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Guidance for Evaluating
Human Health Impacts
in Environmental Assessment:

# RADIOLOGICAL IMPACTS

Canada

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*Conseils pour l'évaluation des impacts sur la santé humaine dans le cadre des évaluations environnementales : Les effets radiologiques*

To obtain additional information, please contact:

Health Canada
Address Locator 0900C2
Ottawa, ON  K1A 0K9
Tel.: 613-957-2991
Toll free: 1-866-225-0709
Fax: 613-941-5366
TTY: 1-800-465-7735
Email: publications@hc-sc.gc.ca

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Publication date: January 2017



Cat.: H129-54/4-2017E-PDF
ISBN: 978-0-660-03349-5
Pub.: 160333

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This document may be cited as follows:

Health Canada. 2016. *Guidance for Evaluating Human Health Impacts in Environmental Assessment: Radiological Impacts*. Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario.

Any questions or comments on this document may be directed to:
Environmental Assessment Program, Ottawa, Ontario K1A 0K9
Email: ead@hc-sc.gc.ca

# 1 ACRONYMS

| ACRONYM | MEANING |
|---|---|
| ALARA | As Low as Reasonably Achievable |
| Bq | becquerel |
| CANDU | CANada Deuterium Uranium reactor |
| CEAA 2012 | *Canadian Environmental Assessment Act*, 2012 |
| CNSC | Canadian Nuclear Safety Commission |
| CSA | Canadian Standards Association |
| DNA | deoxyribonucleic acid |
| DRLs | derived release limits |
| EA | environmental assessment |
| Gy | gray |
| HLW | high-level wastes |
| HHRA | human health risk assessment |
| ICRP | International Commission on Radiological Protection |
| ILW | intermediate-level wastes |
| LD50 | lethal dose—50% mortality |
| LLW | low-level wastes |
| LNT | linear-non-threshold |
| MAC | maximum acceptable concentration |
| NaI(Tl) | sodium iodide (thallium) |
| NEWs | nuclear energy workers |
| NORM | naturally occurring radioactive materials |
| NRC | nominal risk coefficient |
| NSCA | *Nuclear Safety and Control Act* |
| NWMO | Nuclear Waste Management Organization |
| RA | responsible authority |
| RPB | Radiation Protection Bureau |
| SI | système internationale |
| Sv | sievert |
| TLD | thermoluminescent dosimeter |
| UNSCEAR | United Nations Scientific Committee on the Effects of Atomic Radiation |

# 2 PURPOSE OF THIS DOCUMENT

This document provides generic guidance on predicting health risks of air quality in federal environmental assessments (EAs) of proposed major resource and infrastructure projects (such as mines, dams, pipelines and other projects). It presents the principles, current practices and basic information Health Canada looks for when it reviews the environmental impact statements or other reports submitted by project proponents as part of the EA process.

It was prepared for the benefit of proponents and their consultants and to support an efficient and transparent project review process. The foundational information described here should be supplemented appropriately with additional information relevant to specific projects.

The guidance was also prepared for responsible authorities and stakeholders to the EA process to communicate our normal areas of engagement and our priorities within these areas to help ensure that sufficient evidence is available to support sound decisions. As part of its review, Health Canada may suggest that a responsible authority (RA), review panel or others collect information not specifically described here in order to assess the health effects of specific projects. As the guidance provided here is generic and designed to support EA under multiple jurisdictions, the scope of our review will also necessarily be amended according to specific jurisdictional requirements.

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

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**www.canada.ca/en/health-canada/corporate/publications/health-canada-participation-environmental-assessments.html**

# 3 INTRODUCTION AND CONTEXT

Health Canada provides expertise to assist RAs, review panels and/or other jurisdictions leading environmental assessments to determine whether there are potential health risks associated with proposed projects and how to prevent, reduce or mitigate them.

Health Canada brings to bear its expertise in health risks associated with air quality, water quality, radiation, noise and country foods when it reviews and provides comments on information submitted by proponents in support of proposed projects. Health Canada also provides guidance to help stakeholders, including responsible authorities, review panels and affected communities, better understand how to conduct health assessments for proposed major resource projects.

This document concerns the assessment of 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 contains a checklist that can be used to record that the main components of a risk assessment of radiological impacts are complete and to show where this information can be found within an EA document.

Appendix B contains a Glossary that defines the technical terms used throughout.

# 4 ROLES AND RESPONSIBILITIES WITH RESPECT TO RADIOLOGICAL IMPACTS AND ASSESSMENTS

It is important for stakeholders involved in assessing radiological/nuclear impacts on human health to have knowledge of the regulatory regimes at both the federal and provincial/territorial levels.

In Canada, the Canadian Nuclear Safety Commission (CNSC) is responsible for the regulation of the development, production and use of nuclear energy and the production, possession and use of nuclear substances, in order to protect the health of Canadians from the effects of radiological exposure that are associated with that development, production, possession or use. Health Canada also maintains expertise in the health effects of radiological exposure. Additional aspects of protecting human health rest with provincial and territorial governments.

