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Radon*

Guideline

A maximum acceptable concentration (MAC) for radon in drinking water has not been established.

Identity, Use and Sources in the Environment

Radon-222 is a chemically inert gas formed through the radioactive decay of ^{226}Ra. Both are members of the ^{238}U decay series. Radon-222 has a half-life of 3.82 days. Its decay products form a series of short-lived radionuclides (all solid elements) that decay within hours to ^{210}Pb (half-life of 22 years). Because of their short half-lives, the radon daughters rapidly approach radioactive equilibrium with their radon parent.

Radon is soluble in water, its solubility decreasing rapidly with an increase in temperature (510, 230 and 169 cm^3/kg at 0°C, 20°C and 30°C, respectively).[1] Radon is extremely volatile and is readily released from water.

Uranium and radium are present in varying amounts in all rocks and soils. Although most of the radon produced in soil from radium is retained in the earth, where it decays, a small portion diffuses into the pore spaces and hence into the atmosphere. One square metre of typical soil containing radium at 0.03 Bq†/g will release between 1000 and 2000 Bq of radon to the atmosphere each day.[2] Other sources of radon include groundwater that passes through radium-bearing rocks and soils, traditional building materials such as wallboard and concrete blocks, uranium tailings, coal residues and fossil fuel combustion.

*The term "radon" is used in this supporting document to refer to the isotope ^{222}Rn. Other radon isotopes are also ubiquitous in nature but generally present a much smaller risk than ^{222}Rn.

†The international unit that measures radioactivity is the becquerel (Bq), which is equal to one transformation per second. One becquerel is approximately equivalent to 27 picocuries (pCi) (1 Ci = 3.75×10^{10} Bq).

Exposure

Radon is the major source of naturally occurring radiation exposure for humans. Exposure occurs via the ingestion of radon dissolved in water and the inhalation of airborne radon.

There are few data on radon concentrations in Canadian drinking water supplies. Water drawn from surface supplies does not generally contain appreciable levels of radon, which are expected to be on the order of 0.01 Bq/L.[2] One survey of Canadian groundwater sources containing elevated levels of radon found radon concentrations in the range 1.7 to 13.7 kBq/L in Halifax County, Nova Scotia.[3] A second survey detected radon at concentrations as high as 3 kBq/L in well water in Harvey, New Brunswick, with 80% of the wells containing radon concentrations below 740 Bq/L.[4] A U.S. survey estimated geometric mean radon levels in public water supplies, public groundwater supplies and private wells of 2.5, 4.8 and 34 Bq/L.[5] Public wells analysed by King *et al.*[6] and Krishnaswami *et al.*[7] contained radon at an average concentration of about 40 Bq/L. Hopke[8] cited a U.S. study that found that 74% of wells surveyed contained less than 74 Bq/L radon and no more than 5% contained concentrations at or above 370 Bq/L. Nazaroff *et al.*[9] reported a geometric mean radon concentration of 5.2 Bq/L in public well water supplies in the United States, based on population-weighted statistics. Cothern[10] tabulated U.S. data on radon in groundwater and calculated that the national average population-weighted concentration of radon in drinking water is about 9 Bq/L for public water supplies that serve more than 1000 people and about 29 Bq/L for supplies serving fewer than 1000 people. Crawford-Brown and Cothern[11] estimated the population-averaged concentration of radon in U.S. public drinking water supplies to be 5.6 Bq/L. In Finland and Sweden, the population-weighted average for drinking water from private wells has been estimated at 60 and 38 Bq/L, respectively.[2]

Outdoor radon concentrations vary seasonally and diurnally and are influenced by height above ground level and meteorological conditions such as wind speed and temperature.[2] Outdoor radon levels were measured in 78 communities across Canada during the summers of 1990 and 1991.[12] Under unusually low precipitation conditions, outdoor radon levels for the Prairie provinces averaged 60 Bq/m^3 during the summer of 1990. The much lower 1991 measurements for Manitoba (10 Bq/m^3) and Saskatchewan (15 Bq/m^3) were believed to be due to the increased precipitation in the prairie regions that summer compared with the previous summer. In general, the average radon level in outdoor air for continental locations in temperate latitudes is about 9 Bq/m^3.[2,13] Enhanced levels will be found in the vicinity of uranium mines and mill and tailings operations.[10]

