Radon Soil Gas in the Halifax Regional Municipality: Should We Be Concerned?[1]

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Introduction

Recently, Health Canada lowered the guideline for exposure to indoor radon from 800 Bq/m^3 to 200 Bq/m^3. This decision was made on the basis of new scientific information linking radon exposure with increased incidences of lung cancer. Radon (Rn^{222}) is a naturally occurring, invisible, odourless, tasteless gas that is highly radioactive.

Research elsewhere has established a positive correlation between the presence of radon soil gas and indoor radon gas levels. Some parts of the Halifax Regional Municipality (HRM) have a history, albeit limited, of elevated indoor radon. Approximately 40% of the residents of Nova Scotia currently live within the HRM.

Radon soil gas data are severely lacking for Nova Scotia. Limited and focused data were collected by mineral exploration companies engaged in the search for uranium during the 1970s and early 1980s (Nova Scotia Department of Mines and Energy, 1982). A recent comprehensive, province-wide, regional sampling program, however, has detected radon in every soil type tested throughout Nova Scotia (Goodwin *et al*., 2009).

Radon soil gas data are absent for HRM, although radon has been previously recognized as a potential health hazard by Lewis *et al.* (1998) and White *et al*. (2008). During the 2008 field season, soil gas radon data were collected from 20 sites in HRM. Preliminary results for the regional radon soil concentrations in HRM are presented here for the first time. Funding for the program was provided by the Geological Survey of Canada and Health Canada (Radiation Protection Bureau), as part of the North American Soil Geochemical Landscapes Project (Goodwin, 2008, and Goodwin *et al.,* 2009).

Geology of HRM

"Geology is the most important factor controlling the source and distribution of radon" (Appleton, 2005). The relevance of this statement is very important for HRM, and indeed Nova Scotia as a whole, because of its complex bedrock and surficial geology.

Bedrock Geology

The bedrock of HRM consists of metasandstone and subordinate slate associated with the Late Neoproterozoic to Cambrian Goldenville Group, which is in turn overlain by slate, siltstone and minor metasandstone of the Middle Cambrian to Early Ordovician Halifax Group. Variably phased Devono-Carboniferous granites intrude both the Goldenville and Halifax groups.

Recent bedrock mapping of HRM by White *et al*. (2008) has subdivided the Goldenville and Halifax groups into new formations on the basis of stratigraphic position, lithology and mineralogy. The granites have also been subdivided on the basis of geochemistry, mineralogy, grain size and colour by MacDonald and Horne (1987).

The metasediments have been altered to regional greenschist facies metamorphic assemblages, except proximal to the granite where contact thermal metamorphic aureoles are superimposed upon the regional metamorphism (White *et al*., 2008).

Surficial Geology

The surficial geology of HRM is dominated by glacially derived sediment that commonly reflects the underlying bedrock, mineralogically, texturally

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and chemically. The following description of the surficial geology of HRM is summarized and modified from Stea and Fowler (1981), Finck and Stea (1995) and Lewis *et al.* (1998).

Locally derived ground moraine of the Beaver River Till (BRT) dominates the surficial geology of HRM. The BRT can be subdivided into three units: (1) metasandstone facies (Quartzite Till of Stea and Fowler, 1981); (2) slate facies (Slate Till of Stea and Fowler, 1981); and (3) granite facies (Granite Till of Stea and Fowler, 1981). The BRT is generally approximately 1 m in thickness, but can locally attain a thickness of approximately 10 m.

A fourth till unit, the distally derived Lawrencetown Till, is also common in HRM and occurs as a ground moraine and drumlins. Lawrencetown Till as a ground moraine is typically 2-5 m thick but can reach a maximum thickness of 25 m in drumlins. Sources of the Lawrencetown Till include highly variable intrusive and volcanic rocks from the Cobequid Highlands as well as Carboniferous sedimentary rocks located tens of kilometres up-ice, and from as far away as Prince Edward Island. Where present, Lawrencetown Till does not reflect the underlying bedrock lithologically, mineralogically, texturally or chemically. Small local deposits of glaciofluvial sediments and peat also occur in HRM.

