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Indoor Radon in Micro-geological Setting of an Indigenous Community in Canada: A Pilot Study for Hazard Identification

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Abstract

Background: Radon is the second leading cause of lung cancer after smoking. In Canada, the health authorities have no access to comprehensive profile of the communities built over uranium-rich micro-geological settings. The present indoor radon monitoring guideline is unable to provide an accurate identification of health hazards due to discounting several parameters of housing characteristics.

Objective: To explore indoor radon levels in a micro-geological setting known for high uranium in bedrock and to develop a theoretical model for a revised radon testing protocol.

Methods: We surveyed a remote *Inuit* community in Labrador, located in the midst of uranium belt. We selected 25 houses by convenience sampling and placed electret-ion-chamber radon monitoring devices in the lowest levels of the house (basement/crawl space). The standard radon study questionnaire developed and used by Health Canada was used.

Results: 7 (28%) houses had radon levels above the guideline value (range 249 to 574 Bq/m^3). Housing characteristics, such as floors, sump holes, ventilation, and heating systems were suspected for high indoor radon levels and health consequences.

Conclusion: There is a possibility of the existence of high-risk community in a low-risk region. The regional and provincial health authorities would be benefited by consulting geologists to identify potentially high-risk communities across the country. Placing testing devices in the lowest levels provides more accurate assessment of indoor radon level. The proposed protocol, based on synchronized testing of radon (at the lowest level of houses and in rooms of normal occupancy) and thorough inspection of the houses will be a more effective lung cancer prevention strategy.

Keywords: Radon; Radioactive hazard release; Geology; Radiation; lung cancer; Background radiation; Electromagnetic radiation; Canada

Introduction

Radon is a colorless, dense, radioactive gas, formed by decay chain of uranium and its exposure is the second leading cause of lung cancer after smoking.[1,2] Uranium naturally occurs in small amounts in rocks, but its levels vary considerably.[3] Radon enters a house through cracks in foundation walls and floor slabs, construction joints, gaps around service pipes, window casements,

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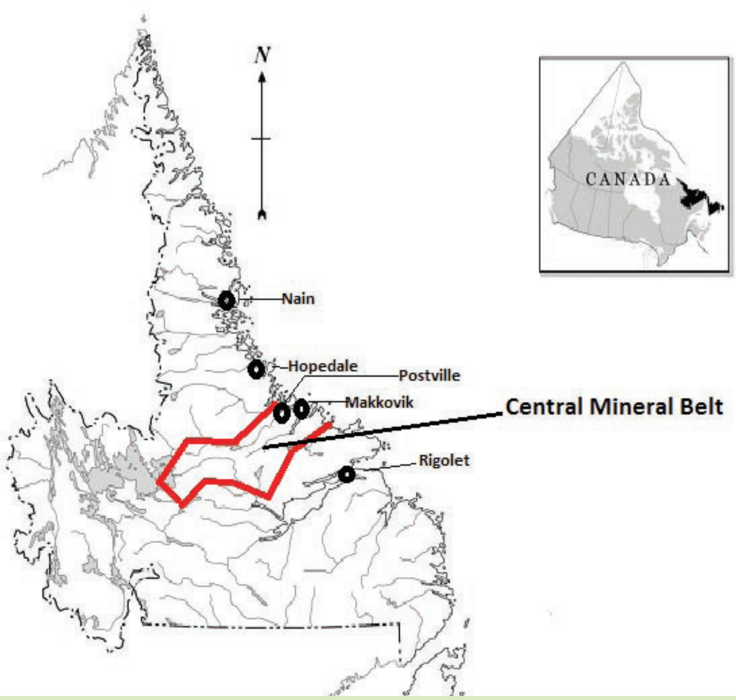

Figure 1: Map of Labrador-Grenfell health region showing Makkovik and four other *Inuit* communities and Central Mineral Belt (adapted from Geological Map of Labrador, Government of Newfoundland and Labrador)

