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AN UPDATED ASSESSMENT OF RADON EXPOSURE IN CANADA

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Based on data from a national residential radon survey performed in 18 cities in Canada in the 1970s, an annual effective dose to the Canadian population due to indoor radon exposure was estimated at 0.71 mSv. An updated estimate of radon exposure in Canada has been made using additional indoor radon data from recent surveys in Ontario and Nova Scotia, and in 28 communities of British Columbia and 15 regions of Quebec. The associated annual effective dose to the Canadian population is now estimated to be 1.15 mSv. The percentage of homes in Canada with radon concentrations above the Canadian Radon Guideline of 200 Bq m^{-3} is estimated to be about 3.3 %. As might be expected, this number varies significantly (from a low of 1 % of homes above the Guideline to a high of 19 %) from region to region. Because more radon data are included in the current assessment, and the data set covers broader geographical areas, the current assessment better represents the radon exposure in Canada.

INTRODUCTION

Naturally occurring radon in indoor air has been identified as the second leading cause of lung cancer after tobacco smoking[1]. To establish the geographical variation of radon and radon progeny, a multi-year survey was carried out in more than 14 000 homes during 1977, 1978 and 1980 in 19 cities[2]. Information on radon concentrations was available for 18 of the cities from this survey. Based on the populations of those 18 cities in the early 1980s, population-weighted national averages were estimated for the arithmetic mean radon concentration, 28.3 Bq m^{-3}, and the geometric mean radon concentration, 11.2 Bq m^{-3}, with a geometric standard deviation of 3.9, as given in the original publications[2,3]. With these characteristics, the annual effective dose to the Canadian population due to indoor radon exposure was estimated to be 0.71 mSv[4].

Since then, more residential radon surveys have been conducted in various communities across Canada. With the additional information, an update on radon exposure in Canada is provided here. In addition to the characteristics of radon distribution and associated annual effective dose, percentages of dwellings above the Canadian guideline of 200 Bq m^{-3} were assessed for individual provinces of Canada.

METHODS

Assessments were performed for individual provinces with additional radon survey results available in recent years. Radon information for the three territories is still very limited. Radon results were available in different forms. Some survey results were given as arithmetic mean radon concentration (AM) with or without standard deviation (SD), and others as geometric mean radon concentration (GM) and associated geometric standard deviation (GSD).

To calculate annual effective doses from radon exposure, the formula recommended by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)[4,5] was applied:

$$\text{Annual effective dose} = \text{AM (Bq m}^{-3}) \times 0.4 \times 7000\ \text{(h)} \times 9\ \text{(nSv (Bq m}^{-3}\ \text{h)}^{-1}),$$

where AM is the arithmetic mean radon concentration in the units of Bq m^{-3}, the typical value of 0.4 was used as the equilibrium factor for radon indoors, a recommended value of 9 nSv (Bq m^{-3} h)$^{-1}$ was used to convert radon equilibrium-equivalent concentration to population effective dose, and 7000 h or 80 % of home occupancy was assumed. The annual effective dose depends only on the AM. In the case where the value of AM was not specifically given in the original survey report of a community, the arithmetic mean radon concentration was derived from the given radon distribution, i.e. calculated from the radon distribution of given GM and GSD.

To derive the average parameters for a province, such as the average AM, results of individual communities were weighted with the current population (2006 Census). The national average is the population-weighted average of results from each province.

The percentage of dwellings above the Canadian guideline of 200 Bq m^{-3} in a city or community is either taken directly from the original survey report or calculated from the log-normal radon distribution of a given GM and GSD.

