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Radon exhalation from building materials for decorative use

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ABSTRACT

Long-term exposure to radon increases the risk of developing lung cancer. There is considerable public concern about radon exhalation from building materials and the contribution to indoor radon levels. To address this concern, radon exhalation rates were determined for 53 different samples of drywall, tile and granite available on the Canadian market for interior home decoration. The radon exhalation rates ranged from non-detectable to 312 Bq m^{-2} d^{-1}. Slate tiles and granite slabs had relatively higher radon exhalation rates than other decorative materials, such as ceramic or porcelain tiles. The average radon exhalation rates were 30 Bq m^{-2} d^{-1} for slate tiles and 42 Bq m^{-2} d^{-1} for granite slabs of various types and origins. Analysis showed that even if an entire floor was covered with a material having a radon exhalation rate of 300 Bq m^{-2} d^{-1}, it would contribute only 18 Bq m^{-3} to a tightly sealed house with an air exchange rate of 0.3 per hour. Generally speaking, building materials used in home decoration make no significant contribution to indoor radon for a house with adequate air exchange.

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1. Introduction

Recent studies of people exposed to radon have confirmed that radon in homes represents a serious health hazard (WHO, 2005, 2009). The main health risk associated with long-term, elevated exposure to radon is an increased risk of developing lung cancer, which depends on the radon concentration and the length of exposure. Although radon is formed mainly in the soil and rock upon which a house is built, exhalation from building materials is another potential source of radon in the indoor environment (Cothern and Smith, 1987; UNSCEAR, 2000, 2008; WHO, 2009). There is considerable public concern about radon exhalation from building materials, especially those used for interior decoration, as can be found on the internet and listed as one of frequently asked questions (AARST, 2008; USEPA, 2009; HPS, 2008; MacAuley, 2008; Prentice, 2008; Richardson, 2009). The purpose of this study is to address this public concern and to estimate the contribution of building materials to indoor radon levels.

As in soil and rock, radon gas is formed inside building materials by decay of the parent nuclide ^{226}Ra. However, it is not possible to determine the radon exhalation rate simply from the activity concentration of ^{226}Ra. Instead one must measure radon exhalation rates directly from the surface of the material, as shown by many studies in the literature, especially for granites (Ackers, 1984; Mustonen, 1984; Chao and Tung, 1999; Al-Jarallah, 2001; Keller et al., 2001; Stoulos et al., 2003; Arafa, 2004; Kitto and Green, 2005; Righi and Bruzzi, 2006; Allen et al., 2009; Steck, 2009). Studies found in the literature consistently demonstrate that radon exhalation rates of building materials varied widely and some building materials may contribute to indoor radon levels. Although many data are available, especially for granites commonly used in home decoration, large variability has made the existing data insufficient to conclude which types of granites have higher radon exhalation rate than others. Even though such variation of radioactivity in natural materials can not be reduced by conducting more and intensive measurements, it is of interest to the Canadian public to assess radon contribution from building materials commonly available in the Canadian market, and to verify whether materials used in Canadian homes have any difference in radon exhalation characteristics as reported elsewhere. Although granite is believed to have a higher radon exhalation rate on average (Keller et al., 2001; Petropoulos et al., 2002; Righi and Bruzzi, 2006; Allen et al., 2009), other building materials such as drywall and various tiles used to cover large surfaces were also considered in this study.

2. Materials and methods

2.1. Samples

Drywall is commonly used for interior walls and ceilings. They are panels made of gypsum plaster pressed between two thick sheets of paper, then kiln dried. Because drywall covers most interior surfaces, especially in homes in Canada, four types of drywall were also chosen, two types for regular use and two for bathrooms with high humidity. They were the most common brands available in two nation-wide hardware retailers, sampled in their outlets in Ottawa.