## 4.1 FEDERAL LEGISLATION AND REGULATIONS

### 4.1.1 Nuclear Safety and Control Act

The federal *Nuclear Safety and Control Act* (NSCA) regulates nuclear fuel-cycle activities and management of anthropogenic (generated by human activity) radioisotopes. The NSCA, which focuses on the protection of human health and the environment, was passed by Parliament in 1997 and came into force in May 2000. The CNSC is the regulatory agency responsible for enforcing the NSCA. Under the NSCA, the CNSC regulates the production, possession, use and transport of nuclear substances, and the production, possession and use of prescribed equipment and prescribed information.

The *Radiation Protection Regulations* enacted under the NSCA stipulate allowable radiation dose limits for regulated activities in Canada, for both members of the public and for nuclear energy workers (NEWs). These dose limits essentially follow the International Commission on Radiological Protection (ICRP) recommendations and are as follows:

- 1 millisievert per year (mSv/year) for members of the public from all CNSC licensed activities; and
- 50 mSv in a one-year dosimetry period and 100 mSv over a five-year dosimetry period, for NEWs.

These dose limits represent the upper levels of acceptability. In addition to meeting these dose limits, licensees are required to keep radiation exposures and doses As Low as Reasonably Achievable (the ALARA principle). Keeping doses ALARA is a regulatory requirement, not a recommendation.

Those planning an EA as part of the CNSC licensing process should consult Canadian Standards Association (CSA) Standards N288.1-2008 and N288.6-2012 for information on:

- Modelling the movement of radionuclides released from a facility to a specified "representative person;" and
- Completion of environmental and human health assessments for nuclear facilities and uranium mines and mills, respectively.

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

### 4.1.2 Other Acts/Guidelines

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

- *Nuclear Fuel Waste Act*;
- *Canadian Environmental 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; and*
- *Transport of Dangerous Goods Regulations.*

The Canadian Standards Association also publishes radiation standards and guidelines linked to different industrial activities. These standards can be obtained from CSA's website: at **www.scc.ca/en/search/standardsdb**. Although compliance with CSA standards is voluntary, government authorities often refer to the Association's methodology for an example of best practices.

## 4.2 HEALTH CANADA ROLE

Within Health Canada, radiological expertise rests primarily within the Environmental and Radiation Health Sciences Directorate. In this Directorate, the Radiation Protection Bureau (RPB) has a 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:

- Operating the Canadian Radioactivity Monitoring Network;
- Supporting Canada's role in the Comprehensive Nuclear-Test-Ban Treaty;
- Leading the Federal Nuclear Emergency Plan;
- 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 and food, radon in indoor air, and naturally occurring radioactive materials (NORM) from non-nuclear industries;
- Providing inter-comparison programs through the National Calibration Reference Centre for Bioassay and *InVivo* Monitoring;
- Managing the National Dose Registry of all monitored radiation workers in Canada, and conducting research on exposure trends for radiation workers and on the health outcomes of occupational exposures to radiation;
- 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 *Canadian Environmental Assessment Act,* 2012 (CEAA 2012).

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

- Reviewing the predicted radionuclide emissions into the atmospheric and aquatic environments, and uptake into country foods, to assess whether the predicted releases are realistic—based on the nature of the project and what is known about past radionuclide releases from similar projects;
- Indicating whether all main routes of human exposure (i.e. cloudshine, groundshine, inhalation and ingestion[1]) 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 EA'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 regulated dose limits; and
- Expressing an opinion on whether mitigation, monitoring and follow-up programs are appropriate, in the interests of protecting human health.

1 See page 17 for a description of these terms

Health Canada provides human health expertise concerning radiological emissions to which the public and NEWs may be exposed, and may also act as an advisor to the federal nuclear regulator, the CNSC. Health Canada also plays a role, through the National Dose Registry, in monitoring and reporting on radiation doses to occupationally exposed workers.

## 4.3 PROVINCIAL AND TERRITORIAL ROLES

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

Naturally occurring radioactive materials (NORM) are encountered during many types of industrial activities and are exempt from the NSCA. The *Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials* (NORM) have been developed by the Federal Provincial Territorial Radiation Protection Committee to provide a harmonized approach to NORM management in Canada. However, 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 provide recommendations on 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**

# 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 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 ($\alpha$) 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 ($\beta$) 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 ($\gamma$) radiation 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 emits radiation 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.

### 5.1.2 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, $^{235}$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 (Knolls, 2002)**

| Radionuclide | Symbol | Half-life (Years) | Isotope composition, %* | Specific activity (Bq/g)** |
|---|---|---|---|---|
| Potassium-40 | $^{40}$K | 1.27 x $10^{9}$ | 0.0117% | 30 |
| Thorium-232 | $^{232}$Th | 1.40 x $10^{10}$ | 100% | 4070 |
| Uranium-235 | $^{235}$U | 7.04 x $10^{8}$ | 0.72% | 568 |
| Uranium-238 | $^{238}$U | 4.468 x $10^{9}$ | 99.28% | 12,340 |

* Each radionuclide is an isotope of an element. Generally, there are several isotopes of each element. The isotope composition is the percentage (%) of that particular element that is naturally found in that radioactive isotope. For example, natural uranium is 99.28% U-238 and 0.72% U-235.

