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Paper

A COMPARATIVE STUDY OF RADON LEVELS IN FEDERAL BUILDINGS AND RESIDENTIAL HOMES IN CANADA

Jeffrey Whyte,[1,2] Renato Falcomer,[1] and Jing Chen[1]

Abstract—**Shortly after revision of the Canadian radon guideline from 800 to 200 Bq m^{-3}, Health Canada established the Federal Building Testing Program in 2007 to demonstrate federal leadership in raising awareness about radon risk and the need for testing. By the end of 2017, more than 7,600 federal workplaces had been tested for radon. As is the case in all radon surveys, radon levels vary widely; federal building results ranged from below the detection limit to more than 2,500 Bq m^{-3} in a few rooms of a few buildings. Weighted by the population of federal public servants across Canada, the average radon distribution in federal workplaces has a geometric mean of 22.0 Bq m^{-3} with a geometric standard deviation of 2.3. The population-weighted arithmetic mean is 34.3 Bq m^{-3}, significantly lower than the population-weighted average radon concentration of 72.9 Bq m^{-3} in residential homes across Canada. On average, 2% of federal workplaces have radon concentrations above 200 Bq m^{-3}, which is also significantly lower than the 7% of residential homes that tested above 200 Bq m^{-3}. This comparative study demonstrated clearly that radon education and awareness in Canada should focus more on residential testing and remediation actions to effectively reduce the burden of radon-induced lung cancer.**

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INTRODUCTION

RADON IS a naturally occurring radioactive gas generated by the decay of uranium-bearing minerals in rocks and soils. Since radon is a gas, it can move freely through the soil, enabling it to escape into the atmosphere or seep into homes and buildings. Epidemiological studies have confirmed that exposure to radon in workplaces and homes increases the risk of developing lung cancer. Exposure to indoor radon has been determined to be the second leading cause of lung cancer after tobacco smoking (WHO 2009).

In collaboration with provincial and territorial governments, the Canadian guideline was lowered from 800 to 200 Bq m^{-3} in June 2007 (Health Canada 2007). At about the same time, Health Canada embarked on multiple campaigns to collect indoor radon measurements from workplaces and residences.

The first and longest running campaign was the Federal Building Testing Program. It was initiated in 2007 to gain a better understanding of the distribution of radon concentrations in homes and workplaces across the country and to demonstrate federal leadership in raising awareness about radon risk and the need for testing. The program offered free radon testing for all buildings under the jurisdiction of the Government of Canada, thereby providing federal employers and building managers with information to assess whether remediation was necessary. All federally owned properties were eligible to participate, including many different types and sizes of workplaces as well as residential homes owned by federal departments. Between 2007 and 2017, the approximately 20,000 federally owned properties across Canada were tested. For the purposes of this study, only the results for workplaces (mainly office buildings) are reported and used in the analysis.

To better characterize Canadians' exposure to radon in their homes, a national residential radon survey was launched in April 2009. Radon testing was performed in 2009–2010 and 2010–2011 during the fall/winter periods, and results were obtained from about 14,000 homes across Canada. Results of

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Table 1. Annual population in federal public service as of March 2015 (Statistics Canada 2018) and Canadian population from 2006 census (Statistics Canada 2010).

Location	Public servants	Population
British Columbia (BC)	22,923	4,113,487
Alberta (AB)	14,428	3,290,350
Saskatchewan (SK)	5,884	968,157
Manitoba (MT)	10,088	1,148,401
Ontario (ON)[a]	37,791	11,313,161
National Capital Region (NCR)	107,288	1,130,761
Quebec (QC)[b]	29,374	7,262,491
New Brunswick (NB)	8,281	729,997
Prince Edward Island (PEI)	3,115	135,851
Nova Scotia (NS)	10,549	913,462
Newfoundland (NL)	4,711	505,469
Yukon Territory (YT)	367	30,372
Northwest Territories (NWT)	472	41,464
Nunavut (NU)	286	29,474
Canada	**255,557**	**31,612,897**

[a]Ontario, excluding the National Capital Region.
[b]Quebec, excluding the National Capital Region.

this 2 y residential radon survey were reported in 2012 (Health Canada 2012) and broken down by province and health region. Following the cross-Canada radon survey, a smaller survey of about 3,200 homes was conducted to quantify indoor radon and thoron concentrations separately. The study area included 33 census metropolitan areas, covering approximately 70% of the Canadian population (Chen et al. 2015).