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Tiles are manufactured pieces of durable material such as ceramic or stone and are commonly used for covering floors and walls, or other objects such as tabletops. Samples of tile were chosen from the two hardware outlets mentioned above. These included four types each of porcelain tiles, marble tiles, ceramic tiles, and slate tiles. Tiles are normally sized as 30 cm × 30 cm. Each tile sample consisted of four pieces of the same type in this size, in order to have a surface larger than the base area of the cylindrical container in the measurement system (see Fig. 1b).

Granite has been used extensively as flooring tiles in public and commercial buildings. Its natural beauty has attracted home builders and polished granite is popular for kitchen countertops. A total of 33 granite samples were obtained from 4 stores in Ottawa. The stores are specialized in granite countertops and differ from the two hardware outlets mentioned above. Each store was asked to provide their top selling brands in a minimum surface of 40 cm × 40 cm. Top selling was the only criterion for selecting granite samples. There were no considerations on ^{226}Ra concentration, hardness index, grain size, colour or other properties. Three granite samples #3, #6 and #24 have the same names and origins as the granite samples #16, #18 and #30, respectively. Because they were obtained from different stores, they were treated as different samples.

2.2. Experiments

Radon exhalation measurements are usually based on the principle of hermetically enclosing or covering the sample with a container/accumulator and measuring the radon activity growth as a function of time inside the container, as summarized by Petropoulos et al. (2001). This study used a simple accumulator method involving the continuous measurement of the radon concentration in a container placed on the surface of a sample of building material. The container was a stainless steel cylinder with a wall thickness of 2 mm, an inner height of 100 mm, and a diameter of 350 mm. To maintain air tightness a chemically resistant adhesive rubber (1 mm thickness) was fixed on the base of the container. The top of the container had two ports which could be connected to a continuous radon monitor by means of silicon hoses (Radon V.O.S., 2007). Radon concentrations in the container were determined by means of a Lucas cell (Model 300A) and a portable continuous radon monitor AB-5 (Pylon Electronics Inc., Canada) operated in the continuous flow-through mode. The input hose to the AB-5 was equipped with a filter to suppress radon decay products. The experimental setup is illustrated in Fig. 1. The system is a continuous loop with practically no loss of air. The AB-5 has a built-in pump with adjustable flow rate ranging from 0 to 0.05 L/s. The system was first used for several samples at various flow rate from 0.01 to 0.05 L/s. Since no significant influence of flow rate was observed, experiments were conducted at a flow rate of 0.05 L/s.

Although radon exhalation is governed primarily by the content of its parent radionuclide ^{226}Ra in the material, it depends also on several other parameters, such as humidity and temperature (Stranden et al., 1984). To assess exhalation from building material in the indoor environment, all experiments were carried out in a laboratory having normal indoor humidity and temperature, as in most Canadian homes.

Once the sample has been covered by the container, the radon activity (C, Bq m^{-3}) as a function of time is given by the formula:

$$C = \frac{E \cdot A\left(1 - e^{-\lambda^* t}\right)}{\lambda^* \cdot V} + C_0 \cdot e^{-\lambda^* t} = \frac{E\left(1 - e^{-\lambda^* t}\right)}{\lambda^* \cdot H} + C_0 \cdot e^{-\lambda^* t} \quad (1)$$

where E is the radon exhalation rate (Bq m^{-2} d^{-1}) from the sample surface; A is the area (m^2) of the sample covered by the container with volume V (m^3) and height H (m); C_0 is the initial radon concentration (Bq m^{-3}) in the container at time $t = 0$, i.e. the background radon concentration in the laboratory. The effective decay constant λ^* (d^{-1}) is the sum of radon decay constant λ_0 (0.181 d^{-1}) and the first order removal rate by back-diffusion and container leakage, $\lambda_{b,l}$ in d^{-1}.