** The activity is equal to the number of disintegrations per second occurring within the nucleus of a radioactive element (for example, 1 Bq = 1 disintegration per second). Specific activity tells us the amount of radioactivity per unit substance. Specific activity is one of the defining characteristics of a radionuclide.

Many radionuclides in the uranium-238 ($^{238}$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 |
| Polonium218 | $^{218}$Po | 3.05 min | short-lived decay products of $^{222}$Rn | attach themselves to aerosol particles and become deposited in the lungs when inhaled |

| Radionuclide | Symbol | Half-life | Other characteristics | Health considerations |
|---|---|---|---|---|
| Lead-214 | $^{214}$Pb | 26.8 min | | |
| Bismuth-214 | $^{214}$Bi | 19.7 min | | |
| Polonium-214 | $^{214}$Po | 1.64 x $10^{-4}$ s (164 µs) | | |
| Lead-210 | $^{210}$Pb | 22 years | long-lived decay products of radon | not considered as inhalation hazards in the environment; can build up to significant levels in certain foods consumed by humans (e.g. caribou and shellfish) |
| Polonium-210 | $^{210}$Po | 138 days | | |

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 $^{222}$Rn—a daughter product in the $^{238}$U series—was a concern. However, similarly to radon, $^{220}$Rn also decays to daughter products with the potential to irradiate the lungs. Potassium-40 ($^{40}$K) 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. $^{40}$K 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;[2]
2. Neutron 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.

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

**Table 5.3: Artificial radionuclides likely to occur in the environment (Knolls, 2002)**

| Radionuclide | Symbol | Half-life | Production mechanism | Health considerations |
|---|---|---|---|---|
| Tritium | $^{3}H$ | 12.3 years | n-capture on deuterium in CANDU 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 |
| 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 bombs or reactors | deposited in bone |
| Technetium-99m* | $^{99m}Tc$ | 6.02 hours | fission product of $^{99}Mo$ 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 | 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 U-238 in reactors | not considered an ingestion hazard, as it passes through the body without being absorbed; if inhaled, can pass into the bloodstream through the lungs and can remain in the body for decades |

* 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 tritium, $^{14}C$, $^{137}Cs$ and $^{90}Sr$ 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—and are now falling below the detection limits. Artificial radionuclides now contribute less than 0.005 mSv/year to the total background radiation dose.

## 5.2 RADIATION AND HUMAN HEALTH EFFECTS

The biological effect of radiation results from its ability to produce ionizations and molecule excitations as it passes through living cells. The most sensitive target in a cell is the DNA (deoxyribose nucleic acid) 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 induction.

More information is available at: **www.nuclearsafety.gc.ca/eng/pdfs/Reading-Room/radiation/Introduction-to-Radiation-eng.pdf**

The fundamental concept in assessing radiological impacts is the "absorbed dose." 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 weighted 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. 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. For beta and gamma radiation, the effective dose in Sv is numerically equal to the absorbed dose in Gy. For alpha radiation, the effective dose in Sv is 20 times greater than the absorbed dose. The Gy and the Sv are both very large units, and are subdivided into milligrays (mGy) or millisieverts (mSv) and micrograys (μGy) or microsieverts (μSv) for levels of radiation normally encountered in the environment.

At the level of a multi-cellular organism, the effects of radiation may be described as "deterministic"[3] (also referred to as tissue effects) or "stochastic." Deterministic effects are effects that are certain to occur in all exposed individuals, once the radiation dose has exceeded a certain threshold for a given

3 Not to be confused with deterministic risk assessment. See Glossary for further details.

effect. High doses of radiation may cause a substantial amount of cell killing, resulting in detectable tissue reaction (or deterministic effects). These reactions may occur early or late after irradiation, depending on the tissue in question. 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, the probability of occurrence for the effect increases with increased exposure. Unlike deterministic effects, 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, although cardiovascular disease and other effects have also been observed in highly exposed populations.

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 International Commission on Radiological Protection (ICRP) reviews and assesses these studies periodically. Table 5.4 shows nominal risk coefficients for stochastic effects established by the ICRP in its general recommendations for radiological protection (1991 and 2007).

**Table 5.4: ICRP Nominal Risk Coefficients for the Whole Population[1] (ICRP, 1991 and 2007)**

| Type of Effect | 1991 Recommendations (% increase in risk per sievert) | 2007 Recommendations (% increase in risk per sievert) |
|---|---|---|
| Fatal cancer | 5.0 | Not provided* |
| Total cancer | 6.0 | 5.5 |
| Heritable effects | 1.3 | 0.2 |
| Total risk | 7.3 | 6 |
| Dose and dose rate effectiveness factor | 2.0 | 2.0 |

* As the recovery rates in cancer patients increase, the ICRP has decided to publish nominal risk coefficients only for total cancer.

