

The Prevalence of High Residential Radon in Thunder Bay, Ontario

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TITLE:

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Executive Summary

During the winter of 2014/2015, 468 long-term alpha track radon detectors were distributed to homes in the city of Thunder Bay, Ontario to determine the prevalence of elevated residential radon.

The results show that 16% of Thunder Bay homes have radon in excess of the Health Canada guideline of 200 Bq/m³ of radon. This result is well above the Canadian and Ontario averages of 6.9% and 4.6% respectively. The prevalence of excessive radon varied significantly by city ward with McIntyre at 43%, Neebing at 30%, Red River at 15%, Current River at 13%, Northwood at 5%, and McKellar at 2%. No homes with elevated radon were found in Westfort.

Numerous organizations in Thunder Bay can play significant roles in helping citizens to address the increased risk of elevated radon in the city. The Thunder Bay District Health Unit and other community agencies should promote radon awareness, testing and mitigation both to citizens and to building and trade associations, real estate associations, banks and insurers. Residents of the City of Thunder Bay should test their homes for radon, regardless of where they live, and mitigate as appropriate to the lowest practical radon concentration. Smokers should be specially targeted because of the significantly

increased risk of lung cancer when smoking and exposure to radon are combined. The City of Thunder Bay, in addition to the soil gas control measures already adopted, should require all new homes to be tested for radon prior to sale. Local entrepreneurs should be encouraged to become certified in radon testing and mitigation through the Canadian National Radon Proficiency Program. All levels of government should consider programs to make radon testing and mitigation more financially accessible. In addition to private homeowners, landlords and tenants should be encouraged to test for radon and mitigate as appropriate, and public health units should respond to complaints about high radon in residential tenancy arrangements in a manner similar to other health hazards.



Introduction

The purpose of this study is to determine the prevalence of high levels of radon in Thunder Bay homes. The aim was to develop local recommendations about testing for radon and mitigation, and to inform public policy that would reduce the prevalence of excessive radon.

EPIDEMIOLOGY OF RADON AND LUNG CANCER

Radon is a colourless, odourless radioactive gas that is present to some degree in most soils. From the soil, it can seep into your home and accumulate to dangerous levels. The gas decays into a series of radioactive elements called radon progeny. If you inhale dust covered with these radon progeny, some of that dust remains in your airways. While in contact with your lungs, these radon progeny release ionizing radiation that causes cellular damage. Exposure to this radiation increases your risk of cancer.

It is interesting to consider that even a single alpha particle can cause major genetic damage to a cell, so it is possible that radon-related DNA damage can occur at any level of exposure. Therefore, there is probably no threshold concentration below which radon does not have the potential to cause lung cancer. There is a dose-response relationship between exposure to radon gas and the incremental risk of lung cancer. In other words, the more radon you are exposed to, and the longer you are exposed to it, the greater your risk of lung cancer.

About 85% of lung cancer is caused by smoking – both active smoking and second-hand smoke. Exposure to radon is the second leading cause of lung cancer, after tobacco smoking, and the leading cause of lung cancer among non-smokers. Virtually everyone today knows that smoking tobacco is a cause of cancer. What many people do not know is that radon and tobacco are a particularly potent combination. Active smokers who are also exposed to radon have a one in four chance of developing lung cancer during their lifetime.

Most lung cancers do not cause any symptoms until they have spread too far to be cured. Lung cancer typically has a poor prognosis, usually because it is diagnosed at a late stage and has already spread to other parts of the body. The chance of surviving to 5 years after diagnosis is only 17%.

Nationally, it is estimated that 3261 lung cancer deaths (16% of all lung cancer deaths) are attributable to radon each year, and we could prevent 927 deaths per year if everyone with more than 200 Becquerels per cubic meter of air (Bq/m³) remediated their homes to outdoor radon levels. The number of lung cancer deaths that could be prevented increases to 1700 per year if everyone with more than 100 Bq/m³ remediated their homes.

RESIDENTIAL RADON

Radon levels in soil vary considerably across Canada depending on soil characteristics and underlying geology. The amount of radon in your home is influenced partly by those natural factors, but also by house construction, home maintenance, type of heating system, ventilation and other characteristics. Properly constructed and ventilated houses can draw less than 1% of their indoor air from the underlying soil, or up to 20% if the foundation is poorly designed, built and maintained and the home is inadequately ventilated. Radon can accumulate to high levels in a home with restricted exterior air exchange and a slight negative pressure that draws soil gas in through cracks or other openings in the foundation. Homes that draw their water from wells can also release radon during washing and showering, although it is generally thought to be small contributor to the overall level of radon in most homes.