When applying Eq. (1), it was necessary to minimize the background term C_0, especially for materials of low radon exhalation rates. The radon concentration in the laboratory where all testing was performed was about 15 ± 10 Bq m^{-3}. Therefore, the contribution from the term $C_0 \cdot e^{-\lambda^* t}$ in Eq. (1) can be neglected. The back-diffusion effect was effectively avoided by choosing a large container with a free volume at least 10 times larger than the pore volume of the sample (Krisiuk et al., 1971; Chao and Tung, 1999). Under these conditions, the surface exhalation rate in the hermetically sealed container should be close to the free surface exhalation corresponding to the actual room conditions.

The radon concentration (Bq m^{-3}) in a closed volume increases approximately linearly from about 1 h after starting to 10 h later Ackers 1984. For $\lambda^* t \ll 1$,

$$C(t) = \frac{E}{H} t \quad (2)$$

The radon exhalation rate (Bq m^{-2} d^{-1}) can be determined by the slope of the initial growth curve multiplied by the height of the container:

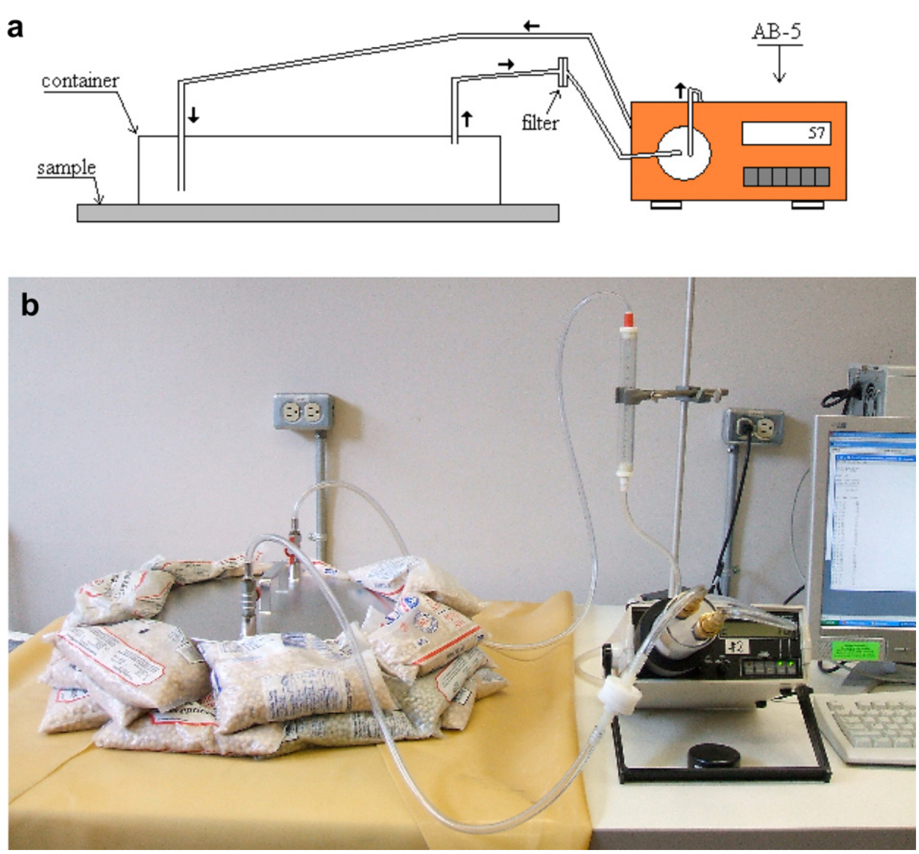

Fig. 1. Experiment set-up for surface radon exhalation measurement, a sketch (a) and a photograph (b).