1 These values give an idea of increased risk per sievert exposure (for example, exposure to 1 Sv of radiation increases the total cancer risk by 5.5%). Note that these are calculated values by the ICRP and do not differentiate between radiation types, exposure durations, etc. Therefore, they are only approximations.

There have been very few changes in the ICRP risk coefficients since 1991. The latest recommendation of ICRP indicates an absolute total risk of 6% per sievert, which includes fatal cancers plus a weighted risk (probability multiplied by effect) for non-fatal cancers and other conditions. This risk is observed to be directly proportional to radiation doses that range from several Sv down to as low as 100 mSv. Below this latter level, it is very difficult to detect any increase in cancer incidence as compared to the overall cancer incidence rate, estimated at 40% in the general population (Canadian Cancer Society, 2014). For lower doses, the radiation protection framework relies on mathematical models to estimate risks. The most frequently used model 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 implicitly assumes the validity of the LNT hypothesis in its three fundamental principles of radiation protection:

1. ***Justification:*** No radiation practice shall be undertaken unless there is a net positive benefit.
2. ***Optimization:*** All exposures shall be kept As Low as Reasonably Achievable (ALARA), economic and social factors taken into account.
3. ***Dose Limitation:*** No dose shall exceed the following established limits:
    - *Radiation workers:* not more than 50 mSv in any one year nor more than 100 mSv in a running (continuous) 5-year period; and
    - *General public:* not more than 1 (one) mSv/year, over and above background, from all industrial applications of radiation. Exposures for medical purposes are excluded.

Table 5.5 summarizes these dose limits and the associated risks of selected effects at various levels of exposure, assuming the validity of the LNT hypothesis.

**Table 5.5: Scale of radiation doses and risks**

| Description | Dose (mSv) | Risk, one in …* |
|---|---|---|
| $LD_{50}$ for humans | 5,000 (acute total dose) | 2 |
| Threshold for acute radiation syndrome | 1,000 (acute total dose) | 20 |
| No observed cancers below this level | 100 | 200 |
| Regulated annual dose limit for workers in any one year** | 50/y | 1,000 |
| Annual background dose | 2.5/y | 7,000 |
| Annual dose limit for public from regulated activities | 1/y | 20,000 |
| Annual limit used to derive drinking water guidelines | 0.1/y | 200,000 |
| Annual limit for exclusion from regulatory concern (*de minimis*) | 0.01/y | 2,000,000 |

* Based on ICRP, 2007

** The regulated dose limit for NEWs is 100 mSv over a 5-year period, with a limit of 50 mSv in any one year.

# 6 ADDRESSING THE POTENTIAL IMPACTS OF RADIOLOGICAL EXPOSURE IN ENVIRONMENTAL 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 whether there are 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).

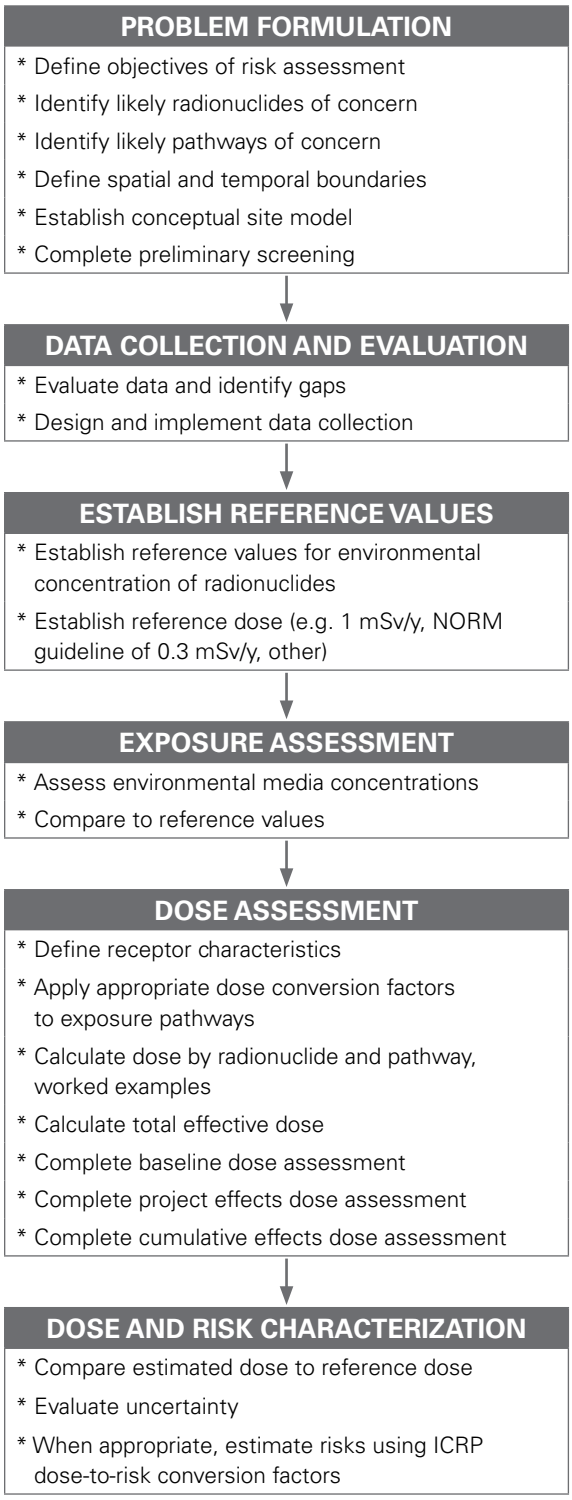
Within an environmental assessment, an HHRA is defined as the process used to estimate the probability of adverse health effects for people who may be exposed to contaminants through different pathways (ingestion and/or inhalation) in specific environmental media (air, foods, soil, water and/or sediment).