Because radon is colourless and odourless, the only way to know if your home has high levels of radon is to test for it. Testing is inexpensive and easy. Health Canada recommends that all homes be tested for radon concentration, and that those with radon levels of 200 Bq/m³ or higher should have their radon levels reduced. It is not practical to reduce radon levels in your home below that of outdoor air, but it should be reduced as low as reasonably possible.

In 2012, Health Canada published the results of their Cross-Canada Survey of Radon Concentrations in Homes (which we will refer to throughout this paper as the Health Canada study), which found that the 6.9% of Canadians are living in homes with radon levels at or above the Canadian guideline of 200 Bq/m³. The Health Canada study results were broken down by health region across Canada. For the Thunder Bay District Health Unit, it found that 12% of homes tested had radon levels at or above the Canadian guideline, which was 50% higher than the Ontario average. Unfortunately, the sample size in our health region was small and our geographic area is large, so it is hard to draw conclusions about the amount and distribution of radon in our area from the Health Canada study.

National efforts to motivate people to test and remediate their homes for high radon have met with mixed success. Expressing radon risk at a high level prevents individuals from assessing their personal risk. The personal danger remains remote. Research has shown that people make their decision about whether to test for radon based on their perceived community concern, perceived susceptibility, perceived severity of radon exposure, social influence by others, tobacco use, and the presence of children in the home. In order for public health units and municipal governments to plan effective policy, more local level information is needed.

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- Radon concentration is measured in Becquerels per cubic meter of air. One Becquerel is amount of radioactive material required to generate one nuclear decay per second.

Methods

This was a prevalence study using a convenience sample of volunteer residents of the City of Thunder Bay who self-identified following an advertising campaign. A sufficient number of detectors were purchased to distribute to 533 residential homes, as well as duplicates and blanks for quality assurance purposes. Each participant in this study was provided with a long-term (3-month) radon detection kit to measure the level of radon in their home. The availability of radon kits for residents was advertised in the newspaper, the health unit website, on social media, and via the radio and television media. Participants self-selected by their interest and whether the advertising and public notices reached them, and were required to apply online or in person at the health unit. The intended sampling period was the months of October 2014 to February 2015, when radon concentrations are usually highest. The cost of the kit and the laboratory processing and report were free to participants as an incentive to participate.

ELIGIBILITY CRITERIA

Applicants to participate in the study were required to answer a pre-test eligibility questionnaire either on line or in person. To be eligible, participants had to have a residence within the City of Thunder Bay for the duration of the study. They also had read, write and follow instructions in English, and agree to complete pre- and post-test questionnaires about their radon attitude, the type of home they lived in and few demographic questions. Both homeowners and renters were eligible. The detectors were meant to be placed on the lowest lived level in which someone in the household spent an average of 4 hours per day. The participant had to provide a reasonable expectation that the detectors could remain in place undisturbed for at least 3-months. People living in apartment buildings above the ground floor were excluded. Candidates had the option to pick up or have the radon detector delivered.

DATA COLLECTION

Radon concentration varies considerably by the hour, day, week and season, so a long-term (3-month) test is required to get an accurate assessment of radon levels in a home. This study used long-term radon detectors of the alpha track detector type manufactured by Landauer of Glenwood, Illinois. The detectors were deployed by the participants following the instructions provided. Instructions were in both written and video format, and verbal reinforcement was provided when the detectors were distributed. Those participants who received duplicate detectors were instructed to place the two units within 10 cm of each other. The radon detectors were to be sealed according to manufacturer's requirements 91 days after deployment and returned to the Thunder Bay District Health Unit along with a post-test evaluation form.

When the survey period was over, the participants returned the detector unit and the HU staff checked the forms for completeness before sending them in a batch to sample collection centre in Ontario. The collection centre then sent the detectors to the manufacturer's laboratory for analysis.

Participants who did not return their detector after 91 days received three or more telephone and email reminders to promote detector return. If necessary, arrangements were made for staff to retrieve the detector if a participant was not able to return it to the health unit. The returned detectors were mailed in eight batches to the laboratory at different times. The laboratory emailed the results to the Thunder Bay District Health Unit and to the email address provided by the participant.

QUALITY ASSURANCE

Duplicate detectors were randomly distributed to nine percent of participants. Seventeen detectors were retained unopened in their packaging as blanks. They were opened, immediately sealed and sent for analysis with the last batch of returned detectors.



