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Guidelines for Canadian Drinking Water Quality

Radiological Parameters

Guideline Technical Document

Consultation period ends
January 10, 2025

Canada

Purpose of consultation

This guideline technical document outlines the available information on radionuclides with the intent of updating the guidelines for radionuclides in drinking water. The purpose of this consultation is to solicit comments on the proposed guidelines, the approach used for their development, and the potential impacts of implementing them.

Health Canada is basing the proposed guidelines on a new reference level of 1 millisievert per year (mSv/y), which is higher than the value in past recommendations. In the previous Canadian drinking water guidelines (2009), the reference level of 0.1 mSv/y was used, consistent with the values chosen to regulate emissions from industrial activities for which measures can be planned in advance (when the facility is built) to keep releases and subsequent public exposure very low. This is no longer considered appropriate, because radionuclides in Canadian drinking water sources are overwhelmingly of natural origin, so the very stringent requirements for industrial releases do not apply. Furthermore, higher concentrations of radionuclides tend to occur in small community water sources or private wells. In these cases, the challenges of meeting the requirement for very low radionuclide concentrations can be significant, whereas the difference in health risk between 0.1 mSv/y and 1 mSv/y is negligible. On balance, it is not reasonable to imply that intervention is required below 1 mSv/y. An overly conservative reference level can create an exaggerated impression of health risk and lead to interventions that do more harm than good, especially when their social, environmental, and financial costs are borne by small communities or private individuals. The new reference level, and proposed maximum acceptable concentrations (MACs), are tools to support a more balanced assessment of risks, benefits and costs, without sacrificing health protection. The MAC for uranium has been removed as it is a chemical hazard covered by the drinking water guidelines for uranium. New proposed MACs for the most significant radionuclides, including radium-228 (Ra-228), and new health-based values (HBVs) for other radionuclides of interest, including polonium-210 (Po-210) and radon-222 (Rn-222), have also been included.

This document is available for a 60-day consultation period. Please send comments (with rationale, where required) to Health Canada via email at:

water-eau@hc-sc.gc.ca

All comments must be received before January 10, 2025. Comments received as part of this consultation, along with the name and affiliation of the author will be shared with members of the Federal-Provincial-Territorial Committee on Drinking Water (CDW). Authors who do not want their name and affiliation shared with CDW members should provide a statement to this effect along with their comments.

It should be noted that this guideline technical document will be revised following the evaluation of comments received, and a drinking water guideline will be established, if required. This document should be considered as a draft for comment only.

Proposed guideline

Maximum acceptable concentrations (MACs) are proposed for the most significant radionuclides in the uranium- and thorium-decay chains. In addition, new health-based values (HBVs) are presented in Appendix D for radionuclides that may be of interest, such as radon and tritium, and isotopes of polonium, strontium, iodine and cesium. The HBVs and proposed MACs are derived from a reference level of 1 millisievert per year (mSv/year) and are listed in Tables 1 and 7.

Water supplies should be screened against a gross alpha radiation level of 0.5 Bq/L (becquerel/litre) and a gross beta level of 1.0 Bq/L before individual radionuclide analysis is undertaken. The radionuclides that have been assigned a MAC should be prioritized over those with an HBV during individual analysis, based on their probability of occurrence at levels that warrant investigation. If more than one radionuclide is detected, the sum of the ratios of the observed concentration to the HBV or proposed MAC for each contributing radionuclide should not exceed 1.

Table 1. Proposed maximum acceptable concentrations for radionuclides in drinking water

Natural radionuclides	MAC (Bq/L)
Lead-210	2
Radium-226	5
Radium-228	2

MAC – Maximum acceptable concentration; Bq/L – becquerels per litre

Executive summary

This guideline technical document was prepared in collaboration with the Federal Provincial-Territorial Committee on Drinking Water and assesses all relevant information on radionuclides.

Radionuclides are naturally present in the environment. Everyone is exposed to background radiation from cosmic and terrestrial sources, including food and drinking water. While natural sources of radiation are responsible for most of a person’s radiation exposure (accounting for over 98% of exposure, excluding medical sources), drinking water tends to be a minor component of those natural sources. The guidelines concern radionuclides present in existing and new water distribution systems under routine operational conditions. These guidelines do not apply in the event of a nuclear accident, which is covered under provincial emergency plans.

This Guideline Technical Document draws upon international assessments of the human health risks of radionuclides in drinking water and considers new studies and approaches, including dosimetric information released by the International Commission on Radiological Protection (ICRP) in 2007. MACs in drinking water are proposed for the 3 natural radionuclides (Pb-210 [lead-210], Ra-226 [radium-226] and Ra-228 [radium-228]) that are considered to be the most significant, based on the radiation dose received from Canadian water supplies. Health-based values (HBVs) are also derived for two additional natural radionuclides (polonium-210 and radon-222) in Appendix D. Four HBVs are also included for artificial radionuclides (tritium, strontium-90, iodine-131, and cesium-137) for reference purposes. The HBVs and proposed MACs were derived using internationally accepted equations and principles. They are calculated using a reference dose level of 1 millisievert (mSv) for one year’s consumption of drinking water, assuming a consumption rate of 1.53 L/day.

Exposure

Natural radionuclides are present at low concentrations in all rocks and soils. When groundwater has been in contact with rock over hundreds or thousands of years, radionuclide concentrations may build up in the water. These concentrations are highly variable and are determined by the composition of the underlying bedrock as well as the physical and chemical conditions in the aquifer. Natural radionuclides have also been known to occur in shallow wells, although this is rare.

Increased levels of natural radionuclides in surface waters may be linked to industrial processes such as uranium mining and milling, or to environmental processes such as cosmogenic fallout and radon progeny washed out of the atmosphere. Sources of artificial radionuclides include fallout from above-ground nuclear weapons testing (before 1963) and emissions from nuclear reactors and other activities (such as research, and diagnostic and therapeutic medicine). In Canada, levels of artificial radionuclides in the environment are very low.

Health effects, risk and reference level

In the field of radiation protection, the main concern associated with chronic radiation exposure is stochastic effects. When such effects occur, the probability of unrepaired DNA damage leading to cancer is assumed to increase or decrease with the dose. The ICRP’s 2007 recommendations assume a linear-no-threshold relationship between exposure and cancer risk. Risk estimates were obtained by extrapolating downward from the results of epidemiological studies in humans exposed to high levels of radiation/radioactivity. Although there is uncertainty about the relationship between exposure and health effects at low doses and dose rates, the linear-no-threshold model is generally accepted as being both appropriate and conservative for the purposes of radiation protection. The International Atomic Energy Agency (IAEA) recommends 1 mSv/year as a reference level or target for most water treatment plants, which balances the risks against the ICRP’s justification and optimization principles.

Treatment and analytical considerations

The guideline development process considers the ability to measure (quantify) and remove (treat) a contaminant from drinking water supplies. Methods are available for screening water supplies for radioactivity, and individual radionuclides can be reliably measured to levels below the HBVs and proposed MACs.

At the municipal level, most radionuclides can be effectively removed from water supplies using treatment technologies such as reverse osmosis, ion exchange and lime softening. For radon, granular activated carbon and aeration are effective methods. For artificial radionuclides (including tritium, which cannot be removed from water), the strategy should be to prevent contamination of the source water. It should be noted that residuals from treatment may cause a low-level radioactive waste disposal problem, and water utilities should take this into consideration when choosing a treatment option.

At the residential level, multiple point-of-entry and point-of-use treatment technologies are available, which have a similar removal efficiency to municipal-scale technologies.

Distribution systems

According to studies found in the scientific literature, some radionuclides (for example, Pb-210, Ra-226 and Ra--228) have been shown to accumulate in distribution system piping, depending on the source water characteristics, distribution system materials, and the presence of co-occurring metals. When radionuclides are present in the source water, systems should determine if they need to be included in their monitoring and distribution system management plans, to prevent their accumulation on corrosion scales and their subsequent release into the distributed water. It is recommended that water utilities develop a distribution system management plan to minimize the accumulation and release of radionuclides and co-occurring contaminants in the system. This typically involves reducing concentrations entering the distribution system and implementing best practices to maintain stable chemical and biological water quality throughout the system and reduce physical and hydraulic disturbances which can release corrosion products and co-occurring contaminants (such as radionuclides).

Application of the guideline

Note: Specific guidance related to the implementation of drinking water guidelines should be obtained from the appropriate drinking water authority in the affected jurisdiction.

MACs have been proposed for 3 natural radionuclides (Pb-210, Ra-226 and Ra-228), which represent the most significant radionuclides in Canadian drinking water supplies. In addition, the HBVs for 6 radionuclides (polonium-210, radon-222, tritium, strontium-90, iodine-131 and cesium-137) that are of interest in specific scenarios can be found in Appendix C.

Screening criteria of 0.5 Bq/L for gross alpha activity and 1 Bq/L for gross beta activity are recommended. These values are conservative, as they represent one third of the reference dose levels used in determining the HBVs and proposed. Measurements of treated water and water at the point of consumption can be evaluated against the screening criteria in order to assess whether individual radionuclide measurements are required. Exceedances of the proposed MACs should be investigated with additional monitoring, and a risk assessment should be conducted to determine the most appropriate way to handle the exceedance.