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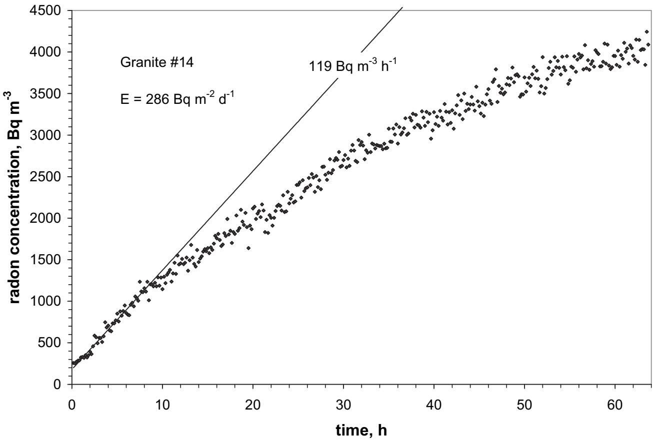

Fig. 2. Radon concentration as a function of time inside the container due to radon exhalation from the granite slab #14.

$$E = H \times \frac{dC}{dt} \tag{3}$$

With this simple method, measurements were performed for all 53 samples. Radon concentrations within the container were monitored every 10 min for at least 7 h. The radon exhalation rates in Bq m^{-2} d^{-1} were determined by the initial linear increase of the radon concentration within the closed volume from 1 h after start of radon build-up to 7 h later. For each sample, measurements were performed twice. If results of the two measurements differed more than 50%, the measurements were then repeated twice.

Most of the granite samples have only one side polished, but a few pieces were polished for both sides. A previous study suggested that there might be different exhalation rates from the different surfaces (Brodhead, 2008), so the measurements were performed for both polished and unpolished sides.

3. Results

Fig. 2 shows an example of the growth curve of radon concentration due to exhalation from granite slab #14. Its exhalation rate was determined from the initial slope of the growth curve to be 286 Bq m^{-2} d^{-1}. Three more examples are given in Fig. 3 for various radon exhalation rates. Results for samples of drywall, marble, porcelain, ceramic and slate are summarized in Table 1. These values are average radon exhalation rates and standard deviations of repeated measurements for individual samples. The ranges of actual measured values are given in the brackets. The radon exhalation rates ranged from non-detectable (ND) to 63 Bq m^{-2} d^{-1} with higher values occurring among slate tiles. The average radon exhalation rate for the slates was 30 ± 16 Bq m^{-2} d^{-1} while a very low average radon exhalation rate, 0.9 ± 0.8 Bq m^{-2} d^{-1}, was observed for drywall, marble, ceramic and porcelain tiles.

Results for various granite samples are given in Table 2. The radon exhalation rates of granite ranged from non-detectable to 312 Bq m^{-2} d^{-1} with an average (arithmetic mean) of 42 Bq m^{-2} d^{-1}, a geometric mean of 11.5 Bq m^{-2} d^{-1} and a geometric standard deviation of 6.3. The average radon exhalation rate observed here was similar to many other investigations reported in the literature (Chao and Tung, 1999; Al-Jarallah, 2001; Keller et al., 2001; Stoulos et al., 2003; Arafa, 2004; Kitto and Green, 2005; Allen et al., 2009). Generally speaking, some granite and slate materials have higher radon exhalation rates than other materials, such as marble or ceramic tiles.

No significant differences were observed between radon exhalation rates from the polished and un-polished side of granite slabs studied here. In the literature, reported results of radon exhalation measurements for both polished and unpolished sides of granite samples showed large variations, some samples had similar radon exhalation rates from both sides while other samples demonstrated significant differences and some even differed by a factor more than 10 (Kotrappa et al., 2009).

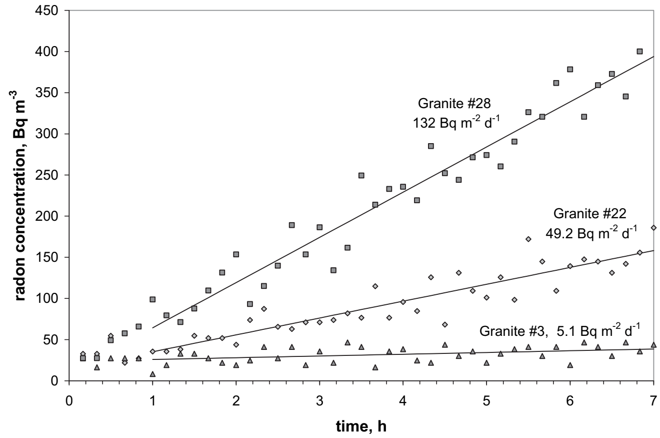

Fig. 3. Examples of radon growth curves and the derived radon exhalation rates for Granite #3 (5.1 Bq m^{-2} d^{-1}), #22 (49 Bq m^{-2} d^{-1}), and #28 (132 Bq m^{-2} d^{-1}).