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RESULTS

Information on radon concentration distributions (GMs and GSDs) was available for 18 cities in the past national radon survey[2]. These cities were Vancouver, Calgary, Edmonton, Regina, Saskatoon, Winnipeg, Brandon, Thunder Bay, Toronto, Sudbury, Montreal, Sherbrooke, Quebec, Fredericton, Saint John, Charlottetown, St. Lawrence and St. John's. For most of those cities, they are the only information available up to now for radon in homes. Therefore, for those cities where more recent radon information is not yet available, the results of the last national radon survey were used in the present assessment. The justification for the inclusion of those data was validated by a recent radon/thoron survey in the city of Winnipeg[6] where no significant changes in the characteristics of indoor radon concentrations were observed 30 years after the first radon survey in Winnipeg. In Letourneau *et al.*[2], parameters of radon distributions, i.e. GMs and GSDs, were given for the 18 cities. For the current assessment, arithmetic mean radon concentrations and percentages of dwellings above 200 Bq m^{-3} were derived from the corresponding log-normal radon distributions, and are summarised in Table 1.

In the past national radon survey, radon data were not available for the province of Nova Scotia (NS).

Table 1. Derived arithmetic mean (AM) radon concentrations and the percentage of dwellings above 200 Bq m^{-3} in the 18 cities surveyed in late 1970s.

City	Population (2006 Census)	AM (Bq m^{-3})	Percentage of dwellings above 200 Bq m^{-3}
Vancouver, BC	2 199 100	9.6	0.1
Calgary, AB	1 100 700	26.2	1.3
Edmonton, AB	1 051 500	50.6	5.0
Regina, SK	198 800	111	14.5
Saskatoon, SK	236 800	43.9	4.0
Winnipeg, MB	707 500	146	19.8
Brandon, MB	41 511	95.8	12.0
Thunder Bay, ON	125 400	57.0	6.0
Toronto, ON	5 424 000	19.5	0.3
Sudbury, ON	162 300	54.7	5.4
Montreal, QC	3 669 000	21.9	0.7
Quebec, QC	720 900	25.5	1.4
Sherbrooke, QC	165 100	51.7	5.5
Saint John, NB	126 100	43.0	4.3
Fredericton, NB	105 300	61.6	6.4
Charlottetown, PEI	114 500	55.9	6.1
St. Lawrence, NL	1350	125	16.1
St. John's, NL	182 300	33.1	2.6

In 1990, 719 individual dwellings in Nova Scotia were measured for radon concentration[6]. The mean radon level, the AM, was found to be 108 Bq m^{-3} with a standard deviation of 400 Bq m^{-3}. About 10 % of homes tested had radon concentrations above 200 Bq m^{-3}. Since cities or communities were not specified for those dwellings, a population weighting could not be performed for the Nova Scotia data. Therefore in this re-assessment, results for Nova Scotia were taken directly from the summary of the 1990 Survey[7].

The provincial government of British Columbia (BC) published the results of a radon survey in more than 1500 homes in 2007[8]. Those homes tested for radon were distributed in 28 cities or communities. Twenty-five cities/communities had more than 10 homes surveyed. Based on the populations in those 25 cities/communities, the population-weighted average radon concentration (arithmetic mean) in British Columbia was estimated to be 43.8 Bq m^{-3} with 2.5 % dwellings above the current Canadian radon guideline of 200 Bq m^{-3}, as given in Table 2. Those results were used for the province of British Columbia in the re-assessment instead of the single data point for the city of Vancouver from the past national radon survey as listed in Table 1.

Radon information for the capital city of Ottawa became available recently[9,10]. The arithmetic mean radon concentration in Ottawa was 120 Bq m^{-3}; and 12 % of Ottawa homes had radon concentrations above 200 Bq m^{-3}. Together with three other cities (Thunder Bay, Toronto and Sudbury) surveyed in the past as given in Table 1, the population-weighted average radon concentration for the province of Ontario (ON) was estimated to be 38.7 Bq m^{-3}. It was estimated that 2.5 % of dwellings in Ontario could have radon levels higher than 200 Bq m^{-3}.