Drinking water supplies that exceed the guideline values will rarely pose a health risk, especially in the short term. Discontinuing use of the water—while characterizing the radionuclide content and, if necessary, implementing remedial actions—is only necessary if levels are very high (for example, ten times the criterion for assessment). Any decisions to discontinue the use of the water for drinking purposes need to be carefully considered in light of the overall costs and benefits. Factors such as the extent to which the reference level is exceeded, the costs of remediation and the availability of other drinking-water supplies should be considered. Ensuring that a better option is available is essential before discontinuing the use of the drinking water supply (WHO, 2018).

Since the reference level is not a limit, international organizations recommend a single value, established for adults. If either screening criterion for gross alpha or gross beta is exceeded, it is recommended that an alternative source of water (such as bottled water) be used to prepare formula. This is a precautionary measure, because of the time it may take to characterize a water supply. The water is still acceptable for children (older than 1 year) and adults to consume and use.

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1.0 Exposure Considerations

1.1 Radionuclides of interest, sources and environmental behaviour

1.1.1 Radionuclides of interest

Radioactivity is present everywhere in the environment, and has been since the earth was formed. Naturally occurring radionuclides are predominantly primordial (having half-lives comparable to the age of the earth) isotopes of potassium, uranium and thorium, and their decay products, or they can be produced from the interaction of cosmic rays with the earth's atmosphere. Artificial radionuclides are produced for medical and industrial purposes or as by-products of energy production and historical weapons testing. The radionuclides of interest identified in this guideline document, shown in Table 2, come from all of these sources.

Pop-out/Information Box:

Radionuclides that occur in drinking water due to a nuclear emergency are not covered in these guidelines. Please see "Generic Criteria and Operational Intervention Levels for Nuclear Emergency Planning and Response" (Health Canada, 2018), as well as provincial nuclear emergency plans, for more information and guidance.

In Canada, most radionuclides in drinking water are naturally occurring. They enter the source water via natural processes such as the erosion of radionuclide-bearing minerals in rock and soil. Inputs from human activities—such as mining, nuclear power production or nuclear medicine—tend to be much smaller, because industrial and medical uses of radionuclides are regulated at the source and environmental emissions are optimized to be well below regulatory limits (IAEA, 2016; WHO, 2017). Contributions from past nuclear weapons testing and accidents are nearly negligible (UNEP, 2016).

Table 2. Radionuclides of interest

Radionuclide	Half-life	Decay mode	Source
Radium-226	1600 y	alpha	Uranium decay chain
Radium-228	5.75 y	beta	Thorium decay chain
Radon-222	3.82 d	alpha	Uranium decay chain
Lead-210	22.2 y	beta, gamma	Uranium decay chain
Polonium-210	138.3 d	alpha	Uranium decay chain
Tritium	12.3 y	beta	Naturally produced due to interactions of cosmic rays with molecules in the air Artificially produced by nuclear reactors
Cesium-137	30.08 y	beta, gamma	Nuclear reactors, historical nuclear weapons testing
Iodine-131	8.02 d	beta, gamma	Nuclear reactors, nuclear medicine
Strontium-90	28.9 y	beta	Nuclear reactors, historical nuclear weapons testing

y – year; d – day

Testing for artificial radionuclides is only recommended if there is reason to suspect their presence (i.e., the water source is near hospitals or certain industrial operations).

Proposed maximum acceptable concentrations (MACs) or health-based values (HBVs) for 3 radionuclides have been added since the 2009 edition of this document. The MAC for radium-228 (Ra-228) and HBV for radon-222 (Rn-222) were added because of the discovery of localized concentrations in Canadian well water that could lead to exceedances of the reference level (Health Canada, unpublished data). The HBV for polonium-210 (Po-210) was added, because it is part of the uranium-238 decay chain and is therefore ubiquitous, and also has a very high dose coefficient. The MAC for uranium has been removed because uranium is only weakly radioactive and, therefore, is treated as a chemical hazard. Information on uranium in drinking water can be found elsewhere (Health Canada, 2019).

1.1.2 Sources and environmental behaviour

The occurrence of natural radionuclides in drinking water is most commonly associated with groundwater. Natural radionuclides are present in all rocks and soils, but their concentrations vary depending on the mineral content. Examples of rocks that tend to contain higher levels of uranium and thorium include crystalline rocks such as granite and quartz-conglomerate metamorphic rocks, and sedimentary rocks such as organic shales, sandstones, carbonates and phosphorites (Cowart and Burnett, 1994). When groundwater has been in contact with rock over hundreds or thousands of years, significant concentrations of radionuclides may leach into the water.

The environmental transport of radionuclides is influenced by radionuclides’ physical and chemical properties, as well as the properties of the medium or environment in which they are travelling. A radionuclide’s mobility is governed mainly by its non-nuclear properties, and thus isotopes of the same element behave in the same way chemically. Hydro-chemical behaviour like mobility and solubility are dependent on water quality, including alkalinity, pH, redox and chemical composition (WHO, 2018). Volatile radionuclides (like radon) will escape from water into the atmosphere, meaning that they are less likely to accumulate in water sources exposed to the air (Otton, 1992; WHO, 2011).

Because water quality may fluctuate seasonally, the levels of radionuclides may also fluctuate. This is why seasonal testing is sometimes recommended to characterize a water source. For example, surface water acidity may increase in the fall when leaves and needles fall into the water and decompose (USU, 2020). The parent radionuclide uranium is more mobile in waters with a near-neutral pH and high carbonate alkalinity (WHO, 2018). Seasonal differences may also occur in water-table levels, surface run-off patterns, water source volume and soil saturation (Bartram and Balance, 1996).

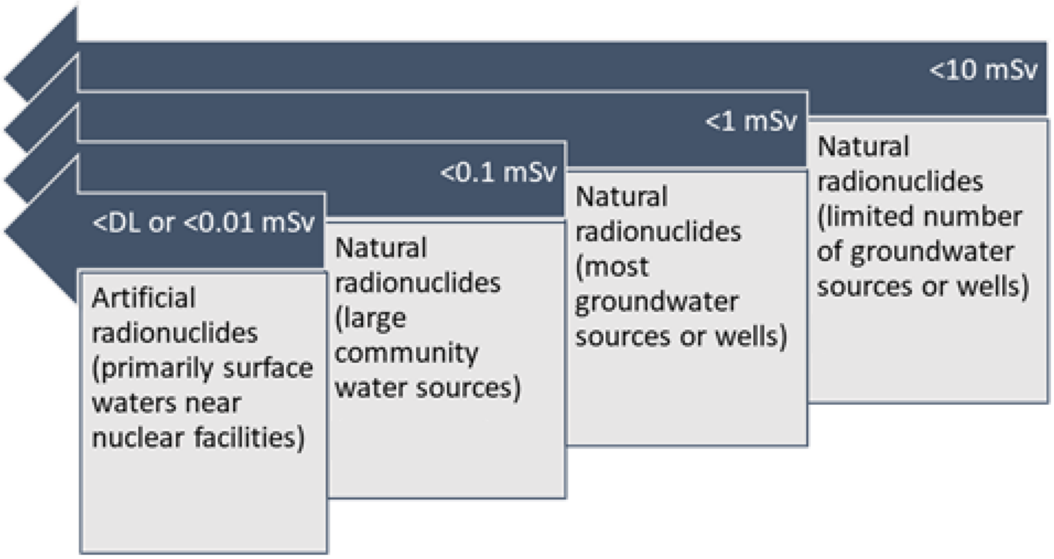
Pop-out/Information Box:

It is difficult to predict whether radionuclides are present (and in what quantities) in a specific geographical location, even when the geology is known. Therefore, it is recommended that each situation be evaluated on a case-by-case basis. On the basis of previous data (such as that presented in Section 1.2), only a very small fraction of water sources are be expected to have radionuclide concentrations that exceed the guideline values.

1.2 Exposure

1.2.1 Radionuclide dose data from various studies in Canada

The data available on radionuclide concentrations in drinking water in Canada indicate a general trend as depicted in Figure 1. The concentrations of natural radionuclides in most water systems remain low and contribute to an annual dose of less than 1 millisievert (mSv). On occasion, groundwater sources or wells may contain natural radionuclides that could result in an annual dose approaching or exceeding 1 mSv. Artificial radionuclides are found in very low concentrations, resulting in a negligible annual dose.



DL – detection limit; mSv – millisievert

Figure 1. Characteristic ranges of annual doses of radionuclides in drinking water, based on typical concentrations in water sources and daily drinking water consumption of 1.53 L (sources of information described below)

Radioactivity levels from artificial radionuclides measured in waters near nuclear facilities in recent years (before 2022) have consistently been below detection limits, or below 0.01 mSv/y, according to the results of the Independent Environmental Monitoring Program (IEMP) of the Canadian Nuclear Safety Commission (CNSC). Specifically, cesium-137 (Cs-137) in waters near 9 nuclear facilities, cobalt-60 in waters near 7 nuclear facilities, americium-241 in waters near 1 nuclear facility, iron-59 in waters near 1 nuclear facility and iodine-131 (I-131) in waters near 1 nuclear facility, were all below detection limits. Measurements of tritium (H-3) in waters near 10 nuclear facilities all corresponded to doses below 0.01 mSv/y (CNSC, 2023).