2008 Sampling Program

Introduction

Twenty sites from within HRM were sampled for radon soil gas during July and August 2008, resulting in an overall average sampling density of approximately 1 sample per 100 km^2 (Fig. 1). Most of the sampling sites were located in parks throughout HRM.

Representative samples of soil gas were collected and tested for radon over the various representative bedrock units namely: (1) slate, (2) metasandstone and (3) granite. Sampling over granite was further refined based on the various phases of the granite as defined by MacDonald and Horne (1987): (1) an early, primitive monzogranite phase; (2) a middle medium- to coarse-grained leucomonzogranite phase; and (3) a late, highly evolved fine-grained leucomonzogranite phase. One additional refinement of the sampling program was the collection of radon soil gas measurements from all surficial units within HRM. This would include the four main till units: (1) metasandstone facies of the BRT, (2) slate facies of the BRT, (3) granite facies of the BRT and (4) Lawrencetown Till (both the moraine and drumlin facies).

Field Sampling Methodology

Most of the samples sites associated with the HRM survey were located in parks. The field sampling protocol and procedures employed in the HRM study, however, were identical to those used in the provincial radon survey described by Goodwin *et al.* (2009).

Similar to the provincial survey, each sample ‘site’ is represented by a single radon concentration. The radon concentration reported for a ‘site’ is actually a composite of five individual readings that have been averaged (mean) to represent the ‘site’. At each ‘site’, measurements of soil permeability and *in situ* gamma ray spectrometric readings of Total Count, equivalent uranium (eU), equivalent Thorium (eTh), and potassium (K) were also collected following the procedures described by Goodwin *et al.* (2009). Sample location co-ordinates (UTM 20T, NAD83) were geo-referenced with a GARMIN 12 GPS. Descriptive notes were recorded for each sample site.

2008 Results

Radon soil gas, measured in kBq/m^3 (1 kBq/m^3 = 1000 Bq/m^3; note that radon in indoor air is measured in Bq/m^3), was detected at all 20 sample sites tested within HRM during the 2008 sampling program. More importantly, radon soil gas was detected at all sites regardless of the (1) soil type/ conditions associated with variable glacially derived sediments or (2) variable underlying bedrock. It is also important to stress that the radon soil gas concentrations measured for this project represent natural background conditions and are not related to uranium mineralization.

It is acknowledged that there are limitations with applying rigid statistics to a small dataset, but some general observations and correlations can be made from the limited dataset. Radon soil gas

