

Chapter 11: Radiological compliance

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11.1 Introduction

This chapter provides information on the sources and occurrence of the radiological determinands covered by the *Drinking-water Standards for New Zealand 2005, reviewed 2008* (DWSNZ, Ministry of Health), and discusses the current and potential risks of contamination of water supplies.

It explains the methods used to derive the Maximum Acceptable Values (MAVs) for determinands of health significance and provides information on how to apply the DWSNZ to these determinands.

The MAV of a determinand is the maximum concentration of that determinand, which does not result in any significant risk to the health of a 70 kg consumer over a lifetime of consumption of two litres of the water a day.

DWI (2008a) provides a tool for the water supply industry to evaluate the following in the event of a radiological incidence:

- a) the effectiveness of drinking water treatment processes in removing radionuclides
- b) the radiation exposure to operatives working within drinking water treatment works for both routine and infrequent tasks
- c) the prediction of where radionuclides may concentrate within drinking water treatment works and the impact of this on concentrations of radionuclides in waste products.

WQRA (2012) summarised a paper where the authors searched the databases PubMed and Scopus to identify all epidemiological studies dealing with potential health effects of naturally occurring radionuclides in drinking water reported for 1970–2009. Only relevant articles published in English in peer reviewed journals were kept. There were 27 peer-reviewed published reports identified of original epidemiological studies, including studies of uranium, radium and radon. Although there were cases where there appeared to be a relationship between the incidence of cancer and the concentration of radionuclides in the drinking water, the authors concluded that 'the available studies do not clearly demonstrate the health effects of radionuclides at levels naturally occurring in drinking water'. Most of the reviewed studies are affected by methodological limitations which should be remedied in future studies.

Section 6.9 of DWI (2017) covers standards and monitoring requirements in the UK for indicative dose, radon and tritium.

11.2 Radiological determinands

11.2.1 Overview and occurrence of radiochemicals

Radioactivity in drinking-water is principally derived from two sources:

- the leaching of radionuclides from rocks and soils into water
- the deposition of radionuclides from the atmosphere.

Naturally occurring radionuclides from both these sources account for almost the entire radioactivity present in New Zealand drinking-waters. Health Canada (2009) states that excluding medical exposure, natural sources of radiation are responsible for the large majority of radiation exposure (greater than 98%). Traces of artificial radioactive fallout from above ground nuclear weapons tests (conducted up to 1980) are, or were, detectable in the environment but their contribution to drinking-water radioactivity is negligible. For example, levels of strontium-90 and caesium-137 in the environment have decreased substantially since atmospheric testing of nuclear weapons ceased, and these radionuclides are no longer detectable in drinking-water.

Cosmogenic radionuclides, which are produced naturally by continuous cosmic ray bombardment of gases in the Earth's atmosphere, provide a small additional exposure to radiation. These radionuclides are removed to the Earth and enter surface drinking water supplies by the same processes as for nuclear weapons fallout. The important cosmogenic radionuclides, ^{14}C , tritium, ^{22}Na , and ^7Be , together contribute a total dose to humans of about 15 $\mu\text{Sv}/\text{year}$.

The naturally occurring radionuclides originate in the Earth's crust where uranium, thorium and potassium are widely distributed and detectable in all soils and rocks.

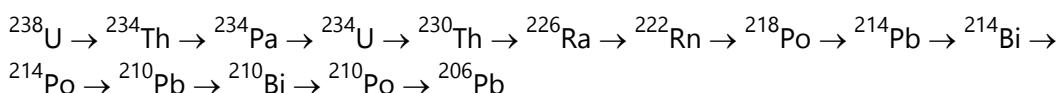
Uranium and thorium are radioactive, and each decays through a series of radionuclides to stable isotopes of lead, as shown in the decay schemes below.

Uranium is a radioactive heavy metal which occurs commonly in small amounts in all rock, soil and other natural materials. Naturally occurring uranium consists of a mixture of three radioactive isotopes, ^{234}U (0.006 percent), ^{235}U (0.72 percent) and ^{238}U (99.27 percent), which have half-lives of 2.4×10^5 , 7.0×10^8 and 4.5×10^9 years, respectively. Natural uranium decays mainly through emission of α -particles. The very long half-life of ^{238}U , the most abundant isotope, results in a very low decay rate per unit mass of uranium. Because of the high percentage of ^{238}U and its slow decay rate, naturally occurring uranium is, in fact, one of the least radioactive of the unstable isotopes. Uranium ore deposits are typically found in sandstone formations.

