



Radon and Health

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1.0 INTRODUCTION

Radon is an odourless, colourless radioactive gas that occurs naturally in the environment. Radon gas emanates from the earth's crust and is therefore present in outdoor air and all buildings, including workplaces. It is released into the air when uranium ore is mined and, to a lesser extent, during the production of uranium fuel for nuclear power plants. Radon is the largest source of naturally occurring radiation exposure for Canadians.

There is a lot of available radon-related information under discussion. There are also many concerns and misconceptions about radon's impact on workers and communities near uranium mines or mills.

As Canada's nuclear regulator, the Canadian Nuclear Safety Commission (CNSC) regulates radon in Canada's nuclear facilities to protect workers, the public and the environment. The CNSC also communicates objective information about its licensees' activities and their effects on the environment and the health and safety of people.

This document compiles information from various sources to help clarify the facts about radon. It addresses what radon is, what we know about its health effects, its levels in Canada and how it is regulated, and radon in homes.

2.0 WHAT IS RADON?

2.1 Physical Properties

Radon is a chemical element with the symbol Rn. It is a naturally occurring radioactive gas and is a product of the natural radioactive decay of uranium, as found in small quantities in most rocks, soils and water [1]. Radon gas is odourless, tasteless and colourless, and therefore cannot be detected by the human senses [1]. It is the heaviest of the noble gases in the periodic table of elements. Because it is denser than air, radon gas in the environment tends to settle in lower areas where the air is still and can concentrate in poorly vented rooms and basements.

2.2 Isotopes

The nucleus of an atom consists of protons and neutrons. An isotope is one of two or more atoms having the same atomic number (number of protons), but different mass numbers (number of neutrons). Radon has no stable isotopic form; all of its isotopes are radioactive.

There are three naturally occurring isotopes of radon:

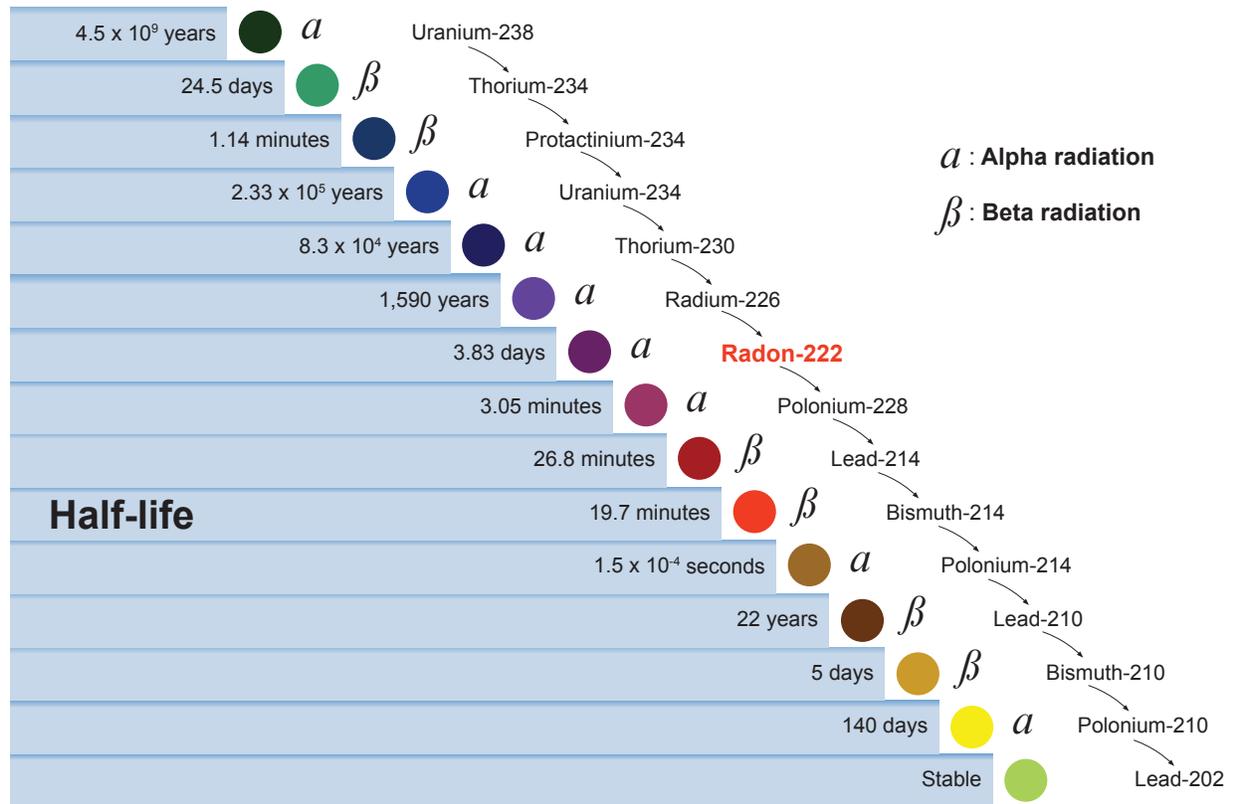
- Radon-222 is formed from the decay of Uranium-238 as part of a series of transformations referred to as a decay chain (see Figure 1). Radon-222 is the radon isotope that causes the most concern, because of the natural abundance of Uranium-238 in the earth's crust and the health effects of its further decay products.
- Radon-219 is formed during the decay of Uranium-235 [1].
- Radon-220 (also known as thoron) is formed during the decay of Thorium-232 [1].