STATISTICAL METHODS

Planning for the study involved a sample size calculation. Our primary research objective was to confirm the presence of a higher than average proportion of homes with elevated radon. The Canadian average based on 13,807 homes in the Health Canada study was 6.9% of homes with radon concentrations at or above 200 Bq/m³. The same study, based on 108 homes, found that 12% of Thunder Bay District Health Unit homes were above the Canadian guideline. A sample size calculation indicated that 427 valid results would be required to statistically distinguish between the Canadian average and the anticipated 12% rate in Thunder Bay, at the 5% significance level and with 90% power. Assuming that the sample size was evenly divided among the 7 city wards, this sample size would have 50% power to detect a high radon rate of less than 6%, or greater than 22%. Assuming 20% losses to follow up we attempted to distribute detectors to 535 households.

Participants were asked four questions about radon awareness and their willingness to remediate their home if high levels of radon were detected. Two demographic questions focused on how the participant heard of the study and their attitude to remediation and radon risk.

The laboratory reported the average radon exposure of each detector in Bq/m³. For participants with duplicate detectors, the average of the two results was used. The main outcome analyzed was dichotomous variable indicating whether or not the radon test result was above or below the Health Canada guideline of 200 Bq/m³.

All data were tracked in Microsoft Excel before being converted to Stata 13 format for further analysis.



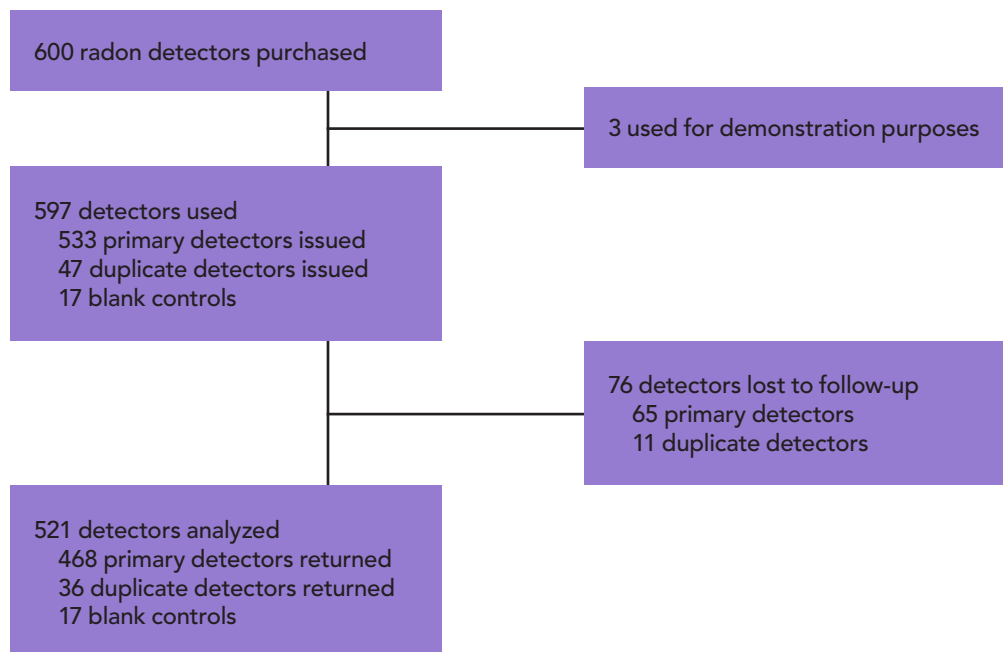
Results

There were 609 eligible applicants for this study. Applicants were given a date by which they had to pick-up their detector. As the number of applicants exceeded the availability of detectors, new applicants were waitlisted. Those approved applicants that did not pick-up their detector by their assigned date were removed from consideration and their detectors were offered to the next person on the wait list until all of the detectors were distributed.

Of the 533 participants who received radon kits, 468 (88%) returned their detector(s) and received their report. Of the 47 assigned duplicates, 36 (77%) were returned. Of the 65 households with detectors lost to follow-up, we were not able to contact 26, 19 completed the test but failed to return the detector(s), 19 failed to deploy or destroyed their detector(s), and one household

returned a detector but it was rejected after it was determined that the house fell outside of the study area. Figure 1 diagrams the disposition of all detectors.

Figure 1: Accounting of detectors



QUALITY ASSURANCE

The 17 blank detectors sent for analysis indicated no significant contamination. All of the blanks had radon concentrations less than the detectable level of the alpha-track detector used.

