Guidance for Evaluating Human Health Effects in Impact Assessment:

RADIOLOGICAL IMPACTS

Health Canada Santé Canada

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1 ACRONYMS

ACRONYM	MEANING
Agency	Impact Assessment Agency of Canada (also known as the IAAC)
ALARA	as low as reasonably achievable
Bq	becquerel
CNSC	Canadian Nuclear Safety Commission
CRMN	Canadian Radiation Monitoring Network
CSA	Canadian Standards Association
DNA	deoxyribonucleic acid
FPT	Federal, Provincial and Territorial
GBA Plus	gender-based analysis plus
Gy	gray
HHRA	human health risk assessment
HIA	health impact assessment
HLW	high-level waste
IA	impact assessment
IAA	*Impact Assessment Act*
IAAC	Impact Assessment Agency of Canada (also known as the “Agency”)
ICRP	International Commission on Radiological Protection
ILW	intermediate-level waste
IS	impact statement
LLW	low-level waste
LNT	linear-non-threshold
MAC	maximum acceptable concentration

mSv	millisievert
NFWA	*Nuclear Fuel Waste Act*
NORM	naturally occurring radioactive materials
NSCA	*Nuclear Safety and Control Act*
NWMO	Nuclear Waste Management Organization
RPB	Radiation Protection Bureau
SI	*système international*
Sv	sievert
TISG	tailored impact statement guidelines

2 PURPOSE OF THIS DOCUMENT

This document provides generic guidance on assessing potential human health risks of ionizing radiation in federal impact assessments (IAs) of proposed major resource and infrastructure projects in Canada. It presents the principles, current practices and basic information Health Canada looks for when reviewing the impact statement (IS) or other documentation submitted by project proponents as part of the IA process.

This document was prepared to support an efficient and transparent project review process. The foundational information described here should be supplemented appropriately with additional information relevant to proposed projects. The guidance was prepared for the Impact Assessment Agency of Canada (the Agency) and stakeholders involved in the IA process to communicate Health Canada's standard areas of engagement and priorities to help ensure that sufficient evidence is available to support sound decisions. As part of its review, Health Canada may suggest that the Agency, review panels or others collect information not specifically described in this document to assess the health effects of proposed projects. As the guidance provided here is generic and designed to support the IA process, the scope of Health Canada's review may also be amended to reflect project-specific circumstances.

Health Canada updates guidance documents periodically and, in the interest of continuous improvement, accepts comments and corrections at the following address: ia-ei@hc-sc.gc.ca.

In the same series, the following guidance documents are available:

- *Guidance for Evaluating Human Health Effects in Impact Assessment: AIR QUALITY*
- *Guidance for Evaluating Human Health Effects in Impact Assessment: COUNTRY FOODS*
- *Guidance for Evaluating Human Health Effects in Impact Assessment: DRINKING AND RECREATIONAL WATER QUALITY*
- *Guidance for Evaluating Human Health Effects in Impact Assessment: HUMAN HEALTH RISK ASSESSMENT*
- *Guidance for Evaluating Human Health Effects in Impact Assessment: NOISE*

Please verify that you are reading the most recent version available by consulting the Government of Canada Publications: https://www.publications.gc.ca/site/eng/home.html.

3 INTRODUCTION AND CONTEXT

The key objectives of Health Canada's IA program are to inform and improve understanding of the potential risks to human health associated with proposed projects, to help prevent, reduce, and mitigate negative impacts and foster positive impacts. Health Canada's expert information and knowledge are available to assist the Agency, review panels and others in assessing the potential project-related health effects.

As a federal authority, Health Canada provides specialist or expert information or knowledge in the Department's possession (expertise) to support the assessment of impacts on human health from projects considered individually and cumulatively under the *Impact Assessment Act* (IAA). This complement of expertise may change or evolve over time. The Department provides scientific expertise; it does not play a regulatory role. The use of expertise provided by Health Canada in the IA process will ultimately be determined by the reviewing body(ies).

In comparison to the *Canadian Environmental Assessment Act* 2012, the IAA expands the assessment of health to promote a broader understanding of the biophysical environment and supports assessment of the social and economic effects of projects. Among other things, the IAA includes specific requirements to consider positive and negative effects on the health, social and economic conditions of the public, including Indigenous peoples. In addition, the IAA includes the requirement for potentially affected Indigenous groups to be consulted during the planning phase of the project and incorporate Indigenous traditional knowledge, if provided, alongside other evidence. The IAA also requires consideration of the intersection of sex and gender with other identity factors.

Gender-Based Analysis Plus

Gender-based analysis plus (GBA Plus) identifies and analyzes the differential impacts of designated projects on diverse population groups. The "plus" in GBA Plus acknowledges that GBA goes beyond biological (sex[1]) and socio-cultural (gender[2]) differences. It highlights the pathways on which those differences develop and how they intersect with other determinants to shape health and well-being. It guides how we consider sex and gender when we frame, plan for, and implement the impact assessment of designated projects. Gender-based analysis plus includes other individual and social identity factors such as race, religion, social position, income, age, ability, and education; this is called intersectionality[3]. The basic steps to applying GBA Plus include gathering appropriate data,understanding context, and asking analytical questions to determine whether the project is expected to have disproportionate effects on diverse populations. By working through a GBA Plus analysis, experts can better understand the possible differential effects of a project on distinct groups of people, including on disproportionately affected or impacted populations and populations identified by sex and gender. Considering how a program, policy, plan, or product might impact groups differently provides an opportunity for all those involved to help address potential pitfalls before they become a problem or identify opportunities that would not have been otherwise considered.

1 Sex refers to physical and physiological features including chromosomes, gene expression, hormone levels and function, and reproductive/sexual anatomy. https://cihr-irsc.gc.ca/e/48642.html

2 Gender refers to the socially constructed roles, behaviors, expressions and identities of girls, women, boys, men, and gender diverse people. https://cihr-irsc.gc.ca/e/48642.html

3 Government of Canada's Approach Gender Based Analysis Plus. https://women-gender-equality.canada.ca/en/gender-based-analysis-plus/government-approach.html

Key GBA Plus considerations in IA of designated projects:

- Does the proposal identify the diverse communities of women, men and children who will be directly and indirectly affected by the proposed project's activities?
- Are the data about potential impacts disaggregated by sex, age, language and other social identities relevant to the local communities?
- Have the views of the affected women, men, Indigenous peoples and other disproportionately impacted groups been included in the proposed project's design?
- What are the implications of the proposed project's health and socio-economic effects on the well-being of women, men, Indigenous peoples and disproportionately affected populations?
- What types of measures are needed to ensure equitable representation during consultation processes and subsequent stages of the IA?
- What measures are needed to enhance the positive effects or mitigate any adverse effects of the designated project on women, men, children, and other disproportionately affected groups?

Identifying the range of concerns and interests of, and impacts on, diverse groups based on social characteristics like gender, age, ethnicity, occupation, and length of residency, for example, can help foster the development of more comprehensive mitigation and enhancement strategies. A health impact assessment (HIA) is a systematic, objective, yet flexible and practical way of assessing the potential positive and negative impacts of a proposal on health and well-being. In the context of designated projects under the IAA, an HIA aims to characterize the anticipated health effects, both adverse and positive, and the distribution of those effects within the population. The Agency determines the scope of the factors taken into account, including their relevance to the IA as outlined in the tailored impact statement guidelines (TISG). The steps of an HIA include screening, scoping, assessment, recommendations, reporting, monitoring and evaluation of the effectiveness of the HIA process, and the impact on decision-making.

Health Canada has been working with key partners and rights holders, including Indigenous organizations, federal partners, provinces/territories, and other key stakeholders, to develop HIA guidance and tools for a more comprehensive assessment of potential health effects of proposed projects. The document provides guidance to scope and address the broader social and economic conditions underlying the health of potentially affected communities and Indigenous peoples. Health Canada has developed an interim HIA Guidance Document to bridge the gap between the IAA coming into force on August 28, 2019, and the planned publication by the Department of the guidance document and complementary materials on HIA. The interim guidance document is available upon request at the following address: ia-ei@hc-sc.gc.ca.

Health Canada provides its expertise in human health risks associated with air quality, drinking and recreational water quality, ionizing radiation, electromagnetic fields, noise, and country foods when it reviews and provides comments on information submitted by proponents in support of proposed projects. Health Canada also provides general information on the subject of health assessments in relation to proposed projects subject to the federal IA review process.

This document concerns the assessment of human health risks associated with ionizing radiation. It contains information on the division of roles and responsibilities for issues related to ionizing radiation at various levels of government in Canada; health effects associated with radiation; indicators of these effects; and steps in Health Canada's preferred approach to assessing radiation-related health effects.

APPENDIX A provides a checklist for verifying that the key elements of a risk assessment of radiological impacts are complete and to show where this information appears in the assessment documents.

APPENDIX B provides a glossary of specific terms used throughout.

4 ROLES AND RESPONSIBILITIES

It is essential for stakeholders involved in assessing radiological/nuclear impacts on human health to know the regulatory regimes at both the federal and provincial/territorial levels. These regimes are governed by the respective legislations and associated roles provided in the following sub-sections.