TAKE-HOME MESSAGE

- Due to wide geological variations in uranium deposits, there is a possibility of the existence of high-radon hazards areas within a low-risk region.
- Placing radon testing devices in the lowest levels of house provides more accurate identification of indoor radon "hazards," however, actual potential health "risk" can be measured by testing radon in the rooms of normal occupancy.
- Indigenous communities in Canada require more attention in indoor radon hazard assessment.
- Indoor radon testing should be mandatory for all houses.
- A nationwide multicenter study is required on synchronized testing of radon (at the lowest level of houses and in rooms of normal occupancy).
- Thorough inspection of housing conditions is also necessary.

floor drains, sumps inside walls, and dirt floors.[4]

Indoor radon is considered one of the most significant environmental carcinogens in Canada causing almost 3000 deaths each year due to lung cancer.[2,5] The risk of lung cancer due to combined smoking and radon exposure is higher than the sum of lung cancer risks due to these two individual risk factors separately.[2,4] The level of indoor radon depends on (a) amount of uranium in the ground, (b) number of entry points into the house, and (c) ventilation.[6] Therefore, the levels of indoor radon significantly differ, depending upon the housing conditions.[7] In 2009–2011, Health Canada conducted the first nationwide survey of radon levels in 13 814 houses, recruited from a list of randomly selected 100 000 telephone numbers. As per the guidelines, the radon detectors were kept in the "normal occupancy (>4 hrs/day) areas" at the lowest "lived-in" level of the house.[8] The report provided the health region-wise (in each province/territory) proportion and distribution of high-risk houses exhibiting indoor radon concentrations above the Canadian guideline value[9] of 200 Bq/m^3. However, there are significant variations in indoor radon levels between the basement and the first floor.[10] Moreover, there is evidence of significant year-to-year indoor radon level variation of individual houses, mostly due to modifications (aging) of house structure and changing of heating-ventilation air conditioning system.[11] Since, each health region covers a large land area, there is a possibility of wide variation in uranium amount present in its underground bedrock. Therefore, the communities developed over uranium-rich micro-geological setting might have a higher probability of radon entry into houses. In other words, there is a probability of existence of a high-risk community in a low-risk health region. In this regard, Canada's *Inuit* (*Es-*

kimo) population is more vulnerable due to (a) living in remote northern parts of the country known for high uranium deposition,[12] (b) poorer housing conditions (28% of houses need major repair *vs* 7% for non-indigenous houses),[13] and (c) high smoking rates (39% of the population above 12 years of age *vs* 15% for non-indigenous population of the same age group)[14]. The rates of lung cancer in *Inuit* men and women in Canada are the highest in the world, and increasing.[15,16]

Assessment of "hazard" (source of potential adverse health effects from radon exposures) is necessary for enduring assessment of "risk" (probability of getting exposed to a hazard). Considering the complexity of indoor radon exposure in *Inuit* population, one-time health-risk assessment of randomly selected houses (by Health Canada) may not be appropriate for developing a long-term lung cancer prevention strategy at the health region levels. With passage of time, any aging-related changes in housing structure may eventually aggravate the health risks.[11] Therefore, the Health Canada survey may not remain very reliable guiding information for long-term remedial policies for respective health regions.

We, a team of experts from public health and geology, intended to conduct a pilot study in an *Inuit* community to identify hazards of indoor radon in a micro-geological setting known for high uranium in bedrock, and also their housing condition and smoking habit. We also intended to develop a theoretical model for a revised radon testing protocol.

Materials and Methods

Makkovik, a remote sub-Arctic community in Labrador (population of ≈380), was selected for the study. The community lies at the northeastern end of a geological region termed the "Central Mineral Belt," which contains potentially economically exploitable concentrations of uranium.[17] Makkovik is one of the five small communities (total population of ≈2400) scattered along the northern coast of Labrador (Fig 1). These five communities formed an autonomous area in 2005, known as *Nunatsiavut*. The people of *Nunatsiavut* are *Inuit*, descendants of the prehistoric *Thule* people, who have lived on the Labrador coast for thousands of years and share similar cultural, social and spiritual values.[18,19] *Nunatsiavut* means "our beautiful land" in *Inuktitut*, the language spoken by the Labrador *Inuit*. It is important to note that Postville (Fig 1) is also located within Central Mineral Belt, but it was beyond our scope to include Postville in our research as its population was very low (≈180).