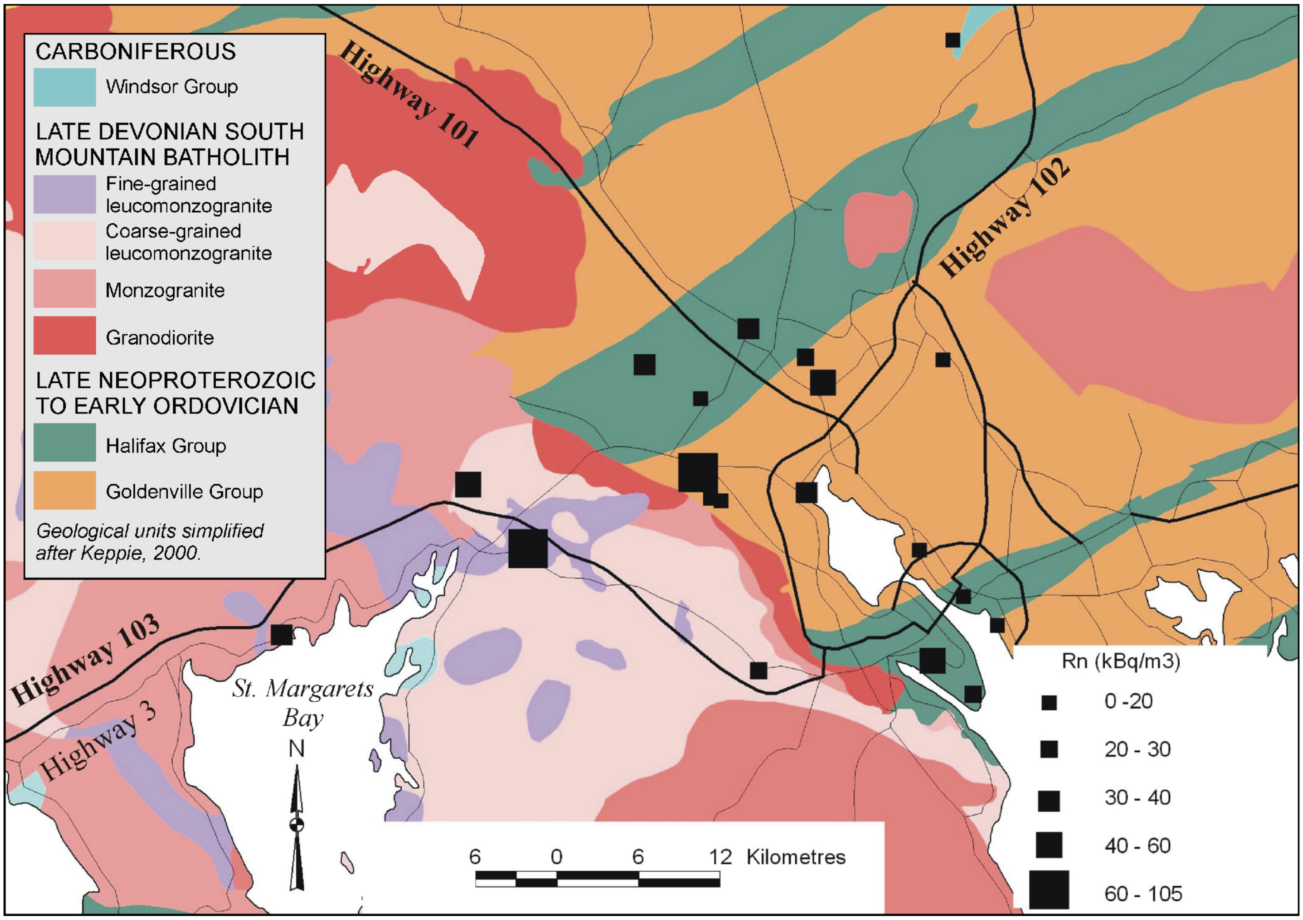

Figure 1. Sample locations and results for radon soil gas concentrations (kBq/m^3) from sample sites tested during the 2008 summer field season. Geology simplified after Keppie (2000).

concentrations (calculated as the mean of concentrations from the five probes) ranged from a low of 5.7 kBq/m^3 to a high of 104.4 kBq/m^3 with a mean of 32.2 kBq/m^3 (median of 27.2 kBq/m^3). Results are presented in Figure 1 and tabulated by bedrock type in Table 1.

The highest radon soil gas concentrations in the HRM survey are, generally, associated with late stage, highly evolved leucomonzogranite of the Halifax Pluton, which constitutes the easternmost end of the South Mountain Batholith. The highest radon soil gas concentration of 104.4 kBq/m^3 was found over this leucomonzogranite. The high radon soil gas associated with leucomonzogranite was also noted by Goodwin *et al*. (2009) in a regional radon soil gas survey completed across Nova Scotia. Within the HRM survey, the second highest radon concentration of 71.9 kBq/m^3, however, was associated with metasandstone bedrock.

