Radiological Characteristics

Guidelines

The maximum acceptable concentrations (MACs) for selected radionuclides (both natural and artificial) in drinking water are presented in Table 1. They are derived from a 50-year committed effective dose of 0.1 millisievert (mSv) from one year's consumption of water and are expressed in activity concentration units of becquerels per litre (Bq/L). Recommended screening levels for radioactivity in water samples are 0.1 Bq/L for gross alpha radiation and 1 Bq/L for gross beta radiation.

The derivation of radiological guidelines conforms to international radiation protection methodologies. The approach accounts for the total lifetime exposure that will result from any radionuclide ingested in one year, based on its retention in human tissue. Guidelines for radionuclides are derived differently from those for microbiological and chemical/physical parameters in drinking water. Health Canada has established a committee to re-evaluate the approaches used in deriving microbiological, chemical/physical and radiological guidelines.

Identity, Use and Sources of Exposure in the Environment

Radionuclides are found in the environment as naturally occurring elements and as products or by-products of nuclear technologies (artificial radionuclides).

Natural Radioactivity

By far the greatest contribution to the average public radiation exposure comes from radioactive elements in the Earth's crust and from natural radio-activity originating in deep space. Natural sources contribute on average more than 98% of the human radiation dose, excluding medical exposures.[1] The global average dose from natural sources has been estimated to be about 2.4 mSv*/year[1]; this can be compared with an estimate of 2.6 mSv/year for Canada.[2]

Exposure from natural sources is both external, from direct cosmic and terrestrial radiation, and internal, from inhalation and ingestion of cosmogenic and terrestrial radionuclides found in air, water, food and soil. The major sources of radiation are the long-lived terrestrial (primordial) radionuclides and the secondary radionuclides produced by their radioactive decay. These radionuclides belong principally to three decay chains — the uranium, thorium and actinium series — and are ubiquitously present in low concentrations in soil and water as a result of weathering and erosion of rock. The most important source of internal exposure is the short-lived decay products of radon,[†] a gaseous element formed in the uranium decay series. Potassium-40, a non-series primordial radionuclide, is also a major contributor to both internal and external exposure. However, as the absorption of elemental potassium by the body is under strict homeostatic control and is therefore not influenced by variations in environmental levels, ^{40}K is not considered further in these guidelines.

Additional but minor contributions to exposure come from the remaining non-series primordial radionuclides, primarily ^{87}Rb,[‡] and the cosmogenic radionuclides produced in the atmosphere by the interaction of cosmic rays with atmospheric argon, oxygen and nitrogen.[1] Cosmogenic radionuclides are removed to the Earth by atmospheric mixing, precipitation scavenging and gravitational settling. The four cosmogenic radionuclides that contribute a measurable dose to humans are ^{14}C, ^{3}H (tritium), ^{22}Na and ^{7}Be. The total annual contribution from cosmogenic radionuclides is about 12 μSv; most of this comes from ^{14}C received internally.[1]

External radiation accounts for about one-third of the total background dose. The average annual contribution from all internally deposited natural radionuclides is on the order of 1.6 mSv, of which about 1.1 mSv results from inhaled radon decay products.[1] The

---

*Sievert (Sv) is the unit of dose. It replaces the old unit, rem (1 rem = 0.01 Sv).

[†]As the major dose to the body from radon and its decay products is through inhalation, a guideline for radon is the subject of a separate criteria summary in the Supporting Documentation.
[‡]See Table 1 for radionuclide symbols.

remainder is from ingestion of other radionuclides in food and drinking water. Actual individual exposures to background radioactivity in air, food and water are, however, highly variable and depend on numerous factors, including the amount, type and availability of the radionuclide in the environment and the amount inhaled or ingested by the individual.

Artificial Radionuclides and Technologically Enhanced Natural Radionuclides

In addition to natural background radiation, nuclear technologies over the past 50 years have introduced significant quantities of artificial radionuclides into the global environment. The majority of these radionuclides have come from atmospheric nuclear weapons tests conducted prior to 1963. Of the many elements produced during nuclear detonations, tritium, ^{14}C, ^{90}Sr and ^{137}Cs have received the greatest attention in environmental monitoring programs. Other radionuclides include ^{95}Zr, ^{95}Nb, ^{106}Ru, ^{131}I, ^{144}Ce, ^{239,240}Pu, ^{241}Pu and ^{241}Am. The total dose received by individuals in the North Temperate Zone (40 to 50°N) from all atmospheric weapons tests conducted between 1945 and 1980, accumulated to the year 2050, is estimated to be about 1.9 mSv, the majority of which has already been delivered.[1]