There were seven detectors with results lower than the detectable limit, indicating a very low level of exposure. These detectors were given a concentration value equal to $1110 \text{ Bq/m}^3\text{-day}$ divided by the number of days exposed (range: 8 to 12 Bq/m^3).

Analysis of the duplicate detectors indicated little variation. None of the duplicates differed by more than 40 Bq/m^3 , with 60% differing by less than 10 Bq/m^3 .

RADON PREVALENCE

Radon concentrations are exponentially distributed as would be expected of a nuclear decay event, with a geometric mean of 75 Bq/m^3 .

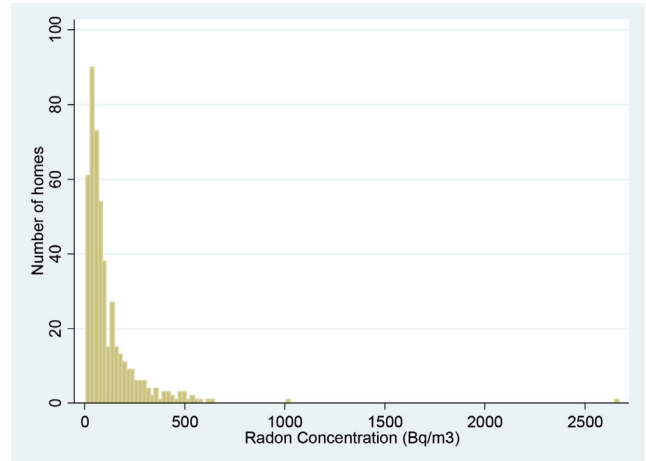


Figure 2: Distribution of Radon Measurements in Thunder Bay, Ontario.

In Thunder Bay, 16% of the sampled homes had concentrations at or exceeding the Health Canada guideline of 200 Bq/m^3 . Table 1 indicates the proportion of homes tested that exceeded various threshold concentration values.

Table 1. Homes tested for radon with concentrations exceeding various threshold values*.

| Radon Concentration (Bq/m^3) | Number of homes | Percent of homes tested |
|---|-----------------|-------------------------|
| 100 or higher | 168 | 36% |
| 150 or higher | 109 | 23% |
| 200 or higher | 76 | 16% |
| 400 or higher | 22 | 4.7% |
| 600 or higher | 4 | 0.9% |

* Different agencies recommend different radon threshold concentrations above which homes should be remediated. The Health Canada guideline suggests that homes with radon concentrations of 200 Bq/m^3 or higher should be remediated. The United States Environmental Protection Agency recommends that homes with radon concentration of approximately 150 Bq/m^3 be remediated. The World Health Organization recommends that countries should adopt a reference standard of 100 Bq/m^3 if possible.



The prevalence of high radon varied greatly across the city. Thunder Bay is divided into 7 electoral wards. Table 2 shows the proportion of homes in each city ward with radon concentrations exceeding the Health Canada guideline of 200 Bq/m³. McIntyre, Neebing, Red River and Current River wards had high radon levels well in excess of the Canadian average of 6.9%. The proportions of homes with high radon in McKellar, Northwood and Westfort wards were below the Canadian average. Figure 2 provides this information in map format, showing the proportion of homes with high radon (200 Bq/m³ or higher) within each city ward. The map also shows the proportion of homes tested that had high radon at a lower level of aggregation. In order to preserve the confidentiality of study participants, a fine 300m x 300m grid was placed over the areas where homes were tested and proportion of homes with high radon (200 Bq/m³ or higher) was calculated within each cell of the grid. This distribution of high radon is more clearly seen at this level of aggregation. It also makes clear that there is significant variability in radon levels even this relatively small scale.

Table 2: Percentage of Thunder Bay Homes Exceeding the Health Canada Guideline Arranged by Wards.

| City Ward | Homes tested | Percent with radon concentration of 200 Bq/m ³ or higher |
|---------------|--------------|---|
| McIntyre | 82 | 43% |
| Neebing | 47 | 30% |
| Red River | 79 | 15% |
| Current River | 68 | 13% |
| McKellar | 63 | 6% |
| Northwood | 75 | 3% |
| Westfort | 54 | 0% |