Two samples of Ornamental granite and two samples of Uba Tuba granite obtained from different stores showed similar and low radon exhalation rates. However, radon exhalation rates of two Tan Brown samples from two different granite stores differed by a factor of 7. This difference is due to the variation of radioactivity concentrations in natural stone. Even larger variations were observed on the surfaces of individual slabs (Steck, 2009).

4. Assessments and discussions

Under steady conditions, the radon level in a room due to exhalation from indoor material approaches a steady-state concentration, Bq m^{-3}:

Table 1
Radon exhalation rates of decorative materials: drywall, marble, porcelain, ceramic and slate.

Material	Sample	Radon exhalation rate (range), Bq m^{-2} d^{-1}
Drywall	Regular #1	0.9 ± 0.5 (0.5–1.3)
	Regular #2	1.1 ± 0.9 (0.4–1.7)
	Humidity #1	1.1 ± 1.2 (0.3–2.0)
	Humidity #2	2.7 ± 0.3 (2.5–2.9)
Marble	#1	0.1 ± 0.1 (ND–0.2)
	#2	0.4 ± 0.2 (0.3–0.6)
	#3	ND
	#4	0.2 ± 0.4 (ND–0.6)
Porcelain	#1	ND
	#2	1.4 ± 1.4 (0.2–2.9)
	#3	1.0 ± 1.1 (0.2–1.7)
	#4	0.5 ± 0.7 (ND–1.3)
Ceramic	#1	0.2 ± 0.3 (ND–0.4)
	#2	2.2 ± 0.3 (2.0–2.4)
	#3	1.2 ± 0.4 (0.8–1.8)
	#4	1.6 ± 1.3 (0.7–3.0)
Slate	#1	30 ± 4 (25.3–33.0)
	#2	46 ± 4 (42.2–49.2)
	#3	35 ± 18 (6.9–62.5)
	#4	8.6 ± 2.9 (6.3–12.9)

ND, not detectable.
The values are average radon exhalation rates and standard deviations of repeated measurements for individual samples. The ranges of actual measured values are given in the brackets.

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Table 2
Radon exhalation rates of granites from various countries.