Increases in local exposures above natural background levels may also result from radionuclides released during the various stages of the nuclear fuel cycle, including uranium mining, nuclear fuel preparation, nuclear power generation and waste disposal. Uranium mining and fuel preparation operations release ^{238}U, ^{234}U, ^{226}Ra and ^{222}Rn and its decay products, elevating terrestrial radionuclide levels above background. Low levels of radionuclides are also released to the environment from nuclear power reactors under controlled and monitored conditions, in quantities dependent on the reactor type and design. Atmospheric releases include tritium, radioiodine, fission product noble gases (^{88}Kr, ^{133}Xe), activation gases (^{14}C, ^{16}N, ^{35}S, ^{41}Ar) and particulates such as ^{60}Co, ^{90}Sr and ^{137}Cs. Radionuclides released into the aquatic environment include tritium and other fission products and activated corrosion products.[1] Tritium in aqueous and gaseous emissions is the principal radionuclide released from Canadian CANDU reactors.

The Atomic Energy Control Board (AECB) imposes a strict design objective for releases from CANDU power reactors of 0.05 mSv/year to the critical group — i.e., that group of individuals that, by virtue of their location and lifestyle, will receive the highest dose. The design objective is 5% of the public dose limit and applies to both the external exposure received during the year and the internal exposure that will be received over the subsequent 50 years from radionuclides ingested

during the year. Doses to the rest of the population will be lower. In general, radionuclide emissions from the nuclear fuel cycle result in minor contributions to the total radiation exposure of humans and are well below the contributions from natural background radiation and atmospheric weapons fallout.

Artificial radionuclides may also be released into the environment from non-nuclear fuel cycle activities in industry and research and from usage in diagnostic and therapeutic medicine. Canadian facilities using radionuclides are licensed by the AECB, and their emissions of radionuclides into the environment are usually insignificant.

Other incidental radionuclide sources include non-nuclear technologies and industrial activities that enhance environmental levels of natural radionuclides, such as fossil fuel combustion and the production and use of phosphate rock products. The combustion of fossil fuels (e.g., coal) for electric power generation releases ^{238}U and ^{232}Th decay series radionuclides and ^{40}K in fly ash. However, normal environmental levels of uranium and thorium are sufficiently high that changes due to emissions from coal-fired power plants are barely detectable.[3] The mining of phosphate rock, which contains relatively high concentrations of uranium, may release radionuclides in mining and processing effluent, as may the use of phosphate rock products (e.g., fertilizer). Erosion of agricultural soils, for example, may input the ^{238}U decay radionuclides into drinking water supplies in areas with heavy fertilizer usage.

Radionuclide Levels in Drinking Water Supplies

The radiological impact of a particular radionuclide released into an ecosystem is a function of its availability, its radiological properties and its behaviour in the environment. The environmental availability and behaviour of radionuclides are dependent on complex interactions between physical, chemical and biological parameters, particularly in aquatic environments.

Many radionuclides released into the aquatic environment are readily adsorbed onto the surfaces of suspended particulates as a result of their low water solubilities and are removed from the water column by sedimentation. Examples of such radionuclides are the isotopes of cesium, manganese, iron, cobalt and the actinides (including thorium and uranium). Elements that tend to remain in solution in water include strontium, chromium and antimony. The level of radioactivity in natural waters is therefore usually low, although contaminated sediments can serve as a source of radionuclides long after the dissolved radionuclides have been removed from the system. In general, surface waters will have lower radionuclide concentrations than

groundwater, in which large variations in concentration are possible as a result of natural radionuclides in surrounding soil and rock.

Typically, the contribution to total radiation exposure from drinking water is small and due largely to the naturally occurring radionuclides in the uranium decay series. Uranium is one of the most important natural radionuclides that may be found in water supplies. In general, levels of uranium in both surface water and groundwater are low, typically less than 1 µg/L; however, substantially higher concentrations have been measured in both private and community groundwater sources across Canada. Uranium concentrations in some community supplies in southern Saskatchewan ranged from 1 to 16 µg/L between 1980 and 1990; a concentration of 90 µg/L was measured at a community supply in southern Ontario in 1991; several private wells in Nova Scotia had uranium concentrations ranging from 100 to 200 µg/L in 1992, with one well reporting a concentration as high as 780 µg/L.[4] As a result of their long half-lives, the specific activities of the natural uranium isotopes are low. In terms of Canadian drinking water guidelines, concentrations of uranium in drinking water are therefore limited by chemical, rather than radiological, toxicity.**