In Canada, the Canadian Nuclear Safety Commission (CNSC) is responsible for regulating nuclear energy and materials, in order to protect the health of Canadians. Naturally occurring radioactive material (NORM), which is exempt from CNSC jurisdiction except for import, export, and transport, falls under the jurisdiction of provinces and territories. Health Canada maintains expertise in the health effects of radiological exposure and works with the provinces and territories on guidance in areas outside of CNSC's jurisdiction. In order to advance the development and harmonization of radiation protection practices and standards within Federal, Provincial and Territorial (FPT) jurisdictions, representatives from CNSC, Health Canada, and the provinces and territories participate in the Federal Provincial Territorial Radiation Protection Committee.

4.1 CANADIAN NUCLEAR SAFETY COMMISSION'S ROLE

The *Nuclear Safety and Control Act* (NSCA) came into force on May 31, 2000 when it replaced the *Atomic Energy Control Act*. It established the CNSC's mandate, responsibilities, and powers. The NSCA provided the CNSC with the authority to regulate the development, production and use of nuclear energy, as well as the production, possession and use of nuclear substances, prescribed equipment and prescribed information. The fulfillment of the CNSC's mandate serves to protect the health and safety of persons, the environment and national security, associated with development, production, possession or use of nuclear materials, as well as implement and maintain Canada's international obligations. The CNSC's mandate also requires it to disseminate objective scientific, technical and regulatory information to the public.

The *Radiation Protection Regulations* enacted under the NSCA stipulate radiation dose limits for regulated activities in Canada, for both members of the public and nuclear energy workers. Licensees are further required to keep radiation exposures and doses as low as reasonably achievable (the ALARA principle).

Under the IAA, designated projects regulated by the CNSC will be assessed by an integrated review panel process. For these projects, the Agency will develop the TISG in coordination with the CNSC and will identify information requirements under both the IAA and the NSCA. A TISG template for designated projects subject to the IAA and the NSCA is available on the Agency's website at: https://www.canada.ca/en/impact-assessment-agency/services/policy-guidance/practitioners-guide-impact-assessment-act/tailored-impact-statement-guidelines-projects-impact-assessment-nuclear-safety-act.html.

For designated projects that are regulated by the CNSC and are subject to an integrated impact assessment, the following Canadian Standards Association (CSA) Standards should be consulted:

- Modelling the movement of radionuclides released from a facility to a specified "representative person;" (CSA N288.1-20: *Guidelines for Calculating Derived Release Limits for Radioactive Material in Airborne and Liquid Effluents for Normal Operation of Nuclear Facilities*); and
- Completion of environmental and human health risk assessments for nuclear facilities and uranium mines and mills (CSA N288.6-22: *Environmental risk assessments at nuclear facilities and uranium mines and mills*).

Further information on nuclear safety regulations and dose limits may be obtained from the CNSC website: www.nuclearsafety.gc.ca.

4.2 HEALTH CANADA'S ROLE

Within Health Canada, radiological expertise rests primarily within the Environmental and Radiation Health Sciences Directorate of the Healthy Environment and Consumer Safety Branch. In this Directorate, the Radiation Protection Bureau (RPB) has the mandate to promote and protect the health of Canadians by assessing and managing the risks posed by radiological exposure in living, working, and recreational environments. Specifically, the RPB is responsible for the following activities that are relevant to IA:

- Operating the Canadian Radioactivity Monitoring Network (CRMN);
- Conducting research on the health effects of radionuclides in the environment;
- Developing guidance to protect Canadians from the effects of nuclear accidents, radioactivity in drinking water, radon in indoor air, and NORM from non-nuclear industries;
- Providing advice to federal departments and agencies, other levels of government, industry, universities, hospitals, workers and the public on health issues related to radiological exposure; and
- Providing advice for projects under the IAA.

Health Canada considers several aspects of the radiological information presented in an IA, including the following:

- Indicating whether all main routes of human exposure (i.e., cloudshine, groundshine, inhalation and ingestion1[4]) for the transfer of radiation to a human receptor have been considered and adequately described, to ensure that potential human health implications are characterized accurately;
- Expressing a view on whether the IA's estimated doses to human receptors are realistic, based on the nature of the project;
- Indicating whether the estimated doses are acceptable, when compared with the relevant dose limits or reference levels; and
- Expressing an opinion on whether mitigation, monitoring and follow-up programs are appropriate, in the interests of protecting human health.

4 See section 6.1 for a description of these terms

When requested, Health Canada provides expertise to provinces and territories, through FPT committees, in areas concerning radiological emissions to which the public may be exposed. Additionally, Health Canada cooperates and exchanges information with the CNSC under a memorandum of understanding: www.nuclearsafety.gc.ca/eng/pdfs/MoU-Agreements/MOU-between-CNSC-and-Health-Canada-eng.pdf.

4.3 PROVINCIAL AND TERRITORIAL ROLES

In Canada, natural resources are primarily regulated by the provinces or territories. The exception is the mining and milling of uranium, which fall under the NSCA and are regulated by the CNSC. However, prior to the mining and milling stage, exploration for uranium is still the responsibility of the provinces and territories.

All minerals and raw materials of a geological nature contain radionuclides of natural origin, including radionuclides from the uranium-238 (^{238}U) and thorium-232 (^{232}Th) decay series, as well as potassium-40 (^{40}K). When these materials are recovered, processed, used, or moved, there is a risk of creating an environment where radiation levels are high enough to require management as NORM. Jurisdiction over public and occupational exposure to NORM rests with the provincial and territorial governments. The *Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials (NORM)* (NORM guidelines) provide a harmonized approach to NORM management in Canada. It is up to provincial and territorial governments to include the NORM guidelines in the development of enforceable regulations. The NORM guidelines were updated in 2013 and are available on Health Canada's website at: www.hc-sc.gc.ca/ewh-semt/pubs/contaminants/norm-mrn/index-eng.php.

The quality of drinking water supplies is also primarily regulated by the provinces and territories. Similar to the development of the NORM guidelines, the *Guidelines for Canadian Drinking Water Quality* and the associated Guideline Technical Documents have been developed by the Federal-Provincial-Territorial Committee on Drinking Water. These guidelines recommend maximum acceptable concentrations (MACs) for several natural and artificial radionuclides. It is up to provincial and territorial governments to include these guidelines in the development of enforceable regulations. The *Guidelines for Canadian Drinking Water Quality: Guideline Technical Document—Radiological Parameters* is available on Health Canada's website at: www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/radiological_para-radiologiques/index-eng.php.

4.4 RELEVANT ACTS/GUIDELINES

Knowledge of other acts and regulations may be helpful for those conducting an IA for a project that may have radiological impacts. In particular, assessors are encouraged to consult the following legislation and regulations:

- *Nuclear Fuel Waste Act;*
- *Impact Assessment Act;*
- *Canadian Environmental Protection Act;*
- *Nuclear Safety and Control Act;*
- *General Nuclear Safety and Control Regulations;*
- *Radiation Protection Regulations;*
- *Class I Nuclear Facilities Regulations;*

- *Uranium Mines and Mills Regulations;*
- *Packaging and Transport of Nuclear Substances Regulations;*
- *Transport of Dangerous Goods Regulations;*
- NORM guidelines;
- Guidelines for Canadian Drinking Water Quality; and
- *Federal Contaminated Site Risk Assessment in Canada, Part VI: Guidance on Human Health Detailed Quantitative Radiological Risk Assessment* (*DQRA*$_{RAD}$).

The CSA also publishes radiation standards and guidelines linked to different industrial activities. These standards can be obtained from CSA's website at: www.csagroup.org/ca/en/services/codes-and-standards. Although compliance with CSA standards is voluntary, government authorities often refer to CSA's methodology for an example of best practices. The CNSC includes some CSA standards in the Licence Conditions Handbooks of licencees as a Compliance Verification Criteria, which makes them a requirement for licensees to follow and implement.

5 BASICS OF RADIATION

5.1 RADIATION TYPES AND SOURCES

5.1.1 Types of Radiation

All forms of radiation in the environment may be classified as either "ionizing" or "non-ionizing." Ionizing radiation consists of particles and photons with sufficient energy capable of removing electrons from atoms, thus creating electron-ion pairs as the radiation passes through matter. Non-ionizing radiation is lower in energy than ionizing radiation and does not possess enough energy to produce ions. This document discusses ionizing radiation only.

Ionizing radiation is produced by various processes. Of interest to this document is ionizing radiation produced by the radioactive decay of atoms with unstable nuclei. The following three types of ionizing radiation are normally encountered in the environment:

Alpha radiation: An alpha (α) particle consists of two protons and two neutrons bound together. Alpha radiation is the least penetrating of the different types of ionizing radiation and can be stopped by a sheet of paper. It cannot penetrate human skin but if the alpha source is inside the body, it is more damaging than the other types of ionizing radiation.

Beta radiation: Beta (β) radiation consists of either positively charged positrons or negatively charged electrons. Beta radiation is more penetrating than alpha but can be stopped by a few millimetres of aluminum.

Gamma radiation: Gamma (γ) radiation[5] consists of high energy photons and is a form of electromagnetic radiation. Gamma radiation is much more penetrating than alpha or beta radiation and can enter deeply into the human body. Thick, dense shielding, such as lead, is required to effectively shield against gamma radiation.