Sites underlain by granite (monzogranite to leucomonzogranite) returned the highest minimum and maximum radon soil concentrations in HRM as well as the highest mean radon concentration of 54.1 kBq/m^3. This was followed by Halifax Group slate which has a mean of 29.3 kBq/m^3 and Goldenville Group metasandstone with a mean of 25.1 kBq/m^3. The mean radon soil concentrations for slate and metasandstone are approximately 50% of those reported for granite bedrock (Table 1) but very similar to the provincial mean of 25.3 kBq/m^3 reported by Goodwin *et al.* (2009). Additional data points are required to further refine these levels and increase the confidence of this very limited dataset.

In order to determine the surficial geology of each site, samples were plotted in a Geographic Information System (GIS) and compared to the mapped surficial units of Stea and Fowler (1981). Thirty per cent (6 out of the 20) of the sites

Table 1. Radon soil gas concentrations for the various underlying bedrock types.

Bedrock Geology	n =	Minimum (kBq/m^3)	Maximum (kBq/m^3)	Mean (kBq/m^3)
metasandstone	10	5.7	71.9	25.1
slate	6	12.8	45.8	29.3
monzogranite - leucogranite	4	27.3	104.4	54.1

sampled had till units that were not derived directly from the underlying bedrock. Radon results for each sample site were re-classified by the surficial geology type (instead of bedrock geology) and are summarized in Table 2. The net result was a very slight change in the radon soil gas concentration of the locally derived BRT metasandstone and slate till facies, which strongly reflect the underlying bedrock. There was no change with the locally derived granite facies of the BRT. The distally derived Lawrencetown Till, however, does not reflect the underlying bedrock so these data are treated as a separate population. The mean radon soil concentration value of the Lawrencetown Till is very similar to the BRT metasandstone and slate till facies (as well as the provincial average) but significantly less than the granite facies of the BRT.

Radon soil gas concentrations and soil permeability levels are recognized as the two most important factors in determining the availability of radon from soil to air (Chen *et al.,* personal communication). The soil radon potential (*SRP*) index has been used by Chen *et al.* (personal communication) for a study of five of the most populated communities in Ottawa, Ontario, in an attempt to correlate soil gas radon and soil permeability with indoor radon potential. The *SRP* index is mathematically defined as (Neznal *et al.,* 2006):

$$SRP = C\text{-}C_0/\ \text{-}\log(P)+\log(P_0)$$

where C is the radon soil gas concentration for a site in units of kBq/m^3, and P is the soil permeability of the site in units of m^2. Constants C_0 and P_0 are set to 1 kBq/m^3 and $1x10^{-10}m^2$, respectively.

The HRM survey differs slightly from the Ottawa survey in the following three ways. First, the HRM survey is subdivided on the basis of the bedrock and surficial geology, not on community

Table 2. Radon soil gas concentrations for the types of surficial material sampled.

Surficial Geology	n =	Minimum (kBq/m^3)	Maximum (kBq/m^3)	Mean (kBq/m^3)
BRT (metasandstone facies)	7	5.7	71.9	26.2
BRT (slate facies)	4	12.8	45.8	25.4
BRT (granite facies)	4	27.3	104.4	54.1
Lawrencetown Till	5	15.9	44.0	28.3

boundaries. Second, probe depths for the HRM survey were 60 cm versus 80 cm used in the Ottawa survey. Finally, the HRM survey used the mean radon soil gas concentration from all five probes whereas the Ottawa survey excluded any levels below 0.7 kBq/m^3, plus the lowest measured level prior to the calculation of the mean radon soil gas concentration for the site. The net effect of removing these low concentrations is to increase the mean radon soil gas concentrations of the Ottawa survey relative to the HRM survey. The rationale for using 60 cm probe depth and the mean radon soil gas concentration from five probes is described in Goodwin *et al.* (2009), which suggests that there is no appreciable difference between radon concentrations obtained from 60 cm of depth versus 70, 80 or 90 cm depth.