2.3 Decay Products

When uranium decays, it goes through a series of 14 transformations called a decay chain. This process takes several billion years to complete. At the end of radon's decay chain is Lead-206, a stable, non radioactive element. Radon-222 belongs to the radium and Uranium-238 decay chain and has a half-life (the time that the original amount has taken to decay to one half) of 3.8 days. In turn, radon decays into a series of solid, short-lived radioisotopes called radon progeny or radon decay products (RDPs).

Due to their short half-lives, radon progeny emit radiation more quickly and present greater health risks than radon itself. Two decay products of radon, Polonium-218 and Polonium-214, pose a major health risk because they emit alpha radiation [1], which has a greater relative biological effectiveness (the ability to cause a biological effect) than beta or gamma radiation.

Figure 1: Uranium-238 Decay Chain [2]



3.0 WHAT DO WE KNOW ABOUT THE HEALTH EFFECTS OF RADON?

3.1 How are People Exposed to Radon?

People are exposed to radon¹ every day as a result of the natural radioactive decay of uranium in soils and rocks. In addition, workers in underground mining (notably uranium mining) are exposed to many forms of radiation, including those emitted from radon during the decay of uranium ore.

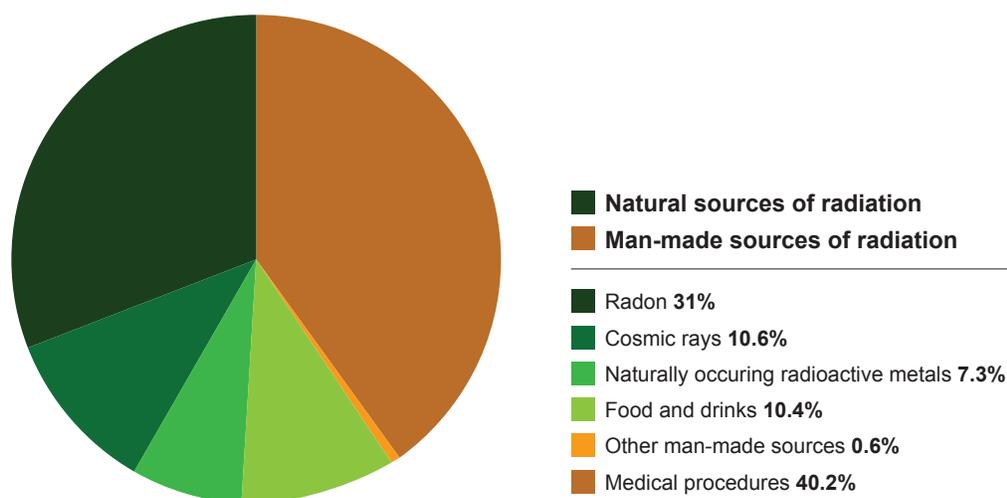
Radon is an odourless, colourless radioactive gas that occurs naturally in the environment. Radon gas emanates from the earth's crust and is therefore present in outdoor air and all buildings, including workplaces. Indoor air concentrations of this gas vary widely, depending mainly on the geology of the area and factors that affect the pressure difference between the inside and outside of the building, such as ventilation rates, heating within the building and meteorological conditions.

Radon is the largest source of naturally occurring radiation exposure for Canadians as members of the general public due to its presence in buildings and houses. It represents about half of the exposure from natural background radiation and a third of the total exposure from all sources of radiation for an average adult Canadian (see Figure 2). In Canada, the average radiation exposure due to background radiation ranges from 2 to 3 millisieverts (mSv) per year [2].