The radionuclides of greatest concern from a health perspective in terms of the potential for normal or accidental release from nuclear fuel cycle industries into drinking water supplies are tritium, ^{90}Sr, ^{131}I, ^{137}Cs and ^{226}Ra. Average tritium concentrations in surface waters across Canada are on the order of 5 to 10 Bq[††]/L,[5] owing primarily to residual fallout from atmospheric weapons tests. Average levels in the Great Lakes ranged from 9 to 11 Bq/L during 1991 to 1993.[6] An average concentration of about 6 Bq/L was recorded at locations throughout Ontario in 1990.[7] Activity concentrations in community water supplies near all Ontario nuclear reactors ranged from 12 to 35 Bq/L, slightly higher than background levels.[7]

Mean activities of ^{90}Sr in the Great Lakes during 1981 to 1982 ranged from 15 mBq/L in Lake Superior to 29 mBq/L in Lake Ontario.[8] Average concentrations recorded in the Winnipeg, Ottawa and St. Lawrence rivers and in Lakes Huron and Ontario near the Bruce and Pickering generating stations ranged from 1 to 12 mBq/L in 1988.[9] These values are indistinguishable from background values due to nuclear weapons fallout.

** A drinking water guideline for uranium is discussed in a separate criteria summary on uranium in the Supporting Documentation.
†† Becquerel (Bq) is the unit of activity of a radioactive substance, or the rate at which transformations occur in the substance. One becquerel is equal to one transformation per second and is approximately equivalent to 27 picocuries (pCi).

Iodine-131 is important in terms of its mobility in the environment and its selective irradiation of the thyroid gland when taken into the body. As a result of its short half-life (eight days), ^{131}I is of concern only immediately following a significant release from a reactor.

Cesium-137 is strongly affixed to sediments in aquatic environments, which reduces its concentration in the water column. Concentrations of ^{137}Cs measured in surface waters of the Great Lakes averaged about 0.5 mBq/L in 1992.[4] No enhancement in concentration was observed in the vicinity of nuclear reactor installations.

The contribution of drinking water to total ^{226}Ra intake is small when supplies are drawn from surface waters, which typically display a narrow range of concentrations. Concentrations in groundwater sources, however, are highly variable and result mainly from the interaction between the groundwater aquifer and radium-bearing materials, such as rock, soil and ore deposits. Radium-226 concentrations in water samples measured at various sites across Canada between 1981 and 1984 ranged from about 1 to 13 mBq/L.[5] Radium levels in water samples from Port Hope (Ontario) and Regina (Saskatchewan) averaged less than 5 mBq/L in 1988. Levels recorded during the same period in Elliot Lake (Ontario) ranged from 8 to 18 mBq/L.[9] In general, higher levels of ^{226}Ra can be expected in areas containing uranium mining and milling operations or where rock containing high concentrations of the natural radionuclides is in contact with the water.

Analytical Techniques and Treatment Technologies

Water samples may be initially analysed for the presence of radioactivity using techniques for gross alpha and gross beta determinations. Although facilitating routine examination of large numbers of samples, these procedures preclude confirmation of the identities of the contributing radionuclides. They are, therefore, suitable only as a preliminary screening procedure. Recommended screening values for gross alpha and gross beta activity have been set at 0.1 Bq/L and 1 Bq/L, respectively. Radionuclides emitting low-energy beta activity, such as tritium and ^{14}C, and some gaseous or volatile radionuclides, such as iodine, will not be detected by standard gross activity measurements. If their presence is suspected, radionuclide-specific sampling and measurement techniques should be used.[10]

In the event that the limits for gross alpha and gross beta activity are exceeded, individual radionuclide concentrations must be determined. Specific radionuclides can be identified and measured using liquid scintillation or alpha, beta and gamma radiation

spectroscopy, following appropriate separation chemistry, as required. The detection limits of a sample are dependent on the activity in the sample and the counting time. General compendium sources of analytical methods for radionuclides are available, in addition to specific methods in the technical literature, such as Health and Environmental Chemistry,[11] HASL-300,[12] Official Methods of Analysis,[13] Radiochemistry Procedures Manual[14] and CANMET Report 78-22.[15]

Radionuclides that can be effectively removed from water supplies using conventional treatment technologies such as lime softening include ^{131}I, ^{226}Ra, ^{90}Sr and uranium. Special treatment technologies that have been found to be effective in removing ^{137}Cs, ^{131}I, ^{226}Ra and ^{90}Sr include reverse osmosis, anion and cation exchange and electrodialysis. Conventional methods have limited effectiveness in removing tritium, and little information is available to assess the effectiveness of special treatment processes. It should be noted that treatment may cause a low-level radioactive waste disposal problem. The decision to tolerate, relocate or treat the water source depends on many local factors, including the extent and duration of contamination, the population size affected and the proximity of alternative sources.