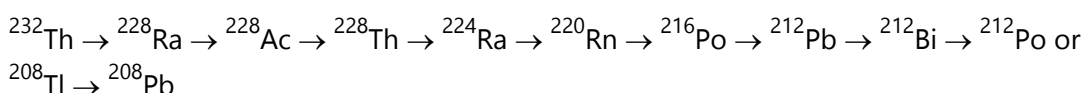
Thorium ores and purified thorium materials contain ^{232}Th , ^{228}Th and varying amounts of their radioactive decay products. ^{232}Th is an α -particle emitter with a half-life of 1.4×10^{10} years; ^{228}Ra (half-life, 5.75 years), ^{224}Ra (half-life, 3.62 days) and ^{220}Rn (thoron, an isotope of radon) (half-life, 55.6 seconds) are among its decay products (Stehney et al 1980). ^{228}Th is an α -particle emitter with a half-life of 1.9 years.

Recent studies (Seiler and Wiemels 2012) have shown that polonium (^{210}Po) can occur in some groundwaters. It is one of the most toxic substances known because of its intense radioactivity, with 1 μg having the activity of 1.66×10^8 Bq. ^{210}Po has a relatively short half-life of 138.4 days and decays to lead (^{206}Pb) by emitting an alpha particle. It is the last unstable isotope in the ^{238}U series. ^{210}Po in groundwater is usually <0.03 Bq/L because it is strongly adsorbed to aquifer materials.

Uranium series



Thorium series



where the symbols represent elements as follows:

Ac, actinium; Bi, bismuth; Pa, protactinium; Pb, lead; Po, polonium; Ra, radium; Rn, radon; Th, thorium; Tl, thallium; U, uranium.

The radionuclides in these decay series display a great range of radioactive half-lives from approximately 10^{10} years for ^{232}Th to 0.0001 seconds for ^{214}Po . Every radionuclide emits either alpha or beta radiation but their radiological significance varies. The solubility of thorium, for example, is so low, that it is only found in water as a component of suspended mineral particles. The natural radionuclides primarily regarded as being of radiological interest in drinking water appear in Table 11.1.

Table 11.1: The natural radionuclides that may be found in drinking-water

Radionuclide	Radiation	Half-life
uranium – 238	alpha	4.5×10^9 y
uranium – 234	alpha	2.5×10^5 y
radium – 226	alpha	1600 y
radium – 228	beta	6.7 y
radon – 222	alpha*	3.8 d

* Radon decay products emit both alpha and beta radiation.

Note that potassium-40 has a half-life of 1.3 billion years.

Only a very small percentage (0.0118 percent) of all potassium is the radioactive isotope potassium-40 (^{40}K). The gross beta measurement includes a contribution from potassium-40, a beta emitter that occurs naturally in a fixed ratio to stable potassium. Potassium is an essential metabolic element for humans and is absorbed mainly from ingested food. Potassium-40 does not accumulate in the body but is maintained at a constant level independent of intake. The contribution of potassium-40 to beta activity should therefore be subtracted following a separate determination of total potassium. The specific activity of potassium-40 is 30.7 Bq/g of potassium. However, not all the

radiation from potassium-40 appears as beta activity. The beta activity of potassium-40 is 27.6 Bq/g of stable potassium (ie, 0.0276 Bq/L per mg of total potassium), which is the factor that should be used to calculate the beta activity due to potassium-40 (WHO 2004).

An example calculation follows:

A bore water sample was found to contain 0.252 Bq/L beta activity. On the face of it, this bore water would become a P2 determinand, being >50 percent of the MAV. But the potassium content was 0.98 mg/L K. Therefore the potassium-40 component was $0.98 \times 0.0276 = 0.027$ Bq/L, so the activity that is relevant for DWSNZ compliance purposes is $0.252 - 0.027 = 0.225$ Bq/L, which is less than half the MAV of 0.5 Bq/L, so will not become a P2 determinand.

Note that 18.1 mg/L K will contribute 0.50 Bq/L. There will be just a few bore waters in New Zealand with that much potassium. Bores with 18.2 mg/L K would **appear** to exceed the MAV unless the 'correction' has been made.