Due to differences in building characteristics and construction requirements/standards, radon levels in workplaces can differ significantly from the levels in residential homes. In this study, measurements collected are summarized to compare radon distribution parameters for Canadian workplaces and Canadian homes, and the implications are briefly discussed.

MATERIALS AND METHODS

Participation in the Federal Building Testing Program was voluntary. To test for radon in federally owned properties, Health Canada provided long-term radon detectors and instructions on where to place them to building owners or their delegates. Health Canada also conducted all laboratory analyses. Each individual department or building manager was responsible for deploying detectors in the buildings and sending them back to Health Canada's National Radon Laboratory for analysis (the uncertainty of detector analyses was checked annually and kept within 10%). All radon tests were conducted for at least 3 mo, generally in the fall/winter period. The results analyzed here are all from tests using alpha track radon detectors. Test results were reported to property owners for action.

As mentioned, in this study only indoor workplaces, i.e., nonresidential federal properties, are considered in the statistical analysis. Federally owned indoor workplaces include office buildings, laboratories, healthcare facilities, penitentiaries, bank buildings, schools, daycares, and others.

For some workplaces, especially large office buildings, multiple occupied spaces were tested in each building to account for differences across the building footprint. When a test involved two or more measurements in a single building, the average radon concentration was calculated and assigned as the representative radon concentration for that workplace. As well, some properties were tested more than once to confirm earlier results or to assess the effectiveness of remediation actions. When the data set contained multiple test results for a single address location, the most recent test results are considered in the current analysis.

Because more than 40% of federal public servants are employed in the National Capital Region (NCR), the NCR is treated as a special region excluded from the provinces of Ontario and Quebec in all analyses.

For calculating population-weighted radon distribution characteristics in federal workplaces, the annual total population in the federal public service by province was used (Statistics Canada 2018), as given in Table 1. The total population of public servants includes indeterminate, term, and casual employees as well as students.

Table 2. Radon distribution characteristics (GM and GSD), average radon levels (AM), and percentage of buildings above 200 Bq m^{-3} in federal workplaces from 10 provinces, 2 territories, and the National Capital Region (GM is the geometric mean in Bq m^{-3}, GSD is the geometric standard deviation, AM is the arithmetic mean in Bq m^{-3}; location abbreviations from Table 1).

Location	Employees	Buildings tested	GM	GSD	AM	>200 Bq m^{-3}(%)
BC	22,923	1,272	17.3	2.5	32.9	2.0
AB	14,428	733	23.8	2.1	32.8	1.0
SK	5,884	342	40.0	2.8	70.8	8.2
MB	10,088	852	39.5	2.6	64.0	4.7
ON[a]	37,791	1,475	20.4	2.4	33.2	2.1
NCR	107,288	282	20.8	2.1	29.2	1.4
QC[b]	29,374	1,242	18.6	2.5	32.1	1.3
NB	8,281	418	32.6	2.7	58.8	4.8
PEI	3,115	51	17.3	2.1	24.6	2.0
NS	10,549	581	21.6	2.5	37.5	2.2
NL	4,711	265	22.6	2.3	34.7	0.8
YK	367	56	40.6	2.3	57.7	1.8
NT	472	37	20.8	2.4	29.3	0.0
NU	286	—	—	—	—	—
Canada	**255,557**	**7,606**	**22.0**	**2.3**	**34.3**	**2.0**

[a]Ontario, excluding the National Capital Region.
[b]Quebec, excluding the National Capital Region.