Based on the last national radon survey in the three cities in the province of Quebec, the population-weighted arithmetic mean radon concentration is estimated to be 23.5 Bq m^{-3}, and 1.0 % of dwellings in the province of Quebec could have radon concentrations in excess of 200 Bq m^{-3}. In recent years, the Quebec provincial government has conducted a series of radon surveys in 15 regions[11], as shown in Table 3. The population-weighted arithmetic mean radon concentration and standard deviation for Quebec are estimated to be 34.5 and 41.8 Bq m^{-3}, respectively. It is commonly agreed that radon concentrations follow a log-normal distribution[4,5]. A log-normal distribution is described with a geometric mean and geometric standard deviation. A log-normal radon distribution with GM = 22.1 Bq m^{-3} and GSD = 2.58 best fits the radon results (AM = 34.6 Bq m^{-3} and STD = 41.7 Bq m^{-3}) for the province of Quebec, i.e. the parameters of GM = 22.1 Bq m^{-3} and GSD = 2.58 provide a radon distribution of AM = 34.6 Bq m^{-3}

Table 2. Provincial radon survey in British Columbia.

Location	Population	No. of homes tested	AM (Bq m^{-3})	Percentage of dwellings above 200 Bq m^{-3}
Atlin	400	12	118	14.4
Barriere	1723	38	201	30
Castlegar	7359	68	240	30.9
Clearwater	2383	50	447	40.3
Cranbrook	18 493	88	50	4.3
Fernie	4289	10	78	10
Fort Nelson	4612	50	67	4
Fort St. John	17 933	68	50	4.4
Kamloops	83 129	75	39	0
Kelowna	110 351	71	83	4.3
Kimberley	6184	24	99	16.7
Nelson	9326	71	120	15.7
Pemberton	2349	15	29	0
Penticton	32 544	68	108	12.1
Prince George	72 889	75	127	12
Queen Charlotte Island	950	67	16	0
Quesnel	9475	68	53	1.5
Squamish	15 495	26	29	0
Terrace	11 475	70	40	0
Trail	7248	67	107	10.1
Valemount	1018	47	79	6.4
Vancouver	599 780	135	18	0
Vernon	36 922	65	73	5.1
Victoria	80 871	58	19	0
Whistler	9795	60	26	0
Population-weighted provincial average			43.8	2.5

Table 3. Provincial radon survey in Quebec.

Regions	Population	AM (Bq m^{-3})	STD (Bq m^{-3})
Bas Saint Laurent	201 642	45.4	57.2
Saguenay/Lac Saint Jean	273 434	33.9	43.5
Quebec	675 450	57.4	121
Mauricie	261 149	13.3	10.5
Estrie	303 730	28.5	19.9
Montreal	1 871 846	20.1	19.0
Outaouais	349 377	27.2	25.8
Abitibi-Temiscamingue	145 192	12.4	12.0
Cote-Nord	95 668	40.0	63.4
Gaspesie	95 461	71.9	84.6
Chaudiere-Appalaches	399 563	62.2	80.6
Laval	381 651	35.5	29.2
Lanaudiere	445 188	38.3	48.3
Laurentides	528 318	25.7	32.2
Monteregie	1 403 360	41.5	38.5
Population-weighted provincial average		34.5	41.8

and STD = 41.7 Bq m^{-3}. With this best-fit log-normal radon distribution, it is estimated that only 1.0 % of Quebec dwellings would have radon levels above 200 Bq m^{-3}, the same estimation as that obtained from the three cities surveyed in the late 1970s.

In recent years, especially after the announcement of the new Canadian guideline for radon in indoor air[12], many small scale radon surveys have been conducted in various jurisdictions, in particular in schools and public buildings. Because the number of buildings being tested for radon in individual communities were very limited, those results were not included in the current assessment. For a province where no additional radon data is currently available, the population-weighted average radon concentration and percentage of dwellings above 200 Bq m^{-3} was assessed based on the available information listed in Table 1. This applied to Alberta (AB), Saskatchewan (SK), Manitoba (MB), New Brunswick (NB), Prince-Edward-Island (PEI), and Newfoundland and Labrador (NL. A summary of the updated assessment for the ten provinces is given in Table 4. For each province, the results were population-weighted averages of the results from individual cities/communities/regions except for the province of Nova Scotia. Weighted with populations of individual provinces, the national average radon concentration is estimated to be 45.5 Bq m^{-3}, and 3.3 % Canadian homes are estimated to have radon concentrations above the guideline.

