that forest matter in the contaminated areas around Chernobyl is taking years or even decades longer to decay[70] than is normal.
- Thirty-five years after the Chernobyl catastrophe began in 1986, radioactive pollution is a continuing threat, linked with birth defects in humans that could be *de novo*, meaning they are appearing for the first time. The study also indicates that exposure to chemicals is additive, even synergistic.[71],[72]
- Monkeys in Fukushima-contaminated areas[73] are born with fewer blood components, including white blood cells, now that their environment is radioactively contaminated from the reactor explosions of 2011. Having a diminished number of white blood cells, which fight disease, can lead to a compromised[74] immune system.
- Negative impacts[75] on animals such as smaller brains and lower sperm counts, to name just two, are also occurring at Chernobyl and Fukushima.
- Research of Chernobyl indicates that laboratory study may underestimate radiation's impact on organisms by eight to 10 times. This implies that using laboratory studies of animals under controlled conditions is not representative of what is happening in a natural setting, calling into question any reliance on lab results for environmental protection.[76]

Part 4. In order to have a more complete understanding of radionuclide impacts on the Great Lakes environment and human and non-human animals, additional research must be conducted including:

- a comprehensive review of all monitoring activities.
- altering monitoring to accommodate proper assessment of environmental cycling of radioactive contaminants, including more frequent monitoring and greater environmental sampling, especially timed with any large releases from nuclear facilities.
- Inclusion of biological monitoring of radionuclides and consistency in collection and reporting of same
- Assessment of environmental cycling of radionuclides and adjustment according to unique properties of the Great Lakes region such as the fresh water component, the closed system, and prevailing weather and water patterns.
- Establishing consistent analyses and reporting protocols between the U.S. and Canada for the GL
- An analysis of toxic chemicals released from nuclear facilities including those toxins that result from radionuclide decay

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- Offer whole genome testing for human and non-human animals that reside around nuclear facilities.
- Offer to measure radiation-specific bioindicators in human and non-human animals that reside around nuclear facilities. Testing should be particularly timed with large releases from nuclear facilities