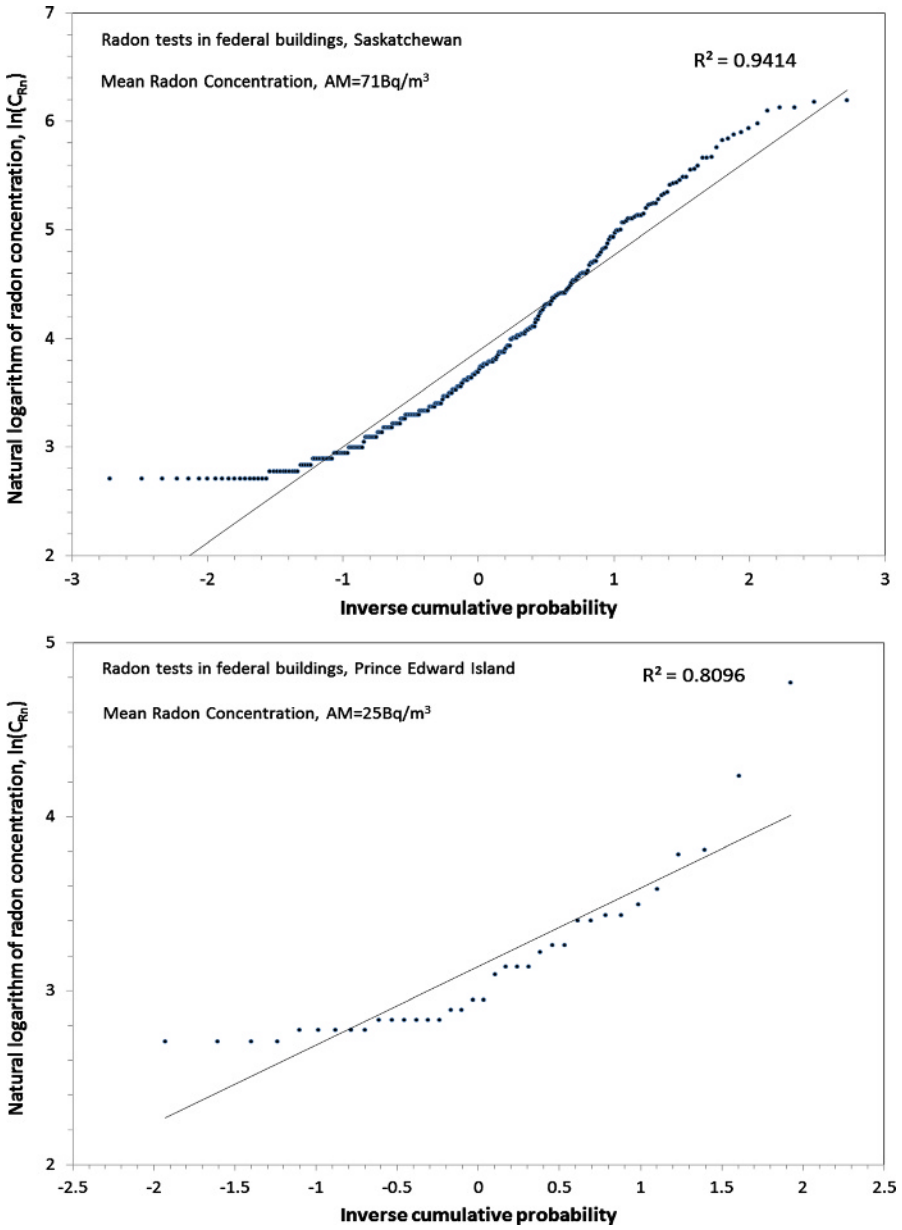

Fig. 1. Inverse cumulative probability distribution of radon concentration (C_{Rn}) in federal buildings within Saskatchewan (upper panel) and Prince Edward Island (lower panel).

Data for radon levels in residential homes are taken from various surveys (Chen et al. 2008, 2015; Health Canada 2012). Detectors and the instructions for deploying them were sent to homeowners; the instructions followed the procedure outlined in Health Canada's guide for radon measurements in residential dwellings (Health Canada 2008). All studies recruited participants during the summer so that testing could be done in fall/winter (October to March) for at least 3 mo. Alpha track detectors were used in all residential surveys considered here. During the past decade, three residential radon surveys were conducted in the NCR with a total of 330 homes tested for radon (Chen et al. 2008, 2015; Health Canada 2012). The results of radon in NCR homes were pulled together for calculation of radon distribution parameters which then were compared to radon distribution characteristics in federal workplaces in the NCR.

To compare radon exposure in federal workplaces to that in residential homes, radon distribution characteristics of the cross-Canada radon survey were calculated for provinces and the NCR. As in the report *Cross-Canada Survey of Radon Concentrations in Homes* (Health Canada 2012), the population of the 2006 census, which was the most currently available population estimate at the time the study

Table 3. Radon distribution characteristics (GM and GSD), average radon levels (AM), and percentage of homes above 200 Bq m^{-3} in residential homes from 10 provinces, 3 territories, and the National Capital Region (Chen et al. 2008, 2015; Health Canada 2012). Location abbreviations from Table 1.