Health Effects

Behaviour in the Body

The persistence of a radionuclide in the body, and therefore the resulting dose, is a function of its radiological and biological half-lives. For example, if the biological half-life is shorter than the radiological half-life, the radionuclide will be cleared from the body before it undergoes significant decay. Taking these parameters into consideration, the National Radiological Protection Board[16] has derived factors to convert a unit intake of a specific radionuclide into a dose.

Radionuclides that are in soluble form and chemically analogous to essential nutrient elements will tend to follow pathways in a fashion similar to their nutrient analogues. For example, $^{89,90}Sr$, ^{140}Ba, ^{226}Ra and ^{45}Ca behave like calcium and are bone-seeking elements; ^{137}Cs, ^{86}Rb and ^{40}K follow the general movement of potassium and will be found throughout the body; ^{129}I and ^{131}I behave like stable iodine and accumulate in the thyroid; and tritium resembles hydrogen and, as tritiated water, will be distributed throughout the body. Elements that demonstrate unique behaviour include ^{144}Ce, ^{106}Ru, ^{95}Zr, ^{85}Kr and ^{239}Pu. Detailed descriptions of the behaviour and dosimetry of important radionuclides can be found in United Nations[1] and World Health Organization[17] publications.

The Biological Effects of Ionizing Radiation

Exposure to ionizing radiation, whether natural or artificial, can cause two kinds of health effects as a result of changes to the atoms and molecules of body tissues. Effects for which the severity of the tissue damage caused is proportional to the dose, and for which a threshold dose exists below which they do not occur, are called *deterministic effects*. Although the severity of deterministic effects (e.g., damage to the nervous system, gastrointestinal tract, lung or bone marrow) varies primarily with dose, it is also dependent upon other factors, including the type, energy and dose rate of the radiation and the sensitivity of the irradiated organ. Under normal conditions, doses received from natural radioactivity and routine exposures from regulated practices are well below the threshold levels, and therefore deterministic effects are not relevant to these guidelines.

Effects for which the probability of occurrence, rather than the severity of the damage, is proportional to dose for doses well below the thresholds for deterministic effects are known as *stochastic effects*, and it is assumed that there is no threshold below which they do not occur. The main stochastic effect of concern from low-level radiation exposure is the induction of leukaemias and other cancers (e.g, in the bone, thyroid, lung or breast) following a variable latent period of up to several decades. Such late effects arise from imperfect DNA repair in somatic cells damaged by radiation. There is also a small probability associated with hereditary effects (i.e., the radiation damage occurs in germinal cells responsible for transmitting genetic information to the descendants of the exposed individual). Stochastic effects, particularly late somatic effects, are the most important consequence of exposure to environmental levels of radiation.

Stochastic effects are random in nature, in that it is impossible to identify a causal relationship for them in any given case. The correlation between dose and cancer induction may be shown on large populations of irradiated individuals only as an increase of cancers over the background incidence. Although the risk of cancer is assumed to be broadly proportional to dose, other biological factors affecting risk include age and health at the time of exposure, sex, sensitivity and confounding factors, such as interactions with other chemical agents.

The main sources of epidemiological information on radiation risks and effects have been studies of individuals or groups who have received high or intermediate exposures, the most important of which are the survivors of the atomic bombings at Hiroshima and Nagasaki, patients who received high doses for medical or therapeutic reasons and occupationally exposed workers, including uranium mine workers, radium dial painters and the early radiologists. The dose–response

relationship in humans at low levels of exposure is extrapolated from these results using a linear, no-threshold model. The assumption of linearity is simple, and there is considerable evidence that it is a conservative assumption. The absence of a threshold dose has important implications in risk assessment, in that it postulates that there is no dose, however small, that may in principle be considered absolutely safe. Another consequence that arises from the model is that even when the risk to an individual is small, a finite number of cancers, theoretically attributable to the exposure, can be predicted if a sufficiently large population is exposed.