Over a lifetime, a Canadian is exposed to the following sources of radiation:

1. natural background radiations (59.3% of total exposure) including:
 - radon (31%)
 - food and drinks, like bananas (Potassium-40) (10.4%)
 - radioactive metals naturally present in the Earth's crust and rocks (e.g., uranium) (7.3%)
 - cosmic rays (10.6%)
2. man-made or artificial sources of radiation including:
 - medical procedures (40.2% of total exposure)
 - radiation released from nuclear facilities (0.6% of total exposure)

Figure 2: Sources of Radiation Exposure for an Average Adult Canadian [1]



¹ When discussing the health effects of radon, the term “radon” refers to both radon and radon decay products (RDPs), as a means of simplifying the text.

3.1.1 Radon in Homes

Radon gas can move through small spaces in the soil and rock upon which a house is built. It can seep into a home through dirt floors, cracks in concrete, sumps, joints, basement drains, under the furnace base and jack posts if the base is buried in the floor. Concrete-block walls are full of tiny pores and can allow fluids or gas such as radon to pass through and be released into the air. Radon trapped in well water can also be released into the air when the water is used in the home [3].

A survey conducted by Health Canada (HC) in the 1970s showed that radon levels in certain Canadian cities were higher than in others. However, these same studies showed it is impossible to predict whether any one house will have a high level of radon. Factors such as the location of the house and its relation to the prevailing wind may be just as important as the source of the radon [3].

HC developed a guideline for radon levels (200 Bq/m³) [4] in indoor air to help protect Canadians from the health risks associated with radon exposure in homes and buildings.

3.1.2 Radon in Uranium Mines and Uranium Processing Facilities

Radon gas is released into the air when uranium ore is mined and, to a lesser extent, during the production of uranium fuel for nuclear power plants. The CNSC regulates radon in Canada's nuclear facilities to protect workers, members of the public and the environment through the *Radiation Protection Regulations* [5].

Table 1 lists the average exposures of today's uranium mine and mill workers and underground miners from all sources of radiation exposure, as presented in the 2008 Annual National Dose Registry Report [6].

Table 1: 2006 Average Radiation Exposure of Uranium Mine and Mill Workers and Uranium Miners (Underground)

Worker	Average Dose (mSv)	Contribution from Radon Decay Products (%)
Uranium mine/mill workers	1.19	48.5
Underground uranium miners	1.74	53.3

3.2 Health Effects

Many studies looking at the health effects of radon have been conducted throughout the years. These studies have helped understand the importance of controlling radon. Their main finding is that long-term exposure to above-background levels of radon increases the risk of developing lung cancer. Exposure to radon has not been linked to other cancers or causes of death.

The health risk of radon is caused by exposure to its progeny or radon decay products (RDPs), which are produced when radon decays. If radon gas is present, the decay products will become suspended in the air. Because they are electrically charged, most will attach to dust particles or the surface of solid materials; some may remain unattached. Both attached and unattached fractions may be inhaled. Once deposited in the lungs, radon emits alpha radiation, which irritates and can damage the living cells lining the lung.

Because of their relatively short half-lives (less than half an hour), RDPs mainly decay while still inside the lung. Two of these short-lived products — Polonium-218 and Polonium-214 — emit alpha particles, whose energy dominates the dose to the lung and the associated risk of lung cancer.

In the open air, the concentration of radon gas is very small and does not pose a health risk. However, in some confined spaces like basements and underground mines, radon can accumulate to relatively high levels and become a health hazard.

Health effects of radon have been investigated for several decades. Initially, investigations focused on underground miners exposed to high levels of radon in their occupational environment.

In the early days of uranium mining, little was known about the health effects of radon, so there was no or very little radiation protection. Ventilation was poor or non-existent. As a consequence, uranium miners were exposed to very high levels of radiation (e.g., over 2,200 mSv per year in Port Radium in the 1940s). This resulted in high rates of lung cancer among early uranium miners.

Epidemiology studies have allowed us to measure the risk of lung cancer from RDPs. As a result, radiation protection programs have been established in uranium mines and are regulated. Some radiation protection measures include improved ventilation, improved mining techniques, dose limits, area RDPs monitoring, individual RDPs monitoring, and ALARA (a principle stating to keep doses As Low As Reasonably Achievable). With these measures, levels of RDPs exposure among uranium miners have decreased considerably. Figures 3 and 4 illustrate how much dose rates have been lowered (note the change in scale between the two figures).