The annual effective doses due to radon exposure are also provided in Table 4. They are effective doses based on the formula recommended by the UNSCEAR[4,5]. On average, the annual effective dose to the Canadian population is estimated to be 1.15 mSv.

DISCUSSION

Radon concentrations vary geographically. The average indoor radon concentration was 33.8 Bq m^{-3} in Newfoundland and Labrador while the radon level reached 143 Bq m^{-3} in Manitoba. It is well known

Table 4. Available information on radon exposure in the 10 provinces of Canada.

Province	Population	Percentage of dwellings above 200 Bq m^{-3}	AM (Bq m^{-3})	Population annual effective dose (mSv)
British Columbia	4 310 452	2.5	43.8	1.10
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	3.60
Ontario	12 686 952	2.5	38.7	0.98
Quebec	7 651 531	1.0	34.5	0.87
New Brunswick	749 168	5.3	51.5	1.30
Nova Scotia	934 405	10	108	2.72
Prince Edward Island	138 519	6.1	55.9	1.41
Newfoundland Labrador	509 677	2.7	33.8	0.85
Canada	Population weighted	3.3	45.5	1.15

that within a community, radon levels can vary significantly from one home to another. The distribution of radon concentration is normally a log-normal distribution. The log-normal distribution has a long tail at high radon concentrations indicating that the vast majority of houses have radon levels below the average concentration. If the average radon level in a community is below the national guideline of 200 Bq m^{-3}, it does not mean that this community does not have homes with elevated radon levels. The parameter, *percentage of homes above the guideline value*, is a better parameter for clear communication with the public. Percentages of homes above 200 Bq m^{-3} in each province are given in Table 4. On average, fewer than 3.3 % of Canadian homes have radon levels in excess of 200 Bq m^{-3}. Depending on local radon characteristics, it can vary from 2.5 % in British Columbia and Ontario to 19 % in Manitoba.

Population-weighted annual effective doses due to indoor radon exposure in ten provinces of Canada are given in Table 4 as well. On average, the annual effective dose to the Canadian population due to indoor radon exposure is estimated to be 1.15 mSv. The population radon doses varied from 0.85 mSv in Newfoundland Labrador to 3.60 mSv in Manitoba. The doses were significantly above the national average in three provinces, namely Saskatchewan, Manitoba and Nova Scotia.

The geology of Canada and associated background radiation levels are constant, and it is assumed that there have been no significant changes in home construction practices in the past decades[13] or increased efforts by homeowners to perform mitigative actions on their homes following the first national radon survey, as demonstrated by the similar radon results observed recently compared with the results surveyed in 1970s in Manitoba and Quebec. However, the estimated annual effective dose to the Canadian population due to indoor radon exposure has increased from 0.71 mSv (corresponding to 28.3 Bq m^{-3}) based on data available in the 1970s to 1.15 mSv (corresponding to 45.5 Bq m^{-3}) today. Changes in the population distribution could contribute to the change of AM and associated population-weighted radon dose. If the radon results of 1970s were weighted with current populations (2006 Census) as listed in Table 1, the arithmetic mean radon concentration would be 37.5 Bq m^{-3}. This indicates that among 61 % increase in radon exposure, changes in population distribution alone contributed to about 33 %. The other 28 % of increase is then due to the availability of more indoor radon data, especially data for radon prone areas. The radon level in Nova Scotia is significantly higher than the national average, however, this information was not previously available and has only been included in the current assessment. In addition in British Columbia, Vancouver had been the only city surveyed for radon in the 1970s. With more radon surveys conducted in many other communities in the province, especially in communities of mountain areas, the arithmetic mean radon concentration for British Columbia has been updated and increased from 9.6 using 1970s' data to 43.8 Bq m^{-3} today. Radon information for Canada's national capital, the city of Ottawa, also became available recently. The average indoor radon level in Ottawa homes was found to be 120 Bq m^{-3}, almost three times the national average of 45.5 Bq m^{-3}. As more radon data are included in the current assessment and the data set covers a much broader geographical area, the current assessment should better represent the radon exposure in Canada. It should be pointed out that indoor radon data are not yet available for the three territories in Canada. Even though only 0.3 % Canadians live in the three

territories, future radon surveys should cover those sparsely populated areas.

