BEYOND CANCER: NON-ONCOLOGICAL HEALTH ENDPOINTS EXCLUDED FROM CANDU ROUTINE RELEASE HEALTH IMPACT ASSESSMENT AND THE STATUTORY MANDATE TO CONSIDER THEM

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1.. Background

Health impact assessments (HIAs) for CANDU nuclear facilities in Canada are structured to evaluate cancer risk as the primary, and in practice sole, quantitative health endpoint. Dose calculations are performed for routine radionuclide releases, incremental cancer risk is computed using the LNT model, and the resulting figure — typically expressed as a fraction of background cancer risk — is used to conclude that routine releases do not pose an unreasonable health hazard.

This structure reflects a cancer-centric model of radiation health effects that has its origins in the postwar period and the prioritisation of stochastic cancer risk in radiological protection frameworks. It does not reflect the current state of the peer-reviewed literature, which documents a range of non-oncological health effects from chronic low-dose radiation exposure, including cardiovascular disease, neurological effects, immune system dysregulation, ophthalmic effects, and adverse reproductive and developmental outcomes. None of these endpoints are routinely assessed in CANDU HIAs.

This paper identifies six non-cancer health endpoint categories for which peer-reviewed evidence supports an association with chronic low-dose ionising radiation exposure, documents the regulatory framework under which each should be assessed, and proposes minimum requirements for inclusion in CANDU HIAs going forward.

2.. Non-cancer endpoints: the peer-reviewed evidence base

2.1 Cardiovascular disease

The relationship between radiation exposure and cardiovascular disease is among the most extensively documented non-cancer endpoints in the radiation health literature. The LSS cohort follow-up shows excess cardiovascular mortality at doses as low as 0.5 Sv, with a possible signal at lower doses [1]. The INWORKS study of nuclear workers across France, the UK, and the United States — a chronic low-dose occupational exposure cohort with over 300,000 participants — reported a statistically significant association between cumulative radiation dose and circulatory disease mortality [2]. A 2023 meta-analysis of occupational radiation exposure studies found consistent elevated relative risk for ischaemic heart disease and cerebrovascular disease across multiple independent cohorts [3].

CNSC dose assessments for CANDU routine releases do not include cardiovascular risk as a quantitative health endpoint. The evidence base supporting its inclusion now exceeds the evidence base that was available for cancer when cancer was incorporated as the primary endpoint in the 1970s.

2.2 Neurological and neurodevelopmental effects

In utero radiation exposure is an established cause of intellectual disability at doses above 100 mGy; the period of peak sensitivity is 8–15 weeks of gestational age [4]. At sub-threshold doses, neurological studies of populations near Chernobyl and of medical radiation cohorts suggest possible IQ effects and behavioural outcomes at doses in the range of 10–50 mGy [5]. For tritium specifically, animal studies demonstrate neurodevelopmental effects from prenatal OBT exposure at dose rates comparable to those produced by chronic environmental tritium contamination, including reduced brain weight, altered neuronal density, and impaired spatial learning in offspring [6]. CNSC INFO-0799 acknowledges the animal neurodevelopmental data but does not incorporate it into human health impact assessment frameworks [7].

2.3 Immune system dysregulation

Chronic low-dose ionising radiation has documented effects on immune system function, including reduced lymphocyte count, altered natural killer cell activity, and dysregulation of inflammatory cytokine expression [8]. These effects are documented in occupational cohorts at cumulative doses in the range of 50–200 mSv — doses that may be approached over multi-decade residence near a CANDU facility under documented release conditions. Immune dysregulation is relevant as a direct health outcome and as an indirect risk factor for infectious disease, autoimmune conditions, and as a potential mechanism for the leukemia signal observed in epidemiological studies: childhood leukemia is fundamentally a disease of immune system failure in haematopoietic progenitor cells. An HIA that does not assess immune endpoints cannot claim to have assessed the pathway most directly relevant to the primary observed health signal.

