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Control of Radon in Houses

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Abstract

Careful attention to construction details that minimize soil gas entry points and properly designed and maintained ventilation systems can help to reduce potential radon problems.

Radon and Its Decay Products

Radon is a radioactive gas that has been associated with adverse health effects. Colourless, odourless and tasteless, it is impossible to detect without some form of measuring apparatus. It is a natural radioactive decay product of radium, which is in turn a decay product of uranium. As uranium is present in small amounts in soil and rock throughout the planet, the only locations where levels of radon gas are undetectable are in parts of the ocean. With a molecular weight of 222, radon is nine times heavier than air, so that it tends to remain close to the ground. According to a study carried out in Ottawa,[1] radon levels in the basements of a group of houses were, on average, two to five times higher than the levels on the upper floors.

The decay products of radon are known as radon daughters. Radon gas (Rn-222) breaks down in eight radioactive decay steps to become the stable element, lead 206. During this process both alpha and beta particles and gamma radiation are released. Radon daughters are of specific concern to health professionals[2] since they can be inhaled and deposited in the lung. The subsequent release of energy during the remaining decay steps can cause damage to surrounding tissue and this can lead to lung cancer. The decay byproducts of radon and its short-lived daughters are given in Table 1.

Table I. Radon Decay Process

	Decay Byproduct	Half-life
Radon, 222_{Rn}	alpha particle	3.82 day
Radon A, 218_{Po}	alpha particle	3.05 min
Radon B, 214_{Pb}	beta particle & gamma radiation	26.8 min
Radon C, 214_{Bi}	beta particle & gamma radiation	19.7 min
Radon C', 214_{Po}	alpha particle	0.000003 min

At any time radon gas and its various daughters can all be present. Since radon daughters have an electrical charge, they tend to attach to surfaces, including walls, furniture, and airborne dust particles. When attached to large surfaces (a process called plate-out), they no longer represent a health risk since they cannot be inhaled. If they are not attached to anything or are attached to small airborne dust particles, however, they may be inhaled. The ratio of the actual airborne daughter concentration to the theoretical daughter concentration, based on radon gas decay, is called the equilibrium factor. Variables including ventilation, humidity and dust particle concentration all affect the value of the equilibrium factor, which typically ranges from 0.3 to 0.5.

Radon gas levels are normally expressed in pico-curies per litre of air (pCi/L) and are related to the total number of particles emitted during the radioactive decay process.[*].

Codes, guidelines and various field studies may refer to either radon gas levels (pCi/L) or radon daughter concentrations in milliworking levels (mWL). If the equilibrium factor is known or can be accurately estimated, radon gas concentrations can be converted to radon daughter levels by using the equation:

Rn daughters (mWL) = Rn gas (pCi/L) · 10 · equilibrium factor

Acceptable Levels of Radon Daughters

A number of sources give recommendations for acceptable levels of radon daughters, but to date Canada has not established radon exposure guidelines for residences. The guideline[3] suggested for residential occupancy in uranium mining communities is 20 mWL. The proposed ASHRAE[4] standard has a value of 27 mWL. For comparison, field data obtained from a major cross-Canada survey[5, 6] of 14 000 houses,conducted by Health and Welfare Canada from June to August in 1977, 1978 and 1980, are summarized in Table II.

Table II. Summary of radon and radon daughter survey of houses in Canadian cities

Location	No. of Homes	Radon Daughters (mWL), Geometric Mean	Radon (pCi/L), Geometric Mean	Percent >,= 20 mWL
Vancouver, B.C.	823	0.9	0.14	0.0
Calgary, Alb.	900	1.9	0.31	0.2
Edmonton, Alb.	603	2.8	0.46	2.2
Saskatoon, Sask.	770	3.4	0.42	3.8
Regina, Sask.	961	4.4	1.33	9.6
Winnipeg, Man.	563	5.8	1.54	15.9
Brandon, Man.	561	3.4	0.94	5.3
Thunder Bay, Ont.	627	2.5	0.54	2.2
Sudbury, Ont.	772	3.6	0.58	6.9
Toronto, Ont.	751	1.8	0.31	0.9
Montreal, Que.	600	1.4	0.29	1.0
Sherbrooke, Que.	905	2.3	0.36	6.3
Quebec, Que.	584	1.3	0.28	2.1
St. John, N.B.	867	1.8	0.27	2.8
Fredericton, N.B.	455	3.2	0.66	3.3
Halifax, N.S.	881	3.1	-	5.1
Charlottetown, P.E.I.	814	1.8	0.41	0.09

St. Lawrence, Nfld.	435	1.7	0.88	-
St. John's, Nfld.	585	1.5	0.30	0.07

Radon Sources

Soils

According to most studies, soil surrounding foundations is usually the most important source of radon. Across Canada, soils that have been assessed[7] show approximately a 35 to 1 variation in radium content. Major pathways by which radon gas can enter a building are through the foundation wall or floor, or through cracks, joints and plumbing penetrations. Crawlspaces and areas with exposed soil may also facilitate the transport of soil gas. The transport process will increase if the building interior is at a lower pressure than the gas in the soil.