Radiological Guidelines for Drinking Water

The International Commission on Radiological Protection (ICRP) recommends a limit on effective and committed effective dose[‡] of 1 mSv for any combination of external and internal doses, respectively, received or committed in one year, excluding natural background radiation and medical or therapeutic exposures. The excess lifetime risk of fatal cancer, all non-fatal cancers weighted for severity and ease of curing and hereditary effects from a single exposure to 1 mSv has been estimated to be 7.3×10^{-5}.[18] At a rate of exposure of 1 mSv/year over a lifetime (70 years), the total risk for all fatal cancers, weighted non-fatal cancers and hereditary defects is about 6×10^{-3}.[19]

In setting dose guidelines for radionuclides in drinking water, it is recognized that water consumption contributes only a portion of the total radiation dose and that some radionuclides present are natural in origin and therefore cannot be excluded. Consequently, maximum acceptable concentrations (MACs) for radionuclides in drinking water have been derived based on a committed effective dose of 0.1 mSv from one year's consumption of drinking water, or one-tenth of the ICRP's recommendation on public exposure. This dose represents less than 5% of the average annual dose attributable to natural background radiation (i.e., 2.6 mSv).

The guideline reference dose is based on the total activity in a water sample, whether the radionuclides appear singly or in combination, and includes the dose due to natural radionuclides, in contrast to the ICRP guideline. The risk of fatal and weighted non-fatal conditions at a lifetime exposure of 0.1 mSv/year is between 10^{-5} and 10^{-6} per year, or about 6×10^{-4} over a

lifetime. The guideline dose limit is based solely on health considerations and has not been adjusted to incorporate any limitations in the sampling and treatment capability of water supplies.

To facilitate the monitoring of radionuclides in water, the reference level of dose is expressed as an activity concentration, which can be derived for each radionuclide from published radiological data. The NRPB[16] has calculated dose conversion factors (DCFs) for radionuclides based on metabolic and dosimetric models for adults and children. Each DCF provides an estimate of the 50- or 70-year committed effective dose resulting from a single intake of 1 Bq of a given radionuclide.

The MACs of radionuclides in public water supplies are derived from adult DCFs, assuming a daily water intake of 2 L, or 730 L/year,[20] and a maximum committed effective dose of 0.1 mSv, or 10% of the ICRP limit on public exposure:

$$\text{MAC (Bq/L)} = \frac{1 \times 10^{-4} \text{ (Sv/year)}}{730 \text{ (L/year)} \times \text{DCF (Sv/Bq)}}$$

Adult consumption of drinking water containing a single radionuclide at its MAC for one year would result in a committed effective dose of 0.1 mSv.

Based on a survey of drinking water consumption in Canada,[20] 82% of adults, 88% of school children and 98% of preschoolers consume less than 2 L of water per day. In the case of certain radionuclides, DCFs are higher for children than for adults, which would result in a lower MAC; however, this is balanced by lower water consumption rates for children.

Maximum acceptable concentrations of several radionuclides that have half-lives longer than one day and that could possibly enter public water supplies from natural sources or human activities are provided in Table 1. This list, however, does not preclude the presence of other radionuclides in water supplies.

Where two or more radionuclides that affect the same organ or tissue are found to be present in drinking water, the following relationship should be satisfied:

$$\frac{c_1}{\text{MAC}_1} + \frac{c_2}{\text{MAC}_2} + \quad ... \quad \frac{c_i}{\text{MAC}_i} \leq 1$$

where c_i and MAC_i are the observed and maximum acceptable concentrations, respectively, for each contributing radionuclide.

Application of the Guidelines

The levels of radionuclides normally encountered in drinking water are far below the threshold for acute effects of radiation. In virtually every case, the limitation is governed by the chronic or cumulative exposure over a period of one year. The sampling and analyses for individual radionuclides should be carried out often

---

[‡]Effective dose is the quantity obtained by multiplying the absorbed doses (the energy imparted by ionizing radiation to tissue) to various tissues and organs by radiation weighting factors (to allow for the different effectiveness of the various ionizing radiations in causing harm to tissue) and by tissue weighting factors appropriate to each tissue or organ (to account for their various susceptibilities to cancer induction) and summing the products. The committed effective dose is the effective dose that will be accumulated over a period of time following a single intake of radioactive material into the body.