Location	Population	Homes tested	GM	GSD	AM	>200 Bq m^{-3} (%)
BC	4,113,487	1,817	24.2	2.2	40.3	3.9
AB	3,290,350	1,131	64.5	2.3	87.8	5.7
SK	968,157	1,206	89.2	2.4	127.8	15.7
MB	1,148,401	1,183	95.1	2.6	137.9	19.4
ON[a]	11,313,161	3,886	35.0	2.8	61.2	4.4
NCR	1,130,761	328	64.0	2.5	97.4	9.9
QC[b]	7,262,491	1,722	36.2	3.1	70.7	7.9
NB	729,997	830	67.6	3.7	154.6	20.6
PEI	135,851	113	23.7	2.9	45.7	3.5
NS	913,462	592	40.1	3.5	100.9	10.6
NL	505,469	713	32.4	3.1	63.8	5.1
YK	30,372	225	87.2	3.1	175.1	19.6
NT	41,464	185	38.6	3.0	69.5	5.4
NU	29,474	78	9.3	1.5	10.3	0.0
Canada	**31,612,897**	**14,009**	**42.7**	**2.8**	**72.9**	**7.0**

[a]Ontario, excluding the National Capital Region.
[b]Quebec, excluding the National Capital Region.

was initiated in 2009, was used in the current analysis, as shown in Table 1.

RESULTS AND DISCUSSION

In the past 10 y, more than 7,600 federal workplaces were tested for radon. Radon distribution characteristics derived from these results are summarized in Table 2 by province, territory, and the NCR. As is the case in all radon surveys, radon levels in indoor workplaces vary widely; Table 2 presents a range from below the detection limit (DL ≈ 15 Bq m^{-3}) to more than 2,500 Bq m^{-3} in a few rooms of a few buildings. The average radon concentration, i.e., the arithmetic mean (AM) radon concentration, was highest in Saskatchewan at 71 Bq m^{-3} and lowest in Prince Edward Island at 25 Bq m^{-3}. Percentages of buildings above 200 Bq m^{-3} varied from 0% in the Northwest Territories to 8.2% in Saskatchewan.

Generally speaking, radon levels follow a lognormal distribution, as demonstrated in many residential radon surveys including the cross-Canada radon survey in each province. Two examples of radon measurements in federal buildings are shown in Fig. 1: the radon distribution in (1) 306 federal buildings that tested above the DL in Saskatchewan (upper panel) and (2) 37 federal buildings that tested above the DL in Prince Edward Island (lower panel). Except for data points close to the DL at the bottom left corner and a few outliers with high radon concentrations, most data points fall on a nearly straight line implying that the data fit reasonably well a lognormal distribution (R^2 = 0.94 for buildings in Saskatchewan, R^2 = 0.81 for buildings in Prince Edward Island).

The characteristic parameters of radon distributions in federal buildings were calculated. When calculating the averages, results below the detection limit were assigned a value of roughly half of the DL, i.e., 8 Bq m^{-3}. Weighted by the population of federal public servants across Canada, the average radon distribution in federal workplaces has a geometric mean (GM) of 22.0 Bq m^{-3} with a geometric standard deviation (GSD) of 2.3. The population-weighted AM is 34.3 Bq m^{-3}. On average, 2% of federal workplaces have radon concentrations above 200 Bq m^{-3} at which value remediation is recommended. Since federal workplaces cover a variety of indoor workplaces across Canada from major cities to remote areas, the radon distribution characteristics derived from the federal workplace radon survey can be considered representative for indoor workplaces in Canada.

Radon distribution characteristics in residential homes are calculated based on three previous surveys (Chen et al. 2008, 2015; Health Canada 2012). Results are summarized in Table 3 by province, territory, and the NCR. More than 14,000 homes were tested for radon. Weighted by population, the average radon distribution in Canadian homes has a GM of 42.7 Bq m^{-3} with a GSD of 2.8. The population-weighted AM is 73 Bq m^{-3}. On average, 7% of Canadian homes have radon concentrations above 200 Bq m^{-3}. Since the cross-Canada residential radon survey covered all 123 health regions defined by the provincial ministries of health as administrative areas across Canada, the radon distribution characteristics derived from the above-mentioned residential radon surveys can be considered representative for radon in Canadian homes.