A summary of the calculated *SRP* indexes, subdivided by bedrock geology, is presented in Table 3. The results follow the same trend as the radon soil concentration values presented in Table 1. Granite (monzogranite to leucomonzogranite) returned the highest mean *SRP* index value of 43.6 followed by slate (20.4) and metasandstone (16.6). When compared to the results presented by Chen *et al.* (personal communication), the highest reported mean *SRP* index value was 16.0 for the community of Kanata, which is still lower than the mean *SRP* index value of 16.6 for the metasandstone tested in HRM, and significantly lower than the mean *SRP* index value of 43.6 for granite (monzogranite to leucomonzogranite) tested in HRM.

The *SRP* indexes were re-calculated on the basis of the surficial geology and results are presented in Table 4. The granite facies of the BRT returned the highest mean *SRP* index value of 43.6, followed by the slate facies (22.0) and the metasandstone facies (19.0), a similar trend to the bedrock geology presented in Table 3.

The generally clay-rich Lawrencetown Till is characterized by very low permeability. The very low permeability of the Lawrencetown Till is reflected in the mean *SRP* index value of 13.4, the lowest value of any of the till units tested. Lawrencetown Till effectively dilutes the *SRP* index of the underlying bedrock geology. Once the distally derived Lawrencetown Till data are removed, the *SRP* index for each of the locally derived BRT till facies increases approximately 10% from the results presented in Table 3 (except the granite facies because, where tested, the granite facies was always overlying granite bedrock).

Mean results for the *in situ* gamma ray spectrometric readings for eU and K by till type are summarized in Tables 5 and 6, respectively. Mean eU concentrations are highest in the granite (2.0 ppm) and slate facies (2.0 ppm) of the BRT

Table 3. SRP indexes for the various underlying bedrock types.

Bedrock Geology	n =	Minimum SRP	Maximum SRP	Mean SRP
metasandstone	10	6.0	37.7	16.6
slate	6	9.5	39.9	20.4
monzogranite - leucogranite	4	24.3	83.8	43.6

Table 4. SRP indexes for the types of surficial material sampled.

Surficial Geology	n =	Minimum SRP	Maximum SRP	Mean SRP
BRT (metasandstone facies)	7	5.0	37.7	19.0
BRT (slate facies)	4	9.5	39.9	22.0
BRT (granite facies)	4	24.3	83.8	43.6
Lawrencetown Till	5	7.5	19.1	13.4

followed by the metasandstone facies (1.4 ppm) of the BRT and the Lawrencetown Till (1.2 ppm). Mean K concentrations follow a similar trend with the highest mean level associated with the granite facies (1.7 %) of the BRT followed by the slate facies (1.5 %) and the metasandstone facies (1.1 %) of the BRT. The lowest K concentrations are associated with the Lawrencetown Till (1.1 %).

Discussion

It is important to reiterate that radon soil gas was detected at all sample sites tested in HRM during the 2008 sampling program, regardless of the (1) soil type/conditions or (2) the underlying bedrock. It is also important to note that the soil concentrations reported are the result of natural background conditions and are not related to any known uranium mineralization.

The complex surficial geology of HRM likely contributes to local and regional variability. The texture of various till units, for example the Lawrencetown Till, could also make a significant contribution to the local variability. In an urban setting, additional variability is likely to be associated with fill material that has been trucked in to level off a residential or commercial building lot. Since the fill material can be considered an anthropogenic input, it raises many questions. What is the geologic source of the fill material? What is the uranium concentration of the fill? What is the radon concentration of the fill? What is the aerial distribution and thickness of the fill? What is the permeability of the fill material?

Similarly, in a park setting (used for the majority of sample sites for the HRM radon survey), has fill material been trucked in? Has the soil been compacted by machinery or by humans, thereby reducing soil permeability? Are radon concentrations different in a grassy picnic area in middle of a park (where the majority of the sample sites were located) compared to an adjoining greenbelt?