A radionuclide is a radioactive atom with an unstable nucleus. In order to achieve stability, the nucleus will often emit radiation, mainly in the form of alpha or beta particles, or gamma radiation, depending on the radionuclide. This process is known as radioactive decay. Each radionuclide is characterized by a certain "half-life," which is the time required for its activity to decrease by a factor of two through radioactive decay. The strength of a radioactive source is measured in activity units called becquerels (Bq), where one Bq is one nuclear disintegration per second.

5 The radioactive decay of some nuclei also results in the emission of x-rays, which are taken into account in dose coefficients used for dose assessments.

5.1.2 Sources of Natural Radionuclides

Radionuclides in the environment may be of natural or artificial origin. Natural radionuclides are either:

- Primordial (present since the formation of the earth);
- Members of a primordial decay series (in which the primordial parent radionuclide decays to another radionuclide, which then decays to another radionuclide and so on, until a stable isotope is reached); or
- Cosmogenic (continuously being produced by cosmic-ray bombardment of atoms in the upper atmosphere).

The most significant primordial radionuclides are shown in Table 5.1. Note that these radionuclides all have half-lives that are comparable to the age of the earth (4.5 billion years). The radionuclides ^{232}Th, uranium-235 (^{235}U) and ^{238}U each give rise to a long series of alpha and beta decays that eventually end up as a stable isotope of lead.

Table 5.1: Major primordial radionuclides found in the environment

Radionuclide	Symbol	Half-life (Years)
Potassium-40	^{40}K	1.27×10^{9}
Thorium-232	^{232}Th	1.40×10^{10}
Uranium-235	^{235}U	7.04×10^{8}
Uranium-238	^{238}U	4.468×10^{9}

Uranium-234 (^{234}U) is not included in Table 5.1 because it is not primordial; however, it is a small but very significant component of natural uranium. Dose assessments for exposure to natural uranium should always consider the contribution from ^{234}U, ^{235}U, and ^{238}U. Many radionuclides in the ^{238}U chain have environmental significance—Table 5.2 sums up their characteristics.

Table 5.2: Radionuclides of interest in the uranium-238 chain

Radionuclide	Symbol	Half-life	Other characteristics	Health considerations
Radium-226	^{226}Ra	1,600 years	Chemical analogue of calcium, more mobile in the environment than uranium	Can substitute for calcium in bone
Radon-222	^{222}Rn	3.8 days	Inert gas (i.e., having a very low chemical reactivity) can diffuse out of the ground	Can build up in confined living or working spaces; decay products can damage lungs
Polonium-218	^{218}Po	3.05 min	Short-lived decay products of ^{222}Rn	Attach themselves to aerosol particles and become deposited in the lungs when inhaled. One of the principal contributors to dose from radon decay products since it emits alpha radiation.
Lead-214	^{214}Pb	26.8 min	Short-lived decay products of ^{222}Rn	Attach themselves to aerosol particles and become deposited in the lungs when inhaled
Bismuth-214	^{214}Bi	19.7 min	Short-lived decay products of ^{222}Rn	Attach themselves to aerosol particles and become deposited in the lungs when inhaled
Polonium-214	^{214}Po	1.64×10^{-4} s (164 µs)	Short-lived decay products of ^{222}Rn	Attach themselves to aerosol particles and become deposited in the lungs when inhaled. One of the principal contributors to dose from radon decay products since it emits alpha radiation.
Lead-210	^{210}Pb	22 years		Typically received through the ingestion pathway rather than the inhalation pathway, as can build up to significant levels in certain foods consumed by humans (e.g., caribou and shellfish)
Polonium-210	^{210}Po	138 days		A decay product of ^{210}Pb, it can also build up to significant levels in certain foods consumed by humans (results in a greater dose than ^{210}Pb when ingested).

The ^{232}Th and ^{235}U decay series are generally of lesser concern in the environment. However, in the thorium series, such elements as radium-228 (^{228}Ra: half-life = 5.75 years) and radon-220 (^{220}Rn: half-life = 56 seconds, often referred to as *thoron* gas) should also be considered in certain cases, such as mining projects. Until recently, the health impacts of exposure to thoron were not considered and only radon-222 (^{222}Rn)—a decay product in the ^{238}U series—was a concern. However, similarly to radon, ^{220}Rn also produces decay products with the potential to irradiate the lungs. Potassium-40 is not considered an environmental hazard because it is homeostatically regulated in the body. In other words, an increased ingestion of ^{40}K will be offset by an increased excretion.

Natural radionuclides are commonly present in the environment. Potassium-40 is generally present in rocks and soils at about 500 Bq/kg (which means that there are about 500 nuclear disintegrations per second in a kilogram of rock or soil). Uranium and thorium concentrations in rocks and soils are typically 25 to 50 Bq/kg, although they vary widely from region to region, and may be higher in areas where uranium and thorium minerals are present at levels sufficient for mining operations. In solid rocks and tightly packed soils, these series will generally be in secular equilibrium with the uranium or thorium parent. In loosely packed soils, radon gas may escape into the atmosphere or confined spaces.

5.1.3 Sources of Artificial Radionuclides

Artificial (or anthropogenic) radionuclides are produced and used widely in medical, industrial and research applications. They are also released as waste products from many nuclear operations. Artificial radionuclides are produced by three main mechanisms:

1. Nuclear fission, either in a reactor or from the detonation of a nuclear weapon;[6]
2. Neutron capture (n-capture) on a stable element, utilizing the neutron flux of a reactor; and
3. Spallation reactions with high-energy charged particles from an accelerator.

Table 5.3 lists significant artificial radionuclides that may be found in the environment.

Table 5.3: Artificial radionuclides likely to occur in the environment

Radionuclide	Symbol	Half-life	Production mechanism	Health considerations
Tritium	^{3}H	12.3 years	N-capture on deuterium in Canada Deuterium Uranium reactors	Often found in water; disperses uniformly throughout the body; low energy of emitted radiation and rapid excretion rate generally result in little health risk
Carbon-14	^{14}C	5,730 years	N-capture on nitrogen annulus gas in reactors	Disperses throughout the body via the bloodstream

6 Canada uses and exports nuclear materials for peaceful purposes only, thus radionuclides associated with weapons detonation would only be assessed in IAs as they pertain to existing background doses for a project.

Radionuclide	Symbol	Half-life	Production mechanism	Health considerations
Cobalt-60	^{60}Co	5.27 years	N-capture on stable cobalt-59 in reactors	Main concern is external exposure to gamma radiation; can also be absorbed into the liver, kidney and bones if ingested
Strontium-90	^{90}Sr	29 years	Nuclear fission in I albombs or reactors	Deposited in bone
Technetium-99m*	^{99m}Tc	6.02 hours	Fission product of molybdenum-99 in reactors	Most commonly used medical isotope; excreted from the body within a month
Iodine-131	^{131}I	8.041 days	Nuclear fission in bombs or reactors	A fission product, concentrates in the thyroid gland
Cesium-137	^{137}Cs	30.17 years	Nuclear fission in bombs or reactors	External gamma radiation hazard; if ingested, distributes fairly uniformly through the body but is eliminated fairly quickly
Iridium-192	^{192}Ir	74.02 days	N-capture on stable iridium-191 in reactors	External gamma radiation hazard; if ingested, can concentrate in several organs
Plutonium-239	^{239}Pu	24,110 years	N-capture on ^{238}U in reactors	Not considered a significant ingestion hazard, as it passes through the body with minimal absorption; if inhaled, can pass into the bloodstream from the lungs and can remain in the body for decades, oxides are retained in the lungs for an extended period of time

* m stands for metastable.

Some of these radionuclides are also produced naturally by cosmic-ray bombardment of molecules in the upper atmosphere. The most important cosmogenic radionuclides are tritium (^{3}H), beryllium-7 (^{7}Be), carbon-14 (^{14}C) and sodium-22 (^{22}Na). However, their natural production is very low and they contribute only a small fraction to background radiation doses.

The largest source of artificial radionuclides in the environment has been worldwide fallout from the atmospheric testing of nuclear weapons between 1945 and 1980. Residual levels of ^{3}H, ^{14}C, cesium-137 (^{137}Cs) and strontium-90 (^{90}Sr) are still present in the environment from this source. The concentrations of ^{137}Cs and ^{90}Sr in Canadian milk have been steadily decreasing since the period of most intensive testing in the 1960s. Artificial radionuclides now contribute less than 0.005 millisieverts (mSv)/year to the total background radiation dose in Canada.

5.2 RADIATION AND HUMAN HEALTH EFFECTS

The biological effect of radiation results from its ability to produce ionizations as it passes through living cells. The most sensitive target in a cell is the deoxyribonucleic acid (DNA) molecule, which carries the genetic code of the organism. The disruption of a cell's DNA can result in a number of different outcomes, including:

- Successful repair of the DNA damage and continued proper functioning of the cell;
- Cell death or the inability of the cell to divide and reproduce due to the severity of the DNA damage; and
- Incorrect repair but continued survival of the cell with the potential for disrupted functioning in the future or in future daughter cells. This impaired functioning can lead to cancer.