Sample index (product name)	Origin	Radon exhalation rate (range), $Bq\ m^{-2}\ d^{-1}$
#1 (Nero Assoluto)	Africa	2.3 ± 2.8 (0.3–4.3)
#2 (Nero Asoluto)	Africa	16 ± 5 (11.3–21.5)
#3 (Ornamental)	Brazil	3.1 ± 2.8 (1.1–5.1)
#4 (Brasil Colonial)	Brazil	8.7 ± 1.5 (7.7–9.8)
#5 (Bianco Antico)	Brazil	50 ± 6 (45.6–54.3)
#6 (Uba Tuba)	Brazil	5.1 ± 1.5 (4.0–6.1)
#7 (Verde Butterfly)	Brazil	5.6 ± 2.7 (2.6–7.9)
#8 (Silver Sea Green)	Brazil	53 ± 10 (41.4–59.4)
#9 (Tan Brown)	Brazil	10 ± 12 (ND–22.6)
#10 (Tropical Brown)	Brazil	58 ± 26 (25.4–89.3)
#11 (Giallo San Cecilia)	Brazil	9.2 ± 4.1 (5.8–13.8)
#12 (Carmen Red)	Brazil	103 ± 37 (49.0–165)
#13 (Ivory Brown)	Brazil	130 ± 9 (123–136)
#14 (Red Dragon)	Brazil	261 ± 37 (212–299)
#15 (Serrizo Formaza)	Brazil	70 ± 16 (49–89)
#16 (Ornamental)[a]	Brazil	2.9 ± 1.6 (1.2–5.0)
#17 (Oubatouba)	Brazil	0.6 ± 0.7 (ND–1.1)
#18 (Uba Tuba)[b]	Brazil	2.5 ± 0.8 (1.6–3.3)
#19 (Golden Leaf)	Brazil	208 ± 97 (120–312)
#20 (Astra)	Canada	9.6 ± 3.3 (7.2–11.9)
#21 (Caladonia)	Canada	0.4 ± 0.4 (0.2–1.0)
#22 (Cashmere Gold)	India	54 ± 5 (49.2–61.2)
#23 (Cashmere White)	India	16 ± 1 (15.5–16.8)
#24 (Tan Brown)	India	73 ± 6 (69.0–76.9)
#25 (Giablly)	India	0.5 ± 0.7 (ND–1.0)
#26 (Cremo Romano)	India	2.2 ± 0.2 (2.0–2.3)
#27 (Lavender Blue)	India	2.9 ± 0.8 (2.3–3.4)
#28 (Jade Green)	India	128 ± 6 (123–132)
#29 (Himalayan Blue)	India	7.2 ± 5.7 (0.6–14.3)
#30 (Tan Brown)[c]	India	10 ± 5 (5.9–17.3)
#31 (Rosa Beta)	Italy	2.2 ± 1.3 (0.8–3.7)
#32 (Tropic Brown)	Saudi Arabia	83 ± 13 (73.6–97.1)
#33 (White Geogia)	USA	0.9 ± 0.4 (0.6–1.3)

ND means not detectable. The values are average radon exhalation rates and standard deviations of repeated measurements for individual samples. The ranges of actual measured values are given in the brackets.
[a] Granite #16 has the same name and origin as granite #3. They were obtained from different stores, therefore, treated as different samples.
[b] Granite #18 has the same name and origin as granite #6. They were obtained from different stores, therefore, treated as different samples.
[c] Granite #30 has the same name and origin as granite #24. They were obtained from different stores, therefore, treated as different samples.

$$C = \frac{E \cdot A}{(\lambda_0 + \lambda_v)V} \tag{4}$$

where E is the radon exhalation rate ($Bq\ m^{-2}\ d^{-1}$) of the material installed, A the area (m^2) of the material exhaling radon, V the air volume (m^3) of the room, i.e. the room volume minus the volume occupied by room contents. λ_0 is the radon decay constant ($0.181\ d^{-1}$) and λ_v the air removal rate due to ventilation. It is clear that the steady-state radon concentration depends on the strength of the radon source and the effective air exchange/removal rate. Both the Canadian Standards Association Standard CAN/CSA-F326 (CSA, 1991) and the National Building Code of Canada (NRCC, 2005) suggest residential mechanical ventilation systems should provide a total indoor/outdoor air exchange rate of at least 0.3 air changes per hour (ACH). Assuming outdoor fresh air has a negligible concentration of radon, the effective radon removal rate $\lambda_v = 24 \times \mathrm{ACH}$ in units of d^{-1}.

To assess the contribution of building materials to indoor radon concentrations, three scenarios were considered. In all cases, a tightly sealed house with an air change rate of a given ACH was assumed.