We selected 25 single detached houses (20% of the total houses in the community) by convenience sampling. For indigenous health study, convenience sampling is considered an ideal method (compared to conventional random sampling) for the demographic profile, and cultural norms of the communities.[20,21] Any community-based research in indigenous communities in Canada requires special attention due to past record of centuries long racial exploitation, discrimination and unethical practices in research.[20] Despite reconciliation between the indigenous communities and the state, many *Inuit* people still bear mistrust and hence deny participating in research by direct approach (like random sampling). They, however, trust, if approached by their own community members, instead.

We obtained electret ion chamber radon monitoring devices from the Radiation Safety Institute of Canada, Saskatchewan, Canada, installed one in each of the 25 houses for 4–5 months (October 2013 to February/March 2014) and shipped them back to the Institute for analysis. Four devices (*ie*, 16% of total devices) were

Figure 2: Duplicate electret for quality control hanging in a basement

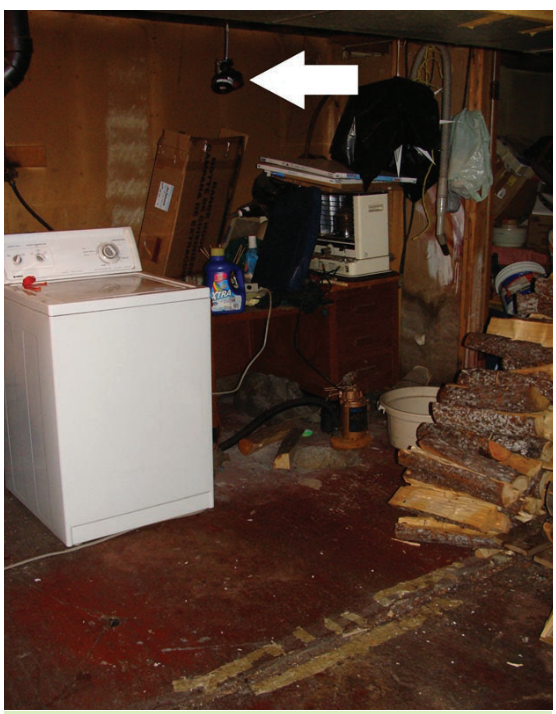

Figure 3: Electret hanging from the ceiling of the basement. The cracked floor is common in many basements of the surveyed houses.

attached with duplicate electret for quality control (Fig 2). We kept the devices closest to the possible radon entry points, *ie*, in the lowest levels of the house such as basement or crawl space (Figs 3 and 4). It was a

Figure 4: Hanging electret in a crawl space, under bedroom. The crawl space was made over bare rocks.

deliberate attempt to deviate from the general norm of testing "normal occupancy areas" in order to identify the hazards (not risk). Since, the guideline of Health Canada has only focused on radon level, we focussed only on radon testing (not gamma radiation) in data analysis.

The standard radon study questionnaire developed and used by Health Canada in its nationwide survey was adapted to derive relevant background information for each house.[9] To study smoking, we used validated questionnaires developed by Statistics Canada's Canadian Community Health Survey of 2007.[22] The combined schedule was administered to one of the adult members of the selected houses. The research was duly approved by the Health Research Ethics Authority (#12.135), Nunatsiavut Government (10/04/2012) and Labrador-Grenfell Health Authority (11/27/2012).

Results

Of the 25 houses tested, seven (28%) had radon levels above the guideline value (range 249 to 574, 95% CI 276 to 502 Bq/m^3); the level in the remaining 18 houses ranged from 51 to 194 (95% CI 100 to 144) Bq/m[3]. The Health Canada study indicated that in the Labrador-Grenfell Health region, of which Makkovik was a part, the proportion of houses exhibiting radon concentrations above the guideline value was only 3%—lower than the national (7%) and provincial averages (5%).[9] Health Canada tested bedrooms of three houses in Makkovik in its survey, and all had normal levels. Coincidentally, two of the tested houses were also included in our study, and both of them had high radon levels in their basements (335 and 501 Bq/m[3]). This finding clearly exposed our concern of hidden hazard in apparently risk-free homes.