Three kinds of dose that are commonly used in radiation protection are "absorbed," "equivalent," and "effective." Absorbed dose is the amount of energy deposited in a medium (such as a person, a plant, air, etc). The SI unit (abbreviated "SI" from the French Système International d'Unités) for measuring the absorbed dose is the gray (Gy)—defined as one joule of energy absorbed per kilogram of matter. A closely related concept is the "equivalent dose" (measured in sieverts (Sv)), which is defined as the sum of the weighted average absorbed dose in a tissue or organ—recognizing that different types of radiation give rise to differing degrees of biological harm at the same absorbed dose. For example, for beta and gamma radiation, the equivalent dose in Sv is numerically equal to the absorbed dose in Gy. For alpha radiation, the equivalent dose in Sv is 20 times greater than the absorbed dose. The "effective dose"—also measured in Sv—is the sum of the equivalent doses in all tissues and organs of the body, weighted to represent the relative contributions of different tissues and organs to the total health detriment resulting from radiation exposure. Reference levels and dose limits of relevance to IAs are typically expressed as effective dose, and this is the appropriate measure to use to quantify radiological impacts for impact assessments.

At the level of a multi-cellular organism, the effects of radiation may be described as "tissue reactions" or "stochastic effects". Tissue reactions have a threshold, below which they do not occur and above which the severity increases with dose. The threshold may be different for different individuals. An example of a deterministic effect is acute radiation syndrome, which begins to occur in humans at doses approaching one Sv (1,000 mSv) during a short-term (acute) exposure. Doses of this magnitude are not encountered in environmental situations and could occur only as a result of direct exposure in the case of a severe radiation accident.

Stochastic effects are assumed not to have a threshold; the severity of a stochastic effect is independent of exposure. However, for the purposes of risk assessment, the probability of occurrence for the effect is assumed to increase with increased exposure. Unlike tissue reactions, it has not been possible to establish a clear threshold below which there is no risk of a stochastic effect. The most significant stochastic effect from radiological exposure is cancer.

The risks of stochastic effects are well documented at high levels of radiological exposure through studies of exposed populations, such as the atomic bomb survivors and persons exposed in occupational and medical settings. The United Nations Scientific Committee on the Effects of Atomic Radiation assesses such information, and the International Commission on Radiological Protection (ICRP) considers the studies in their recommendations.

The latest recommendation of ICRP includes an assessment of detriment of about 5% per sievert (ICRP, 2007a). Detriment is defined as "the excess of stochastic health effects in a group of individuals exposed to low-level radiation and their descendants compared with a non-exposed group. It is determined from sex-averaged and age-at-exposure-averaged life-time risk estimates for a set of organs and tissues, taking into account the severity in terms of quality of life in non-lethal conditions and length of life lost" (ICRP, 2022). The risk assessments underpinning the detriment calculations assume that any exposure to radiation carries a risk, and that the dose-response is linear for solid cancers and linear-quadratic for leukemia. Scientific evidence continues to support use of this model for the purposes of radiation protection (e.g., UNSCEAR, 2021; Richardson et al., 2018), although the evidence becomes increasingly uncertain as dose decreases. This is, in part, because at doses below about 100 mSv, the population-level increase in cancer is expected to be quite small and is therefore difficult to detect compared to the overall cancer incidence rate, which is estimated at over 40% in the general population (Canadian Cancer Society, 2021).

For lower doses, the radiation protection framework relies on mathematical models to estimate risks. The model often used for radiation protection purposes is the linear-non-threshold (LNT) model, which assumes that there is no threshold for radiation-induced cancer and that the risk is directly proportional to dose. Since the 1950s, regulators and radiation protection authorities have consistently used this approach in setting dose limits. The ICRP (2007a) endorses use of the LNT model as a basis for radiation protection, along with the following fundamental principles:

- *Justification*: No radiation practice shall be undertaken unless there is a net positive benefit.
- *Optimization*: All exposures shall be kept ALARA, economic and social factors taken into account.
- *Dose Limitation*: No dose shall exceed the established limit for the general public of 1 (one) mSv/year for planned exposure situations, over and above background, from all industrial applications of radiation. Exposures for medical purposes are excluded.

More information is available at: Introduction to radiation - Canadian Nuclear Safety Commission (https://nuclearsafety.gc.ca/eng/resources/radiation/index.cfm).

6 ADDRESSINGTHE POTENTIAL IMPACTS OF RADIOLOGICAL EXPOSURE IN IMPACT ASSESSMENTS

One of the key tools that Health Canada promotes for evaluating the potential health impacts of project-related exposure to contaminants is called a “human health risk assessment” (HHRA). An HHRA can help identify potential human health risks associated with a proposed project.

Three components must be present for a “risk” to exist:

1. a hazard (for example, a chemical or a radionuclide);
2. a receptor (individuals or communities); and
3. an exposure pathway (a means by which people are exposed to the contaminant).

Within an IA, an HHRA is defined as the process used to estimate the probability of adverse health effects for people who may be exposed to contaminants through different pathways (ingestion and/or inhalation) in specific environmental media (air, foods, soil, water and/or sediment).

An HHRA provides qualitative and/or quantitative estimates of the likelihood of adverse effects to human health, depending on the available information. These estimates are based on the inherent characteristics of the contaminants and factors specific to the project being assessed—such as the characteristics of the exposed population and the media through which the exposure would take place.

Although conducting an HHRA is not always a requirement of an IA and is dependent on the scope of a particular project, it can provide increased defensibility for the conclusions of an IA. The findings of an HHRA are particularly useful for determining the significance of a potential effect and for establishing appropriate mitigation measures, follow-up programs, and plans for monitoring, remediation and/or risk management plans.

Detailed information on HHRA methodologies in the context of IA can be found in the *Guidance for Evaluating Human Health Effects in Impact Assessment: HUMAN HEALTH RISK ASSESSMENT* (Health Canada, 2023). The general framework for assessing radiological risks is similar to a general model used in HHRA, although methods and reference levels may vary between different regulatory agencies. Figure 6.1 represents a general model for radiological risk assessment presented in a Health Canada publication (2010) and follows general guidance from United State Environmental Protection Agency publication (1989). Each of the steps is expanded in the sections that follow.

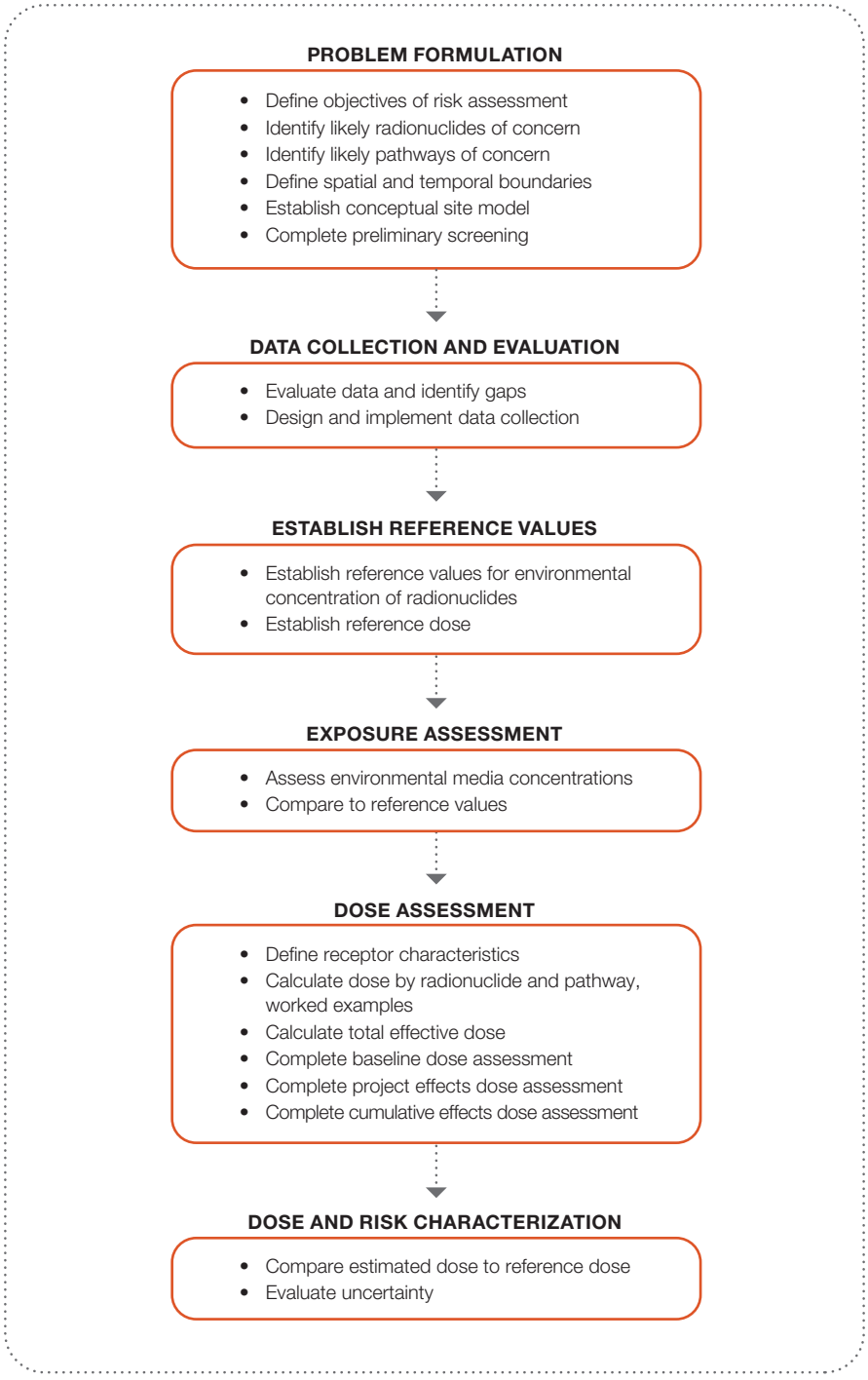

Figure 6.1 Paradigm for assessing human health radiological risks (based on Health Canada, 2010)

6.1 PROBLEM FORMULATION

Problem formulation is the first and most crucial step when planning an HHRA of potential radiological impacts. The decisions about what to include in the assessment will influence the identification of potential remedial actions. A problem formulation that provides clearly defined objectives for the risk assessment helps determine the type of assessment needed—screening, deterministic or probabilistic.