Historic Finn Hall ©Lake Superior Visits

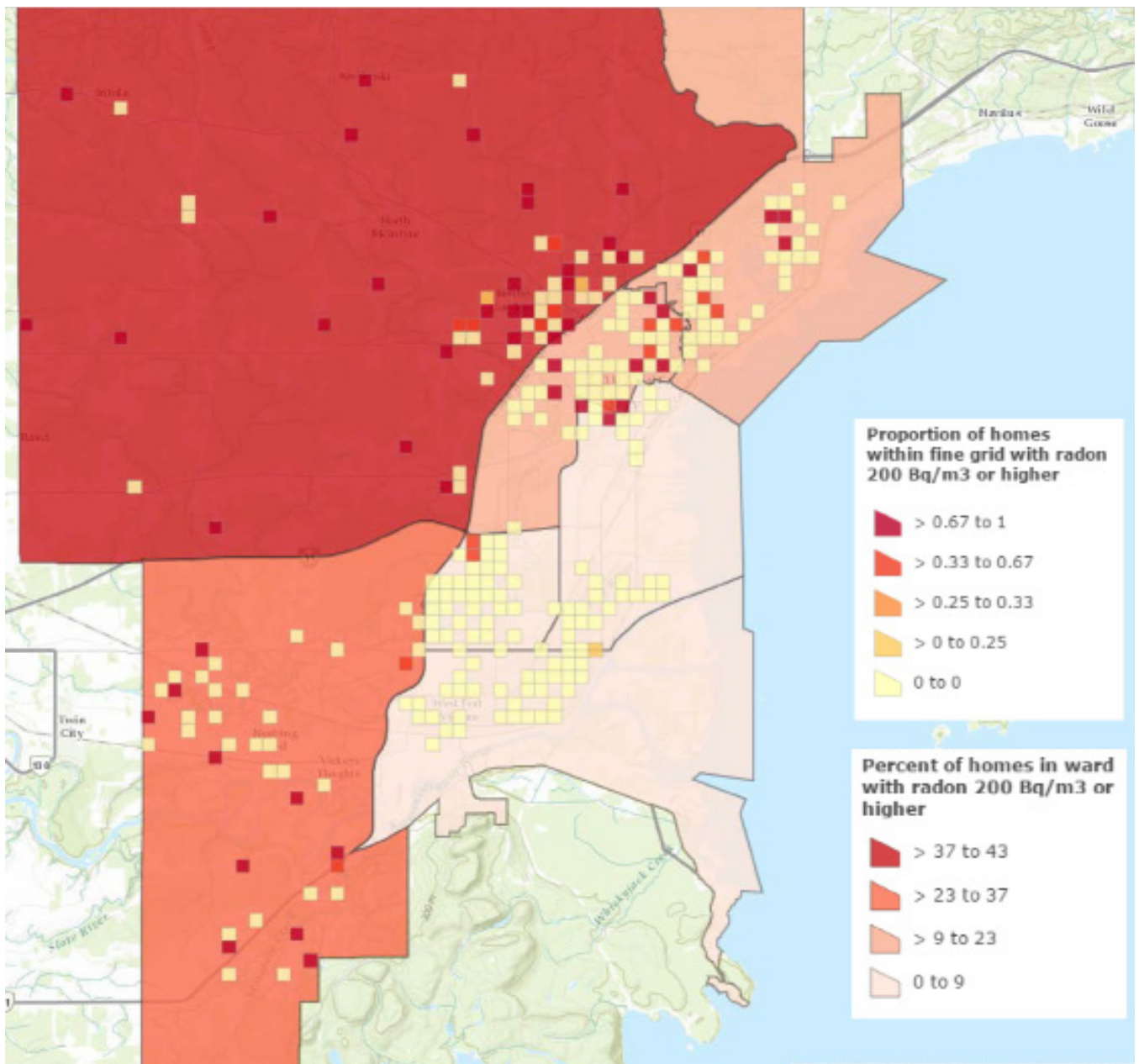


Figure 2. Proportion of homes with high radon (200 Bq/m³ or higher) within each grid cell and at the city ward level.

HOME CHARACTERISTICS

Radon concentration is known to vary according to a number of home characteristics. The age of the home reflects building standards of the era in which it was built. The presence of openings in the foundation, such as cracks or a sump hole is important because it is a portal of entry for radon gas from the soil. We did not ask participants about cracks in their foundation, but we did ask about the presence of a sump hole. Radon concentration also varies depending on the level of the home tested, with lower levels generally having higher concentrations. Following the Health Canada guidelines, we instructed participants to place the radon detector on the lowest level of their home where they spend at least 4 hours per day. Table 3 shows the proportion of homes that tested above the Canadian guideline of 200 Bq/m³ broken down by home characteristics.