Figure 3: Average Radon Progeny Exposures from 1940 to 1970

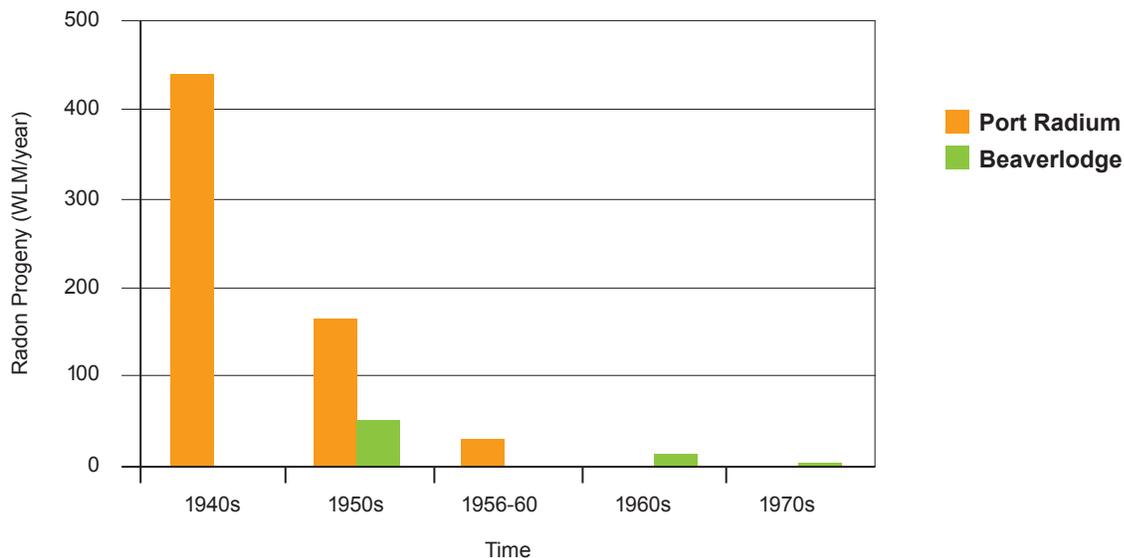
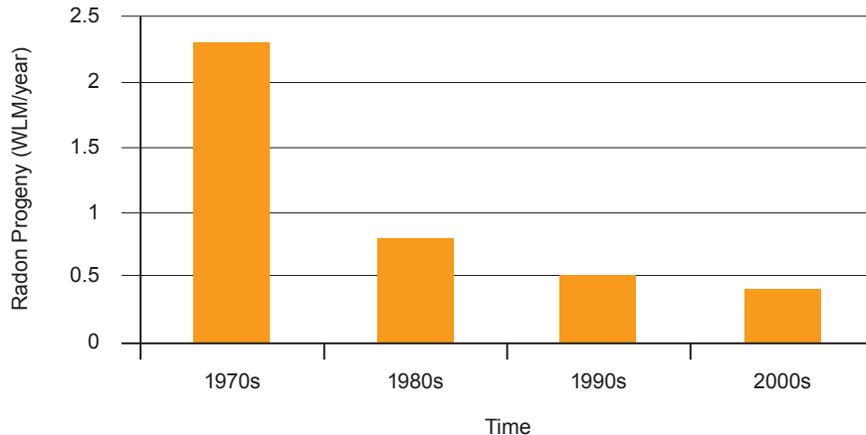


Figure 4: Average Radon Progeny Exposures from 1970 to 2000



Recently updated miner studies have been able to look at the health effects at moderate and lower levels of radon exposure, which are more reflective of today's work environment.

In the early 1980s, several surveys of radon concentrations in homes and other buildings were carried out, and the results of these surveys, together with risk estimates based on the studies of mine workers, provided indirect

evidence that radon may be an important cause of lung cancer in the general population [7]. Recent efforts to investigate the direct association between indoor radon and lung cancer have provided convincing evidence of increased lung cancer risk at levels commonly found in buildings [8]. Risk assessment for radon both in mines and in residential settings have provided clear insights into the health risks due to radon. Radon is now recognized as the second most important cause of lung cancer, after smoking, in the general population.

It has been demonstrated that the combined effects of radon exposure and tobacco use significantly increase the risk of lung cancer. It is estimated that a non-smoker exposed to elevated levels of radon over a lifetime has a 1 in 20 chance of developing lung cancer. That estimate increases to a 1 in 3 chance if a smoker is also exposed to elevated levels of radon over a lifetime [9].

3.3 Regulations and Guidelines

3.3.1 Canadian Nuclear Safety Commission

As Canada's nuclear regulator, the Canadian Nuclear Safety Commission (CNSC) regulates radon and radon progeny in Canada's nuclear facilities to protect the health of uranium workers and the public.