A radiological risk assessment usually takes a "deterministic" approach (use of a single value for each variable in the exposure equation). Such an approach permits conservative assumptions, which ensures that estimated doses and risks are based on worst-case (but still reasonable) scenarios. In cases where it is justified, sensitivity analysis may help identify the parameters with the most significant influence on predicted doses and risks.

A "probabilistic" approach is used when it is necessary to more fully and precisely quantify the effects of uncertainty or when the frequency of doses and the risk levels across a target population need to be established (for example, when risks of accidents or malfunctions are predicted). Sources of uncertainty may exist at multiple levels:

- Receptors (age groups, scale of activities, residences and temporal scales);
- Pathways for potential exposure (irradiation, inhalation, ingestion, and/or dermal);
- Dose assessment; and
- The quality of the available data.

Conceptual site models are often utilized at the problem-formulation stage of radiological risk assessments. A conceptual model is a generic diagram of the project that facilitates the identification of the following:

- All relevant emission sources;
- Potential radionuclides of concern;
- Potential exposure pathways; and
- Any potentially affected receptor groups.

The problem formulation stage should also define the spatial and temporal boundaries (including regional, local and site study areas) to be used in the assessment.

Generally, there are four main routes of human exposure by which members of the public may be exposed to radiation:

- Cloudshine—direct exposure to a cloud of radioactive material;
- Groundshine—direct exposure to a layer of radioactivity deposited on the ground;
- Inhalation of radioactive aerosols; and
- Ingestion of radioactivity from food, drinking water or soil.

The dermal pathway is generally not considered one of the main routes to human exposure, although it should be considered in specific instances.

Preliminary screening may be utilized to eliminate radionuclides and pathways predicted to have negligible influence on the dose to the receptors; this allows the assessment to focus on relevant data collection and analyses. However, the HHRA should provide a justification for the exclusion of any pathways or radionuclides.

6.2 DATA COLLECTION AND EVALUATION

Baseline concentration data for radionuclides of natural and/or artificial origin that are relevant to the project should be determined in key environmental compartments within the study areas, including the following:

- Atmosphere;
- Soils and sediments;
- Common terrestrial plants and animals, especially if consumed by humans;
- Surface water bodies, especially if used for drinking water or recreation;
- Fish and aquatic plants; and
- Groundwater, especially if wells are present.

Baseline data may come from a number of sources, including historical records and/or measurements made to support the IA. In the case of projects occurring at existing nuclear facilities, annual environmental monitoring reports are required as part of the CNSC reporting requirements and may provide relevant data on the radiological environment and associated annual radiation doses to the public (e.g., representative person and/or critical group or groups). These reports are typically found on licensees' websites. Data is also available online from the CNSC's Independent Environmental Monitoring Program (for existing nuclear facilities only) and from Health Canada's environmental radiation monitoring networks (e.g., CRMN).

If new baseline measurements are required, simple gamma spectrometric analysis of bulk field samples (e.g., soil, water, air) should be sufficient to characterize and quantify any natural and artificial gamma-emitting radionuclides that may be present. If radionuclides of concern are pure alpha- or beta-emitters, alternative measurement techniques will be required. Background dose rates of ambient gamma radiation should also be assessed using long-term monitors. The uncertainty of any measurements should be estimated considered throughout the assessment.

In cases where historical information is not available—and direct measurement is not possible or practical—environmental data will have to be modelled. Modelling can be conducted using environmental fate and transfer models, which are described in more detail in the following section. Preference should always be given to measured data, if such data are available. Empirical models derived from measured data or from combinations of measured and literature data are most useful for filling in missing or inadequate data. If a model is used to substitute for measured values, the model should be validated against reference data or monitoring data from a similar site or development. Any remaining gaps in the data must be identified.

6.3 ESTABLISHMENT OF REFERENCE VALUES

At this stage of the assessment, reference values[7] should be established as benchmarks or limits for the project. In most cases, the reference values should be adopted from relevant federal and/or provincial regulations or guidelines. When these are expressed in terms of dose (often annual dose), it could be useful to derive operational criteria, such as dose rates or activity concentrations, using realistic dose assessments (see next section) and clearly stating all assumptions.

The following guidelines contain examples of operational criteria derived from annual dose constraints:

- *Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Radiological Parameters;*
- *Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials (NORM);* and
- *Government of Canada Radon Guideline.*

6.4 EXPOSURE ASSESSMENT

The exposure assessment consists of estimating releases from the project for all radionuclides of concern and calculating the concentrations in environmental media. The project releases may be into water, soil or air. Once the environmental concentrations of radionuclides have been estimated, they should be compared to the reference values. Typically, the exposure assessment for project effects should be completed for all phases of the project, including construction, operation, decommissioning and abandonment.

One method for completing these estimates is the use of environmental transport models. Although developed for calculating the derived release limits of radionuclides from nuclear facilities, CSA N288.1-20 (*Guidelines for modelling radionuclide environmental transport, fate, and exposure associated with the normal operation of nuclear facilities*) can be employed in the exposure assessment. This standard outlines the main environmental pathways of exposure. It provides a set of tables and formulae that include all the necessary transfer coefficients and other parameters to calculate radiation concentrations in various environmental compartments, as well as human doses. The standard was intended primarily to ensure that regulatory dose limits are not exceeded; however, the methodology can also be used to predict the impact of a proposed facility on a human population.

Additionally, *Federal Contaminated Site Risk Assessment in Canada, Part VI: Guidance on Human Health Detailed Quantitative Radiological Risk Assessment* (*DQRA*$_{RAD}$), (Health Canada, 2010), contains an overview of available fate and transport models that can be used in radiological risk assessments. It contains an inventory of Canadian and American models, with references and general information on how to select an appropriate model. This information may also be obtained from other non-government sources. When an assessment uses modelling to predict environmental concentrations, any assumed parameters should be identified and the rationale for the assumption should be described. Assumptions should be conservative but reasonable.

7 Note that the term "reference value" is defined as above for the purposes of this document, but may have alternative, or more specific meanings in other documents. For example, "reference level", which is close to the term "reference value", has specific definitions in the context of other guidance including drinking water or protection strategies for nuclear emergencies.)

6.5 DOSE ASSESSMENT

Dose assessment uses information related to contaminants, receptor characteristics, behaviour, and activity patterns in order to quantify dose. For radiological assessments, exposure assessment identifies the radiation dose (whole body or specific tissue).

In a radiological HHRA, the endpoints for human health impacts are based on a "representative person" (ICRP, 2007b; CSA 2020). The representative person is an individual or group of people whose location, habits and metabolic characteristics would lead to the highest radiological effects, due to exposures from a particular source. The choice of a representative person requires careful judgment.

Usually, the most exposed individual lives at or near the site boundary of a project. They may have a vegetable garden or keep livestock from which they meet a percentage of their food requirements. Their drinking water supply may be a surface water or groundwater source near the project. The representative person may be a member of an Indigenous community, who occasionally visits the area for hunting or fishing purposes. Age may also play a factor in the selection of a representative person—as infants and children are usually more susceptible than adults to radiation effects.

The dose assessment consists of establishing the characteristics and behaviours of the representative person, such as ingestion rates and time on location (duration of exposure); analysing the exposure pathways; and calculating the effective dose. Dose assessment should include all exposure pathways and radionuclides of concern that were identified in the project formulation stage. If any pathways or radionuclides are excluded, adequate justification must be provided. The effective dose should be determined individually for each radionuclide and pathway, and summed, to determine the total effective dose. References for dose coefficients should be current and cited. The dose assessment should be completed for the baseline conditions, project effects and cumulative effects.

The assessment of project effects should be completed using the environmental concentrations of radionuclides determined in the exposure assessment. If appropriate, the dose assessment for project effects should be completed for various phases of the project, such as construction, operation, decommissioning and abandonment. Environmental concentrations can be used to determine internal (for example, ingestion) and external (for example, groundshine) exposures using the same environmental pathways models previously described. To ensure clarity, the assessment should provide a worked example for one radionuclide in each of the environmental pathways—showing the step-by-step method used for each dose calculation.