4.1. Case I – radon exhalation from a granite countertop

Consider a granite countertop ($0.67\ m \times 2.50\ m \times 0.025\ m$) installed in a kitchen with an area of $20\ m^2$ and a height of 2.5 m, with the assumption that 75% of the kitchen volume is air with the remainder occupied by kitchen wares and furniture. Assuming the kitchen is ventilated with the minimum required ACH of $0.3\ h^{-1}$, the radon concentration in the kitchen due to exhalation from both sides of a granite countertop is then $0.5\ Bq\ m^{-3}$ for granite countertops having the average exhalation rate of the different granites studied here, i.e. $42\ Bq\ m^{-2}\ d^{-1}$. For granite countertops having the highest radon exhalation rate ($300\ Bq\ m^{-2}\ d^{-1}$) observed in this study, the radon concentration in the kitchen will be $3.6\ Bq\ m^{-3}$. It can be concluded that under normal ventilation in a kitchen granite countertops contribute very little to the radon concentration for the range of radon exhalation rates reported here. Similar assessments were reported in the literature (Kitto and Green, 2005; Allen et al., 2009; Alvarcz et al., 2009; Kitto et al., 2009).

Based on more data available recently, it was assessed that the average radon concentration in Canadian homes is $45.5\ Bq\ m^{-3}$ (Chen and Moir, in press). The above assessment showed that on average, granite countertops could add a radon concentration of only $0.5\ Bq\ m^{-3}$ in the kitchen and much less to the entire house. It indicates that on average, granite countertops could contribute to less than 1% of radon concentration in Canadian homes.

4.2. Case II – radon exhalation from a floor area

If a room has its entire floor decorated with ceramic tiles or slate or granite and 10% of the room volume is occupied by furniture, the radon concentration, $Bq\ m^{-3}$, due to radon exhalation from the floor can be determined by

$$C = \frac{E \cdot A}{(\lambda_0 + \lambda_v)V} = \frac{E}{0.9(\lambda_0 + \lambda_v)H} \tag{5}$$

where H is the room height in meters. For $H = 2.5$ m, radon concentration in the room depends on the radon exhalation rate from the surface of the floor material and the air change rate of the room. The resulting radon concentrations are calculated for materials of various radon exhalation rates and for various air change rates, as shown in Table 3.

One can see from Table 3 that even if the entire floor were covered with a material of a relatively high radon exhalation rate, $300\ Bq\ m^{-2}\ d^{-1}$, it would contribute only $18\ Bq\ m^{-3}$ to a tightly sealed house (minimum required ACH of 0.3 per hour). This is only 9% of the Canadian radon guideline level. Higher ventilation rates will reduce the contribution proportionally. If the ventilation system operates at half its required full capacity (ACH = 0.15), the radon contribution from the indoor building material will be doubled. In the worst case when the mechanical ventilation system failed completely and no natural ventilation alternative was provided (ACH = 0), the indoor radon concentration would rise above the Canadian guideline of $200\ Bq\ m^{-3}$ if the floor were covered with a material having a radon exhalation rate of $100\ Bq\ m^{-2}\ d^{-1}$ or more. Five out of 33 or 15% of granite slabs tested here could cause concern in such a worst case scenario.

Table 3
Estimate steady-state radon concentration ($Bq\ m^{-3}$) due to radon exhalation from floor material.

E ($Bq\ m^{-2}\ d^{-1}$)	ACH = 3	ACH = 1	ACH = 0.3	ACH = 0.15	ACH = 0
5	0.03	0.09	0.3	0.6	12
10	0.06	0.2	0.6	1.2	25
50	0.3	0.9	3.0	5.9	123
100	0.6	1.8	6.0	12	246
300	1.8	5.5	18	35	737
500	3.1	9.2	30	59	1228

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Table 4
Estimated steady-state radon concentration (Bq m^{-3}) due to radon exhalation from 300 slabs of building materials (1.5 m × 3 m × 0.025 m) stored in a room (350 m^3) with various air exchange rates of ACH.