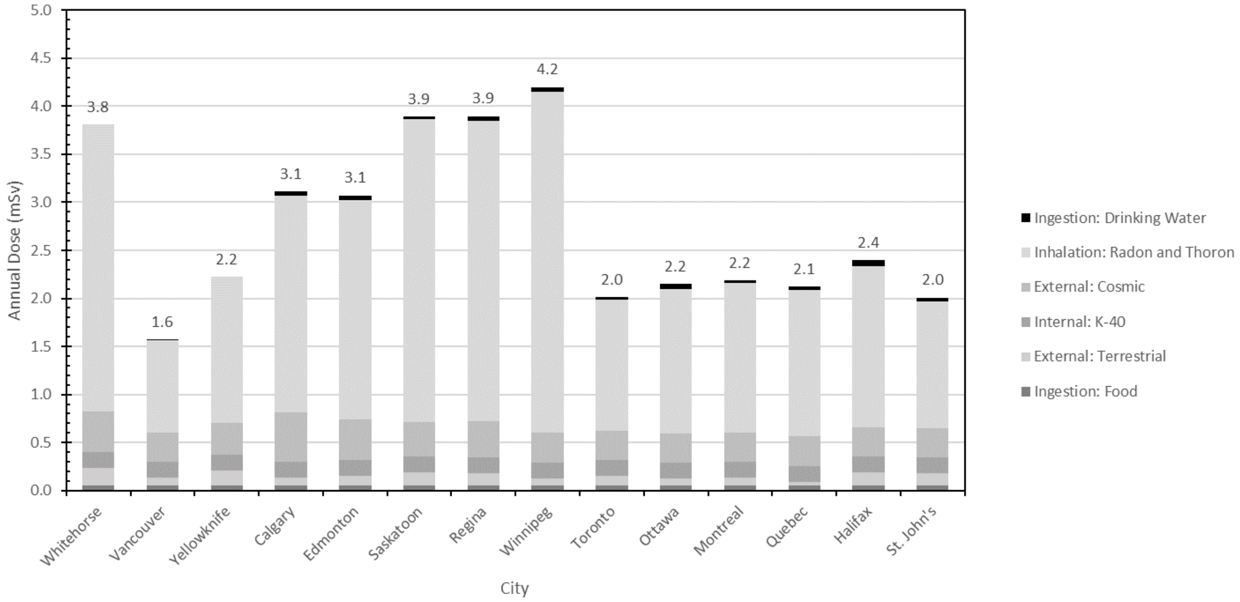
Three published studies summarizing the available Canadian data for large community water sources all indicate that doses from Ra-226, Rn-222, lead-210 (Pb-210) and Ra-228 are under 0.1 mSv/y. One reviewed natural radioactivity levels in the public water supply for 24 metropolitan areas and cities (Chen, 2018a). Another summarized the results of a series of analyses characterizing natural radioactivity levels in municipal drinking water supplies, conducted over a 30-year period by Health Canada. Measurements for many of the municipalities were discontinued after a few years as they showed consistently low levels of radioactivity. A third study presented Ra-228 concentrations in municipal drinking water in Regina, Elliot Lake, and Port Hope in 2012–2016 (Chen et al., 2018c). Measurements were continued for 3 municipalities where circumstances indicated a potential for higher radioactivity levels: in Regina, due to high concentrations of uranium in the sedimentary bedrock; in Elliot Lake, due to past and present uranium mining operations; and in Port Hope, due to activities associated with waste management and refining operations (Chen, 2018b).

Health Canada's Radiation Protection Bureau generates and reviews data characterizing groundwater and wells for special projects and consultations (unpublished). Most of these results indicate that concentrations of natural radionuclides, including Ra-226, Ra-228 and Pb-210, are below levels that would correspond to doses of 1 mSv/y. However, instances have occurred of doses that would approach or exceed 1 mSv/y.

1.2.2 Putting exposures from drinking water into perspective

It is important to put exposure to radiation from drinking water into perspective. As shown in Figure 2, annual doses from natural sources of ionizing radiation vary in different Canadian cities, due to factors such as local geology, latitude and altitude. As mentioned in the previous section, the data consistently show that, for most Canadians, typical doses from ingesting drinking water represent a very small percentage of the total exposure from all natural sources.

The most important pathway for exposure to most radionuclides in drinking water is ingestion of the water, which determines the levels for the MACs or HBVs. In contrast, radiological effects from external exposure to the radionuclides of interest in drinking water are negligible and so do not influence the MAC or HBV. Radiological effects from inhalation of these radionuclides are also negligible, except for radon. Radon is discussed in greater detail in Section 1.2.3.



mSv – millisievert

Figure 2. Average annual dose from various sources of natural radiation exposure in Canadian cities (Health Canada, forthcoming publication)

1.2.3 Radon

The largest contributor to the background radiation dose received by most Canadians is inhaled radon and its short-lived decay products (see Figure 2). Radon is a gas that can accumulate in the air in enclosed spaces, such as homes and buildings, sometimes at high levels.

Breathing air that contains high levels of radon can significantly increase lung cancer risk over time, and this is the most important consideration by far when managing radon exposure.

Radon typically enters a building through cracks and other openings in contact with the ground. To a lesser extent, it can also come from groundwater that is brought inside for drinking or other purposes, from which a portion of the dissolved radon will transfer (outgas) to the air, either before or at the tap. This is only a concern for people relying on groundwater. For surface water sources and municipally treated water sources, natural agitation and exposure to the open air allows radon to escape before the water reaches the distribution system.

The HBV for radon in drinking water is based on the ingestion dose, rather than the inhalation dose. Health Canada has established separate guidance for assessing the inhalation hazard from radon. A radon test can be performed using simple and inexpensive devices, and the results can be compared to the national guideline for radon in indoor air to assess the need for mitigation. More information is available elsewhere (Health Canada, 2023).

2.0 Health Considerations

2.1 Health effects

Radionuclides emit ionizing radiation, which has enough energy to remove electrons from atoms and molecules. In very simple terms, when an electron shared by atoms forming a molecular bond is dislodged, the bond is broken and the molecule falls apart. This process may occur by a direct “hit” to these atoms or may result indirectly from free radical formation due to the irradiation of adjacent molecules. When ionizing radiation is absorbed in a human cell, it can cause damage to the DNA molecule. The body’s natural response mechanisms will often deal with the damage before it becomes a problem. However, in some cases, the damage can lead to abnormal cell growth, or cancer. The primary health objective when managing public exposure to ionizing radiation is to reduce the risk of attributable cancer.

Factors relevant to radiation-induced cancer include, among other things, the pathway of exposure, the physical characteristics and chemical behaviour of the radionuclide and the sensitivity of the exposed organs.

The main evidence linking radiation exposure and cancer comes from epidemiological studies of individuals or groups who have had relatively high exposures, such as:

- atomic bomb survivors at Hiroshima and Nagasaki;
- patients who received high radiation doses for diagnostic or therapeutic purposes; and
- occupationally exposed workers (historical records), including uranium miners and radium dial painters

At lower doses and dose rates, the epidemiological evidence is less clear, in part because everyone is exposed to low levels of radioactivity, and in part because radiation-induced cancer cannot be distinguished from cancers due to other causes (ICRP, 2007). However, mechanistic studies indicate that relatively low doses of radiation can trigger biological responses associated with cancer (UNSCEAR, 2021). Furthermore, studies have shown that radiation exposure can lead to heritable effects in animals, although this has not been demonstrated in humans (ICRP, 2007). For the purposes of radiation protection, it is assumed that low doses of radiation have the potential to lead to cancer or heritable effects, and this assumption forms the basis for risk assessment and management as described in the next section. It is recognized that there is a great deal of uncertainty about the relationship between exposure and health effects at low doses and dose rates.

2.2 Risk

Radiation-induced cancer and heritable mutations are stochastic effects whose probability of occurrence is assumed to increase or decrease as exposure increases or decreases. Radiation protection uses calculations that characterize the prospective risk of these effects as the basis for making decisions about managing exposure. The internationally-accepted risk model for these calculations is linear and has no threshold, meaning that it is possible to calculate a risk for any exposure, no matter how small. In daily life, we face health risks from many different sources. Sometimes trying to reduce the risk from a single source, such as insignificant exposure to radiation, can inadvertently lead to undesirable consequences and/or risks from other sources. It is, therefore, important to find a balance. With this in mind, the ICRP has established the principles of justification and optimization as the basis for its system of protection (ICRP 103). Specifically:

- any decision to alter a radiation exposure situation (increase or decrease) should do more good than harm, considering all radiological and all non-radiological risks and consequences; and
- the level of exposure should be as low as reasonably achievable, with economic, societal, environmental and other factors being taken into account.

The ICRP recommendations are used to inform the Canadian and international systems of radiation protection.