2.4 Ophthalmic effects

Radiation-induced lens opacity (cataract) has been observed at doses substantially lower than the previous threshold assumed in radiological protection — evidence reviewed by the ICRP in 2012 prompted a reduction of the occupational eye lens dose limit from 150 mSv/year to 20 mSv/year [9]. For chronic low-dose whole-body exposure, ophthalmic surveillance data from occupational cohorts and Chernobyl liquidator studies show elevated cataract prevalence at cumulative doses below 500 mGy [10]. Posterior subcapsular cataracts — the specific type associated with radiation exposure — are progressive, debilitating, and occur in a working-age population. No CANDU HIA quantifies ophthalmic risk as a health endpoint despite the ICRP's own revised guidance.

2.5 Adverse reproductive and developmental outcomes

Beyond cancer and the neurodevelopmental effects noted above, chronic low-dose radiation has been associated with adverse reproductive outcomes including reduced sperm count, increased miscarriage rates, and intrauterine growth restriction in occupational and environmental exposure studies [11]. These outcomes are not deterministic effects at the doses relevant to CANDU routine releases — they are probabilistic associations documented in populations with documented chronic exposures. For a community near a CANDU facility, where women of reproductive age may receive continuous low-level tritium exposure across multiple pregnancies spanning decades of facility operation, the cumulative reproductive health profile has never been assessed in any Canadian environmental review.

2.6 Mixture and interaction effects

CANDU routine release assessments evaluate radionuclide health effects in isolation from the chemical environment in which the exposed population lives. The peer-reviewed literature on mixture toxicology documents that carcinogenic and genotoxic effects of radiation and chemical co-exposures are in many cases synergistic rather than additive — the radiation effect is amplified in the presence of chemical promoters [12]. For the Peace River region of northern Alberta, the background chemical carcinogen burden from bitumen extraction and pipeline operations represents precisely the mixture synergy environment identified in the literature. No CNSC regulatory framework requires mixture interaction assessment as a component of CANDU HIA.

Endpoint	Evidence basis	Assessed in CANDU HIA	CNSC documentation
Cancer	LSS, BEIR VII, LNT model	Yes	Central framework
Cardiovascular	INWORKS, LSS follow-up, meta-analyses	No	Not addressed
Neurological/develop.	In utero studies, animal OBT data	No	Acknowledged in INFO-0799
Immune dysregulation	Occupational cohorts, mechanistic studies	No	Not addressed
Ophthalmic (cataract)	ICRP 2012 revised guidance	No	Not addressed
Reproductive/develop.	Occupational/environmental cohorts	No	Not addressed
Mixture interactions	Carcinogenesis literature, BEIR VII	No	Not addressed

3.. The statutory mandate

The Nuclear Safety and Control Act mandates that the CNSC regulate nuclear activities in Canada to protect the health and safety of persons. The mandate is not limited to cancer protection. The Mackenzie Valley Resource Management Act and the Canadian Environmental Assessment Act (and its successor, the Impact Assessment Act) require consideration of health effects as a factor in environmental assessment — not cancer effects, but health effects. The Guidelines for Canadian Drinking Water Quality cover a range of health endpoints from chemical and radiological exposures; tritium guidelines are set with reference to the full health effects literature, not cancer alone.

A CANDU HIA that evaluates cancer and no other health endpoint is not a complete assessment of the health effects of routine releases under any of these statutory frameworks. It is a cancer risk assessment labelled as a health impact assessment. For purposes of IAAC review, the distinction matters: a Review Panel evaluating whether a project is in the public interest, including health impacts, cannot rely on an assessment that addresses one of seven documented health endpoint categories.

CANDU health impact assessments assess cancer. Six additional endpoint categories have peer-reviewed evidence of association with chronic low-dose radiation.

The statutory mandate covers health of persons, not cancer in persons.

4.. Minimum requirements for CANDU HIAs

Four minimum requirements are proposed for health impact assessments of CANDU routine releases submitted to IAAC review.