E (Bq m^{-2} d^{-1})	ACH = 10	ACH = 5	ACH = 2	ACH = 1
5	0.2	0.4	0.9	1.8
10	0.4	0.7	1.8	3.5
50	1.8	3.6	8.9	18
100	3.6	7.1	18	35
300	11	21	53	106
500	18	36	89	176

On average, granite floor could contribute about 2.5 Bq m^{-3} (E = 42 Bq m^{-2} d^{-1}, and ACH = 0.3) to indoor radon or contribute to less than 5% of radon concentration in Canadian homes. For ceramic floor (E = 1 Bq m^{-2} d^{-1}, and ACH = 0.3), only 0.06 Bq m^{-3} is due to radon exhalation from the floor material, a contribution of 0.1% of average radon concentration in Canadian homes.

4.3. Case III – radon exhalation from a building material stockpile

Consider 300 slabs of building material (1.5 m wide, 3.0 m long and 2.5 cm thick) stored in a space having a floor area of 100 m^2 and 3.5 m from floor to ceiling. The 300 slabs have a total surface of 2700 m^2 and occupy about 9.6% of the room volume. The total surface of 2700 m^2 is the effective exhalation surface, i.e. slabs are stacked with air gaps that do not inhibit emission. This may be a worst case in terms of radon exhalation from a stockpile because there will be restricted air flow within an actual stockpile. The radon concentration, Bq m^{-3}, due to exhalation from those stockpiled materials can be calculated as

$$C = \frac{E \cdot A}{(\lambda_0 + \lambda_v)V} = \frac{2700E}{316.4(\lambda_0 + \lambda_v)} \quad (6)$$

The resulting radon concentrations are given in Table 4 for materials of various radon exhalation rates and for various air change rates in the room.

Most warehouses and workplaces have an air exchange rate more than 1 h^{-1}, ACH of 2–10 is common. The average radon exhalation rate of 33 different granite slabs studied here is 42 Bq m^{-2} d^{-1}. For the case examined here, radon exhaled from 300 slabs should not be a serious problem if slabs of various types and origins were stored and the average radon exhalation rate was less than 50 Bq m^{-2} d^{-1}. Significant contribution to indoor radon level will occur if most slabs have higher radon exhalation rates (>100 Bq m^{-2} d^{-1}) and the air exchange rate is relatively low (<2 h^{-1}).

Generally speaking, the resulting radon concentration, C, is proportional to the radon exhalation rate, E, and the total area, A, of stockpiled materials. For given E and A, C increases with decreasing air volume, V, of a room i.e. with increased percentage of the space occupied with such slabs. For example, in case of ACH = 2, if granite slabs of the average radon exhalation rate (42 Bq m^{-2} d^{-1}) occupy half of the room volume, they will add 70 Bq m^{-3} to the indoor radon level. If 933 slabs stored in one-third of the room volume and having an average radon exhalation rate of 300 Bq m^{-2} d^{-1}, the slabs alone will generate a radon concentration over the Canadian radon guideline level of 200 Bq m^{-3}, a situation where corrective measures should be taken.

It should be mentioned that in warehouses for stone or granite, exposure to gamma rays due to radioactivity in natural materials could be a health concern in addition to exposure to radon emanated from those stockpiles.

5. Conclusions

There is considerable public concern about radon exhalation from building materials. To address this concern, radon exhalation rates were determined for 53 samples of drywall, tile and granite available in Canadian market for decorative use. Results showed that slate and granite generally had higher radon exhalation rates than other decorative materials. In slate and granite, radon exhalation rates varied widely from non-detectable to about 300 Bq m^{-2} d^{-1}. The average radon exhalation rates were 30 ± 16 Bq m^{-2} d^{-1} for slate and 42 ± 63 Bq m^{-2} d^{-1} for granite, respectively. Analysis showed that granite countertops contribute very little to the radon concentration in a kitchen. If an entire floor were covered with granite slabs of the radon exhalation rate of 300 Bq m^{-2} d^{-1}, it adds only 18 Bq m^{-3} to indoor radon provided an air exchange system was operated properly. Without ventilation and using materials with radon exhalation rates higher than the average, there could be elevated radon levels. Generally speaking, building materials used in home decoration make no significant contribution to indoor radon for a house with adequate air exchange.

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