Concentrations of radon in uranium mines and mills and uranium processing fuel fabrication facilities are strictly contained and controlled and must be monitored in air to protect workers. Controls include sophisticated detection and ventilation systems that effectively protect Canadian uranium workers.

The Canadian *Radiation Protection Regulations* limit doses to nuclear energy workers, including uranium miners. The limits of 50 mSv/year and a maximum of 100 mSv for a period of five years are monitored and strictly enforced. In addition, all doses must be As Low As Reasonably Achievable (referred to as the ALARA principle).

Current worker exposures to radon in the uranium mining and processing industry are as low as or only slightly greater than public exposure from natural radon. As a result, their risk of lung cancer from radon is about the same as that of the general public. Today's miners receive an average effective dose of less than 2.5 mSv per year.

Through its regulatory oversight, the CNSC ensures that radioactive exposures to the workers and the public remain well below their respective limits.

3.3.2 Health Canada Guideline

HC has taken a number of steps to protect Canadians from the potential dangers of radon gas in their homes. These include evaluating measurement techniques, conducting research into the effects of radon exposure and developing guidelines.

HC's guideline [4] for exposure to radon has always been based on the best available scientific evidence of health risk. In 1988, a guideline of 800 becquerels (Bq) per cubic meter was established in Canada. Based on new scientific information and a broad public consultation, the guideline was lowered from 800 to 200 Bq/m³ in June 2007². To support the implementation of the revised guideline, a National Radon Program (NRP) [10] was developed in collaboration with the Federal-Provincial-Territorial Radiation Protection Committee, an intergovernmental committee established to advance the development and harmonization of practices and standards for radiation protection within federal, provincial and territorial jurisdictions.

The NRP consists of 5 components:

1. establishment of a national radon laboratory
2. radon testing projects
3. radon database and mapping
4. radon research
5. education and public awareness

² http://www.hc-sc.gc.ca/ewh-semt/radiation/radon/guidelines_lignes_directrices-eng.php

To better understand radon concentrations in homes across Canada, a national residential radon survey was launched in April 2009, with an objective of testing about 18,000 homes. The homes are roughly uniformly distributed in all Canada health regions, with more sampling occurring in northern communities and in regions where radon concentrations are still unknown. The survey will be conducted over a two-year period and will produce radon maps intended for use mainly by governments to prioritize radon outreach and education efforts, to encourage testing and remediation where necessary, and to assist in community planning and future development.

Radon research is another important component of the NRP. The research activity has been focused on solving practical problems or answering questions raised from the general public.

3.3.3 World Health Organization

Radon was identified as a human lung carcinogen in 1986 by the World Health Organization (WHO). The main source of information on risks of radon-induced lung cancer has been epidemiological studies of underground miners [11]. More recent studies have provided informative data on risks at lower levels of exposure [12][13][14].

In 2005, the WHO established the International Radon Project to identify effective strategies for reducing the health impact of radon and to raise public and political awareness about the consequences of long-term exposure to radon. Participants and contributors from more than 30 countries worked together towards a global understanding of a wide range of issues associated with indoor radon.

The WHO International Radon Project key product is the “*WHO handbook on indoor radon a public health perspective*” [15], which focuses on residential radon exposure, emphasizing its impact from a public health viewpoint. It includes detailed recommendations on radon health risk reduction and sound policy options for prevention and mitigation of radon. WHO recommends that, where indicated, comprehensive radon programs be developed, preferably in close linkage with indoor air quality and tobacco control programs. This handbook reflects the long-standing experience of several countries with such radon programs.

WHO proposes a reference level of 100 Bq/m³ to minimize health hazards due to indoor radon exposure. However, if this level cannot be reached under the prevailing country-specific conditions, the chosen reference level should not exceed 300 Bq/m³ which represents approximately 10 mSv per year according to recent calculations by the International Commission on Radiation Protection [16]. HC’s limit of 200 Bq/m³ is below the WHO’s reference level margin of 300 Bq/m³.

3.3.4 Recommended Guideline Levels

Table 2 lists guideline levels provided by other regulatory organizations around the world.