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, as well as 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 EA and is dependent on the scope of a particular project, it can provide increased defensibility for the conclusions of an EA. 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.

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 U.S. Environmental Protection Agency publication (U.S. EPA, 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 because the decisions about what to include in the assessment will influence the identification of potential remedial actions. A problem formulation that includes clearly defined objectives for the risk assessment helps to determine the type of assessment needed—screening, deterministic or probabilistic.

A radiological risk assessment usually takes a "deterministic"[4] approach (use of a single value for each variable in the exposure equation). Such an approach permits use of 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 to identify the parameters with greatest 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.

A preliminary screening may be utilized to allow for elimination of 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 any pathways or radionuclides that are excluded.

4 Not to be confused with deterministic health effects. See Glossary for further information.

## 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 be historical or measured. Historical data for site-specific radiation levels may be limited. In the case of projects occurring at existing nuclear facilities, annual Radiological Environment Monitoring Program Reports are required as part of the CNSC licensing requirements and may provide relevant data on the radiological environment. These reports can typically be found on the nuclear facilities operator's websites. In the case that new baseline measurements are required, a simple gamma spectrometric analysis of a bulk field sample is sufficient to characterize and quantify any natural and artificial radionuclides that may be present. However, some key radionuclides emit alpha or beta radiation only, and require sample pre-treatment before analysis. Tritium and $^{14}C$ can be measured by liquid scintillation counting; $^{90}Sr$ by a beta proportional counter; and $^{239}Pu$ by alpha spectroscopy. Background levels of ambient gamma radiation should also be assessed using long-term monitors, such as thermoluminescent dosimeters (TLDs). Radioactive gases released from a nuclear fission process, such as xenon and krypton, can be measured by *in situ* sodium iodide detectors activated with thallium (NaI(Tl)). The uncertainty of any measurements should be estimated and taken into account 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 A REFERENCE DOSE

At this stage of the assessment, reference values should be established to act as benchmarks or limits for the project. The selected reference values may be the background concentration of relevant radionuclides in environmental media in a specific geographic or project area, and/or may be obtained from relevant federal and/or provincial guidelines. These guidelines will often provide established maximum acceptable concentrations (MACs). For instance, Health Canada has established MACs in drinking water for more than 80 radionuclides, including the natural and artificial radionuclides that are most commonly detected in Canadian water supplies. The MACs were derived using internationally accepted equations and principles, and are based solely on health considerations. They were calculated using a reference dose level of 0.1 mSv for 1 (one) year's consumption of drinking water, assuming a consumption of 2 litres (L)/day (Health Canada, 2012). Guidelines that may be relevant for establishing reference values include, but are not limited to:

- *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.*

A reference dose is typically the maximum acceptable total effective dose, expressed in millisieverts, which a representative individual of a population may receive over an entire year as a result of the project activities. In Canada, the *Radiation Protection Regulations* state that doses must not exceed 1 (one) mSv/year for the public. This may be used by default as a reference dose. However, the ICRP has also introduced the concept of a source-based dose constraint of less than 1 (one) mSv/year for individual practices (each source of radiological exposure to a particular member of the public), to ensure that the total doses from all practices in the area do not exceed the public dose limit (ICRP, 2007). For example, a dose constraint of 0.3 mSv/year (as per CNSC Regulatory Guide G-320) has been used in Canada for the Port Hope Area Initiative. The *Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials* (NORM) also use a limit of 0.3 mSv/year, to invoke specific management measures to limit exposure from NORM.

The collective dose (the average dose multiplied by the number of people receiving that dose) is a dose quantity that can be useful for comparing and optimizing technologies or procedures, predominantly in the context of operational exposure. However, collective dose should not be used in risk assessment or for use in risk projections (ICRP 103).

## 6.4 EXPOSURE ASSESSMENT

The exposure assessment consists of estimating releases from the project for all radionuclides of concern and determining the concentrations in environmental media. The project releases may be into water or air. Once the environmental concentrations of radionuclides have been estimated, they should be compared to federal and/or provincial guidelines, as appropriate. If appropriate, the exposure assessment for project effects should be completed for various 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 (DRLs) of radionuclides from nuclear facilities, CSA Standard N288.1 (CSA, 2008) 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, it should make conservative assumptions, wherever possible, and should describe all assumptions that have been made.

## 6.5 DOSE ASSESSMENT

In a radiological HHRA, the endpoint for human health impacts is a human receptor or "representative person." 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 judgement.