Under the IAA, subsection 22(1)(a)(ii), an IA must take into account "any cumulative effects that are likely to result from the designated project in combination with other physical activities that have been or will be carried out." Assessing the cumulative effects of projects is a central element of the IA. The cumulative effects scenario represents the potential environmental effects of the existing baseline plus project scenario in combination with effects from reasonably foreseeable future projects within the same area of influence. Reasonably foreseeable future projects include those that are approved but not yet operating, and/or other proposed or likely developments within the potentially impacted area. The cumulative effect scenario provides an estimate of human health risks in the future when other facilities are also in operation. Individual effective doses may already be developed for all projects in the study area; therefore, it is convenient to assess cumulative effects by summing all radiation doses resulting from the individual operations.

This document does not address the combined effects of exposure to radiation and other environmental hazards. Possible interactions or synergies between radiation and chemical contaminants are still poorly understood and should be treated separately. In addition, the chemical hazard is more significant than the radiological hazard for public exposure in many cases (e.g., uranium).

6.6 DOSE AND RISK CHARACTERIZATION

Estimated effective doses resulting from the baseline conditions should be used as a benchmark of normal conditions and can be used for comparison purposes to assess incremental increases and predict project effects.

Estimated total effective doses from the project effects and cumulative effects should be compared to the 1 mSv/year dose limit for members of the public, and/or to any other relevant reference dose decided upon at the outset of the assessment. If cumulative effects are expected, it could be prudent to set a dose constraint for the project (for example, not more than about 0.3 mSv/year) to ensure that the overall public dose limit is not exceeded.

It should be noted throughout the assessment that there will be significant uncertainty in the values used in the dose assessment, whether measured or modelled. It may not always be possible to quantitatively determine the uncertainty—in which case it should be described qualitatively. Conservative estimates (for example, maximum environmental concentrations) can be used to offset the uncertainty; however, care should be taken to avoid using extremely conservative estimates for every variable (ICRP, 2007b). Gross overestimates of dose are not consistent with the principle of optimization.

6.7 MITIGATION MEASURES

An IA should include mitigation measures that are technically and economically feasible and that would mitigate adverse effects of the designated project. Conducting a pathways analysis will aid in identifying adverse effects due to radionuclide releases or other impacts from the project. If warranted, the proponent may be required to specify mitigation measures that will be carried out to alleviate these impacts, assess potential residual effects, and confirm that they are acceptable given the reference values established for the project.

6.8 FOLLOW-UP PROGRAMS

Under Section 2 of the IAA, a follow-up program is defined as a program for:

a) Verifying the accuracy of the IA of a designated project; and

b) Determining the effectiveness of any mitigation measures.

The outputs of a follow-up program can be used to identify methods to reduce the potential risks to acceptable levels. For managing future potential risks, these methods may include:

- Monitoring programs for specific environmental media in the project area at the nearest sensitive human receptor(s);
- Mitigation strategies, such as alterations in the design/layout/location of a project, the introduction of newer technologies, and changes in production capacity and output; and/or
- Strategies guiding communications between the proponent and the public—to keep all relevant stakeholders informed about any project-related changes that may have an impact on human health (for example, emissions, accidents and malfunctions).

Both follow-up and monitoring can be integral parts of any adaptive phased management plan.

Health Canada may make available expert health-related information or knowledge regarding a follow-up program upon request by the Agency, a review panel or others conducting the IA.

For further and up-to-date information on the need or requirement of follow-up programs, contact the Agency.

7 TYPES OF RADIOLOGICAL PROJECTS FOR WHICH IMPACT ASSESSMENT IS PERFORMED UNDER THE IAA

Activities identified in the IAA *Physical Activities Regulations* ("the Project List") must meet the requirements of an IA under the IAA. The Project List is intended to identify those physical activities with the greatest potential to cause significant adverse effects in areas of federal jurisdiction, such as mines and mills (uranium and non-uranium) as well as nuclear facilities. Some of these activities fall under CNSC jurisdiction and some fall under other regulatory authorities, such as provinces and territories.

Sections 7.1–7.4 apply to activities that fall under both the NSCA and the IAA. All facilities conducting activities related to the use, production and distribution of nuclear energy and substances that are licensed by the CNSC under the NSCA must first meet the requirements of an IA under the IAA. Projects that require an IA under the *Physical Activities Regulations* are set out in schedules 18 to 23 and 26 to 29, and include:

- Uranium mining and milling;
- Uranium processing and fuel fabrication;
- Nuclear reactors; and
- Radioactive waste storage.

For more information on the specific regulations pertaining to the NSCA, visit the CNSC website at: https://www.cnsc-ccsn.gc.ca/eng/acts-and-regulations/index.cfm.

The CSA standards and guidelines for facilities dealing with the nuclear fuel cycle may also be consulted as examples of industry best practices, and are available on the CSA website at: www.csagroup.org/ca/en/services/codes-and-standards.

7.1 URANIUM MINING AND MILLING

Existing and future uranium mining and milling is subject to the NSCA for the entirety of the mining lifecycle, including site preparation, construction, operating, decommissioning and abandonment (or release from licensing). Typically, the greatest radiological human health risk associated with the operation of a uranium mine is the workers' exposure to radon. While occupational health and safety is a provincial and territorial responsibility, health risks to members of the public must also be assessed.

Uranium milling is normally carried out at the mine site or nearby, and leaves behind large quantities of residues called "tailings and waste rock". Tailings are the waste produced by grinding the ore and the chemical concentration of uranium. When dried, tailings have the consistency of fine sand. Waste rock is simply rock material removed from the mine to gain access to the ore. It has very little to no concentration of uranium. Waste rock is separated into clean rock or mineralized rock, according to its mineral content. Tailings and mineralized waste rock must be managed over the long term because they could contain significant concentrations of radioactive elements along with their associated decay products.

Both need to be disposed of appropriately and will likely include several long-lived radionuclides, some of which are described in Table 7.1.

Table 7.1: Isotopes of uranium and decay products that may be present in uranium ore

Radionuclide	Symbol	Half-life (years)
Uranium-234	^{234}U	245,000
Uranium-235	^{235}U	704 million
Uranium-238	^{238}U	4.46 billion
Thorium-230	^{230}Th	75,000
Radium-226	^{226}Ra	1600
Lead-210	^{210}Pb	22

7.2 URANIUM PROCESSING AND FUEL FABRICATION

Facilities for the processing of uranium for fuel are regulated by the CNSC under the NSCA.

The licensing process for uranium processing facilities follows the stages laid out in the *Class I Nuclear Facilities Regulations*, proceeding progressively through site preparation, construction, commissioning, operating, decommissioning, and abandonment phases.

Uranium processing and fabricating facilities typically refine uranium ore concentrate (generally called "yellowcake") into fuel bundles through several processing stages. Uranium processing facilities must meet CNSC's safety and security requirements.

When assessing emissions from uranium processing and fuel-fabrication facilities, it is generally only the uranium isotopes that are of concern, since the uranium decay products have been almost entirely removed during the on-site milling process.

7.3 NUCLEAR REACTORS

Two basic types of nuclear reactors are in operation in Canada: power reactors and research reactors. Nuclear power reactors generate electricity, while research reactors are used for scientific research and produce nuclear substances for medical and industrial use.

As with uranium mining, the entire lifecycle of a nuclear reactor—including site preparation, construction, operation, decommissioning and abandonment—is governed by the NSCA. The operating lifespan of a nuclear reactor may be extended through refurbishment, which could include the replacement of various reactor components.

The nuclear reactors at power plants release small quantities of radioactive materials, in a controlled manner into both the atmosphere (as gaseous effluents) and adjoining water bodies (as liquid effluents). The gaseous releases contain tritium in the form of tritium oxide, iodine-131, noble gases, radioactive particulate and ^{14}C, as well as the liquid releases contain tritium in the form of tritium oxide, gross beta-gamma activity and ^{14}C.

Typically, the greatest radiological human health risk will occur during the operational and decommissioning phases of the reactor lifecycle; however, all stages of the lifecycle should be assessed.

7.4 RADIOACTIVE WASTE

The Government of Canada has put in place a regulatory framework of policies and legislation, as well as responsible organizations that govern the management of radioactive wastes in Canada. Canadian government departments, agencies and the nuclear industry have clear roles and responsibilities through the *Canada's Policy for Radioactive Waste Management and Decommissioning* (2023) to ensure the safe management of radioactive waste.

The CNSC is responsible for regulating all steps in the management of radioactive waste, including, as applicable, its generation, handling, processing, transport, storage and disposal.

Radioactive waste in Canada is defined as any material (liquid, gaseous, or solid) that contains a radioactive nuclear substance, as defined in section 2 of the NSCA, for which no further use is foreseen. In addition to containing nuclear substances, radioactive waste may also contain hazardous substances that are not radioactive, as defined in section 1 of the *General Nuclear Safety and Control Regulations* (https://laws-lois.justice.gc.ca/eng/regulations/sor-2000-202/index.html).