The only radionuclides that are actively absorbed in the thyroid gland are the radioiodines. The euthyroid thyroid gland absorbs 20–30 percent of ingested ^{131}I , but a patient with hyperthyroidism could absorb as much as 60 percent, and none might be absorbed after administration of stable iodine. ^{131}I is essentially a β -particle emitter, contributing 85 percent of the absorbed tissue dose, while the contribution of γ -radiation is 15 percent. This fact is used in medical practice, where radioiodines have been administered for the last 50 years in the treatment of hyperthyroidism and thyroid cancer. Radioiodines not only locally irradiate the thyroid gland but are also incorporated into thyroid hormones, thus influencing other organs of the body. At present, there is no direct evidence that medical use of ^{131}I induces thyroid cancers in humans, regardless of the reason for exposure.

Only water supplies from groundwater sources are likely to contain significant concentrations of radionuclides, and the concentrations are as variable as the nature of the soils and rocks themselves.

While groundwaters may contain natural uranium and thorium series radionuclides, surface waters may contain radioactive material deposited from the atmosphere, including both natural radionuclides and materials from artificial sources such as nuclear weapons tests and satellite debris. Although the present levels of contamination from these sources are negligible the DWSNZ apply to radioactivity from all sources, artificial and natural.

Because all radionuclides of interest emit alpha or beta radiation, their levels in drinking-water may be assessed by measurement of the total alpha and beta activities. Such total-activity measurements can be performed rapidly and cost-effectively, and it is only if the total-activity MAVs were exceeded that detailed isotopic analysis would need to be performed. Radon levels are assessed separately because radon is a gas and cannot be analysed in routine alpha activity measurements.

Water supplies in New Zealand servicing population groups of 5000 or more were surveyed for radioactivity levels (Gregory 1980). Samples representing 102 water sources were analysed for total alpha and beta radioactivity and radon concentration, and the results are summarised in Table 11.2.

Table 11.2: Radioactivity in New Zealand waters

Determinand	Range Bq/L	Mean Bq/L ± SD
Total alpha activity, excluding radon	0–0.07	0.01 ± 0.01
Total beta activity, including potassium	0–0.3	0.05 ± 0.04
Radon concentration: surface waters	0–2	0.9 ± 1.1
groundwaters	2–54	16 ± 11

Bq = becquerel

SD = standard deviation

Radon degasses from surface water so concentrations in surface water are expected to be very low. This allows use of radon gas as a natural tracer to study aquifer recharge between rivers and the aquifer system (ESR 2014).

11.2.2 Routes of exposure

The human body is, and always has been, exposed to natural background radiation. This ionising irradiation may arise from outside the body, for example from cosmic rays from outer space and γ -rays from the decay of the natural radionuclides of the uranium and thorium series that are present in rocks and other components of the earth's crust.

All human beings are also irradiated by the radiation emitted within organs and tissues by the decay of natural and anthropogenic radionuclides that have entered the body by inhalation or by ingestion of food and drinking-water. This irradiation arises naturally from the decay of the radioactive isotope of the essential element potassium, ^{40}K , and from uranium and thorium and their radioactive decay products, especially radon. In addition, some individuals or groups may receive whole- or partial-body external radiation from occupational exposure, medical procedures such as X-ray examinations, radiation therapy, from fall-out from atmospheric nuclear weapons testing, or accidents in nuclear facilities resulting in the release into the environment of radionuclides that emit γ -rays.

The passage of ionising radiation through the human or animal body results in the deposition of energy within the irradiated tissue volume. The amount of radiation energy deposited will depend on the length of time over which the individual is irradiated, the strength of the source, the physical half-life of the isotope, and the physical nature of the radiation, eg, X- or γ -rays, cosmic rays, α -, β - or other particles. Once inside the body, the exposure rate of the radionuclide is maximised, and it will continue to irradiate the body until either the radioactivity has decayed (physical half-lives may vary from fractions of a second to millions of years) or until the substance has been excreted from the body. The rate of excretion, expressed as retention half-time in

the body, may vary from a few days to tens of years, depending primarily on the physical and chemical characteristics and the chemical form of the radionuclide.