Table 1 shows the conditions of studied houses (total and high indoor radon). Poured concrete was the main material (56%) used to build floors for the basements/crawl spaces (Fig 3). Otherwise, the house owners left the floors with just bare earth and rocks (Fig 4). Five out of seven houses with high indoor radon belonged to this category. The majority of the sump holes (80%) remained open. Forced air was the main heating system (96%) and only 12% of the houses had proper ventilation (air exchange). In one-fourth of all studied houses, the windows of the basements remained closed for an entire year, and 60% opened only for 2–30 days. These building characteristics are believed to pose further risks of the entry and retention of radon in the lowermost level of the house that eventually could spread to the rest of the house space. The community had a public water supply (piped) from a large pond (*Ranger Bight Pond*) after purification; it was unlikely to be the additional source of radon. Crawl spaces had no ventilation except a single entry-cum-exit door. One-third of the households used their basements for more than four hours a day, and more than one-fifth used it for sleeping. More than half of the houses were built before 1990 (25 years old or older).

Table 1: Conditions of studied houses (total surveyed [n=25], and high indoor radon level [n=7]). Number of high-radon houses is mentioned in parenthesis.

House description	Houses surveyed
Type of Residence	
Bungalow	14 (4)
Two-story	7 (2)
Three-story	2 (1)
Split-level	2 (0)
Foundation type (includes combination)	
Poured concrete	22 (6)
Wood	10 (1)
Floor type (basement/crawl space)	
Poured concrete	14 (2)
Earth/dirt	10 (4)
Rock	1 (1)
Covered sump hole (basement/crawl space)	
Yes	5 (2)
No	20 (5)
Houses with basement (n=13)	
No basement, but a crawl space	12 (5)
Full basement	11 (2)
Partial basement	2 (0)
Quality of basement	
Completely finished	4 (1)
Partially finished	7 (1)
Unfinished	2 (0)
Type of rooms in basement (includes combination)	
Rec/living room	3 (1)
Bed room	3 (0)
Laundry room	8 (1)
Furnace room	12 (2)
Storage room	9 (2)
How often windows in basement open (days/year)	
<1	3 (1)
2–30	8 (0)
31–120	1 (1)
No windows in basement	1 (0)

Continued

Table 1: Conditions of studied houses (total surveyed [n=25], and high indoor radon level [n=7]). Number of high-radon houses is mentioned in parenthesis.

House description	Houses surveyed
Hours/day in basement (hrs/day)	
<4	9 (1)
4–8	2 (1)
>8	2 (0)
Sleep in basement	
Yes	3 (0)
No	10 (2)
Heating/ventilation	
Heating fuel used in house (all that apply)	
Oil	24 (7)
Wood	21 (0)
Electric	1 (0)
Geothermal	1 (0)
Heating system	
Forced air	24 (7)
Baseboard	1 (0)
Air conditioning	
Yes	2 (0)
No	23 (7)
Air conditioning type	
Central air	1 (0)
Window unit	1 (0)
Air exchange	
Yes	3 (3)
No	21 (4)
Don't know	1 (0)
Year of built	
1961–1970	1 (0)
1971–1980	6 (1)
1981–1990	7 (1)
1991–2000	8 (3)
2001–2009	3 (2)

Although one-third of the population regularly smoked, 56% of the houses had at least one smoker. One-fourth of the household members of houses with high radon level regularly smoked; around one-third of the households allowed smoking inside their homes (Table 2). Prolong harsh winter was believed to compel the smokers to smoke indoor; the existing inadequate ventilation thus made non-smokers more vulnerable by making them second-hand smokers.

Discussion

According to the Health Canada survey, all houses in Makkovik were free from any health risk associated with indoor radon. However, the sample size was too small (only 3) to make any decision. Our survey showed that due to geological and housing conditions, one-fourth to one-third of the houses might have radon in the lowermost level of the houses. The "hazard" might turn into a potential health "risk" if the trapped gas escapes to the rest of the house space. Therefore, all regional and provincial health authorities should consult geologists to identify potentially high-risk communities, and follow-up action could include an effective health promotion drive for testing all houses. The geologists can use soil gas radon, gamma spectrometry, and soil permeability data to compile radon potential map. In fact, in Quebec, Canada, a methodology for developing radon potential maps has successfully been tested and it can be replicated in the rest of the country. The method is based on three radio-geochemical criteria including (a) equivalent uranium concentrations from airborne surface gamma-ray surveys, (b) uranium concentration measurements in sediments, and (c) uranium concentration measurements in bedrock and surficial geology.[23]