The HBVs and proposed MACs for drinking water in Canada have been established at levels well below any level of importance to human health, so the radiological risk is very small. In most situations, the non-radiological costs and/or consequences of achieving these targets are relatively minor; however, there are exceptions, particularly for small or private water supplies. The negative consequences of water restrictions or expensive treatment systems may significantly outweigh the benefits of avoiding a small radiation dose. In these cases, it is important to seek the advice of professionals and consider the big picture when deciding how to proceed.

2.3 Reference level and effective dose

The ICRP recommends that exposures from natural and legacy sources be managed using a reference level between 1 mSv/y and 20 mSv/y (ICRP, 2007).

The basis for the HBVs and proposed MACs in this document is a reference level of 1 mSv/y, which is at the lower end of the recommended range. This value is consistent with the reference level recommended in the international safety standards (IAEA, 2014) and acknowledged by the World Health Organization (WHO, 2018). More discussion of how Health Canada's recommendations compare with those of international organizations and peers is provided in Section 6 and Appendix B.

The reference level is neither a limit nor a boundary between what is considered safe and unsafe. Instead, it is a level that involves minimal risk and is reasonably achievable for most water systems in Canada. It is usually a reasonable target for assessing water quality; in situations where it is not, as mentioned earlier, a more detailed assessment of the situation is warranted before making any decisions.

The reference level is expressed in terms of the effective dose, which is developed by the ICRP to relate ionizing radiation exposure to the risk of stochastic health effects, primarily cancer. It combines information about the physical and chemical properties of radionuclides with data that characterizes biological response. This allows exposures to different radionuclides through different pathways to be easily summed and/or compared to limits and reference levels. Estimates of average exposures to different sources of background radiation, as shown in Section 1, are expressed using effective dose. The unit for the effective dose is the sievert (Sv). Because the sievert is a very large unit, doses in the range relevant to drinking water are typically expressed as millisieverts (mSv), or 1/1000 of a sievert.

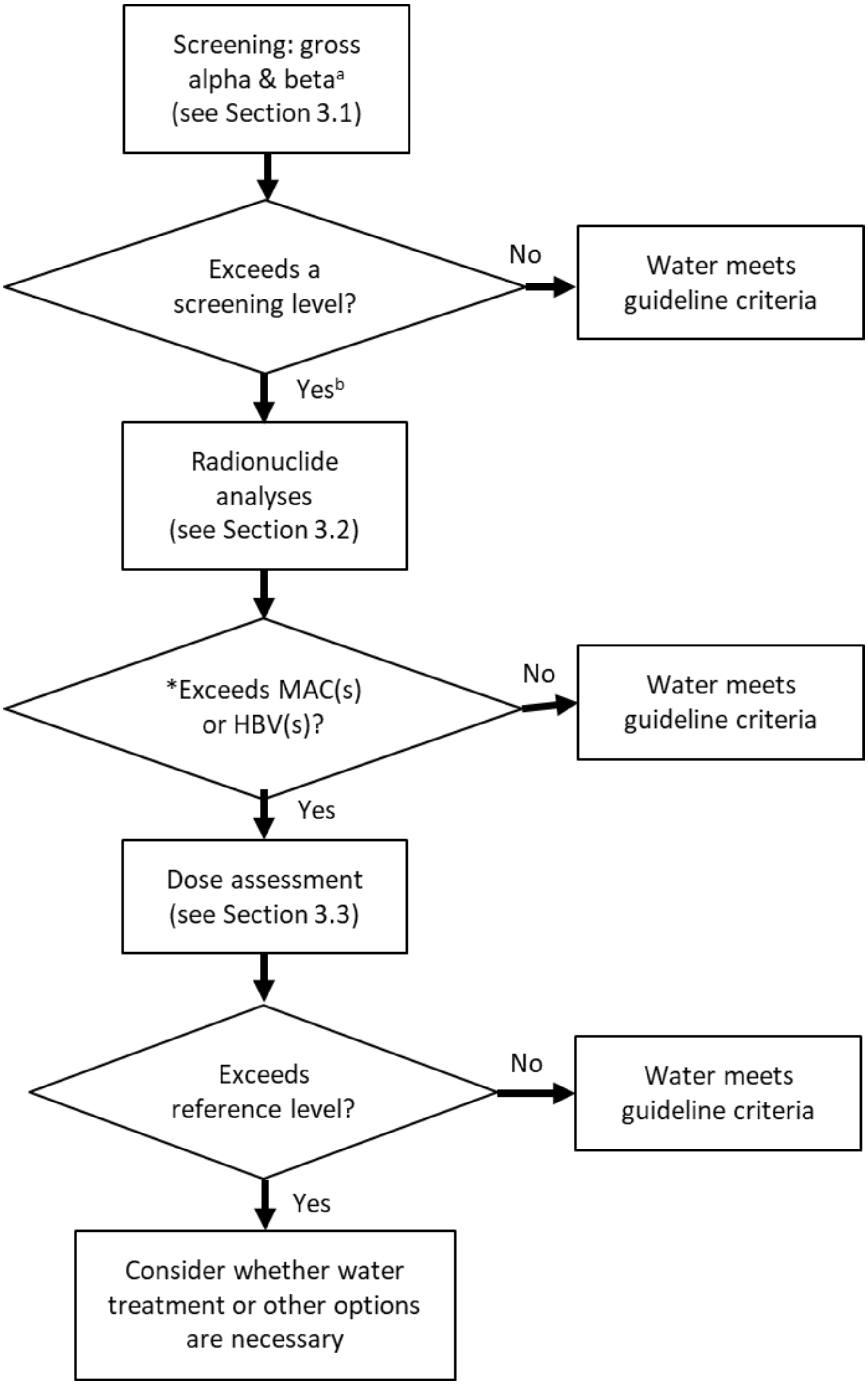
The ICRP has developed dose coefficients (dose per unit intake of a radioactive substance) to facilitate these calculations (ICRP, 2012, 2017). For example, by using dose coefficients for the ingestion of radionuclides, along with information on radionuclide concentrations and consumption rates, it is possible to estimate the dose that an individual would receive from a given source of drinking water. Health Canada used effective dose coefficients and standard assumptions to derive the HBVs and proposed MACs (see Section 3).

3.0 Assessment and Implementation

Figure 3 describes the process for assessing radiological parameters in drinking water. The process begins with rough, and relatively inexpensive, laboratory measurements. It then advances through more precise assessments when the results indicate that this is necessary. Each of these steps is described in more detail in Sections 3.1 and 3.2.

Alpha and beta radiation activity criteria, HBVs and proposed MAC values, summation formula, and the reference level were developed based on annual exposure. This is important to bear in mind when initially characterizing a water source. It may be necessary to repeat the gross alpha and beta measurements and/or radionuclide analyses to capture fluctuations and properly establish a baseline for the water supply. For example, sampling and measuring once per season for the first year is recommended for water sources that approach or exceed the HBV or proposed.

The dose for infants (less than 1 year old) is higher than that for children (over 1 year old) and adults at the HBV or proposed MAC. If the screening criterion for gross alpha or gross beta is exceeded, it is recommended that an alternative source of water (such as bottled water) be used for the preparation of infant formula. The water is still safe for children (less than 1 year old) and adults to consume and use. The ongoing periodic review process is discussed in Section 3.4.



[a] Gross alpha measurements should be corrected for the presence of uranium, and gross beta measurements, for the presence of potassium-40. Refer to specific gross alpha/beta measurement techniques for details, such as those listed in Table 3.

[b] If the water is being used for the preparation of infant formula, consider using an alternative source (such as bottled water).

Figure 3: Flowchart for the assessment of radiological parameters in drinking water supplies (the criteria for a periodic review are described in Section 3.4)

3.1 Gross alpha and beta screening

Since all the key radionuclides targeted in routine drinking water assessment emit alpha and/or beta particles, a water sample can usually be quickly screened using analysis methods that measure gross alpha or gross beta activity (see Section 4.1). However, gross alpha and beta screening are not effective tools for determining radon and tritium levels, respectively. Therefore, specific testing for radon or tritium is required if there is reason to believe that either of these are present in significant quantities.

Gross alpha and beta screening is a relatively inexpensive way of identifying water samples that require further investigation. The screening criterion proposed for each test corresponds to an annual dose of no more than 0.3 mSv, or about 1/3 of the reference level dose. Health Canada bases the gross alpha screening criterion on Po-210 (0.5 becquerel per litre [Bq/L]) and the gross beta screening criterion on Ra-228 (1 Bq/L), as these radionuclides have the highest dose coefficients among those considered significant in Canadian drinking water (ICRP, 2012, 2017). This approach is conservative.

If the results for both the gross alpha and gross beta measurements are below the screening criteria, there is no need for further investigation. If either or both measurements are above the screening criteria, radionuclide-specific analysis is recommended.

3.2 Radionuclide-specific analysis

If the gross alpha and/or gross beta screening criteria are exceeded, or if there is a known concern about radon or tritium in an area, the next step is to measure specific radionuclides and compare their activity levels with the MACs (see Section 4.2).