Table 3: Percentage of homes with a radon concentration of 200 Bq/m³ or higher, by home characteristic.

| Home characteristic | Homes tested | Percent with radon concentration of 200 Bq/m ³ or higher |
|-------------------------------|--------------|---|
| YEAR BUILT | | |
| 1945 or before | 89 | 6% |
| 1946-1960 | 111 | 9% |
| 1961-1980 | 131 | 20% |
| 1981-1990 | 45 | 24% |
| 1991-2000 | 36 | 42% |
| 2001-2010 | 31 | 19% |
| 2011-2014 | 9 | 11% |
| Not sure of age | 16 | 13% |
| PRESENCE OF SUMP HOLE | | |
| Unsealed sump hole | 181 | 23% |
| Sealed sump hole | 29 | 17% |
| No sump hole | 124 | 10% |
| Not sure | 50 | 8% |
| Unstated | 31 | 3% |
| FLOOR TESTED FOR RADON | | |
| Basement | 325 | 19% |
| First floor | 129 | 10% |
| Second floor | 1 | 0% |
| Unstated | 13 | 15% |
| WATER SOURCE | | |
| Private well | 32 | 59% |
| Municipal | 434 | 13% |

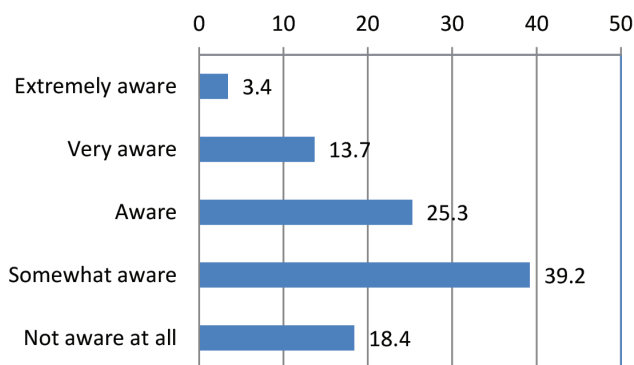
Homes built between 1961 and 2000 had the highest levels of radon. People with sump holes were considerably more likely to have elevated radon than those without. Also, as expected, people who tested their basements reported higher levels of radon than those who tested a different floor. People on private wells were also considerably more likely to have elevated radon

compared to those on municipal water. Note that it is not possible with this type of study to draw conclusions about the reasons why homes may have high radon. For example, the fact that homes with wells are much more likely to have high radon in this study may reflect the fact that rural areas, which are more likely to be on private wells, had a higher proportion of homes with high radon. Homes in the rural Thunder Bay area may have high radon for any number of reasons. Each home has to be evaluated individually to determine the best way to mitigate radon.

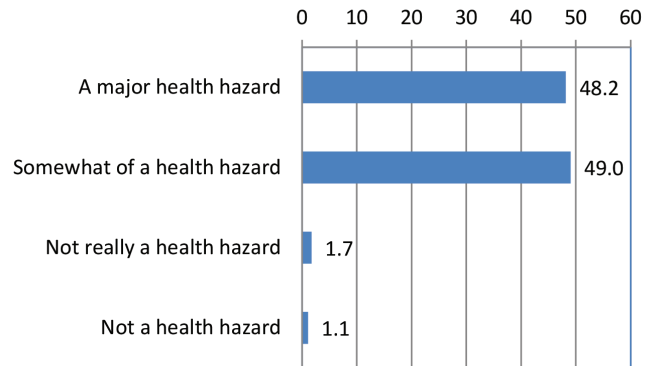
RADON AWARENESS AND REMEDIATION

Participants were asked four questions about radon awareness and their willingness to remediate their home if high levels of radon were detected. Seventeen percent were extremely or very aware of radon as a health hazard, 65% were aware or somewhat aware, and 18% were not aware at all. Forty-eight percent believe radon to be a major health hazard, 48% believe it is somewhat of a health hazard, and 3% believe it is not a health hazard. Ninety-five percent of participants reported that they would mitigate their home if high radon levels were found. The most significant barriers to mitigating their home were reported as finances (59%), knowledge (33%), and resources (32%).