In Canada, radioactive waste may be classified as low-, intermediate-, or high-level waste (LLW, ILW or HLW) or as uranium mine and mill tailings. Radioactive waste is classified according to the degree of containment and isolation required to ensure safety with consideration given to the hazard potential of different types of waste and the timeframe associated with the hazard. Uranium mine and mill waste is a specific type of radioactive waste and is discussed in Section 7.1.

More information on the management of radioactive waste can be found at: http://www. nuclearsafety.gc.ca/eng/acts-and-regulations/regulatory-documents/published/html/ regdoc2-11-1-vol1/index.cfm and in the Canadian Integrated Strategy for Radioactive Waste at https://radwasteplanning.ca.

Low-level Wastes

Most radioactive wastes fall into the LLW category. This waste is more radioactive than clearance levels and exemption quantities allow. It consists primarily of industrial items—mops, rags, paper, protective clothing, and hardware items, such as equipment and tools.

Intermediate-level Wastes

Intermediate-level wastes contain long-lived radionuclides in concentrations that require isolation and containment for periods greater than several hundred years. This waste consists primarily of used nuclear reactor components, ion exchange resins and some radioactive sources used in radiation therapy.

High-level Wastes

High-level waste consists primarily of used nuclear fuel from nuclear power plants, research reactors and test facilities. In 2002, the *Nuclear Fuel Waste Act* (NFWA) was established to provide the oversight that the Government of Canada and the Minister of Natural Resources will exercise in regards to the long-term management of nuclear fuel waste in Canada. Under the NFWA, the Nuclear Waste Management Organization (NWMO) was established to develop and implement Canada's plan for the long-term management of its nuclear fuel waste in a deep geological repository in an informed and willing community. Information on the activities of the NWMO can be found at: www.nwmo.ca.

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APPENDIX A | RADIOLOGICAL IMPACTS ASSESSMENT CHECKLIST

This checklist can be used to verify that the main components of a radiological assessment have been completed. It is helpful to include this checklist with the IS (or equivalent document) to show where the components of the radiological assessment are located in the document. This is especially helpful if the components are located in more than one section of the document.

PROBLEM FORMULATION		
✓	**Item**	**Section in IA**
	1. Does the problem formulation include a statement of goals (e.g., to establish whether non-negligible human health risks may exist in order for the project to proceed)?	
	2. Have the scope and complexity of the risk assessment been adequately described (i.e., qualitative vs. quantitative risk assessment)?	
	3. Is the complexity of the assessment appropriate? Appropriateness can be based on: a. The nature of the project (particularly if it is a new and/or large undertaking that involves or may in the future involve appreciable levels of contamination); b. The number and types of contaminants involved; c. The availability of applicable screening criteria; d. The estimated/predicted exposure concentrations; e. The number and complexity of pathways for human exposure; f. The location and sensitivity of human receptors; g. The quality of the baseline project data; h. The desire by the proponent for additional justification/precision regarding the potential risks associated with a proposed project; and i. The level of public concern.	
	4. Has a conceptual model been presented and does it appear to be complete? (i.e., does it include the following:) a. All potential contamination sources; b. All potential radionuclides of concern; c. All critical receptor groups; and d. All potential exposure pathways?	
	5. Has the proposed project been adequately described in terms of physical setting by maps and site plans?	

PROBLEM FORMULATION		
✓	**Item**	**Section in IA**
	6. Have all relevant radionuclides of concern been identified? Is there sufficient information to determine whether all relevant radionuclides for all project phases have been identified?	
	7. Were the information sources identified for determining the radionuclides of concern (e.g., from other similar projects, documents specific for the sector, etc.)?	
✓	**Item**	**Section in IA**
	8. Has adequate baseline data been collected, and in particular, do data exist for baseline concentrations in the appropriate media (e.g., air, soil, groundwater, surface water and country foods as applicable)?	
	9. Have data gaps related to existing information been identified? If so, is there any information about how these gaps will be reduced/minimized?	
✓	**Item**	**Section in IA**
	10. Have radionuclide concentrations resulting from project effects been calculated for the various environmental media?	
	11. If appropriate, have the radionuclide concentrations resulting from project effects been calculated for various phases of the project, such as construction, operation, decommissioning and abandonment?	
✓	**Item**	**Section in IA**
	12. Have the radionuclide concentrations in environmental media been compared to federal and/or provincial standards?	
	13. Has an appropriate reference dose been selected?	

DOSE ASSESSMENT		
✓	Item	Section in IA
	14. Have the locations and proximity of all existing and potential future human receptors to the project site been identified?	
	15. Have the most sensitive current and potential future human receptors been identified along with their locations and proximity to the project site? (Sensitive receptors would include people occupying schools, day cares, hospitals, seniors' residences, aboriginal reserves, residences and seasonal cabins.)	
	16. Have the most sensitive potential receptors been assessed in the IA? If not, has a rationale been provided for the use of less sensitive receptors?	
	17. Have the expected exposure durations been identified for all relevant receptors (e.g., 24 hours/day, 365 days/year)? 18. If exposure durations lower than the maximum values have been used (e.g., 24 hours/day, 90 days/year for a seasonal cabin user), has justification been provided for using these values?	
	19. Have all of the receptor characteristics been defined (e.g., inhalation rate, ingestion rates)?	
	20. Has the estimated effective dose to the most sensitive receptor from baseline conditions been provided?	
	21. Has the estimated effective dose to the most sensitive receptor from project effects been provided?	
	22. If appropriate, have the estimated effective doses to the most sensitive receptor from project effects been provided for various phases of the project, such as construction, operation, decommissioning and abandonment?	
	23. Have the maximum predicted radionuclide concentrations in all relevant media been used? If not, has justification been provided for using other values?	
	24. Have appropriate dose coefficients been used for calculating effective dose?	
	25. Have worked examples for one radionuclide for each applicable pathway been included? Do these examples provide a step-by-step method showing the dose/risk calculations and how the results were derived?	
	26. Have cumulative effects associated with the all other potential projects been included as a "future development scenario?"	

DOSE AND RISK CHARACTERIZATION		
✓	Item	Section in IA
	27. Have the effective doses from the dose assessment been compared to the reference dose selected for the project?	
	28. Were the uncertainties within each step described either qualitatively or quantitatively?	
	29. Were the pathways, sensitive receptors and radionuclides that had the greatest impact on the results of the dose assessment identified and uncertainties associated with these discussed?	
	30. Were the uncertainties evaluated to determine whether there are unacceptable uncertainties and where more information would be required in order to accurately determine the potential risk to humans?	
	31. Have conclusions regarding the risks posed by the identified hazards and a conclusion about the acceptability of the identified uncertainties and data gaps been provided?	
	32. If unacceptable risks or unacceptable uncertainties/data gaps were identified, have related recommendations been included (e.g. need for additional data collection, proposed mitigation, monitoring, follow-up, or other risk management measures)?	

MITIGATION MEASURES, MONITORING AND RESIDUAL EFFECTS		
✓	Item	Section in IA
	33. If potentially unacceptable risks have been identified, has a risk management plan been prepared that presents appropriate mitigation and monitoring to ensure that there are no unacceptable risks to humans?	
	34. If a risk management plan has not been prepared, have mitigation measures intended to reduce the risks to acceptable levels been described? If no mitigation has been proposed, has monitoring been proposed? If not, has adequate justification been provided to explain why mitigation and monitoring are not necessary?	
	35. If applicable, is the monitoring program provided in sufficient detail to review its adequacy?	
	36. Has adaptive management been considered in the event that the predicted risks do not align with monitoring/ follow-up results?	

FOLLOW-UP		
✓	Item	Section in IA
	37. Has a follow-up program been developed to evaluate the accuracy of the predictions in the HHRA?	

APPENDIX B | GLOSSARY

TERM	DEFINITION
Absorbed dose *(Dose absorbée)*	The quantity of radiation energy absorbed per unit mass of the receiving medium. For health assessments, the medium is normally human organs or tissues. SI unit = gray (Gy) = one joule per kilogram. Absorbed dose is often just referred to as “dose”.
Activity *(Activité)*	The rate of disintegration of a radioactive substance, i.e., the average number of transformations occurring per unit time. SI unit = Becquerel (Bq) = one disintegration per second.
Acute radiation syndrome *(Syndrome d’irradiation aiguë)*	A deterministic health effect resulting from a large short-term exposure to radiation, which begins to occur in humans at doses approaching 1 (one) sievert (Sv). Above 1 Sv, the severity of the effect increases with increasing dose and becomes lethal to 50% mortality at a dose of about 5 Sv.
Alpha radiation *(Rayonnement alpha)*	A form of ionizing radiation consisting of two protons and two neutrons, which is the same as a helium-4 nucleus. Alpha radiation has low penetrating power and can be stopped by a sheet of paper or by human skin.
Atom *(Atome)*	The smallest portion of an element that retains the chemical properties of the element. From the Greek *atomos*, meaning “indivisible”. The atom consists of negatively charged electrons orbiting a positively charged nucleus consisting of protons and neutrons.
Atomic number *(Numéro atomique)*	The number of protons in the nucleus of an atom. The atomic number uniquely defines each element.
Becquerel (Bq)	The SI unit of activity equal to one nuclear disintegration per second. A nuclear disintegration is a process that results in one radionuclide being transformed into another radionuclide or stable element.
Beta radiation *(Rayonnement bêta)*	A form of ionizing radiation consisting of positively charged positron or negatively charged electrons. Beta radiation has medium penetrating power and can be stopped by a few millimetres of aluminum.
Cancer	A disease characterized by the uncontrolled and invasive growth of cells originally derived from a normal tissue in the body.
Collective dose *(Dose collective)*	A summation of individual doses multiplied by the number of people receiving that dose. Collective dose (person Sv) = ∑ (individual dose in Sv) × (number of people receiving that dose).
Contaminant	Substance, both radioactive and non-radioactive, that may be present at levels above those normally or naturally found at the background levels.