Table 1
Maximum Acceptable Concentrations (MACs) of Radionuclides in Drinking Water

Radionuclide		Half-life ($t_{1/2}$)	DCF (Sv/Bq)	MAC (Bq/L)
Natural Radionuclides				
Beryllium-7	^{7}Be	53.3 days	3.3×10^{-11}	4000
Bismuth-210	^{210}Bi	5.01 days	2.1×10^{-9}	70
Lead-210	^{210}Pb	22.3 years	1.3×10^{-6}	0.1
Polonium-210	^{210}Po	138.4 days	6.2×10^{-7}	0.2
Radium-224	^{224}Ra	3.66 days	8.0×10^{-8}	2
Radium-226	^{226}Ra	1600 years	2.2×10^{-7}	0.6
Radium-228	^{228}Ra	5.76 years	2.7×10^{-7}	0.5
Thorium-228	^{228}Th	1.91 years	6.7×10^{-8}	2
Thorium-230	^{230}Th	7.54×10^{4} years	3.5×10^{-7}	0.4
Thorium-232	^{232}Th	1.40×10^{10} years	1.8×10^{-6}	0.1
Thorium-234	^{234}Th	24.1 days	5.7×10^{-9}	20
Uranium-234	^{234}U	2.45×10^{5} years	3.9×10^{-8}	4*
Uranium-235	^{235}U	7.04×10^{8} years	3.8×10^{-8}	4*
Uranium-238	^{238}U	4.47×10^{9} years	3.6×10^{-8}	4*
*Artificial Radionuclides***				
Americium-241	^{241}Am	432 years	5.7×10^{-7}	0.2
Antimony-122	^{122}Sb	2.71 days	2.8×10^{-9}	50
Antimony-124	^{124}Sb	60.2 days	3.6×10^{-9}	40
Antimony-125	^{125}Sb	2.76 years	9.8×10^{-10}	100
Barium-140	^{140}Ba	12.8 days	3.7×10^{-9}	40
Bromine-82	^{82}Br	35.3 hours	4.8×10^{-10}	300
Calcium-45	^{45}Ca	165 days	8.9×10^{-10}	200
Calcium-47	^{47}Ca	4.54 days	2.2×10^{-9}	60
Carbon-14	^{14}C	5730 years	5.6×10^{-10}	200
Cerium-141	^{141}Ce	32.5 days	1.2×10^{-9}	100
Cerium-144	^{144}Ce	284.4 days	8.8×10^{-9}	20
Cesium-131	^{131}Cs	9.69 days	6.6×10^{-11}	2000
Cesium-134	^{134}Cs	2.07 years	1.9×10^{-8}	7
Cesium-136	^{136}Cs	13.1 days	3.0×10^{-9}	50
Cesium-137	^{137}Cs	30.2 years	1.3×10^{-8}	10
Chromium-51	^{51}Cr	27.7 days	5.3×10^{-11}	3000
Cobalt-57	^{57}Co	271.8 days	3.5×10^{-9}	40
Cobalt-58	^{58}Co	70.9 days	6.8×10^{-9}	20
Cobalt-60	^{60}Co	5.27 years	9.2×10^{-8}	2
Gallium-67	^{67}Ga	78.3 hours	2.6×10^{-10}	500
Gold-198	198Au	2.69 days	1.6×10^{-9}	90
Indium-111	^{111}In	2.81 days	3.9×10^{-10}	400
Iodine-125	125I	59.9 days	1.5×10^{-8}	10

* The activity concentration of natural uranium corresponding to the chemical guideline of 0.1 mg/L (see separate criteria summary on uranium in the Supporting Documentation) is about 2.6 Bq/L.

** Tritium and ^{14}C are also produced naturally in the atmosphere in significant quantities.

Table 1 (cont'd)