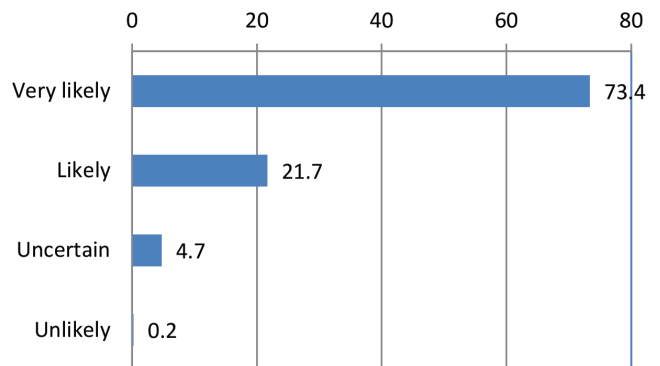
BEFORE YOU HEARD ABOUT OUR RADON PROJECT, HOW AWARE WERE YOU ABOUT RADON AS A HEALTH HAZARD?



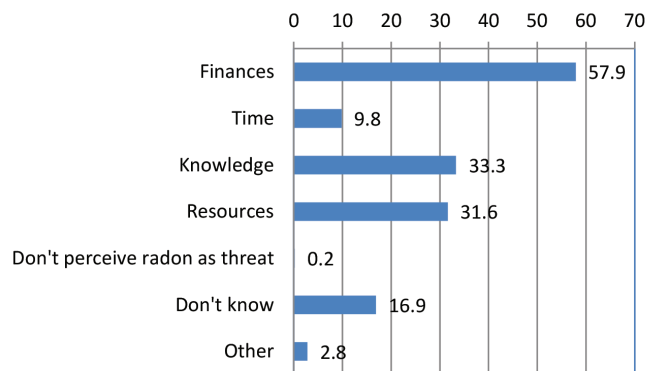
CHOOSE THE STATEMENT THAT BEST DESCRIBES YOUR PERCEPTION OF RADON. RADON EXPOSURE IS:



IF YOU DISCOVER YOUR HOME HAS RADON LEVELS ABOVE THE CANADIAN GUIDELINE, HOW LIKELY ARE YOU TO TAKE STEPS TO ADDRESS IT?



WHAT BARRIERS MIGHT PREVENT YOU FROM REDUCING YOUR HOME'S RADON LEVEL? CHECK ALL THAT APPLY.



Discussion

The present study confirmed that the prevalence of high radon in Thunder Bay is significantly greater than the Ontario and Canadian averages determined by Health Canada's Cross Canada Survey of Radon Concentrations in Homes. This Health Canada study found that 12% of the homes in the larger District of Thunder Bay had radon concentrations in excess of 200 Bq/m³. The present study found that 16% of City of Thunder Bay homes were in excess of 200 Bq/m³. This finding is within the statistical margin of error of the Health Canada study. In comparison, the population-weighted prevalence of high radon was 4.6% in Ontario and 6.9% in Canada.

While we expected some variability in local radon concentrations, this study found a remarkable degree of geographic variation, ranging from zero cases of high radon in the Westfort ward to a very high prevalence of excess radon in the McIntyre (43%) and Neebing (30%) wards. Wards with a significant rural or semi-rural composition were more greatly affected than more urban wards. While the McIntyre and Neebing wards will capture the majority of attention with their high prevalence values, it is important to note that the Red River and Current River wards, at 15% and 13% respectively, are also well above the provincial and Canadian averages. It is also notable that at the lower level of aggregation (represented on the Figure 2 map by the fine grid placed over the areas tested), it is clear that even homes within close proximity to one another could have quite different radon concentrations.

We found higher concentrations of radon when a sump hole was present, on the lower levels of a home, when a well was the water source, and in homes built between 1961 and 2010. It is important, however, to recognize that this study design is not able to disentangle the reasons for high radon homes. Home and occupant characteristics interact with geological characteristics to determine the level of radon in a home, and determining the causes of radon in any particular residence requires evaluation on a case-by-case basis.

Because of this complex interaction of factors, residential radon concentration can vary greatly over a local area. Many studies have found even side-by-side neighbours can have greatly different residential radon concentrations. Thus, as Health Canada and other agencies have emphasized, it is important to test your home even if you live in an area that has relatively low levels of radon overall. Perusal of the map in Figure 2 reveals that homes with high radon are located in close proximity to homes with low radon. Even those who live in Westfort, where we found no instances of high radon, should remember that the sample size at the ward level was small. It is very unlikely that there are no homes with high radon in Westfort. Rather, it is likely that our sample size was simply too small to locate any of them.

The participants in this study reported a high level of awareness of radon as a health hazard, and a willingness to mitigate their homes if high radon levels were found. This should not be surprising given that the study is based on a convenience sample of people who expressed an interest in having their homes tested for radon. This degree of awareness and willingness to act may not be representative of the general population of Thunder Bay.