α -Radiation is not normally regarded as an external radiation hazard (except perhaps to skin) because it is poorly penetrating, but once α -particle-emitting radionuclides are in the body they can become a health hazard. However, X- and γ -radiations and neutrons can generally penetrate sensitive organs of the body. As the higher-energy β -radiation can penetrate to about 10 mm into tissue, it can pose both an external hazard and an internal hazard when emissions occur within the body. Unlike exposure to internal radiation, exposure to external radiation can usually be controlled by reducing its duration, increasing the distance from the radiation source and/or using shielding. Radioactive materials may pose an insignificant external hazard, but once they come into contact with or penetrate the body they increase the risk.

Four main routes result in internal exposure to radionuclides: inhalation (eg, radon), ingestion, dermal absorption and direct injection (or through a wound). Radionuclides may be ingested in food and drink, and are absorbed principally from the small intestine, facilitated by its immense surface area of about 200 m².

Ingestion is an important route of entry into the human body since, in addition to those radionuclides present in drinking-water and the diet, a fraction of any inhaled material is swallowed. Some radionuclides such as ³H, ⁴⁰K, ¹³¹I and ¹³⁷Cs are almost completely absorbed from the human gastrointestinal tract into the systemic circulation, but the absorption of others is incomplete, from about 30 percent of ⁹⁰Sr to <0.05 percent of highly insoluble oxides like ²³⁹PuO₂.

UNSCEAR (2000) reports that the average natural background radiation dose to human beings worldwide is about 2.4 mSv each year, of which about 1.1 mSv is due to basic background radiation (cosmic rays, terrestrial radiation and ingested radionuclides excluding radon) and 1.3 mSv is due to exposure to radon, but this varies typically over the range 1 to 10 mSv. In any large population about 65 percent would be expected to have effective doses between 1 to 3 mSv, and 25 percent at <1 mSv. However, for a limited number of people living in known high background radiation areas of the world, doses can exceed 20 mSv per year. There is no evidence to indicate this poses a health risk.

For monitoring purposes, doses are determined from the activity concentration of the radionuclide in a given material. In the case of water, activity concentration is given in becquerels per litre (Bq/litre). This value can be related to an effective dose per year (mSv/year) using a dose coefficient (mSv/Bq) and the average annual consumption of water (litres/year), see WHO 2004.

For most people more than half of their natural background radiation dose comes from radon, a radioactive gas that can accumulate in homes, schools and workplaces. When inhaled, the radiation exposure from radon may lead to lung cancer. Radiation doses to humans may be characterised as low-level if they are comparable to natural background levels.

Datasheets for caesium, radium, radon, strontium, thallium, thorium and uranium appear in the inorganic chemicals section.

11.2.3 Derivation of radiological MAVs

See Chapter 1: Introduction, section 1.6.2 for a general explanation of maximum acceptable values (MAVs).

All life on earth is exposed to radiation from natural sources including cosmic radiation; external radiation from natural radionuclides present in soils, rocks and building materials; and internal radiation due to potassium-40 and inhaled radionuclides, particularly radon decay products. Natural radiation exposure varies regionally as the compositions of soils and rocks change, and increases with altitude as cosmic radiation intensity increases. Radon is a radioactive gas, which emanates from the ground and can concentrate in buildings. The most important pathway for human exposure is through the permeation of underlying soil gas into buildings (USEPA 2003). Use of water can increase the indoor radon concentration, if radon is present in the water supply.

The risk associated with the presence of radionuclides in drinking-water is an increase in cancer rate. The aim of the DWSNZ is to set limits for radiological determinands, so that the radiation exposure resulting from the presence of radionuclides in water represents only a small part of the total radiation exposure from natural sources.

Radionuclides in drinking-water enter the human body through two pathways leading to radiation exposure:

- 1 internal radiation exposure from ingested radionuclides
- 2 exposure from inhalation of radon gas and its daughter nuclides.

The DWSNZ adopt MAVs that ensure that the committed effective dose from ingested radionuclides is less than 0.1 millisievert per year (5 percent of total average for natural sources). The MAV for radon was chosen to limit the contribution of radon in water to the indoor radon concentration to a level typical for outdoor radon levels (10 Bq/m³).

Different radionuclides have a different radio-toxicity and for an accurate determination of the exposure a detailed radioanalytical assessment would be required. However, an upper limit to the exposure can be derived from a measurement of total alpha, total beta and radon concentration.