The proposed MACs for the individual radionuclides were derived using adult dose coefficients (ICRP, 2012, 2017), assuming a drinking water intake of 1.53 L/day (or 558 L/year), and a reference level of 1 mSv per year.

The proposed MAC for a given radionuclide in drinking water is derived using the following formula:

$$\text{MAC (Bq/L)} = \frac{1\text{mSv/year}}{558\text{ L/year} \times \text{DC (Sv/Bq)} \times 1000\text{ mSv/Sv}}$$

where:

- 1 mSv/year is the reference level.
- 558 L/year is the drinking water consumption rate for an adult, which corresponds to a daily consumption rate of 1.53 L/day. This value is consistent with that used by Health Canada in other drinking water guidelines (Health Canada, 2021).
- DC is the ingestion dose coefficient for a member of the public based on the ICRP 119 standard (or ICRP 137 for radon ingestion). This provides an estimate of the 50-year committed effective dose for adults resulting from a single intake of 1 Bq of a given radionuclide.

The HBVs are calculated in the same manner as the proposed MACs.

3.2.1 Summation formula

The radiological effects of two or more radionuclides in the same drinking water source are assumed to be additive. Therefore, the following summation formula should be satisfied in order to demonstrate compliance with the guidelines:

$$\sum_i \frac{C_i}{MAC_i} \leq 1$$

where C_i and MAC_i are the observed and maximum acceptable concentrations (MAC or HBV), respectively, of each contributing radionuclide. Only those radionuclides that are detected with at least 95% confidence should be included in the summation. Detection limits of undetected radionuclides should not be substituted for the concentrations C_i. Otherwise, a situation could arise where a sample fails the summation criterion, even though no radionuclides are present.

Popout/Information Box:

Chemical MACs should not be included in the radiological summation formula. For example, total natural uranium does not have a radiological MAC, but instead has a chemical MAC, which is more limiting. Because uranium at the chemical MAC generates a very small radiological dose (~0.01 mSv/y), uranium should not be included in the summation formula.

3.3 Dose assessment and mitigation decisions

The HBVs and proposed MACs were derived using default values for some parameters, such as consumption rates. If radionuclide concentrations exceed the HBV or proposed MAC(or 1, if using the summation formula), it might be worthwhile to characterize doses more accurately. The results, when compared against the reference level, can inform decisions on next steps. This is especially true for private wells, where intervention could inadvertently lead to situations where the negative impacts outweigh the positive ones (see Sections 2.2 and 2.3). The dose assessment will depend on many factors, including the radionuclides present in the drinking water, seasonal variations in measured concentrations, that a radiation protection expert be contacted to perform this assessment and provide recommendations. For private wells, the risk tolerance of the individuals served and the impacts of mitigation, including cost, are important and relevant considerations when deciding how best to proceed. For public or larger community-based systems, exceedances should generally be mitigated. Treatment options are discussed in Section 5.

3.4 Periodic review and monitoring

Periodic reviews are recommended in situations where human activities or environmental changes could increase the level of radionuclides in drinking water. The frequency of periodic reviews depends on the specific situation, but if there is no reason to expect concentrations to vary with time, then sampling may be carried out seasonally, semi-annually or annually. If measured concentrations are consistent and well below the HBVs or proposed MACs, this would be an argument for reducing the sampling frequency. Conversely, the sampling frequency should be maintained, or even increased, if concentrations approach individual HBVs or proposed MACs, if the sum of the ratios of the observed concentration to the HBV or proposed MAC for each contributing radionuclide approaches 1, or if the source of the radioactivity is known or expected to change rapidly with time.

Gross alpha and gross beta screening measurements can be adapted for use in periodic reviews, at levels different from the default screening criteria. For example, if the gross levels initially measured are above the screening criteria, but radionuclide-specific testing shows that the water meets the guideline criteria, the measured gross levels can be utilized as the screening criteria for periodic reviews. This is possible because each screening criterion represents a fraction of the reference level. Likewise, in instances where one or two radionuclides predominately contribute to the total dose, the periodic reviews can focus on them. The decision on which method to use is based on efficiency and cost.

Jurisdictions with facilities that generate environmental releases of radionuclides likely to enter drinking water sources may wish to establish agreements with these facilities. Such agreements can allow monitoring data to be shared and early notification of releases given, so that drinking water treatment plant operators can take appropriate action. If ongoing exposure to levels exceeding the HBVs and proposed MACs is likely, a jurisdiction may choose to apply additional measures based on the toxicity, the expected level in the source water, and the frequency of occurrence, in order to mitigate risk.

4.0 Analytical and treatment considerations

A brief summary of analytical methods used to perform the gross alpha and gross beta measurements of radionuclides with HBVs or proposed MACs is provided below (Table 2). Validated methods referenced here include those from the United States Environmental Protection Agency (U.S. EPA), International Organization for Standardization (ISO) and the American Society for Testing and Materials (ASTM). Laboratories in Canada and the U.S. will often refer to these methods directly, or may use them as a basis for developing, validating or testing their own methods. Water samples should be collected at the consumption point. Health Canada recommends using a laboratory with an accreditation relevant to the analysis of radionuclides in drinking water. The laboratory can provide more information about the collection procedure, including sample container and volume.

The detection limits cited in Sections 4.1 and 4.2 are based on those in the reference methods. In practice, detection limits may vary, depending on sample-specific parameters, counting time and modifications to the reference method by the laboratory.

4.1 Gross alpha and gross beta measurements

Analyzing drinking water for gross alpha and gross beta radiation (excluding radon) can be done by evaporating a known volume of the sample until dry and then measuring the radiation activity in the residue. Since alpha radiation is easily absorbed in a thin layer of solid material, the method's reliability and sensitivity in determining alpha activity may be reduced in samples with a high total dissolved solids (TDS) content. Some methods require the subtraction of potassium-40 (K-40) to accurately determine the gross beta activity. The total potassium in the sample by mass can be measured by using atomic absorption spectrophotometry, and the K-40 activity (Bq) can then be calculated by applying the factor of 27.6 Bq/g. Recommended methods for determining gross alpha and beta activity are listed in Table 3, and the detection limit varies with laboratories depending on equipment and procedures used. On average, an interlaboratory comparison puts the detection limit in the range of 1.4–340 mBq/l for gross alpha and 0–424 mBq/l for gross beta (Jobbagy, 2016).

Table 3. Reference methods for gross alpha and gross beta activity measurements

Parameter	Reference Method	Preparation	Detection	Notes
Gross alpha	ISO 9696 (2017)	Evaporation	Gas proportional counting	Requires TDS content lower than 0.1 g/L, and K-40 subtraction; not valid if fission products suspected
	APHA 7110 C (1998)	Co-precipitation	Gas proportional counting	
Gross beta	ISO 9697 (2018)	Evaporation	Gas proportional counting	Requires TDS content lower than 0.1 g/L, and K-40 subtraction
Gross alpha and gross beta	EPA 900.0 (1980a)	Evaporation	Gas proportional counting	Requires TDS content lower than 0.1 g/L, and K-40 subtraction
	ASTM D7283 (2017)	Evaporation	Liquid scintillation counting	

Although gross alpha and gross beta activity screening can reduce the need for specific radionuclide analyses, which are more costly, it has a number of drawbacks as a measurement tool. These drawbacks include false-positive results, particularly for gross alpha measurements when dissolved radon is present. False positives in the range of tens of becquerels per litre (Bq/L) are fairly common, but, in most of these cases, detailed analyses will show that all radionuclides of interest comply with the HBV or proposed MAC. In gas proportional counting, false negatives may occur when large amounts of TDS occur in the water sample. In this case, when the sample has been evaporated and is dry, self-absorption of the particles may lead to a significant reduction in the count rate. Laboratories that carry out gross alpha and gross beta measurements routinely report wide fluctuations in count rates, even for samples taken from the same water source. In gross measurements, using detectors to detect alpha and beta activity simultaneously can lead to crosstalk or spillover between the alpha and beta channels, resulting in an unpredictable increase in analytical errors. To address these drawbacks, the analysis of replicate samples is recommended. Improvements have recently been made in the sequential determination of gross alpha/beta activity in samples with a complex radionuclide composition (Jobbagy, 2022).

If a drinking water sample exceeds the screening criteria for gross alpha (0.5 Bq/L) or gross beta (1 Bq/L) activity, it is recommended that the analysis be repeated twice more to check the validity of the result. If the initial result is confirmed, then the sample should be analyzed for specific radionuclides whose presence is suspected, based on the type and location of the drinking water supply (Table 2).

4.2 Radionuclide-specific analysis methods

Radionuclide-specific analysis should prioritize likely radionuclides with a MAC value, unless there is prior knowledge of the source of contamination (Table 4). Analytical methods for detecting radionuclides with an HBV or proposed MAC are listed in Table 5.