Table 2: Radon Concentration Guidelines for Residential Homes [4][15][16][17]

Organization	Residential Level (Bq/m ³)
Health Canada	200
World Health Organization	100–300
International Commission on Radiological Protection	300
United States Environmental Protection Agency	150
European Union	200

4.0 RADON LEVELS IN CANADA

4.1 Environmental Radon Levels Close to and Far from Uranium Mines/Mills

Canada's current uranium mining and milling activities are situated in remote and isolated areas in Northern Saskatchewan. These activities also took place around Elliot Lake, Ontario during the early to mid-1900s. As radon is a decay product of the radium and uranium-238 decay chain, uranium mining and milling activities would be expected to result in increased background concentrations of radon in the atmosphere. However, at uranium mining and milling facilities, most areas at and around the site (excluding high source related areas) have radon concentrations in the range of less than 1 Bq/m³ to approximately 50 Bq/m³. Within a very short distance from the facilities, usually around the site boundary (a few kilometers from the mine or mill), radon concentrations are close to background levels as determined by reference sites far from the facility. These background levels may range from anywhere between less than 1 Bq/m³ to 20 Bq/m³ [18][19][20][21][22][23][24].

Areas on the site that may have higher radon concentrations are known as high source related areas. These areas are in close proximity to different sources associated with facility operations and include exposed tailings management facilities and ore storage piles. Radon concentrations at these high source related areas may reach values as high as roughly 1,000 Bq/m³ [19][20] and quickly decrease to background levels as one moves away from these sources. Table 3 summarizes these ranges.

Table 3: Range of Radon Gas Concentrations Around Uranium Mines and Mills

Location Relative to Mining/Milling Facilities	Range of Radon Concentrations (Bq/m ³)
On the site before the boundary	1 – 50
Boundary	1 – 20
Reference	1 – 20
High source related areas	1 – 1,000

4.2 Radon Levels in Underground Uranium Mines

As with radon gas concentrations at and around the facility, radon gas levels in underground uranium mines vary considerably depending on the location, type of mining methods, level of radon source control used, and the presence of radon-bearing mine water, which is the largest potential source of radon in the mines in the Athabasca Basin of Northern Saskatchewan.

Although some areas in an underground uranium mine can have radon levels as low as 1 Bq/m³, high source related areas in underground mines may reach radon concentrations just over 100,000 Bq/m³. To prevent miners from being exposed to elevated concentrations of RDPs, engineering design and control processes are applied in these mines, in order to limit radon bearing groundwater sources and to capture the radon gas at the source for direct contained exhaust. These control processes limit radon gas concentrations in the general areas traveled by miners underground to be less than 100 Bq/m³ [18][20][22].

4.3 Radon Levels in Homes in Different Parts of the Country

The first Cross-Canada Radon Survey took place during the summers of 1977, 1978 and 1980, where radon levels were measured in 14,000 homes from 18 cities across Canada [25]. More recent surveys in the provinces of British Columbia (1500 homes in 2007) [27], Quebec (449 in the 1990s) [28], Nova Scotia (719 homes) [27], and the city of Ottawa (169 homes between 2005 and 2007) [29][30] have provided additional data on radon concentrations in Canadian homes.

Vancouver, Montreal and Quebec were all included in the 1970s national survey. Both Vancouver and Quebec show increases in the estimated average radon concentration in the recent surveys compared to the 1970s surveys. Table 4 shows the mean residential radon concentrations in the 10 provinces of Canada. This data combines the information provided by the more recent surveys to those of the 1970s national survey for the provinces of British Columbia, Ontario, Quebec and Nova Scotia.

Table 4: Mean Residential Radon Concentrations in 10 Canadian Provinces
(Table Reproduced from Chen & Moir, 2010 [27])

Province	Population	Percentage of Dwellings Above 200 Bq/m ³	Arithmetic Mean (Bq/m ³)	Population Annual Effective Dose (mSv)
British Columbia	4,310,452	2.5	43.8	1.1
Alberta	3,375,763	3.1	38.1	0.96
Saskatchewan	985,386	8.8	74.5	1.88
Manitoba	1,177,765	19	143	3.6
Ontario	12,686,952	2.5	38.7	0.98
Quebec	7,651,531	1	34.5	0.87
New Brunswick	749,168	5.3	51.5	1.3
Nova Scotia	934,405	10	108	2.72
Prince Edward Island	138,519	6.1	55.9	1.41
Newfoundland and Labrador	509,677	2.7	33.8	0.85
Canada population weighted		3.3	45.5	1.15

Based on the information provided by these surveys and the assessment made by Chen & Moir (2010), the Canada population weighted average of radon in residential homes is 45.5 Bq/m³, with 3.3% of Canadian homes having a radon concentration greater than the Health Canada Guideline Level of 200 Bq/m³. Figure 5 provides a map of Canada and average provincial radon concentrations. The average provincial concentrations are also presented in Figure 6 along with the Health Canada Guideline Level of 200 Bq/m³.