Indoor radon levels are typically much higher and much more variable than outdoor levels. Radon entry into houses and other buildings is primarily from the soil or rock under the structures. Radon in water, building materials and natural gas can also contribute to indoor levels,[2] particularly in confined spaces with low air change rates (e.g., homes that have been tightly sealed for energy conservation). UNSCEAR[2] estimates an average population-weighted indoor radon concentration of about 50 Bq/m^3 for temperate regions of the world.

The relationship between the concentration of radon in the water supply and the concentration of radon in indoor air depends on several factors, including the rate and type of usage of the water (e.g., drinking water, showers, laundry), the loss or transfer of radon from the water to the air and the characteristic ventilation of the house. The rate of release of radon from water depends on such factors as agitation, surface area and temperature.[14] Based on a water-to-air transfer factor of 10^4 to 1,[10,15,16] radon in water contributes on average about 1% to indoor levels.[17] Nazaroff *et al.*,[9] based on measurements in U.S. homes and water supplies, estimated that public supplies derived from groundwater serving 1000 or more persons contribute about 2% to the mean indoor radon concentration for houses using these sources.

In general, under normal conditions, the intake of radon from indoor and ambient air far surpasses the intake of radon from drinking water via both the ingestion and inhalation routes. The global average dose from the inhalation of radon from all sources is approximately 1 mSv[‡]/year,[18] which is slightly less than half the total natural radiation exposure of 2.4 mSv/year.[2] In comparison, the global dose from ingestion of radon in drinking water is relatively low.[18]

[‡]Sievert (Sv) is the unit of equivalent dose, equal to 1 J/kg, that is intended to express the biological implications of radiation exposure. Equivalent dose is the product of absorbed dose (in grays, Gy) and a radiation weighting factor specific to the type of radiation.

Analytical Methods and Treatment Technology

Two methods for the measurement of radon in water have been recommended by the U.S. Environmental Protection Agency (EPA) for routine measurements. The emanation method, in which radon is degassed from the water and transferred into a Lucas scintillation cell, has a detection limit of approximately 0.05 Bq/L for a sample volume of 100 mL.[19] In the liquid scintillation method, the water is injected directly into a scintillation solution and counted in an automated liquid scintillation device; this method has a detection limit of about 0.4 Bq/L using a sample volume of 10 mL.[20,21] All methods require careful sampling because of the rapid loss of radon from the water when it is agitated and open to the atmosphere. The U.S. EPA[15] estimated a practical quantitation limit (PQL) for radon in water (based on the ability of laboratories to measure radon within reasonable limits of precision and accuracy) to be about 10 or 11 Bq/L.

Radon in air can be detected using alpha track detectors (detection limit 40 Bq-month/L) or charcoal canisters (detection limit 20 Bq/L).[22]

There are two principal ways to remove radon from water supplies dependent on groundwater sources (water drawn from surface supplies or temporary storage containers will not contain any appreciable radon[2]). Aeration, which forces radon from the water to the air, can be highly effective; bubble plate aeration and diffused bubble aeration as point-of-entry units are capable of achieving removal efficiencies in excess of 99% at loading rates of 185 Bq/L and up.[23,24] The low-tech spray jet aeration technique, which is the most practical aeration method for small community water supplies, removes between 50% and 75% of the influent radon.[23,25] One concern with aeration is the possibility of creating a large source of airborne radon. Adsorption via granular activated carbon, with or without ion exchange, can also achieve high radon removal efficiencies (up to 99.7%, depending on the loading rate).[24] Two potential concerns associated with this technology are the elevated gamma radiation fields that develop close to the column and the waste disposal difficulties associated with the used carbon.

Health Effects**

Radon consumed in water appears to rapidly enter the bloodstream from the stomach,[26] perfusing all the cells of the body.[27] As it is lipid soluble,[28,29] it does not distribute evenly throughout the body.[30] Clearance of radon from the bloodstream is relatively rapid, with a half-time on the order of minutes.[31,32]

**The reader can refer to the supporting document on Radiological Characteristics for a more detailed description of the biological effects of radionuclides.