Table 4. Possible radionuclides contributing to an exceedance of the screening criteria

Exceedance	Likely radionuclides (with MACs)	Unlikely radionuclides (with HBVs)
Gross alpha	Radium-226	Polonium-210
		Radon-222
Gross beta	Lead-210	Tritium (H-3)
	Radium-228	Strontium-90
		Iodine-131
		Cesium-137

MAC – maximum acceptable concentration; HBV – health-based value

Table 5. Reference methods for radionuclide-specific analyses

Radio nuclide	**Reference Method**	**Preparation**	**Detection Method**	**DL**	**Notes**
Lead-210	ASTM D7535 (2015) ISO 13163 (2021c)	Solid-phase extraction Solid-phase extraction	Gas proportional counting Liquid scintillation counting	37 mBq/L 20–50 mBq/L	If high radon is also suspected, sample should be agitated to remove dissolved radon before storage.
Radium-226 and -228	ISO 22908 (2020b)	Co-precipitation and resuspension	Liquid scintillation counting	0.01 Bq/kg (Ra-226), 0.06 Bq/kg (Ra-228)	N/A
Radium-226	ASTM D2460-07 (2013a)/ EPA 903.0 (1999) ASTM D3454 (2022)/ EPA 903.1 (1980c)	Co-precipitation Radon emanation	Alpha spectrometry or gas proportional Counting Scintillation chamber	ASTM method: 3.7–37 mBq/L	N/A
Radium-228	EPA 904.0 (2022)	Co-precipitation	Gas proportional counting	Not reported	N/A
Polonium-210	ISO 13161 (2020a)	Auto-deposition or co-precipitation	Alpha spectrometry	5 mBq/L	N/A

Radio nuclide	**Reference Method**	**Preparation**	**Detection Method**	**DL**	**Notes**
Iodine-131	EPA 901.1 (1980b)	None	Gamma spectrometry	Not reported	N/A
	ASTM D4785-08 (2013b)	Ion exchange/ solvent extraction	Gamma spectrometry		
Cesium-137	EPA 901.1 (1980)/ISO 10703 (2021a)	None	Gamma spectrometry	ISO method: 5 mBq/L	N/A
Radon-222	7500-Rn B (APHA et al., 2021)	None	Liquid scintillation counting	0.67 Bq/L	Care must be taken when acquiring samples for radon measurement, as radon can easily escape when being transferred into different containers, agitated, or left to stand open.
	ASTM D5072-09 (2016)	None	Liquid scintillation counting	2 Bq/L	
	EPA 600/2-87/082 (1989)	De-emanation	Lucas scintillation cell		
Strontium-90	ASTM D5811-06 (2020b)	Solid phase extraction	Gas proportional counting	37 mBq/L	N/A
	ISO 13160 (2021b)	Solid phase extraction or liquid-liquid extraction	Liquid scintillation counting or gas proportional counting	2 mBq/L	
Tritium	EPA 906.0 (1980d) /ASTM D4107 (2020a)/ISO 9698 (2019)	Distillation	Liquid scintillation counting	0.037–555 Bq/mL	N/A

DL – detection limit; Bq/L – becquerels per litre; mBq/L – millibecquerels per litre; Bq/mL– becquerels per millilitre; Bq/kg – becquerels per kg; N/A – not applicable

5.0 Treatment considerations

5.1 Radioisotope chemistry

Several technologies are available to reduce concentrations of radiological contaminants in drinking water. It should be noted that the chemical characteristics of tritium preclude its removal from water, emphasizing the need to prevent significant contamination of the source water.

The selection of an appropriate treatment process will depend on many factors, including the raw water source and its characteristics, the nature of the radionuclides present in the water, the operational conditions of the selected treatment method and the water utility’s treatment goals. Pilot- and bench-scale testing is critical to ensure the source water can be successfully treated and to optimize operating conditions. In addition, the handling and disposal of the treatment residuals (waste produced by treatment) need to be carefully addressed when removing radionuclides from drinking water.

5.2 Municipal scale

Most radionuclides can be effectively treated in municipal-scale treatment facilities. The best technologies available for the removal of radionuclides at this level are ion exchange (IX), reverse osmosis (RO) and lime softening (U.S. EPA, 2000b). Removal efficiency is affected by the characteristics of the source water, including pH, influent concentration, competing ion concentration (especially sulphate), resin type and alkalinity. Generally, IX resins exhibit a degree of selectivity for various ions, depending on the concentration of the ions in solution and the type of resin selected. IX capacity and resin selectivity are important considerations when selecting a resin for a specific radionuclide.

For RO, the reported removal efficiency typically ranges from 70% to 99% (Annanmäki, 2000). IX removal efficacy has been reported to be as high as 95%, but is dependent on the specific IX media used (U.S. EPA, 2000a).

Both the RO and IX technologies can lower water pH and increase corrosion. In the anion exchange process, freshly regenerated IX resin removes the bicarbonate ions when removing contaminants. This causes reductions in pH and total alkalinity during the initial 100-bed volumes (BVs) of a run, and may require raising the pH of the treated water at the beginning of a run to avoid corrosion (Clifford, 1999; Wang et al., 2010; Clifford et al., 2011). Similarly, the frequent regeneration of an IX resin results in the significant and continual decrease of the water pH, also impacting corrosion (Lowry, 2009, 2010). Since RO continually and completely removes alkalinity in water, it will continually lower the pH of treated water and increase its corrosivity. Therefore, the product water pH must be adjusted to avoid corrosion issues in the distribution system, such as the leaching of lead and copper (Schock and Lytle, 2011)

5.2.1 Radium

The reported efficacy of lime softening in removing radium ranges from 80% to 95% (U.S. EPA, 2000a).

The IX process to remove radium uses a strong acid cation exchange media (i.e., the resin is regenerated by an acid solution) (Annanmäki, 2000; Clifford, 2004). Along with IX, RO and lime softening, Table 6 shows the treatment technologies capable of removing both Ra-226 and Ra-228 which include green sand filtration, precipitation with barium sulphate, electrodialysis/electrodialysis reversal and hydrous manganese oxide filtration (U.S. EPA, 2000b).

Table 6. Treatment technologies and removal efficiencies for radium

Treatment method	**Removal efficacy**	**Comment**
IX softening (Na^+, SAC)	> 95%	Operate to hardness breakthrough; NaCl regeneration
$Ba(Ra)SO_4$ precipitation	50–95%	$BaCl_2$ added to feed water before filtration
MnO_2 adsorption	50–95%	Use preformed MnO_2 or MnO_2-coated filter media
RO	> 99%	Effective, some operational challenges

Adapted from Clifford (2004); IX – ion exchange; RO – reverse osmosis; SAC – strong acid cation

5.2.2 Radon

The U.S. EPA recommends high-performance aeration as the best available technology to remove radon from groundwater supplies. High-performance aeration methods include packed-tower aeration and multi-stage bubble aeration, and can achieve up to 99.9% removal. However, these methods may also generate significant airborne radon. Adsorption using granular activated carbon (GAC), with or without IX, can also remove a large percentage of radon, but is less efficient and requires large amounts of GAC, making it less suitable for large systems.

GAC and point-of-entry GAC may be appropriate for very small systems under some circumstances (U.S. EPA, 1999). Two potential concerns associated with this technology are the elevated gamma radiation fields that develop close to the column and the difficulties of disposing of treatment residuals.

5.2.3 Tritium

For artificial radionuclides such as tritium, the strategy should be to prevent the significant contamination of the source water.

5.3 Management of residuals

To assess disposal options and regulatory requirements, the waste stream (residuals) generated must first be characterized. Characterization must take into account the treatment technology used, the characteristics of the source water (including the raw water concentrations of radiological contaminants and the presence of co-occurring radionuclides), and concentrations of other contaminants in the residuals. Treatment technologies produce a variety of solid waste residuals (spent resin filter media, spent membranes and sludge) and liquid waste residuals (brine, backwash water, rinse water, acid neutralization streams and concentrate). The characteristics and concentration of the radionuclide in the residuals will vary with the treatment technology used and its efficiency (which is associated with factors such as frequency of media replacement, regeneration and filter backwash).

Utilities should conduct pilot tests of the treatment technologies to determine, for example, the regeneration schedule when using IX and the associated waste residuals. Special precautions may be required when the waste stream is treated, stored, disposed of or transported. Operators may need special training to deal with these residuals. Residuals generated by drinking water treatment facilities should be assessed to determine if they should be treated as Naturally Occurring Radioactive Materials (NORM) for disposal (e.g., Health Canada, 2014). If so, the appropriate authorities should be consulted for the requirements associated with their disposal. A list of provincial and territorial radiation protection regulatory authorities can be found on the Federal Provincial Territorial Radiation Protection Committee (FPTRPC) website (https://www.canada.ca/en/health-canada/services/health-risks-safety/radiation/understanding/federal-provincial-territorial-radiation-protection-committee.html). A web-based tool can also be used to estimate the removal efficiency for radionuclides and co-contaminants from drinking water, as well as radioactive concentrations in the waste residual (U.S. EPA, 2005).

5.4 Residential scale

When the removal of radionuclides is desired at the household level—for example, when a household gets its drinking water from a private well—a residential drinking water treatment unit may be an option. In addition, units classified as residential scale may have a rated capacity to treat volumes greater than that needed for a single residence, and therefore can also be used in somewhat larger systems.