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 all or most 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 Aboriginal 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 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. Dose coefficients can then be used to convert these exposures into estimates of the effective dose. For inhalation and ingestion, the most recent dose coefficients from the ICRP should be used (ICRP 119, 2012b). The effective dose should be determined individually for each radionuclide and pathway, and summed, to determine the total effective dose. The dose assessment should be completed for the baseline conditions, project effects and cumulative effects.

Table 6.1 summarizes worldwide averages of the various components of natural background radiation, as provided by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Across Canada, external gamma radiation from terrestrial sources—together with exposure from cosmic rays reaching the earth's surface—adds to a dose of 0.3 to 0.6 mSv/year, depending on location. The added combination of inhaled or ingested radionuclides yields an average background radiation dose of 2 to 3 mSv/year. Although 2–3 mSv/year is the average background radiation dose, the site-specific background radiation dose should be determined—using the baseline environmental concentrations determined in the data collection and evaluation stages.

**Table 6.1: Average worldwide exposures to natural radiation sources (UNSCEAR, 2008)**

| | Annual effective dose (mSv) | |
|---|---|---|
| **Source of Exposure** | *Average* | *Typical range* |
| Cosmic radiation and cosmogenic radionuclides | 0.39 | 0.3–1.0 |
| External terrestrial radiation | 0.48 | 0.3–0.6 |
| Inhalation exposure (mostly radon, thoron and progeny) | 1.26 | 0.2–10 |
| Ingestion exposure (from $^{40}K$ and uranium and thorium series radionuclides) in foods | 0.29 | 0.2–0.8 |
| **Total** | **2.4** | **1–10** |

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 CEAA 2012, subsection 19(1), the environmental assessment must consider "*…cumulative environmental effects that are likely to result from the […] designated project in combination with other physical activities that have been or will be carried out.*" An EA for a project should take into consideration any contaminants that may already be present in the local environment from previous operations, or that may be introduced by other future developments. 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 to other environmental hazards. Possible interactions or synergies between radiation and chemical contaminants are still poorly understood. The only clearly established interaction is between the effects of smoking and exposure to radon gas in uranium-miner cohorts. This interaction was found to be more than additive, but less than multiplicative. However, it is a unique situation involving high levels of exposure to both radon and tobacco smoke. When health risks are very low, as in most environmental situations, it is generally considered adequate to simply carry out a summation of risks from individual contaminants. It should be noted that the summation of risks should only be completed for the same health endpoint (i.e. the radon lung cancer risk should not be combined with the gamma leukemia risk).

## 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 predict project effects. However, the doses resulting from baseline conditions should not be compared to the 1 (one) mSv/year dose limit for members of the public or any other reference dose. The dose limits are intended for "above baseline" exposures.

Estimated total effective doses from the project effects and cumulative effects should be compared to the 1 (one) mSv/year dose limit for members of the public, and to any other relevant reference dose decided upon at the outset of the assessment. If cumulative effects are expected, it would be prudent to set a dose constraint for the project (for example, 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. Whenever possible, conservative values (for example, maximum environmental concentrations) should be used to offset the uncertainty.

In characterizing the risk, the detriment-adjusted nominal risk coefficients recommended by the ICRP may be utilized to assess any increases in risk on a population scale. The risk coefficients are not intended to be used to assess the risk to an individual resulting from a specific dose (ICRP, 2007).

## 6.7 MITIGATION MEASURES AND RESIDUAL EFFECTS

Subsection 19(1) of CEAA 2012 states that the EA should include (where applicable) the implementation of mitigation measures and follow-up programs. 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 effects.

After the mitigation measures have been accounted for, the proponent is required to assess what the residual effects might be. Such residual effects need to be identified during the EA review and brought to the attention of the responsible authority (RA). The RA then determines whether the residual effects are significant or not (i.e. the residual dose is below the dose limit for members of the public).

## 6.8 FOLLOW-UP PROGRAMS

Under CEAA 2012, a "follow-up program" means a program for:

- verifying the accuracy of the environmental assessment of a designated project; and
- 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:

a. Monitoring programs for specific environmental media in the project area at the nearest sensitive human receptor(s);

b. 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

c. 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.

For further and up-to-date information on follow-up programs, contact the Canadian Environmental Assessment Agency, Canadian Nuclear Safety Commission or National Energy Board, as appropriate.

# 7 TYPES OF RADIOLOGICAL PROJECTS FOR WHICH ENVIRONMENTAL ASSESSMENT IS PERFORMED UNDER CEAA 2012

All facilities dealing with nuclear fuel cycle activities are required to be licensed by the Canadian Nuclear Safety Commission (CNSC) under the *Nuclear Safety and Control Act* (NSCA). Prior to issuing a license under the NSCA, nuclear projects identified in the CEAA 2012 *Regulations Designating Physical Activities* must first meet the requirements of an EA under CEAA. The physical activities listed in the Regulations are divided into three parts according to which federal authority—the Canadian Environmental Assessment Agency, the CNSC or the National Energy Board—would be responsible for conducting an environmental assessment of a designated project that included that activity. The Regulations are intended to identify those physical activities with the greatest potential to cause significant adverse environmental effects in areas of federal jurisdiction. Other activities such as uranium exploration do not require an EA under CEAA, as they are not on the *Regulations Designating Physical Activities*. They may, however, require an EA by another authority—such as a province or territory. Guidelines outlining the scope of an EA are issued by the responsible authority (RA) to the proponent. The assessment is carried out to ensure that the activity will not have likely significant adverse effects on human health or the environment.