Radionuclide		Half-life ($t_{1/2}$)	DCF (Sv/Bq)	MAC (Bq/L)
Iodine-129	^{129}I	1.60×10^7 years	1.1×10^{-7}	1
Iodine-131	^{131}I	8.04 days	2.2×10^{-8}	6
Iron-55	^{55}Fe	2.68 years	4.0×10^{-10}	300
Iron-59	^{59}Fe	44.5 days	3.1×10^{-9}	40
Manganese-54	^{54}Mn	312.2 days	7.3×10^{-10}	200
Mercury-197	^{197}Hg	64.1 hours	3.3×10^{-10}	400
Mercury-203	^{203}Hg	46.6 days	1.8×10^{-9}	80
Molybdenum-99	^{99}Mo	65.9 hours	1.9×10^{-9}	70
Neptunium-239	^{239}Np	2.35 days	1.2×10^{-9}	100
Niobium-95	^{95}Nb	35.0 days	7.7×10^{-10}	200
Phosphorus-32	^{32}P	14.3 days	2.6×10^{-9}	50
Plutonium-238	^{238}Pu	87.7 years	5.1×10^{-7}	0.3
Plutonium-239	^{239}Pu	2.41×10^4 years	5.6×10^{-7}	0.2
Plutonium-240	^{240}Pu	6560 years	5.6×10^{-7}	0.2
Plutonium-241	^{241}Pu	14.4 years	1.1×10^{-8}	10
Rhodium-105	^{105}Rh	35.4 hours	5.4×10^{-10}	300
Rubidium-81	^{81}Rb	4.58 hours	5.3×10^{-11}	3000
Rubidium-86	^{86}Rb	18.6 days	2.5×10^{-9}	50
Ruthenium-103	^{103}Ru	39.2 days	1.1×10^{-9}	100
Ruthenium-106	^{106}Ru	372.6 days	1.1×10^{-8}	10
Selenium-75	^{75}Se	119.8 days	2.1×10^{-9}	70
Silver-108m	^{108m}Ag	127 years	2.1×10^{-9}	70
Silver-110m	^{110m}Ag	249.8 days	3.0×10^{-9}	50
Silver-111	^{111}Ag	7.47 days	2.0×10^{-9}	70
Sodium-22	^{22}Na	2.61 years	3.0×10^{-9}	50
Strontium-85	^{85}Sr	64.8 days	5.3×10^{-10}	300
Strontium-89	^{89}Sr	50.5 days	3.8×10^{-9}	40
Strontium-90	^{90}Sr	29 years	2.8×10^{-8}	5
Sulphur-35	^{35}S	87.2 days	3.0×10^{-10}	500
Technetium-99	^{99}Tc	2.13×10^5 years	6.7×10^{-10}	200
Technetium-99m	^{99m}Tc	6.01 hours	2.1×10^{-11}	7000
Tellurium-129m	^{129m}Te	33.4 days	3.9×10^{-9}	40
Tellurium-131m	^{131m}Te	32.4 hours	3.4×10^{-9}	40
Tellurium-132	^{132}Te	78.2 hours	3.5×10^{-9}	40
Thallium-201	^{201}Tl	3.04 days	7.4×10^{-11}	2000
Tritium	^{3}H	12.3 years	1.8×10^{-11}	7000
Ytterbium-169	^{169}Yb	32.0 days	1.1×10^{-9}	100
Yttrium-90	^{90}Y	64 hours	4.2×10^{-9}	30
Yttrium-91	^{91}Y	58.5 days	4.0×10^{-9}	30
Zinc-65	^{65}Zn	243.8 days	3.8×10^{-9}	40
Zirconium-95	^{95}Zr	64.0 days	1.3×10^{-9}	100

enough to accurately characterize the annual exposure. If the source of the activity is known, or expected, to be changing rapidly with time, then the sampling frequency should reflect this factor. If there is no reason to suppose that the source varies with time, then sampling may be carried out seasonally, semi-annually or annually. If measured concentrations are consistent and well below the reference levels, this would be an argument for reducing the sampling frequency. On the other hand, the sampling frequency should be maintained, or even increased, if concentrations are approaching the reference levels.

Water samples may be initially screened for radio-activity using techniques for gross alpha and gross beta activity determinations, subject to the limitations of the method. Compliance with the guidelines may be inferred if the measurements for gross alpha and gross beta activity are less than 0.1 Bq/L and 1 Bq/L, respectively, as these are lower than the strictest MACs (^{210}Pb for alpha activity; ^{90}Sr for beta activity). If either screening level is exceeded, then the specific radio-nuclides should be identified and individual activity concentrations measured. When the additive formula is satisfied, no further action is required, and the water is acceptable for human consumption based on radio-logical considerations (although analyses for chemical or biological contamination may still be necessary). Where the sum exceeds unity for a single sample, the reference dose level would be exceeded only if exposure to the same measured concentration were continued for a full year. Hence, such a sample does not in itself imply that the water is unsuitable for consumption and should be regarded only as a level at which further investigation, including additional sampling, is needed.[10]