Water

Water usage can result in significantly elevated indoor Rn levels, particularly when the Rn concentration in the water supply exceeds 10 000 pCi/L. The problem may occur in houses that have wells for the water supply. Radon gas may be released into the air when the water is boiled, used in a shower, or otherwise agitated. While most water supplies[8] have radon concentrations less than 1000 pCi/L, there are certain areas (e.g., in Maine, U.S.A., and in Finland) where the Rn content of drilled well water can exceed 100 000 pCi/L. A Canadian report[9] presents data on some homes in the Halifax area.

Building Materials

There are only a few instances in which building materials have been cited as contributing significantly to radon problems. Materials such as concrete, brick and tile usually have radiation concentrations similar to those of the major rock types used in their manufacture and because of this may show large geographical variations. In general, they have not proved to be major sources of radon. The use of refined materials such as phosphate slag (a waste product of the phosphate industry) in gypsum board panelling and concrete can result in high radiation sources, but these are not used in Canada.

Measurement

The measurement of radon gas and radon daughter concentrations can be divided into three major categories: time-averaged measurements, where the average concentration over a set period is determined; instantaneous measurements (grab sample), where a single short-term measurement is made; continuous measurements (real time), where the concentration is constantly measured and recorded.

Time-averaged measurements usually involve small, inexpensive monitors that can be left unattended for some period of time (typically 30-90 days) and returned to the supplier for analysis. This level of monitoring is normally used for large surveys or initial investigations. Grab sampling and continuous monitoring require expensive equipment operated by trained personnel. This type is necessary to identify short-term variations in radon levels that could be caused by physical factors such as wind, temperature and ventilation rate.

Radon Control

As with most indoor pollutants, efficient radon control should seek first to minimize the source of the pollutant. Secondary control measures, including improved ventilation, can then be applied to ensure that the radon concentration is maintained at an acceptable level.

New Construction

A number of measures have been used to minimize radon entry into houses. In one extreme case in northern Saskatchewan at the site of a uranium mine the workers' living quarters were built on stilts, about 2.5 m above the ground, because of high ambient radon concentrations at ground level. A less extreme option in areas with lower radon concentrations is to build a house on a well-ventilated crawlspace. For those who use a basement in areas with high radon levels it is important to exclude radon gas entry by carefully sealing leakage paths.

Many techniques for excluding radon are simply good building practice. For example, cast concrete walls and floors should be designed to withstand soil stresses and minimize cracking. A layer of polyethylene should be placed underneath a concrete slab before it is poured. Although some diffusion of radon can occur through it, the polyethylene can limit the convective flow of radon gas. The joint between the floor slab and the concrete wall should be properly sealed. To limit entry of radon gas from weeping tile, open air flow paths between the weeping tile and the floor drain should be avoided.

Houses with a crawlspace should have a polyethylene moisture barrier placed on the crawlspace ground surface. The polyethylene sheet may still allow some radon gas to diffuse through it, but it will limit the migration of air carrying radon into the crawlspace and from there into the living space.

A proper ventilation system is also useful for controlling radon gas levels in houses with moderate radon sources. The National Building Code of Canada 1985 now recommends an installed capacity of 0.5 air changes per hour. In areas of high radon concentration, however, ventilation alone is usually not sufficient to reduce radon levels to those recommended. Unbalanced ventilation systems that depressurize the building envelope can increase radon entry rates through leakage paths and interfere with the proper operation of combustion appliances. Building pressurization can reduce radon entry, but may also result in problems including indoor moisture migration into the building envelope and freeze-up of chimneys in cold weather.

Remedial Measures

There are several means of reducing radon levels in existing houses:

- Seal cracks in basement floors and walls, and block air flow through sump pits and floor drainage holes.
- Cover crawlspace floors and ventilate the crawlspace.
- Increase ventilation in the house, often with an air-to-air heat exchanger to reduce the cost of providing the extra ventilation.
- Vent the space beneath the concrete floor to remove radon gas and create a pressure differential across the concrete slab that will cause basement air to exfiltrate through cracks and other openings in the concrete slab.

The United States Environmental Protection Agency (EPA) has published[10] information on how to reduce radon levels in existing structures. A Canadian publication[11] presents information on remedial measures used for houses at Elliot Lake, Ontario.

Conclusions

At the present time there are no accurate methods of predicting radon levels in homes. Although certain geographic areas and construction practices appear to contribute to elevated radon levels, similar houses within a single neighbourhood can have indoor radon levels that vary by a factor of 20 or more. Careful attention to construction details that minimize soil gas entry points and properly designed and maintained ventilation systems can help to reduce potential radon problems.

The only realistic method of determining the indoor radon concentration is to have it measured. As with all measurements, however, their accuracy and frequency will influence the conclusions reached. Skilled, experienced personnel are required to evaluate a building system and test data.

Information regarding the implications of radon levels on human health can be obtained from the Environmental Radiation Hazards Division, Bureau of Radiation and Medical Devices, Health and Welfare Canada, Ottawa, Canada, K1A 1C1.

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*One curie=3.7 x 10^{10} disintegrations per second; 1 pCi/L=37 Bq/m^3 (becquerels per m^3)