Hursh *et al.*[30] demonstrated that radon is removed from the body primarily through exhalation via the lung. Several studies have found that radon is removed from the body with a primary half-time of between 30 and 70 minutes, with a smaller component (possibly that associated with fatty tissue) having a half-time on the order of several hours.[26,33] The rate of radon elimination from a resting person appears to be slower than that for a physically active person.[27]

Most radon inhaled with indoor air is exhaled and remains in the lungs for only a short time. The radon daughter ^{218}Po is very reactive and electrostatically attracted to tiny particulates in air. These particulates are inhaled and deposited in the lung. Radon's daughters then decay sequentially, releasing damaging alpha and beta particles. Therefore, it is radon's progeny, not radon, that actually cause damage to the bronchial epithelium, because only the progeny remain in the lungs long enough to decay significantly.[10]

Epidemiological data derived from underground miners of various metal ores have shown a relatively consistent relationship between lung cancer incidence and exposure to radon progeny.[10,34] Limitations of the miner studies include crude exposure estimates, inadequate follow-up periods[34] and the inability to account for the confounding factor of cigarette smoking.[10] Although some researchers suggest that there might be a synergistic effect between radon and cigarette smoke, others have suggested that smoking may cause a thicker layer of mucus in the lungs, which may actually protect the lungs from alpha particles.[10]

With respect to inhalation risk, several national and international organizations have developed risk models based on epidemiological and radiobiological data for radon. Risk projections made using three of these models[35–37] suggest that the average lifetime risk from inhalation exposure to radon daughters is likely to be in the order of less than 100 cases per million WLM[††] to perhaps 500 cases per million WLM, with the lower value being applicable to females and non-smoking males and the higher value being applicable to a mixed population of females and smoking and non-smoking males.[38]

Comparatively few epidemiological studies have investigated the exposure to natural background radon levels, and those that are available show no significant increase in lung cancer death rate from inhalation exposure to normally occurring levels of radon and radon progeny.[34,39,40] As well, there are no experimental or epidemiological data available that link ingested radon with any known health impacts in humans.[34]

Animal studies, most of them involving the inhalation of radon and radon progeny,[41,42] have provided considerable data confirming human epidemiology studies.[34] Although there have been some attempts to estimate the risk to animals from ingestion of radon and radon progeny, it has generally been concluded that the risk from ingestion is insignificant compared with the risk from inhalation.[10]

[††]As it is radon's progeny that cause lung damage, the concentrations of radon progeny in air should be measured rather than the concentration of radon. One working level (WL) is defined as the combination of radon progeny in 1 L of air that results in the emission of 1.3×10^5 MeV of alpha particle energy. One WL is numerically equivalent to 3700 Bq/m^3 of radon in equilibrium with its short-lived daughters. One WLM is a unit of exposure corresponding to an exposure to 1 WL for a period of one working month (170 hours).

Classification and Assessment

No experimental or epidemiological studies have linked ingested radon with health impacts in humans, and it has generally been concluded from animal studies that the risk from ingestion is insignificant compared with the risk from inhalation. As well, radon that has emanated from water supplies into air generally contributes only 1% or 2% to the mean indoor radon concentration. Thus, under normal conditions, the intake of radon in ambient and indoor air generally far surpasses the intake of radon from drinking water via both ingestion and inhalation routes. Even these normally occurring levels of radon and radon progeny in indoor and ambient air have not been linked with an increase in lung cancer death rate from inhalation exposure in available epidemiological studies.

It has therefore been concluded that there is no need to establish a maximum acceptable concentration (MAC) for radon in drinking water. However, anyone whose indoor air radon concentrations exceed acceptable levels (800 Bq/m^3 as an annual average concentration in the normal living area)[43] should investigate the possibility that their groundwater also contains high levels of radon. Individuals who attempt to remove radon from their water supply using point-of-use devices containing activated carbon should be cautioned regarding the difficulties of disposing of the used radioactive carbon.

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