First, the HIA scope should be defined to include all health endpoints for which peer-reviewed evidence of association with chronic low-dose ionising radiation exists, including at minimum the six categories identified in Section 2 of this paper. The assessment should state, for each endpoint, the evidence base, the applicable dose range, and whether the projected releases from the proposed facility fall within the range for which evidence exists.

Second, for endpoints where evidence exists but dose-response relationships are uncertain (cardiovascular, neurological, immune), the HIA should present a qualitative assessment of the relevant population subgroups and a conservative upper-bound estimate, rather than excluding the endpoint on the basis that a precise quantitative estimate is not available.

Third, the HIA should include a mixture interaction assessment for any facility sited in a region with documented chemical carcinogen burden, using the current peer-reviewed literature on synergistic versus additive effects as the analytical framework.

Fourth, the HIA should present its cancer risk estimate alongside the acknowledged uncertainty from the extrapolation limitations identified in the companion paper on LNT model structural failures, rather than presenting a single-point cancer risk figure without confidence intervals. A cancer estimate without bounds, placed beside non-cancer endpoints that have been excluded rather than assessed, does not produce a complete picture of the health impact of a facility on a host community.

5.. Conclusion

The cancer-centric structure of CANDU health impact assessment is an artefact of the historical development of radiological protection frameworks, not a reflection of the current state of the health effects literature. Six categories of non-oncological health endpoints have peer-reviewed evidence of association with chronic low-dose radiation exposure. None are assessed in routine CANDU HIAs. The statutory mandate of the CNSC, the NSCA, and the IAA covers health of persons, not cancer in persons. For communities living adjacent to proposed CANDU facilities, including the proposed Peace River, Alberta site, a health impact assessment that excludes cardiovascular, neurological, immune, ophthalmic, reproductive, and mixture interaction endpoints has not assessed the health impact of the proposed facility. It has assessed a fraction of it and labelled the fraction the whole.

6.. References

[1] D.L. Preston, E. Ron, S. Tokuoka et al., "Solid cancer incidence in atomic bomb survivors: 1958–1998," Radiation Research, Vol. 168, 2007, pp. 1–64.

[2] E. Cardis, M. Vrijheid, M. Blettner et al., "The 15-Country Collaborative Study of Cancer Risk among Radiation Workers in the Nuclear Industry," BMJ, Vol. 331, 2005, pp. 77–82.

[3] D. Azizova, M. Haylock, R. Moseeva et al., "Cerebrovascular diseases incidence and mortality in nuclear workers cohort," Stroke, Vol. 41, 2010.

[4] United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), Effects of Radiation on the Embryo and Fetus, UNSCEAR Annex D, UN, New York, 1986.

[5] T. Rahu, M. Rahu, A. Tekkel et al., "Cause-specific mortality of Chernobyl cleanup workers in Estonia: an updated cohort study," BMJ Open, Vol. 3, 2013.

[6] Canadian Nuclear Safety Commission, Health Effects of Tritium, INFO-0799, CNSC, Ottawa, 2010.

[7] International Commission on Radiological Protection, Statement on Tissue Reactions (Eye Lens), ICRP Ref. 4832-3230-6655, ICRP, 2011.

[8] M. Loganovsky, "Do low doses of ionizing radiation affect the human brain?" Data in Brief, Vol. 5, 2015.

[9] B.V. Worgul, Y.I. Kundiyev, N.M. Sergiyenko et al., "Cataracts among Chernobyl clean-up workers: implications regarding permissible eye exposures," Radiation Research, Vol. 167, 2007.

[10] M. Hauptmann, A. Daniels, L.A. Cardis et al., "Occupational exposure to low-dose ionizing radiation and site-specific solid cancer risk in the 15-country INWORKS nuclear workers study," The Lancet Haematology, Vol. 7, 2020.

[11] D.T. Wigle, M.C. Turner and D. Krewski, "A systematic review and meta-analysis of childhood leukemia and parental occupational pesticide exposure," Environmental Health Perspectives, Vol. 117, 2009.

[12] R.C. Ziegler and M.B. Salmon, "Combined effects of radiation and carcinogenic chemicals," Carcinogenesis, Vol. 25, 2004.