The survey results showed that the existing housing conditions, such as open porous floor of basement/crawl space, cracked floor, open sump hole, poor ventilation, lack of insurance coverage, and ongoing mortgage and poor incomes have made the indigenous (*Inuit*) communities living in Arctic/sub-Arctic areas of Canada more vulnerable to radon exposure. High smoking rates in the community has further increased the health risk. The study is also relevant for other *Inuit* communities in rest of the circumpolar regions (Canada, Alaska, and Greenland) due to high rates of lung cancer,[15,16,24] smoking,[14,24] poor housing condition,[13,25,26] and geological features[12,27,28].

The survey demonstrated that small high-risk micro-geological settings can exist in a relatively low-risk health region. Therefore, geological perspectives should be incorporated in identification of high-risk communities across the country, particularly focusing on *Inuit* population. In Quebec, a potential indoor radon map was developed and can be replicated in future for rest of the country.[23] A freely accessible interactive and user-friendly map, showing radon potentials in high-resolution grid would be very helpful to the local health authorities and house owners. Concerned house owners and local health authorities can easily navigate the maps and eventually identify high-risk neighborhoods.[29-33]. For instance, the interactive map based on US Environmental Protection Agency data gives detailed information on predicted average indoor radon screening levels up to the community level.[29] In Australia, such maps provide district averages of radon. This new interactive radon map displays interpolated values for typical Australian houses in census districts.[30] Public Health England and the British Geological Survey have published maps showing where high levels are more likely.[31] There is also a provision of paying a nominal fee to determine the household indoor radon just by postal code.[33] Unfortunately, that facility is not yet available in Canada.

Continued

Table 1: Conditions of studied houses (total surveyed [n=25], and high indoor radon level [n=7]). Number of high-radon houses is mentioned in parenthesis.

House description	
Renovation done to house (previous year)	
Upgraded/changed main ventilation or heating system	4 (2)
Nil	21 (5)
Insurance coverage	
Yes	12 (3)
No	13 (4)
Paying mortgage	
Yes	11 (3)
No	14 (4)
Satisfaction level (dwelling condition)	
Very satisfied	3 (1)
Satisfied	18 (6)
Dissatisfied	2 (0)
Very dissatisfied	2 (0)
Total annual income (C$)	
20 000–30 000	1 (0)
30 000–40 000	4 (1)
40 000–50 000	3 (1)
>50 000	17 (5)
Income support	
Yes	1 (0)
No	24 (7)

We recommend making indoor radon testing mandatory (similar to several states in the USA)[34] for real estate transactions, private and public schools, private and public buildings in high radon zones and rental properties. The testing should not be limited to "normal occupancy areas." The "lowest levels of the house" should be tested, instead, to identify preexisting radon hazards. This strategy will