Treatment of water supplies for radionuclides should be governed by the principle of keeping exposures as low as reasonably achievable, social and economic considerations being taken into account, and should be considered only in the event that alternative water supplies are unavailable. Releases of radio-nuclides to the environment are most effectively limited through regulatory control of the source if they originate from human practices, the exception being the globally dispersed radionuclides (e.g., ^{137}Cs and ^{90}Sr) from nuclear weapons tests and accidents. It is through the regulatory mechanism that remedial action should be taken in the event that these sources result in radio-nuclide levels that exceed the guidelines for extended periods of time. These guidelines apply to the total exposure from drinking water supplies and are not intended to replace regulatory limits governing releases of radionuclides from human practices. Any facility contributing radionuclides to a drinking water source must meet the regulatory requirements as established by the AECB.

These recommendations apply to routine operational conditions of existing or new water supplies. They do not apply in the event of contamination during an emergency involving the release of radionuclides into the environment.

References

1. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Sources and effects of ionizing radiation. United Nations, New York, NY (1993).

2. National Council on Radiation Protection and Measurements (NCRP). Exposure of the population in the United States and Canada from natural background radiation. NCRP Report No. 94, Bethesda, MD (1987).

3. Eisenbud, M. Environmental radioactivity. 3rd edition. Academic Press, Orlando, FL (1987).

4. Department of National Health and Welfare. Radiological monitoring programs. Radiation Protection Bureau, Environmental Health Directorate, Ottawa (1959-1993).

5. Baweja, A.S., Joshi, S.R. and Demayo, A. Radionuclide content of some Canadian surface waters: a report on the National Radionuclides Monitoring Program, 1981–1984. Water Quality Branch, Environment Canada, Ottawa (1987).

6. Chant, L.A., Workman, W.J.G., King, K.J. and Cornett, R.J. Tritium concentrations in Lake Ontario. AECL Research Report No. RC-1149, COG-93-484, Atomic Energy of Canada Limited, Chalk River, Ontario (1993).

7. Ontario Hydro. Annual summary and assessment of environmental radiological data for 1990. HSD-HP-91-20, Health and Safety Division, Toronto, Ontario (1991).

8. International Joint Commission (IJC). 1983 report on Great Lakes water quality, appendix on radioactivity. Great Lakes Water Quality Board, Windsor, Ontario (1983).

9. Department of National Health and Welfare. Environmental radioactivity in Canada (ERIC) 1988. Radiological monitoring annual report. Radiation Protection Bureau, Environmental Health Directorate, Ottawa (1991).

10. World Health Organization (WHO). Guidelines for drinking-water quality. Vol. I. Recommendations. 2nd edition. Geneva (1993).

11. Los Alamos National Laboratory (LANL). Health and environmental chemistry: analytical techniques, data management, and quality assurance. Vol. II. M.A. Gautier and E.S. Gladney (eds.). LA-10300-M, Los Alamos, NM (1992).

12. Environmental Measurements Laboratory (EML). EML procedures manual. HASL-300, U.S. Department of Energy, New York, NY (1990).

13. Association of Official Analytical Chemists (AOAC). Official methods of analysis of the Association of Official Analytical Chemists. 15th edition. Washington, DC (1990).

14. U.S. Environmental Protection Agency (EPA). Radiochemistry procedures manual. EPA 520/5-84-006, Eastern Environmental Radiation Facility, Montgomery, AL (1987).

15. Department of Energy, Mines and Resources (EMR). Radiochemical procedures for determination of selected members of the uranium and thorium series. G.L. Smithson (ed.). CANMET Report No. 78-22, Canada Centre for Mineral and Energy Technology, Ottawa (1979).

16.   National Radiological Protection Board (NRPB). Committed equivalent organ doses and committed effective doses from intakes of radionuclides. NRPB R-245, HMSO, Chilton, London, UK (1991).

17.   World Health Organization (WHO). Selected radionuclides. Environmental Health Criteria 25. Geneva (1983).

18.   International Commission on Radiological Protection (ICRP). 1990 recommendations of the International Commission on Radiological Protection. ICRP Publication 60, Annals of the ICRP 21, No. 1-3. Pergamon Press, Oxford, UK (1991).

19.   Clarke, R.H. 1990 recommendations of the ICRP. Radiological Protection Bulletin 119 (Supplement). National Radiological Protection Board, Chilton, UK (1991).

20.   Department of National Health and Welfare. Tapwater consumption in Canada. Environmental Health Directorate, Ottawa (1981).