The activities set out in schedules 31 to 38 of the *Regulations Designating Physical Activities* are linked to the CNSC when they are regulated under the NSCA. In general, the types of projects that require an EA under the Regulations 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 each project governed by the NSCA, visit the CNSC website at: **www.cnsc-ccsn.gc.ca/eng/acts-and-regulations/index.cfm**

The Canadian Standards Association (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

Uranium mining and milling is subject to the NSCA for the entirety of the mining lifecycle, including site preparation, construction, operating, decommissioning and abandonment. Typically, the greatest radiological human health risk associated with the operation of a uranium mine is the workers' exposure to radon. However, 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," which 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 daughter products that may be present in uranium ore**

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

## 7.2 URANIUM PROCESSING AND FUEL FABRICATION

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

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. 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 STORAGE

The Government of Canada has put in place a structure of policies, legislation and 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 *Radioactive Waste Policy Framework* (1996) to ensure the safe management of radioactive waste.

The radioactive waste itself may be classified as low-, intermediate-, or high-level waste (LLW, ILW or HLW). The CNSC regulates the entire life-cycle of all waste management facilities, including those for LLW, ILW and HLW.

***Low- and Intermediate-level Wastes***

Most radioactive wastes fall into the low-level wastes (LLW) category. These wastes consist mostly of industrial items—mops, rags, paper towels, temporary floor coverings, floor sweepings, protective clothing and hardware items, such as tools. Intermediate-level wastes (ILW) consist primarily of used nuclear reactor components and the presence of nuclear power generation by-product radionuclides, such as $^{60}Co$, $^{137}Cs$ and tritium, will need to be accounted for.

***High-level Radioactive Waste***

Spent fuel from nuclear power plants constitutes the largest component of high-level radioactive waste. In 2002, the *Nuclear Fuel Waste Act* was proclaimed to manage spent nuclear fuel over the long term. The Act required the formation of an independent body supported by the nuclear utilities—the Nuclear Waste Management Organization (NWMO)—to develop and implement a plan for the long-term storage of Canada's used nuclear fuel. Information on the activities of the NWMO can be found at: **www.nwmo.ca**

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# APPENDIX AI **RADIOLOGICAL IMPACTS IN EA CHECKLIST**

This checklist could be used to help verify that the suggested components of a radiological assessment have been completed. It would be useful to include this checklist as an index in an environmental assessment to identify the locations of the key components of a radiological assessment, especially if the components are in multiple sections of the EA documentation.

| **PROBLEM FORMULATION** | | | |
|---|---|---|---|
| ✓ | ***Item*** | ***Section in EA*** | ***Comment*** |
| | 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:<br>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);<br>b. The number and types of contaminants involved;<br>c. The availability of applicable screening criteria;<br>d. The estimated/predicted exposure concentrations;<br>e. The number and complexity of pathways for human exposure;<br>f. The location and sensitivity of human receptors;<br>g. The quality of the baseline project data;<br>h. The desire by the proponent/RA for additional justification/precision regarding the potential risks associated with a proposed project; and<br>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:)<br>a. All potential contamination sources;<br>b. All potential radionuclides of concern;<br>c. All critical receptor groups; and<br>d. All potential exposure pathways? | | |
| | 5. Has the proposed project been adequately described in terms of physical setting by maps and site plans? | | |
| | 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.)? | | |

| DATA COLLECTION AND EVALUATION | | | |
|---|---|---|---|
| ✓ | ***Item*** | ***Section in EA*** | ***Comment*** |
| | 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? | | |
| **EXPOSURE ASSESSMENT** | | | |
| ✓ | ***Item*** | ***Section in EA*** | ***Comment*** |
| | 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? | | |
| | 12. Have the radionuclide concentrations in environmental media been compared to federal and/or provincial standards? | | |
| | 13. Have the radionuclide concentrations been evaluated using the most conservative guideline available? | | |
| **ESTABLISH REFERENCE DOSE** | | | |
| ✓ | ***Item*** | ***Section in EA*** | ***Comment*** |
| | 14. Has an appropriate reference dose been selected? | | |
| **DOSE ASSESSMENT** | | | |
| ✓ | ***Item*** | ***Section in EA*** | ***Comment*** |
| | 15. Have the locations and proximity of all existing and potential future human receptors to the project site been identified? | | |
| | 16. 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 schools, day cares, hospitals, seniors' residences, aboriginal reserves, residences and seasonal cabins.) | | |
| | 17. Have the most sensitive potential receptors been assessed in the EA? If not, has a rationale been provided for the use of less sensitive receptors? | | |
| | 18. Have the expected exposure durations been identified for all relevant receptors (e.g. 24 hours/day, 365 days/year)? 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 EA*** | ***Comment*** |
| | 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 EA*** | ***Comment*** |
| | 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 EA*** | ***Comment*** |
| | 37. Has a follow-up program been developed to evaluate the accuracy of the predictions in the HHRA? | | |