This study is based on a convenience sample of motivated participants. Whether this affects the validity of the prevalence estimates is open to question. People motivated to take part in a radon study may also be more health conscious and radon-aware than the general population. While their interest may have prompted their enrollment, radon is not detectable by human senses and no previous studies have been done to indicate locations of high radon within the city, so it is unlikely that a large number of participants self-selected based on exposure. Similarly, this group indicated a high level of willingness to mitigate high radon, so it seems likely that those with previous radon test results would have already done some mitigation work prior to enrolling, which would result in this study underestimating the true radon prevalence. On the other hand, it is possible that some participants may have been aware of their high radon levels, or of some of the risk factors for high radon, and that this motivated their enrollment. Future radon studies should query participants about any previous radon test results, as well as any previous mitigation work. On balance, we do not believe that selection bias had a significant effect on the study results. This is reinforced by the congruency between the present study results and the previous Health Canada study results.

A further limitation of the current study is the relatively small number of duplicate and control detectors. Although none of the duplicate and control detectors indicated measurement problems in this study, future radon research studies should budget for more extensive and better deployment of controls. The increased use of blank detectors should include a set of blanks attached to duplicate detectors, a set of detectors that remain at the laboratory that are run during the processing, along with a set of detectors that remain at the health unit and are mixed in with the batches being returned. The extra blank detectors would serve to increase the confidence that sampling was not contaminated.



Recommendations

This study has a number of implications for public health and for further research.

PUBLIC HEALTH

1. The Thunder Bay District Health Unit and other partner agencies should promote radon awareness and testing, including the results of this study, to motivate residents to test their homes for radon, and to mitigate their homes as appropriate.
2. Residents of the City of Thunder Bay should test their homes for radon with a long-term 3-month detector and mitigate as appropriate.
3. Smokers should be specially targeted because of the significantly increased risk of lung cancer when smoking and exposure to radon are combined.
4. Residents should be informed that the Health Canada guideline of remediating radon levels at 200 Bq/m³ or above is based on many factors, and that each person should decide what level of risk they are willing to live with. The World Health Organization recommends a much lower guideline limit of 100 Bq/m³. Although radon cannot be eliminated entirely from a home, there is no “safe” level of radon. Radon should be remediated to the lowest practical concentration.
5. The City of Thunder Bay has already taken strides in implementing the soil gas control measures of the Ontario Building Code. Based on the results of this study, the City should complete this process and require all new homes to be tested for radon prior to sale.
6. While some radon mitigation work is simple enough for homeowners to do themselves, some mitigation jobs are beyond the skills of the average homeowner. Local entrepreneurs should be encouraged to become certified in radon testing and mitigation through the Canadian National Radon Proficiency Program.
7. A significant fraction of participants indicated that finances would be barrier to mitigating their homes for high radon. Not all types of radon mitigation are costly. Nonetheless, all levels of government should consider programs to make radon testing and mitigation more financially accessible.
8. Radon is a known environmental health hazard. Landlords and tenants should be encouraged to test for radon and mitigate as appropriate. Public health units should respond to complaints about high radon in residential tenancy arrangements in a manner similar to other health hazards.
9. Building organizations, real estate associations, building trades and professions, and banks and insurers offer promising opportunities for further radon awareness building. The cost of remediating radon is small in the context of buying a house, and buyers and sellers may be particularly motivated to act when the radon concentration in the home could affect the selling price.

FURTHER RESEARCH

1. Conducting radon prevalence studies at the local level is expensive, time-consuming and logistically difficult. Local public health units have limited resources to conduct such research studies, and yet radon is known health hazard prevalent in many communities. The Ministry of Health and Long-Term Care should allocate specific funding to health units to support radon awareness and local prevalence research. This is especially important given that the Ontario Building Code requires that radon prevalence be demonstrated before soil gas control measures are required to be implemented.
2. The radon prevalence map contained in this report indicates that radon prevalence increases in the rural areas of the city. It would be valuable to extend this study in to the rural townships surrounding the city. Since these areas are immediately adjacent to the city, the expense and logistical complexity would probably be similar to the present study.
3. The present study only examined the City of Thunder Bay. Given the high degree of geographic variability found in this study, it is clear that the prevalence results for the City cannot be extended to the rest of the District. Consideration should be given to extending this research to the rest of the District.
4. Additional research should be conducted into the causes of high radon. In particular, it should be determined why radon levels are so much lower in some City wards than in others. Some possible hypotheses about what may influence the differences in radon concentration seen across wards include: the underlying geology, the age structure or other characteristics of the homes, and the possible presence of radon in well water.