Figure 5: Average Radon Concentrations in Canadian Provinces

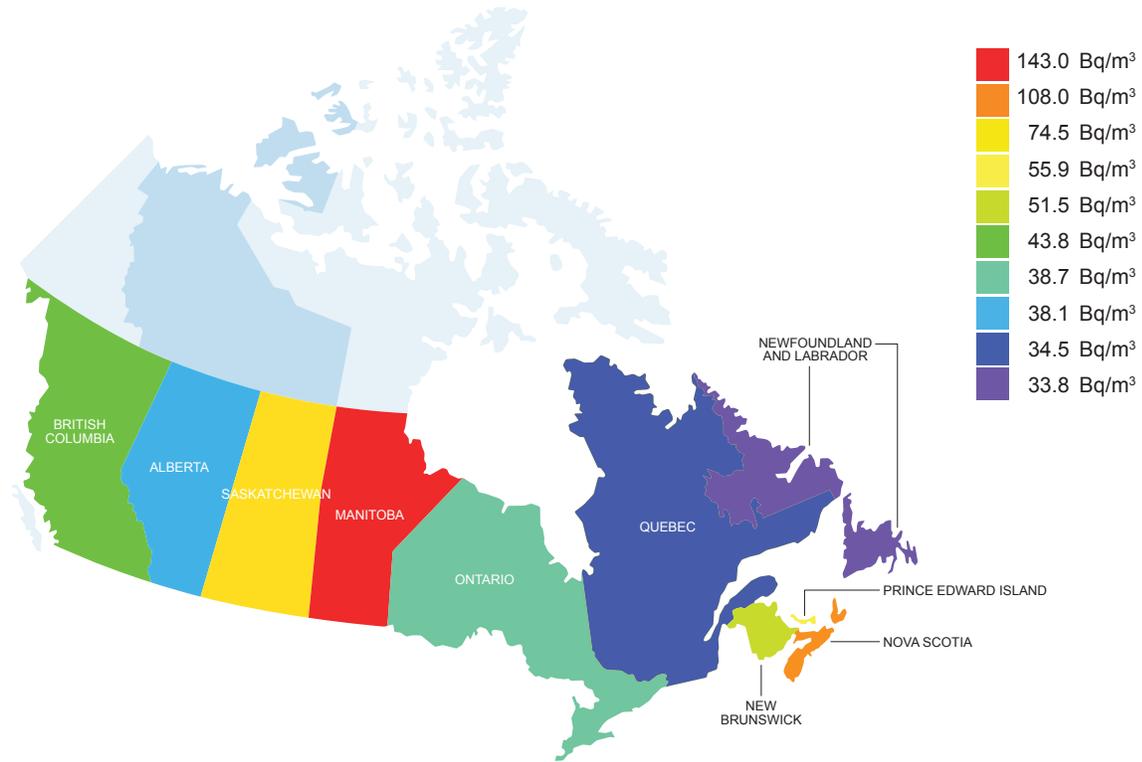
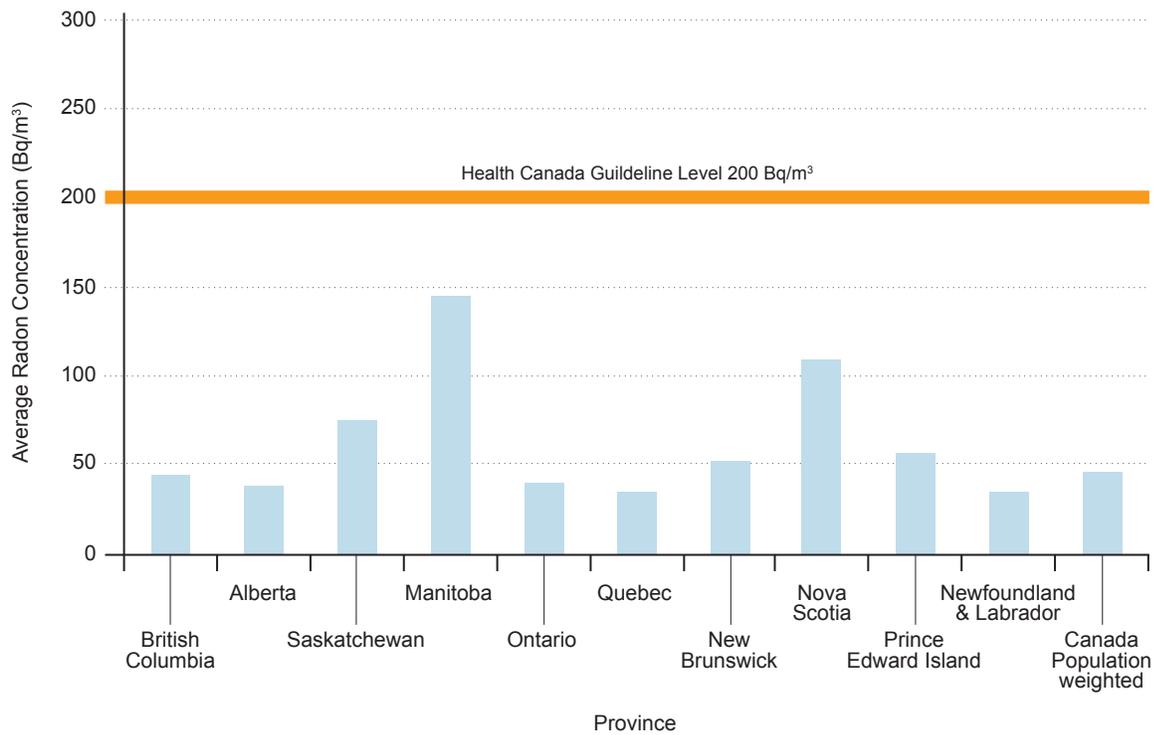