# APPENDIX B1 **GLOSSARY**

| TERM | DEFINITION |
|---|---|
| **Absorbed dose** | The quantity of radiation energy absorbed per unit mass of the receiving medium.<br>For health assessments, the medium is normally human organs or tissues.<br>SI unit = gray (Gy) = one joule per kilogram. Absorbed dose is often just referred to as "dose". |
| **Activity** | 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** | 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** | 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** | The smallest portion of an element that retains the chemical properties of the element. From the Greek *a tomos*, meaning "indivisible". The atom consists of negatively charged electrons orbiting a positively charged nucleus consisting of protons and neutrons. |
| **Atomic number** | 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** | A form of ionizing radiation consisting of positively 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. |
| **Cardiovascular diseases** | Diseases of the heart or circulatory system, including strokes. |
| **Collective dose** | 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** | Presence of a substance, both radioactive and non-radioactive, that may be present at levels above those normally or naturally found at the background levels. |
| **Cosmic radiation** | 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** | Radionuclides produced by the bombardment of molecules in the upper atmosphere by primary or secondary cosmic rays. |
| **Critical group** | 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. |

| TERM | DEFINITION |
|---|---|
| **Curie** | A measure of the amount of radioactivity and is roughly the amount of radioactivity of one gram of radium-226. It equals $3.7 \times 10^{10}$ disintegrations per second or bequerels. |
| **De minimis dose** | A radiation dose too low to be of regulatory concern. From *de minimis non curat lex*—"the law does not concern itself with trifles." For example a dose of 10 microsieverts per year is generally accepted as not being of significance to an individual or to society. |
| **Decay series** | 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** | 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** | 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) mSv on an annual basis. |
| **Deterministic health effects** | 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** | Mathematical approach of using single-point estimates for each variable in the calculation. Often, but not always, worst-case estimates are used. |
| **DNA** | Deoxyribonucleic acid—genetic material found in all living organisms and which carries the inherited instructions for life processes. |
| **Dose** | See absorbed dose. |
| **Dose constraint** | 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** | A subatomic particle orbiting the nucleus of the atom. The electron carries one unit of negative electric charge equal to $-1.602 \times 10^{-19}$ coulombs (a unit of electric charge). |
| **Effective dose** | The tissue-weighted sum of the equivalent doses in all specified tissues and organs of the body. Expressed in units sievert (Sv). |
| **Equivalent dose** | 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 sievert (Sv), which has the same dimensions as the gray (Gy), i.e. joules per kilogram. |
| **Fallout** | 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** | 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** | 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. |

| TERM | DEFINITION |
|---|---|
| **Gray** | 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.<br>For gamma and beta radiation, the absorbed dose is equivalent to the effective dose measured in sieverts (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** | The time required for the activity of a radionuclide to decrease to one half of its initial value. |
| **Heavy Water** | Heavy water is chemically the same as regular (light) water, but with its two hydrogen atoms replaced with deuterium atoms ($D_2O$). The deuterium atom has a proton and a neutron in its nucleus; hence, heavy water is approximately 10% heavier than light water. It is used in CANDU reactors as a moderator. |
| **Ionizing radiation** | Any form of radiation with sufficient energy to strip electrons off atoms and thus produce ions. |
| **Isotopes** | Nuclides having the same number of protons (i.e. belonging to the same element) but different numbers of neutrons. |
| **$LD_{50}$** | A lethal radiation dose, which may result in 50% mortality. |
| **Linear-non-threshold model** | 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** | An uncharged subatomic particle normally contained within the nucleus of the atom. |
| **Neutron capture** | A nuclear reaction in which the nucleus absorbs a neutron to form a different isotope of the same element. |
| **Non-ionizing radiation** | 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** | 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** | The inner core of the atom, containing protons and neutrons, accounting for more than 99.9% of the mass of the atom. |
| **Nuclide** | 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 $1.6 \times 10^{-19}$ coulombs and a mass of $9.1 \times 10^{-31}$ kg (i.e., similar to an electron, but positively charged). |
| **Primordial radionuclide** | Radionuclides with long half-lives, which pre-date the formation of the earth. |
| **Probabilistic risk assessment** | 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** | 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** | An unstable isotope of an element. The term "radioisotope" is often used to describe a radionuclide which has some medical or commercial application. |
| **Radionuclide** | 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** | 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 sievert. |
| **Secular equilibrium** | 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 millisievert (mSv) = 1/1000 sievert and the microsievert (μSv) = one millionth of a sievert. Quantities measured in sieverts 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** | A radiation-induced health effect, usually assumed to have no threshold, for which the probability of the effect increases with the dose received. |
| **Storage** | 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*. |