Dose conversion factors linking concentrations in water to resulting radiation dose, recommended by the International Commission on Radiological Protection (ICRP 1996) were used in deriving the MAV concentrations. This approach is consistent with that of other organisations such as the World Health Organization (2004). The MAVs are deliberately conservative. If the natural radionuclides radium-226 and radium-228 were present in drinking-water at the MAV level (worst case scenario), the annual radiation dose would still be less than 5 percent of the total annual natural dose.

The MAVs for radiological determinands are:

- total alpha concentration: 0.10 becquerel per litre, excluding radon-222
- total beta concentration: 0.50 becquerel per litre, excluding potassium-40
- radon-222 concentration: 100 becquerel per litre.

In the radiological context, the MAV is intended to indicate a level above which the radioactive content of the water should be investigated further and an assessment of all relevant radiological issues undertaken. Radiation protection issues are often complex and many factors would have to be taken into account before a water supply could be classified as unacceptable even though a radiological MAV might have been exceeded. The DWSNZ therefore emphasise that further assessment by the ESR National Centre for Radiation Science is required in such cases. The MAV is thus more of a guideline than necessarily an absolute maximum. It is also intended to be clear however, that at levels below the MAV, there is no need for further assessment.

In 1998, the European Commission issued its Drinking Water Directive. For radionuclides, the Directive gives values for two radiological indicator parameters. These are a concentration of tritium of 100 Bq/L and a total indicative dose (TID) of 0.1 mSv pa; DWI (2013) retains these values. The Directive does not specify the frequency of monitoring that is required, nor the scope of monitoring needed for the estimation of TID. The Directive does specify however that tritium, ^{40}K , radon and radon decay products should not be included in the estimation of TID.

In England, the Drinking Water Directive (DWD) were implemented by means of the Water Supply (Water Quality) Regulations 2000, published by the Drinking Water Inspectorate (DWI). For radioactivity, these require monitoring for tritium together with measurements of gross alpha and gross beta activity. The criteria that would trigger further investigation such as analysis for specific radionuclides are 0.1 Bq/L for gross alpha and 1 Bq/L for gross beta, which are the values specified by the EC. In the United Kingdom, the main contributors to gross alpha activity are likely to be naturally-occurring radionuclides such as radium-226 (^{226}Ra) and isotopes of uranium. The EC Directive emphasises that the TID refers to a dose received over a full year. Consequently, a single measurement need not necessarily be a cause for concern. It should however be a trigger for further sampling and analysis. See DWI (2008 and 2013) for further details. DWI (2013) states that a parametric value is introduced for radon of 100 Bq/L. However, Member States may set a level higher than 100 Bq/L but lower than 1000 Bq/L which is judged inappropriate to be exceeded. Remedial action must however, be taken where radon concentrations exceed 1000 Bq/L.

Drinking water standards in England and Wales are now set out in European and UK legislation; DWI (2010). They are called Prescribed Concentrations or Values (PCVs) and many are different from WHO's Guideline Values. A screening value of 0.1 Bq/L is set for gross alpha radioactivity, and 1 Bq/L for gross beta radioactivity. They set a total indicative dose for radioactivity of 0.10 mSv/year, and 100 Bq/L for radioactive tritium.

In 2009 Health Canada established maximum acceptable concentrations (in Bq/L) for some individual determinands – see their Table 3 (added below for interest).

Their guidelines for radiological parameters focus on routine operational conditions of existing and new water supplies and do not apply in the event of contamination during an emergency involving a large release of radionuclides into the environment. Maximum acceptable concentrations (MACs) have been established for the most commonly detected natural and artificial radionuclides in Canadian drinking water sources, using internationally accepted equations and principles and based solely on health considerations. The health risk from ingesting radon-contaminated drinking water is considered negligible, because most of the radon escapes at the faucet or

water outlet, leaving only minimal amounts in the water itself. However, it should be noted that radon levels in drinking water, if sufficiently elevated, can significantly affect airborne radon concentrations.

Their MACs are based on exposure solely to a specific radionuclide. The radiological effects of two or more radionuclides in the same drinking water source are considered to be additive. Thus, the sum of the ratios of the observed concentration to the MAC for each contributing radionuclide should not exceed 1. Note that their MAC for total uranium is a chemical MAC (0.02 mg/L), not radiological.