TERM	DEFINITION
Cosmic radiation *(Rayonnement cosmique)*	Ionizing radiation originating from the "cosmos" or outer space. Cosmic radiation consists of about 90% protons, 9% helium-4 nuclei, and 1% heavier elements.
Cosmogenic radionuclides *(Radionucléides cosmogéniques)*	Radionuclides produced by the bombardment of molecules in the upper atmosphere by primary or secondary cosmic rays.
Critical group *(Groupe critique)*	A group of members of the public that is reasonably homogeneous with respect to exposure from a given radiation source and is typical of individuals receiving the highest equivalent dose from the specified source.
Decay series *(Famille de désintégration)*	A sequence of radioactive decay processes in which the decay of the parent isotope creates a new isotope, which may itself be radioactive. The series ends in the formation of a stable atom.
Decommissioning *(Déclassement)*	Those actions taken in the interest of health, safety, security and the protection of the environment to remove a licensed facility or site permanently from service and render it to pre-determined end-state condition.
Derived release limit *(Limite opérationnelle dérivée)*	A measure of radiological emissions from a nuclear facility as specified by the regulator, and which is usually based on the average radiation dose to a member of the critical group, which should not exceed a dose of 1 (one) millisievert (mSv) on an annual basis.
Deterministic health effects *(Effet déterministe sur la santé)*	A radiation effect for which a threshold level of dose exists above which the severity of the effect increases with increasing dose.
Deterministic risk assessment *(Évaluation déterministe du risque)*	Mathematical approach of using single-point estimates for each variable in the calculation. Often, but not always, worst-case estimates are used.
DNA *(ADN)*	Deoxyribonucleic acid—genetic material found in all living organisms and which carries the inherited instructions for life processes.
Dose	See *absorbed dose*.
Dose constraint *(Contrainte de dose)*	An administrative level of dose, less than regulatory limits, which is applied to a single source of radiation, in order to ensure that the sum of the doses from all sources does not exceed regulatory limits.
Electron *(Électron)*	A subatomic particle orbiting the nucleus of the atom. The electron carries one unit of negative electric charge equal to -1.602×10^{-19} coulombs (a unit of electric charge).

TERM	DEFINITION
Effective dose *(Dose efficace)*	The tissue-weighted sum of the equivalent doses in all specified tissues and organs of the body. Expressed in units Sv.
Equivalent dose *(Dose équivalente)*	Absorbed dose multiplied by a radiation weighting factor, which varies from one for beta and gamma radiation to 20 for alpha radiation. The equivalent dose allows for the fact that some types of radiation are more damaging than others at the same level of absorbed dose. The SI unit of equivalent dose is the Sv, which has the same dimensions as the Gy, i.e., joules per kilogram.
Fallout *(Retombées)*	Radioactive contamination or debris that becomes attached to small particles in the atmosphere. It is transported over large distances by atmospheric air circulation patterns and eventually settles out onto the ground.
Gamma radiation *(Rayonnement gamma)*	A form of ionizing radiation consisting of photons of very high frequency electromagnetic radiation. Gamma radiation has high penetrating power and requires at least 10 centimetres of lead for effective shielding.
Gamma spectrometry *(Retombées)*	The use of energy sensitive radiation detectors, e.g., sodium iodide or germanium, which give an electrical output proportional to the gamma energy. Since each radionuclide emits gamma radiation of a characteristic energy, gamma spectrometry can be used to determine which radionuclides are present in a sample and how much of each radionuclide is present.
Gray (Gy)	The SI unit of absorbed dose equal to one joule per kilogram. Subdivided into the milligray (mGy) = 1/1000 gray and the microgray (µGy) = one millionth of a gray. For gamma and beta radiation, the absorbed dose is equivalent to the effective dose measured in Sv (i.e., for gamma and beta radiation 1 Gy = 1 Sv). For alpha radiation, the absorbed dose must be multiplied by a quality factor of 20 to calculate the effective dose (i.e., for alpha radiation 1 Gy = 20 Sv).
Half-life *(Période)*	The time required for the activity of a radionuclide to decrease to one half of its initial value.
Ionizing radiation *(Rayonnement ionisant)*	Any form of radiation with sufficient energy to strip electrons off atoms and thus produce ions.
Isotopes *(Retombées)*	Nuclides having the same number of protons (i.e., belonging to the same element) but different numbers of neutrons.
LD50 *(DL50)*	A lethal radiation dose, which may result in 50% mortality.

TERM	DEFINITION
Linear-non-threshold model *(Hypthèse linéaire sans seuil)*	The assumption that all exposures to ionizing radiation, however small, carry some degree of risk and that this risk is directly proportional to the dose.
Neutron *(Capture neutronique)*	An uncharged subatomic particle normally contained within the nucleus of the atom.
Neutron capture *(Capture neutronique)*	A nuclear reaction in which the nucleus absorbs a neutron to form a different isotope of the same element.
Non-ionizing radiation *(Rayonnement non ionisant)*	Any form of radiation with insufficient energy to strip electrons off atoms, thus incapable of producing ions. Non-ionizing radiation comprises all forms of electromagnetic radiation at frequencies up to and including ultra-violet light. It also includes sound and ultra-sound waves.
Nuclear fission *(Fission nucléaire)*	A nuclear reaction in which a heavy nucleus splits into two generally unequal fragments with the release of a large amount of energy and several free neutrons. The reaction is usually induced by neutron bombardment, but may also occur spontaneously.
Nucleus *(Noyau)*	The inner core of the atom, containing protons and neutrons, accounting for more than 99.9% of the mass of the atom.
Nuclide *(Nucléide)*	A nuclear species characterized by the numbers of protons and neutrons in the nucleus.
Photon	One quantum or bundle of energy in an electromagnetic wave. The energy of a photon is directly proportional to the frequency of the wave.
Positron	A stable elementary particle having a positive electric charge of 1.6×10^{-19} coulombs and a mass of 9.1×10^{-31} kg (i.e., similar to an electron, but positively charged).
Primordial radionuclide *(Radionucléide primordial)*	Radionuclides with long half-lives, which pre-date the formation of the earth.
Probabilistic risk assessment *(Évaluation probabiliste du risque)*	Mathematical approach that allows for the use of distributions for uncertain variables in the calculation.
Proton	A positively charged subatomic particle normally contained within the nucleus of the atom.
Radioactive Waste *(Déchet radioactif)*	Any liquid, gaseous, or solid material that contains a radioactive substance as defined under the NSCA, and the owner has declared it to be a waste.

TERM	DEFINITION
Radioisotope *(Radio-isotope)*	An unstable isotope of an element. The term “radioisotope” is often used to describe a radionuclide which has some medical or commercial application.
Radionuclide *(Radionucléide)*	A nuclear species or nuclide which is unstable and undergoes radioactive decay.
Radium	A radioactive element with atomic number 88 and a member of the alkaline earth family. It is also an immediate precursor of radon.
Radon	The heaviest element in the family of noble gases. The word “radon” by itself is often synonymous with its most common isotope, radon-222, a member of the uranium-238 decay series.
Receptor *(Récepteur)*	In human radiological health assessments, a human being that is likely to be exposed to radioactivity released to the environment.
Risk coefficient	The absolute lifetime risk from exposure to one unit of radiation dose, usually expressed as percent per Sv.
Secular equilibrium *(Équilibre séculaire)*	The rate of decay of the radionuclide is equal to the rate of products from decay of the parent radionuclide. Although the radionuclide is constantly decaying, its concentration does not change.
SI (*Système Internationale*)	The officially adopted international system of units, based on the metre, kilogram, second and ampere.
Sievert	The SI unit of equivalent or effective dose with dimensions of joules per kilogram. Subdivided into the mSv = 1/1000 Sv and the microsievert (μSv) = one millionth of a Sv. Quantities measured in Sv represent the stochastic biological effects of ionizing radiation.
Spallation	A nuclear reaction in which a high energy charged particle strikes a nucleus and ejects one or more protons or neutrons.
Stochastic health effects *(Effet stochastique sur ia santé)*	A radiation-induced health effect, usually assumed to have no threshold, for which the probability of the effect increases with the dose received.
Storage *(Entreposage)*	The short- or long-term holding of radioactive waste in a facility that provides for containment with the possibility for retrieval, and where institutional controls and maintenance are required.
Thorium	A primordial radioactive element with atomic number 90.
Thoron	Radon-220, a member of the thorium-232 decay series. Also see *radon*.