Figure 6: Average Radon Levels in Canadian Homes



A new Cross Canada Residential Radon Survey is underway and consists of two phases. The first phase ran from July 2009 to June 2010, testing approximately 7,000 homes nationwide. Phase 2 is to occur between July 2010 and June 2011, with data to be collected from approximately 9,000 homes across Canada [26]. The results of the first survey were released on November 30, 2010. For more information, please visit the Health Canada Web page on the Cross Canada Residential Radon Survey [26].

5.0 CONCLUSIONS

Radon is a natural source of radiation that results from the radioactive decay of uranium in soils and rocks. It is the largest source of naturally occurring radiation exposure for Canadians and varies with geology across the country. It can be found in mines and in buildings and basements, and can be found in the atmosphere at low concentrations. Generally, radon exposures in Canada are very low.

Studies of underground miners and residential radon exposures over the years has confirmed that long-term exposure to elevated levels of radon increases the risk of developing lung cancer. There is currently no convincing or consistent evidence that radon and radon decay products exposures cause other diseases or cancers. Cigarette smoke remains the most significant cause of lung cancer.

In uranium mines and mills, engineering design and control processes are used to capture radon at high source related areas in order to limit exposure and effective doses to miners to levels that are well below the radiation exposure limits. The current risks to lung cancer from radon and radon progeny from the operating mines and mills is very low with these controls in place.

The CNSC regulates radon in Canada's nuclear facilities to protect workers, members of the public and the environment. The CNSC ensures that the air quality in uranium mines is tightly controlled with good ventilation to limit exposure to workers. As a result, the lung cancer risk for today's uranium mining and processing workers is the same as that for the general Canadian public. Radon exposure to members of the public from CNSC-regulated activities is virtually zero.

Because of the regulatory oversight of the CNSC on radon exposure, doses to uranium miners and the public remain low. This promotes confidence that Canadians are being protected.

6.0 GLOSSARY

ALARA principle: a principle for keeping the amount of exposure to radon progeny and doses from radiation As Low as Reasonably Achievable, social and economic factors being taken into account.

Dose: a measure of one's exposure to radiation.

Half-life: the time that an initial quantity of radioactive material takes to decay to one half of its original amount.

Isotopes: different types of atoms of the same chemical element, distinguishable by a different number of neutrons in their nuclei.

Radiation: emission from a nuclear substance with sufficient energy for ionization.

Radioactive decay: the process by which an unstable atomic nucleus loses energy by emitting ionizing particles or radiation, such as alpha, beta particles, and gamma rays.

Radon: a naturally occurring radioactive element.

Radon progeny: the collection of radon decay products in the Radon-222 decay chain (Bismuth-214, Lead-214, Polonium-214 and Polonium-218).

Reference site: a location whose atmospheric radon gas concentrations are considered to be at natural background levels, and that is located far from a mining or milling facility.

Site boundary: the perimeter enclosing the area in which a uranium mining or milling facility is licensed to operate.

7.0 LIST OF ACRONYMS AND ABBREVIATIONS

ALARA	As Low As Reasonably Achievable
Bq	Becquerel
CNSC	Canadian Nuclear Safety Commission
EU	European Union
FPTRPC	Federal-Provincial-Territorial Radiation Protection Committee
HC	Health Canada
ICRP	International Commission on Radiological Protection
NRP	National Radon Program
RDPs	Radon Decay Products
Rn	Radon
USEPA	United States Environmental Protection Agency
WHO	World Health Organization

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