Health Canada's Table 3: Radiological Parameters

Parameter (approval)	MAC (Bq/L)	Common sources	Health basis of MAC	Comments
Cesium-137	10	Nuclear weapons fallout and emissions from nuclear reactors	Cancer of the lung, breast, thyroid, bone, digestive organs and skin; leukaemia	
Iodine-131	6	Sewage effluent	Cancer of the lung, breast, thyroid, bone, digestive organs and skin; leukaemia	
Lead-210	0.2	Naturally occurring (decay product of radon)	Cancer of the lung, breast, thyroid, bone, digestive organs and skin; leukaemia	Corresponds to total lead concentration of 7×10^{-8} µg/L
Radium-226	0.5	Naturally occurring	Cancer of the lung, breast, thyroid, bone, digestive organs and skin; leukaemia	
Radon	None required	Naturally occurring (leaching from radium-bearing rocks and soils; decay product of radium-226)	Health risk from ingestion considered negligible due to high volatility	Mainly a groundwater concern; if concentrations in drinking water exceed 2000 Bq/L actions should be taken to reduce release into indoor air (eg, proper venting of drinking water supply)
Strontium-90	5	Nuclear weapons fallout	Cancer of the lung, breast, thyroid, bone, digestive organs and skin; leukaemia	
Tritium	7000	Naturally occurring (cosmogenic radiation); releases from nuclear reactors	Cancer of the lung, breast, thyroid, bone, digestive organs and skin; leukaemia	Not removed by drinking water treatment

11.3 Monitoring programme design

Natural radioactivity levels in water show seasonal variations, and might change over long periods.

Water from new underground sources should be tested before connection to public supplies, and further testing of bore water supplies that are not considered to be equivalent to surface water is required every 10 years (DWSNZ, section 9.4). Radiological testing of water from other sources is discretionary.

Waters that may present a radiological health concern (from natural causes) are mainly those that have been underground for a long period.

Any water drawn from a confined aquifer is (or could become) secure bore water; in an extreme case – even quite shallow water. These need a radiological check.

Water drawn from unconfined aquifers theoretically could become secure bore water too; but if drawn from less than 10 m the water is considered equivalent to surface water and therefore will not need radiological testing.

Water drawn from bank filtration and infiltration systems is still considered to be surface water and therefore do not require radiological testing.

Regarding bore waters granted interim security – the water supplier is probably hoping that the groundwater will ultimately be granted secure bore water status, so in that case it would be advisable to check out the radiochemical issues before advancing too far into the 12-month interim period.

The same would apply to those waters drawn from underground but which require five years of *E. coli* monitoring etc – even though that water is considered surface water for those five years, the water supplier is presumably hoping that it will ultimately be called secure bore water, so it would be advisable to check out the radiological quality fairly early on.

11.4 Sampling procedures and techniques

A drinking-water assessor and/or the ESR National Centre for Radiation Science (in Christchurch) should be contacted before sampling. General guidance follows:

- **Alpha and beta activity:** Generally a one-litre sample of water representative of the source should be collected in a polyethylene bottle. A small quantity of acid should be added as a preservative; approximately 5 mL of 1 M nitric acid is suitable. The sample should be despatched to the analytical laboratory as soon as possible after collection.

- **Radon:** Expert advice should be sought on appropriate sampling techniques. Radon measurements must be performed promptly after collection so it is essential to make prior arrangements with the analytical laboratory.

11.5 Analytical details

11.5.1 Total alpha and beta radioactivity measurement

Up to DWSNZ 2005, the methods used were:

- United States Environmental Protection Agency. Standard drinking water method for gross alpha by co-precipitation (EPA 520/5-84-006, method 00-02)
- United States Environmental Protection Agency. Environmental Monitoring and Support Laboratory. Prescribed procedures for measurements of radioactivity in drinking water. Gross alpha and gross beta radioactivity in drinking water (Method 900.0, August 1980).

The ESR National Centre for Radiation Science now uses liquid scintillation counting, details available from NRL.

11.5.2 Radiochemical analysis

If the total-alpha or total-beta activity MAV is exceeded radiochemical procedures are required for analysis of uranium and radium isotopes and any other radionuclides that may be present. A wide range of techniques may be applied depending on the nature of the sample and the determinand in question. Details of particular techniques may be obtained from the ESR National Centre for Radiation Science.