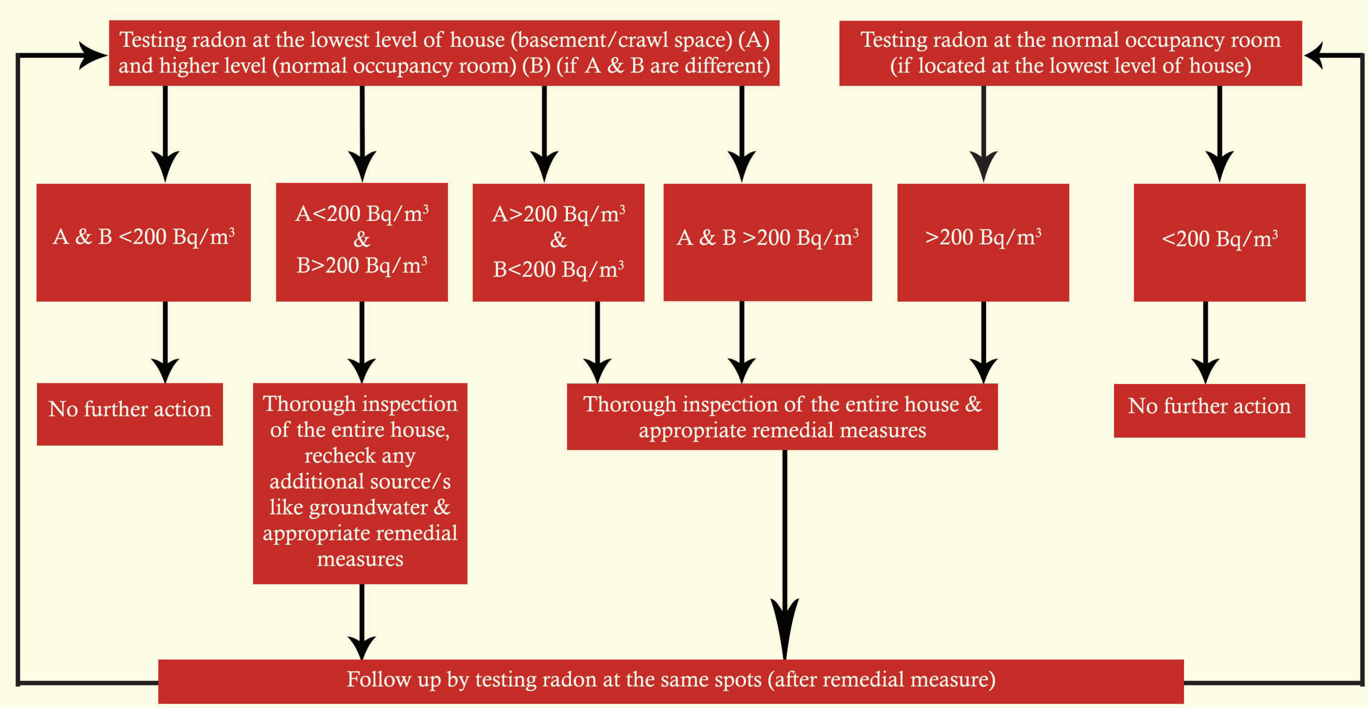

Figure 5: Proposed guideline for integrated indoor radon hazard assessment

prevent a false sense of security and encourage the owners taking precautionary measures in advance. Testing radon in basements/crawl spaces provides more accurate assessment of health hazards. Radon might remain trapped in basements/crawl spaces due to intact surfaces and wall. However, any crack or gap will eventually release radon to the rest of the house space. Therefore, targeting the entry point (*ie*, basement/crawl space), irrespective of the duration of stay, can be a more realistic way to begin with testing radon hazard. Nevertheless, actual potential health risk can be measured by testing radon in rooms of normal occupancy. A study conducted in Quebec in late 1990s identified significant variations in radon levels between the basement and on the first floor.[10] However, the current guidelines do not take into account these important housing characteristics. Indeed, our study did not have enough number of samples and variations (geological and housing) for scientific validation of keeping testing kits in the "lowest levels of the house" and the "normal occupancy areas." We therefore, propose the following guidelines based on the integration of these factors (Fig 5). A nationwide multicenter study is required on synchronized testing of radon (at the lowest level of houses and in rooms of normal occupancy). Thorough inspection

Table 2: Smoking behavior of people living in the surveyed houses. Number of smokers is mentioned in parentheses.

Age-wise population sub-group	Total population (smoker)	Total population of high radon houses (smoker)
Children (<14 yrs)	19 (0)	6 (0)
Adolescents (14–18 yrs)	12 (1)	3 (1)
Adults (18–59 yrs)	51 (22)	13 (4)
Seniors (>60 yrs)	9 (3)	2 (1)
Total	91 (26)	24 (6)

of the respective houses by including the condition of floor and wall, indoor air flow, ventilation, sump hole, heating system, air conditioning, and type of water supply (groundwater) will generate a convincing evidence to validate the guidelines. Indigenous communities deserve special attention with regard to knowledge dissemination on radon testing and financial support for house repair and remedial measures. Lastly, we also recommend regular radon testing (not just once) even after remedial measure in place since the evidence shows that the durability of long-term measures varies.[35]

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Conflicts of Interest: None declared.

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