Bedrock geology and surficial geology are not mutually exclusive, but under some conditions one may be more significant than the other with respect to radon. For example, Smethurst *et al.* (2008) indicate that in Norway, glaciofluvial material makes a significant contribution to the radon potential of a study area. With respect to the HRM study, if 30% of the till units were not derived from the underlying bedrock, it begs the question: what

Table 5. *In situ* gamma ray results (eU) for the types of surficial material sampled.

Surficial Geology	n =	eU Min. (ppm)	eU Max. (ppm)	eU Mean (ppm)
BRT (metasandstone facies)	7	1.2	1.8	1.4
BRT (slate facies)	4	1.2	2.5	2.0
BRT (granite facies)	4	1.5	2.5	2.0
Lawrencetown Till	5	1.0	1.4	1.2

Table 6. *In situ* gamma ray results (K) for the types of surficial material sampled.

Surficial Geology	n =	K Min. (%)	K Max. (%)	K Mean (%)
BRT (metasandstone facies)	7	0.9	1.2	1.1
BRT (slate facies)	4	1.1	1.6	1.5
BRT (granite facies)	4	1.2	2.2	1.7
Lawrencetown Till	5	0.7	1.2	1.0

is the more important factor when completing a spatial analysis study of radon concentrations, bedrock or surficial till type? The importance of the availability of accurate and detailed surficial and bedrock geological maps cannot be underestimated. Bedrock units should not be grouped together. For example, the various phases of granite need to be identified and their aerial extent mapped. As previously mentioned, identification of the various phases of granite is very important because primitive phases of granite tend to have lower uranium concentrations relative to highly evolved granitic phases.

We urge caution, however, even in this type of simplistic characterization of the various phases of granite. The rationale that primitive granites tend to have less uranium and other incompatible elements relative to highly evolved granites may be misleading. At the Millet Brook uranium deposit, located near Vaughan, Hants County, primitive, early phase granodiorite is the host rock of significant uranium enrichment that is structurally controlled in northeast-trending shear zones (Ham, 1990). Another example is Harrietsfield, located less than 10 km south of Halifax. A report by the Provincial Uranium Task Force (Grantham, 1986) identified that some residents of this small village were exposed to elevated concentrations of uranium, radon and radium in their well water. Harrietsfield is underlain by a relatively primitive monzogranite (MacDonald and Horne, 1987). In both of these cases, however, it is possible that a late-phase leucomonzogranite may be present at a shallow depth (<250 m?) and is the source of uranium enrichment in what is otherwise a primitive granite.

These two examples demonstrate that detailed geologic site investigations are required to fully understand the complex relationships between the presence of radon and uranium associated with the surficial and bedrock geology. Not only is the type of bedrock critically important to the overall picture but also: (1) regional and local metamorphism, (2) regional faults and local structure such as shear zones, and (3) the presence of mineralized zones all play important roles in controlling radon and uranium in the local environment.

So should we be concerned about radon soil gas within HRM? The short answer is yes. A study designed to estimate the indoor radon potential of 719 homes tested across Nova Scotia using eU results from an airborne radiometric survey found a good correlation between rocks elevated in uranium (ppm) and homes with elevated radon in indoor air (Jackson, 1992). Je (1997) and Appleton (2005) describe numerous examples of exposure to radon and associated human health risks. Lewis *et al.* (1998) and White *et al*. (2008) have recognized that radon is a naturally occurring geologic hazard in HRM.

Approximately 380,000 people, or 40% of the residents of Nova Scotia, live within HRM and the population of HRM continues to grow and is projected to add an additional 100,000 residents by 2028 (Greater Halifax Partnership, 2005). As residential development of HRM expands, particularly to the west in the vicinity of Highway 103 and Highway 3, there will be an increase in human exposure to granite, in particular leucomonzogranite, which has the highest radon soil gas concentrations tested to date. Current testing of government-owned and -operated buildings for radon in indoor air has shown that a number of schools located in the vicinity of Highway 103 and Highway 3 exceed the recommended national guideline of 200 Bq/m^3 for radon in indoor air (Nova Scotia Department of Environment, 2009). These schools, including Beechville-Lakeside-Timberlea, Ridgecliff Middle School and Tantallon Elementary, are all located on leucomonzogranite, indicating a correlation between radon soil gas and radon in indoor air. It should be reiterated, however, that radon in soil gas exists everywhere in Nova Scotia and human exposure to radon is not limited to those living on granitic terrain.