Table 4. Percentage of test results above 200 Bq m^{-3} in federal workplaces and in Canadian homes (location abbreviations from Table 1).

Location	Workplaces (%)	Homes (%)	Ratio workplace/homes
BC	2.0	3.9	0.52
AB	1.0	5.7	0.17
SK	8.2	15.7	0.52
MB	4.7	19.4	0.24
ON[a]	2.1	4.4	0.47
NCR	1.4	9.9	0.14
QC[b]	1.3	7.9	0.16
NB	4.8	20.6	0.23
PEI	2.0	3.5	0.56
NS	2.2	10.6	0.21
NL	0.8	5.1	0.15
YK	1.8	19.6	0.09
NT	0.0	5.4	0.00
Canada	**2.0**	**7.0**	**0.27**

[a]Ontario, excluding the National Capital Region.
[b]Quebec, excluding the National Capital Region.

Comparing radon levels in federal workplaces with radon levels in residential homes, from Tables 2 and 3, the radon distribution parameters are consistently lower in workplaces than in homes. Significantly lower radon concentrations found in workplaces are likely due to higher standards for building construction, optimized building operation, and especially the higher ventilation rates employed in the majority of workplaces.

The number of test results above 200 Bq m^{-3} is one of the parameters frequently used to describe the potential radon distribution. Table 4 shows that the percentage of workplaces having radon levels above 200 Bq m^{-3} is significantly lower than the percentage of homes above 200 Bq m^{-3} in all provinces and territories as well as in the NCR. In the province of New Brunswick, more than 20% of homes tested have radon concentrations above 200 Bq m^{-3} compared to less than 5% of federal workplaces. On average, the percentage of federal workplaces having radon above 200 Bq m^{-3} is more than 70% lower than the percentage of homes above 200 Bq m^{-3}.

It is well known that an individual's risk of radon-induced lung cancer increases with radon concentration and the duration of exposure. This comparative study shows that indoor radon concentrations are, on average, twice as high in homes as in workplaces. Since Canadians aged 15 y and older spend more than 70% of their time at home (Statistics Canada 2015), it is clear that residential exposure is the larger contributor to radon-induced lung cancer risk. Health Canada maintains that all indoor environments where people spend more than 4 h d^{-1} should be tested and remediated if levels exceed the Canadian guideline; however, these results underscore the important role of homeowners in protecting themselves and their families.

Much of the power to reduce the national burden of radon-induced lung cancer is within the jurisdiction of the Canadian homeowner. However, evidence indicates that homeowners are not exercising that power. While more Canadians in 2016 were aware of the risks of radon than ever before, testing rates remain low, at less than 6% of homeowners who had heard of radon (Statistics Canada 2016). In 2015, participants from the Health Canada residential surveys whose homes had tested near or above the radon guideline were contacted to see if they had done anything to reduce their radon levels (Health Canada 2018). This follow-up study revealed that only about 29% of these people reported taking steps to reduce the radon levels in their homes. For those homeowners who tested above 800 Bq m^{-3}, the mitigation rate was only 39%. These remediation rates are comparable to the rates in other countries, such as 15% in England (Zhang et al. 2011), 22% in Ireland (Dowdall et al. 2016), and 46% in Switzerland (Barazza et al. 2018). The Canadian National Radon Program has worked hard over the past 10 y to educate Canadians about radon and encourage them to take action; however, there is clearly much more work to do.

CONCLUSION

From 2007 to 2017, more than 7,600 federally owned indoor workplaces were tested for radon. Due primarily to much higher ventilation rates employed in workplaces, as well as better construction and often optimized building operation, the percentage of Canadian workplaces having radon levels above 200 Bq m^{-3} is estimated to be 2%, significantly lower than the 7% of Canadian homes above 200 Bq m^{-3} as shown in various residential radon surveys.

People spend more time at home than in workplaces. This comparative study showed that most of the radon exposure received by an individual comes from home where radon levels, on average, are a factor of 2 higher than in the workplace. Because an individual's risk of radon-induced lung cancer increases with radon concentration and the length of exposure time, it is important to further strengthen radon education and awareness activities within the National Radon Program, with the focus on residential homes to effectively reduce the health burden of radon-induced lung cancer in Canada.

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