11.5.3 Radon determination

Up to DWSNZ 2005, the method used was:

- radon concentrations in water are determined either by extraction and measurement of the bismuth-214 decay product by beta measurement, or by liquid scintillation counting. Details of particular techniques may be obtained from the National Centre for Radiation Science.

The ESR National Centre for Radiation Science now uses liquid scintillation counting, details available from ESR.

11.6 Records and assessment of compliance

Radiological compliance should be assessed by the National Centre for Radiation Science.

Records should be kept for future reference, see section 13 of DWSNZ.

11.7 Response to transgressions

If the radioactivity of a drinking-water supply exceeds the MAV, the supply is to be analysed for contributing radioactive materials and an assessment made of their radiological significance by the ESR National Centre for Radiation Science.

If the alpha-radioactivity exceeds the MAV, the water should be analysed for uranium-238, uranium-234 and radium-226.

If the beta-radioactivity exceeds the MAV, the water should be analysed for radium-228 and any artificial radionuclides that may be present.

If the measured levels of these radionuclides do not account for the measured total-activity levels, the water should be analysed for any other radionuclides that may be present such as lead-210 and artificial radionuclides, until a complete assessment can be made.

Remedial action is necessary if the committed effective dose from ingestion exceeds 0.1 mSv/year, or the radon concentration exceeds 100 Bq/L.

The ESR National Centre for Radiation Science will advise on necessary remedial action.

11.8 Radon removal

The most effective treatment device to remove radon from drinking-water is a point-of-entry (POE) device. A POE device removes contaminants immediately before they enter the home USEPA (1999). There are two types of point-of-entry devices that remove radon from water:

- granular activated carbon (GAC) filters which use activated carbon to remove the radon
- aeration devices which bubble air through the water and carry radon gas out into the atmosphere through an exhaust fan.

GAC filters tend to cost less than aeration devices; however, radioactivity collects on the filter, which may cause a handling hazard and require special disposal methods for the filter.

The USEPA formulated a proposed Radon in Drinking Water Bill in 1996 and updated it in April 2000 (see References). This reference leads the reader to several other links. The Fact Sheet states:

Best available technology (BAT) for radon in drinking water removal

High-performance aeration is the proposed BAT for all systems. High-performance aeration is defined as the group of aeration technologies that are capable of being designed for high radon removal efficiencies (up to 99.9 percent removal), ie, packed tower aeration, multi-stage bubble aeration and other suitable diffused bubble aeration technologies, Shallow Tray and other suitable Tray Aeration technologies, and any other aeration technologies that are capable of similar high performance. In addition to listing BAT, which is based on technology evaluations for large systems, the SDWA directs EPA to list small systems compliance technologies (SSCTs): affordable and technically feasible technologies based upon technology evaluations for small systems. EPA is proposing that high performance aeration, granular activated carbon (GAC), and point-of-entry GAC be listed as SSCTs. Issues relevant to safe operation procedures and safe and legal disposal of spent GAC material are addressed in the preamble to the proposed radon rule.

Radon is on the WHO plan of work of the rolling revision of their Guidelines. This is what appears in the draft as at September 2008:

Radon, being a gas, is relatively easy to remove by air stripping. Removal efficiencies of >99 percent were obtained with diffuse bubble and packed tower aeration at air:water ratios of 15:1 and 5:1, respectively (Kinner et al 1990). Other investigations focusing on aeration at public waterworks have given similar results, with 67–99 percent efficiencies (Annamäki and Turtiainen 2000). This is the preferred method of treatment.

GAC is also effective in removing radon from water, with removals of 70–100 percent (Lykins et al 1992). The amount of radon removed by activated carbon is effectively unlimited because the adsorbed radon decays into other radioactive products, such as ^{210}Pb . As the adsorbed radon decays, radioactive progeny emitting gamma radiation is produced, possibly creating a disposal problem (Castle 1988). Elevated gamma dose rates (up to 120 $\mu\text{Sv/h}$) near the filter have been recorded (Annamäki and Turtiainen 2000). Screening of the GAC filter could be required. In some circumstances, a twin tank system, which introduces a time delay that allows the radon to decay to a significant extent, may be a low-cost option.

See Chapter 12: Treatment Processes, Pretreatment, section 12.2.1 for a discussion on aeration treatment systems. A datasheet for radon appears in the inorganic chemicals section.

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