Before a treatment unit is installed, the water should be tested to determine the general water chemistry and radionuclide concentrations. Periodic testing by an accredited laboratory should be conducted on both the water entering the unit and the treated water, to verify that the treatment unit is effective. Units can lose their removal capacity with use over time and will need to be maintained and/or replaced. Consumers should check the expected service life of the components in the treatment unit and service it when required according to the manufacturer's recommendations.

Health Canada does not recommend specific brands of drinking water treatment units. However, it strongly urges consumers to use treatment units that have been certified by an accredited certification body. This ensures that the treatment unit meets the appropriate NSF International/American National Standards Institute (NSF/ANSI) standards. The purpose of these standards is to establish minimum requirements for the materials, design and construction of drinking water treatment units. The certification of treatment units is conducted by a third party, and ensures that the materials in the unit do not leach contaminants into the drinking water (i.e., material safety). The standards also specify performance requirements, i.e., the removal efficiency that must be achieved for specific contaminants that may be present in water supplies.

Certification organizations (i.e., third parties) provide assurance that a product conforms to applicable standards and must themselves be accredited by the Standards Council of Canada. Accredited organizations in Canada include:

- CSA Group
- NSF International
- Water Quality Association
- UL LLC
- Bureau de normalisation du Québec (available in French only)
- International Association of Plumbing and Mechanical Officials
- ALS Laboratories Inc.

An up-to-date list of accredited certification organizations can be obtained from the Standards Council of Canada.

Residential-scale treatment devices are available that can remove some radionuclides from drinking water to achieve the proposed guidelines. The most common types of devices available for this purpose include IX and RO systems. In general, the removal efficacy of point-of-use and point-of-entry treatment technologies is expected to be similar to those for municipal-scale treatment technologies.

The liquid and solid waste from point-of-use or point-of-entry treatment units may be eliminated in sewer or septic systems, and municipal landfills, respectively.

5.4.1 Lead-210

No treatment devices are currently certified for the removal of Pb-210. However, since this isotope behaves chemically like elemental lead, devices certified for the removal of lead should also remove the radioactive isotope.

Drinking water treatment devices can be certified to NSF/ANSI Standard 53 (Drinking Water Treatment Units – Health Effects) (adsorption) or NSF/ANSI Standard 58 (Reverse Osmosis Drinking Water Treatment Systems) for lead removal (NSF, 2022a, 2022b). A number of certified residential treatment devices are available to remove lead from drinking water using adsorption (i.e., carbon block/resin) and RO. An infographic is available to aid in the selection of a certified adsorption filter for lead removal (https://www.canada.ca/en/health-canada/services/publications/healthy-living/infographic-finding-drinking-water-filter.html). Drinking water treatment devices certified to NSF/ANSI Standard 62 (Drinking Water Distillation Systems) can also be used, as this distillation technology is also effective in removing lead at the residential scale (NSF, 2022c). However, no certified distillation systems are currently available.

5.4.2 Radium

Drinking water treatment devices certified to remove Ra-226 and Ra-228 from drinking water using IX and RO technologies are available. Devices certified to meet NSF/ANSI Standard 58 (Reverse Osmosis Drinking Water Treatment Systems) and Standard 44 (Residential Cation Exchange Water Softeners) are capable of reducing radium levels from an influent concentration of 25 picocuries per litre (pCi/L) (925 mBq/L) to a maximum concentration of 5 pCi/L (185 mBq/L) or less (NSF International, 2022b, 2022d).

5.4.3 Radon

Drinking water treatment devices certified to remove radon generally use activated carbon adsorption technology. Treatment devices that are certified to meet NSF/ANSI Standard 53 (Drinking Water Treatment Units – Health Effects) (adsorption) can reduce radon levels from an influent concentration of 4000 pCi/L (148 Bq/L) to a maximum concentration of less than 300 pCi/L (11 Bq/L) (NSF, 2022a).

These filtration systems may be installed at the tap (point of use) or at the location where water enters the home (point of entry). Point-of-entry systems are preferred for radon removal because they provide treated water for bathing and laundry as well as for cooking and drinking. When certified point-of-entry treatment devices are not available for purchase, systems can be designed and constructed from certified materials.

5.5 Distribution system considerations

Radionuclides in treated water can be deposited in the distribution system, where they accumulate (Friedman et al., 2010). Higher concentrations of radionuclides in the water entering the distribution system increases the potential for accumulation. Furthermore, if chemical changes or physical disturbances occur, radionuclides can be remobilized in the water, potentially resulting in increased concentrations of radionuclides, such as radium, at the tap. Discoloration (red or grey water) episodes are likely to be accompanied by the release of accumulated contaminants, including radionuclides, because they are adsorbed onto iron deposits.

The potential accumulation of radiological contaminants in distribution system piping is influenced by a variety of factors, including contaminant concentrations, pipe material, co-occurrence of iron and manganese in the pipe scale deposits, and pH and redox conditions in the water. Distribution system piping is susceptible to corrosion and the accumulation of iron-scale deposits on the interior surface of the pipe. The presence of manganese in the source water may also influence the accumulation of some radionuclides (Friedman et al., 2010).

Radionuclides that, when present, can adsorb and accumulate in distribution systems include Pb-210, Ra-226 and Ra-228 (Valentine and Stearns, 1994; Field et al., 1995; Reiber and Dostal, 2000). Friedman et al. (2010) found that Ra-226 was the sixth most concentrated trace element in deposit samples, with a median concentration of 0.3 Bq/g. The occurrence of radium in pipe-scale deposits is suspected to be due primarily to surface adsorption and co-precipitation reactions involving soluble radium. The adsorption of radium isotopes onto hydrous iron and manganese oxides is well established.

Studies have shown that changes in water chemistry (pH and redox) or in water treatment processes, or physical disturbances can release these radionuclides from pipe scale deposits and cause remobilization and elevated concentrations at the tap. Consequently, discoloured water should not be considered safe to consume or treated as only an aesthetic issue and should also trigger sampling for metals and radionuclides and potentially require additional distribution system maintenance. When radionuclides are present in the source water, utilities should determine if they also need to be included in their monitoring and distribution system management plans.

6.0 International Considerations

6.1 Reference level

Health Canada has adopted a reference level of 1 mSv/y, which is in line with international recommendations, including those by the ICRP and IAEA (ICRP, 2007; IAEA 2014). The WHO acknowledges the IAEA-recommended reference level of 1 mSv/y, but also goes beyond this to generally recommend a modified reference level, or “individual dose criterion,” of 0.1 mSv/y (WHO, 2017, 2018). This value is based on the ICRP-recommended dose constraint for a planned exposure situation of the prolonged component from long-lived nuclides. Health Canada has instead chosen to base its guidance on the lower end of the band that ICRP recommends for reference levels for existing exposure situations (i.e., 1–20 mSv/y) , as this is in agreement with the Canadian exposure considerations explained in Section 1.

From a health perspective, neither 0.1 mSv/y nor 1 mSv/y poses a significant risk. However, for many communities, especially those that depend on groundwater sources in Canada, a level of 0.1 mSv/y may be unjustified given the emotional and financial stress it may place on communities or homeowners. The 1 mSv/y reference level is already met in most drinking water supplies in Canada, and in many cases, should be easily achievable for those that test above this level. It should be noted that sometimes the exceedance of the reference level is also justified.

To summarize, Health Canada has chosen 1 mSv/y as the reference level, as it is in line with international recommendations, is reasonably achievable in most cases, is not expected to place an unfair burden on communities, and does not create a false perception of health risk to the public, which might result from a lower level.

6.2 Methodology

Health Canada follows the methodology recommended by the WHO (WHO 2017, 2018). This includes:

1) establishing a reference level[1] ;
2) screening water samples using gross alpha and beta activity levels that are derived from the reference level; and
3) if alpha/beta levels are exceeded, measuring individual radionuclide concentrations and comparing them to rounded guidance concentration levels that correspond to the reference level.

Note that caution must be exercised if trying to compare different guidance values across organizations. Different organizations may consider different technical, economic, environmental and societal factors when choosing a reference level (or similar value). Screening levels may be based on different reference levels, or fractions of those levels, as well as different radionuclides, drinking water consumption rates and rounding conventions. MACs (or similar values) may also be based on different reference levels, drinking water consumption rates or rounding conventions, or may be defined completely differently. In addition, the various guidance values may be associated with different actions or different optimization expectations.

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[1] Note that WHO acknowledges the reference level recommended in the International Basic Safety Standards (IAEA 2014) but has chosen to use 1/10 of that level as the basis for their drinking water guidance (WHO 2018)

7.0 Rationale for the maximum acceptable concentration

MACs have been proposed for 3 natural radionuclides (Pb-210, Ra-226 and Ra-228) potentially found in Canadian drinking water. Additional HBVs for 6 other radionuclides (Po 210, Rn-222, tritium [H-3], Sr-90, I-131 and Cs-137) are in Appendix C for use in specific scenarios.