CONCLUSION

In this study, the national average radon concentration (arithmetic mean) for Canada has been determined to be 45.5 Bq m^{-3} based on new residential radon data in combination with historic results. The percentage of Canadian homes currently estimated to have indoor radon levels in excess of the Canadian Radon Guideline of 200 Bq m^{-3} has been calculated to be 3.3 %. Although this percentage is relatively low, considerable variation exists from region to region within the country, with Manitoba, Nova Scotia and Saskatchewan having the highest proportion of homes estimated to be above the guideline (19, 10 and 9 %, respectively).

The population-weighted annual effective radiation dose to which Canadians are exposed due to indoor radon has also been reassessed. This dose has been estimated to be 1.15 mSv, which is higher than that estimated from radon data collected in the 1970s and 1980s (0.71 mSv). The doses in Manitoba, Nova Scotia and Saskatchewan were significantly above the national average (3.60, 2.72 and 1.88 mSv, respectively). Because more radon data are included in the current assessment, and the data set covers broader geographical areas, the current assessment better represents the radon exposure in Canada.

REFERENCES

1. The World Health Organization. *Radon and cancer*. Fact Sheet No. 291 (June 2005). Available at http://www.who.int/mediacentre/factsheets/fs291/en/index.html.
2. Letourneau, E. G., McGregor, R. G. and Walker, W. B. *Design and interpretation of large surveys for indoor exposure to radon daughters*. Radiat. Prot. Dosimetry **7**, 303–308 (1984).
3. Letourneau, E. G., Krewski, D., Zielinski, J. M. and McGregor, R. G. *Cost effectiveness of radon mitigation in Canada*. Radiat. Prot. Dosimetry **45**, 593–598 (1992).
4. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). *Sources and Effects of Ionizing Radiation*. Volume I: Sources (New York: United Nations) ISBN 92-1-142238-8 (2000).
5. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). *Effects of Ionizing Radiation. Volume I: Sources-to-Effects Assessment for Radon in Homes and Workplaces* (New York: United Nations) ISBN 978-92-1-142263-4 (2006).
6. Chen, J., Schroth, E., Fife, I., MacKelay, E., Tokonami, S. and Sorimachi, A. *Simultaneous ^{222}Rn and ^{220}Rn measurements in Winnipeg, Canada*. Radiat. Prot. Dosimetry **134**, 75–78 (2009).
7. Jackson, S. A. *Estimating radon potential from an aerial radiometric survey*. Health Phys. **62**, 450–452 (1992).
8. British Columbia Centre for Disease Control (BCCDC). *Radon gas measurements in BC homes* (2007). Available at http://www.bccdc.ca/NR/rdonlyres/B03E2BDA-D01F-4F99-A228-B9F753A451CB/0/RadononMainFloorinBC2007.pdf
9. Chen, J., Falcomer, R. and Tracy, B. L. *Preliminary results of radon measurements in Ottawa homes*. Can. J. Respir. Ther. **43**, 27–28 (2007).
10. Chen, J., Tokonami, S., Sorimachi, A., Takahashi, H. and Falcomer, R. *Results of simultaneous radon and thoron tests in Ottawa*. Radiat. Prot. Dosimetry **130**, 253–256 (2008).
11. Dessau, J. C., Belles-Isles, J. C., Gagnon, F., Leclerc, J. M., Levesque, B. and Prevost, C. *Le Radon au Quebec* (Quebec: Institut National de Sante Publique du Quebec) (2004).
12. Health Canada. *Government of Canada Radon Guideline*. Available at: http://www.hc-sc.gc.ca/ewh-semt/radiation/radon/guidelines_lignes_directrice-eng.php.
13. Burrows, J. and Gallagher, J. F. *Progress on national construction code activities*. NRCC-51357 (Ottawa: National Research Council Canada) (2009). Available at: http://www.nrc-cnrc.gc.ca/obj/irc/doc/pubs/nrcc51357.pdf.