Ultimately, human exposure to radon in a building will likely be heavily dependent upon four main variables: (1) type of surficial material (and bedrock source), (2) uranium/radon content of the surficial deposits, (3) permeability of the surficial deposits and (4) building construction and ventilation.

Regardless of where one lives in Nova Scotia, all residents of the province are encouraged to test their homes for indoor radon gas. Information on radon in Nova Scotia is available from the Nova Scotia Department of Environment on the internet at: http://www.gov.ns.ca/nse/airlandwater/radon.asp. Additional information on radon is also available on-line from Health Canada at http://www.hc-sc.gc.ca/hl-vs/iyh-vsv/environ/radon-eng.php.

Conclusions

Results for 20 sites sampled in HRM during the 2008 field season for naturally occurring radon soil gas concentrations indicate that radon in soil gas was detected at every location tested. Radon soil gas concentrations ranged from a low of 5.7 kBq/m^3 to a high of 104.4 kBq/m^3, yielding a mean of 32.2 kBq/m^3. The 2008 HRM results demonstrate that naturally occurring radon soil gas concentrations represent natural background conditions and are not related to radon emanating from uranium deposits.

When subdivided by bedrock geology, the highest radon soil gas concentrations are associated with granite (mean radon concentration of 54.1 kBq/m^3) followed by Halifax Group slate (mean of 29.3 kBq/m^3) and Goldenville Group metasandstone (mean of 25.1 kBq/m^3). Further subdivision of the granite (monzogranite to leucomonzogranite) indicates the highest radon soil gas concentrations (up to 104.4 kBq/m^3) are associated with late stage, highly evolved leucomonzogranite.

When the results are subdivided by surficial geology, the highest mean radon soil gas concentrations are associated with the granite facies (54.1 kBq/m^3) followed by the metasandstone facies (26.2 kBq/m^3) and the slate facies (25.4 kBq/m^3) of the locally derived Beaver River Till. The distally derived Lawrencetown Till returned a mean radon soil gas concentration of 28.3 kBq/m^3.

The soil radon potential (*SRP*) index was calculated in an attempt to correlate soil gas radon and soil permeability. Granite returned the highest mean *SRP* index value of 43.6 followed by slate (20.4) and metasandstone (16.6).

When the *SRP* indexes were re-calculated on the basis of the surficial geology the granite facies of the BRT returned the highest mean *SRP* index value of 43.6, followed by the slate facies (22.0) and the metasandstone facies (19.0). The generally clay-rich Lawrencetown Till is characterized by very low permeability, which is reflected in the lowest mean *SRP* index value of 13.4. The Lawrencetown Till effectively dilutes the *SRP* index of the underlying bedrock geology.

Mean *in situ* gamma ray spectrometric readings for eU are highest in the granite facies (2.0 ppm) and the slate facies (2.0 ppm) followed by the metasandstone facies (1.4 ppm) and the Lawrencetown Till (1.2 ppm). Mean *in situ* gamma ray spectrometric readings for K are also highest in the granite facies (1.7 %) followed by the slate facies (1.5 %), the metasandstone facies (1.1%) and the Lawrencetown Till (1.0 %).

Radon in soil gas occurs naturally and is present everywhere throughout HRM (and the Province of Nova Scotia). Currently, approximately 380,000 people, or 40% of the province's residents, live within HRM and by 2028, the population of HRM is projected to increase by an additional 100,000 people. With increased urban development, particularly westward along Highway 103 and Highway 3, there is an increased risk of exposure to soils derived from granite, which contain the highest radon soil gas concentrations tested within HRM to date.

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