The HBVs and proposed MACs were determined using internationally accepted equations and principles and can be interpreted as reference concentrations, where an exceedance does not pose immediate risk but triggers investigation as soon as reasonable. They were derived from an annual reference dose of 1 mSv from ingestion only and assuming a consumption rate of 1.53 L/day. Health risks from inhalation or skin absorption at the levels of the HBVs and proposed MACs are almost always negligible, except for radon (see Section 1.3 for more information about radon). The HBVs and proposed MACs for radionuclides do not take treatment or analytical limitations into consideration. The treatment of water supplies to remove radionuclides should be governed by the principle of keeping exposures as low as reasonably achievable, with social, economic, and environmental considerations being taken into account. Both the screening criteria, the HBVs and the proposed MACs for radionuclides apply to routine operational monitoring of existing or new water supplies (see Section 3.4), but do not apply in the event of contamination during an emergency involving a large release of radionuclides into the environment.

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Appendix A: List of abbreviations

ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
AWWA	American Water Works Association
Bq	becquerel
CNSC	Canadian Nuclear Safety Commission
DC	dose coefficient
DL	detection limit
DNA	deoxyribonucleic acid
GAC	granular activated carbon
GSR	General Safety Recommendations
HBV	health-based value
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IE	ion exchange
ISO	International Organization for Standardization
mSv	millisievert (mSv)
MAC	maximum acceptable concentration
NSF	NSF International
pCi/	picocurie
RO	reverse osmosis
SI	International System of Units
Sv	sievert
TDS	total dissolved solids
UNEP	United Nations Environment Programme
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
US EPA	United States Environmental Protection Agency
WEF	Water Environment Federation
WHO	World Health Organization

Appendix B: Detailed analysis of international/national recommendations

The following organizations (with references in brackets) have all established radiological criteria relevant to drinking water assessment:

- International Atomic Energy Agency (IAEA) (ref: IAEA International Basic Safety Standards, GSR Part 3)
- World Health Organization (WHO) (refs: WHO, Guidelines for Drinking-water Quality, Fourth Edition, 2017; WHO, Management of Radioactivity in Drinking-Water, 2018)
- Council of the European Union (ref: Official Journal of the European Union, Council Directive 2013/51/Euratom of 22 October 2013)
- Australian National Health and Medical Research Council (ref: Australian Drinking Water Guidelines, Paper 6, 2011, Version 3.8, Updated September 2022)
- United States Environmental Protection Agency (US EPA) (ref: National Primary Drinking Water Regulations; Radionuclides; Final Rule)

While this may not be an exhaustive list, these represent organizations or countries for which information from the 21st century is readily available, and information is not duplicated (European countries that have adopted EU recommendations are not listed). The following text outlines 3 main steps in the establishment of radiological criteria and the assessment of drinking water, and compares the approaches taken by these organizations and Canada. It should be noted that, while general approaches are compared, specific values cannot be directly compared. This is because these values are defined differently across organizations (for example, values based on a projected dose may be associated with different actions, or different optimization expectations; screening levels are based on different projected dose guideline values, or fractions of those values, as well as different radionuclides, drinking water consumption rates and rounding conventions; and regulatory values are based on different projected dose values, drinking water consumption rates or rounding conventions, or may be defined completely differently (such as in the case of tritium or radon).

1. Establish a guideline value or reference level, based on projected dose.
    a. <u>IAEA</u>: The IAEA, in its Basic Safety Standards (GSR Part 3), cites the recommendations in ICRP 103, and recommends that authorities establish a reference level for drinking water that should generally not exceed 1 mSv/y.
    b. <u>WHO</u>: While the WHO generally recommends a guideline value of 0.1 mSv/y, it also acknowledges the IAEA reference level, and states that a guideline value higher than 0.1 mSv/y (but generally less than 1 mSv/y) may be appropriate in certain situations (such as where there is dependence on groundwater supplies). It should also be noted that the WHO's general recommendation of 0.1 mSv/y is based on the ICRP recommended dose constraint for the planned exposure situation of the prolonged component from long-lived nuclides, rather than the recommended band of reference levels (i.e., 1–20 mSv/y) for existing exposure situations.

c. Council of the European Union: The Council of the European Union has adopted a guideline value that is in line with the lower bound of what is recommended by the WHO (0.1 mSv/y).
d. Australian National Health and Medical Research Council: The Australian National Health and Medical Research Council has adopted a guideline value that is in line with the IAEA reference level and the upper bound of the WHO guideline value (1 mSv/y).
e. US EPA: The US EPA has not established a guideline value based on a projected dose.
f. Health Canada: Health Canada has adopted a reference level that is in line with the lower bound of what is recommended by the ICRP, and the upper bound of what is recommended by the IAEA and WHO (1 mSv/y). The chosen level is also in line with the guideline value adopted by the Australian National and Medical Research Council.
g. Notes: In choosing this level of dose, a number of factors need to be considered (technical, economic, environmental and societal).

2. Screen water samples using gross alpha and beta activity levels that are derived from the guidance level.

a. WHO: The WHO recommends screening for gross alpha and gross beta activity as an initial step towards determining whether water is fit for drinking or if further investigation is required. Their chosen alpha and beta screening concentrations are derived from the guideline dose. If values are below the screening criteria, no further action is required. If either screening level is exceeded, individual radionuclide concentrations should be measured and compared with rounded guidance levels that correspond to the established level of dose.
b. Council of the European Union: The Council of the European Union has adopted the same general screening approach as the WHO.
c. Australian National Health and Medical Research Council: The Australian National Health and Medical Research Council has adopted the same general screening approach as the WHO, with screening concentrations that are based on a fraction of the guideline dose value according to the projected dose.
d. US EPA: The US EPA has established maximum contaminant levels for beta particle and photon radioactivity, in addition to gross alpha activity. Note that these act as limits for community water systems, rather than screening levels for further investigation. This differs from the approach taken by the WHO and by other countries.
e. Health Canada: Health Canada has adopted a similar screening approach as the WHO, the EU, and Australia. Like Australia, the calculated screening

concentrations are based on a dose that is a fraction of the guideline value based on the projected dose (i.e., 0.3 mSv/y rather than 1 mSv/y).

   f. <u>Notes</u>: The values adopted for gross activity screening concentrations are influenced by the way they are calculated, including the dose and radionuclides that they are based on, the assumed consumption rate of drinking water and rounding. The factors used may differ between organizations.

3. Assess exposure more carefully using individual radionuclide concentrations
   a. <u>WHO</u>: If a screening level is exceeded, the WHO recommends measuring the individual radionuclide concentrations and comparing them to rounded guidance levels that correspond to the established dose level. It provides guidance levels for a number of suggested natural and artificial radionuclides: U-238, U-234, Th-230, Ra-226, Pb-210, Po-210, Th-232, Ra-228, Th-228, Cs-134, Cs-137, Sr-90, I-131, tritium, C-14, Pu-239 and Am-241. It notes that the list is not exhaustive, that the chemical toxicity of uranium is more significant than its radiological toxicity, and that certain radionuclides may not occur in drinking water or doses may be too low to be of public health concern. If the sum of ratios of the measured concentrations to the guidance levels is less than or equal to unity, no further action is required. If exceeded, and exposure to the same measured concentrations were to continue for a year, further evaluation is needed. Note that a decision to alter the radiation exposure situation should be justified.
   b. <u>Council of the European Union</u>: The Council of the European Union has adopted the same general approach as the WHO for measuring radionuclide concentrations and comparing results to guidance levels. Differences include its exclusion of radioisotopes of thorium from its list, and the inclusion of a value for tritium to trigger testing for additional artificial radionuclides. Additionally, they identify a concentration for radon in water for the purposes of reducing inhalation exposure.
   c. <u>Australian National Health and Medical Research Council</u>: The Australian National Health and Medical Research Council has adopted the same general approach as the WHO for measuring radionuclide concentrations and comparing results to guidance levels. They state that the list of radionuclides should always include Ra-226 and Ra-228, as well as any other radionuclides where necessary.
   d. <u>US EPA</u>: The US EPA has established a maximum contaminant level for combined Ra-226 and Ra-228. Note that this is intended as a limit for community water systems.
   e. <u>Health Canada</u>: Health Canada has adopted the same general approach as the WHO for measuring radionuclide concentrations and comparing results to guidance levels. The approach is also generally in line with that of the Council of the European Union and the Australian National Health and Medical Research Council. Health Canada's suggested list of radionuclides includes: Ra-226, Pb-210, Po-210, Ra-228, Cs-137, Sr-90, I-131, tritium and radon. Note that Health Canada's guidance level for radon was calculated using the ingestion dose

coefficient; Health Canada recommends testing radon concentrations in air to assess inhalation risk.

f. Notes: The calculated guidance levels for radionuclide concentrations are influenced by the dose they are based on, the assumed drinking water consumption rate and rounding. The factors used may differ between organizations.

Appendix C: Health-Based Values

Table 7. HBVs for less common radionuclidesNatural radionuclides	HBV (Bq/L)
Polonium-210 (Po-210)	1
Radon-222 (Rn-222)[a]	2 000

Artificial radionuclides	HBV (Bq/L)
Tritium (H-3)	100 000
Strontium-90 (Sr-90)	50
Iodine-131 (I-131)	50
Cesium (Cs-137)	100

HBV – health-based value; Bq/L – becquerels per litre

[a] See Section 1.2.3 (Radon) for information on exposure by inhalation.