

Effect of the Extensive Use of Granites as Countertops in Luxury Buildings on the Indoor Radon Concentration and the Potential Risk to Occupants

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Abstract

Radon concentration has been measured inside the new buildings of King Abdulaziz University to study the effect of the extensive use of granites as countertops on the indoor radon concentration. A set of indoor and outdoor measurements has been conducted using radon measurement instruments. For comparison, indoor radon concentration was also measured in the older buildings, where granite countertops were in use at only a few sites near the main entrances. The obtained results indicate that the average indoor radon concentrations were 8.8 ± 4.8 and 11.2 ± 4.9 Bq/m³ in the old and new buildings, respectively. The average outdoor concentration was about 4.4 Bq/m³. These values are lower than the global average values. The average annual effective dose due to indoor radon was calculated for the general public and for the occupants of the new buildings. Risk estimates have been done based on the average radon concentration values. The average annual effective dose for the public due to radon inhalation was estimated to be 0.264 mSv, and for the occupants of the new buildings to be 0.280 mSv. The associated risk of lung cancer mortality to inhabitants due to lifetime radon inhalation is estimated to be 102.9×10^{-5} for the public and 109.5×10^{-5} for the occupants of the new buildings.

Keywords

Radon-222, Granite, Exposure dose rate, Radiation risk, Radiation measurement, Dosimetry

Introduction

Granites are primary igneous rocks formed by the Earth's geological processes during the slow cooling age. They contain varying concentrations of uranium and thorium which are the primary sources of the γ -emitting radionuclides, including radon (²²²Rn) gas, a

source of alpha and beta particles and gamma rays^[1-5]. Granites are quarried and processed to produce commercial products such as countertops, widely used in building construction, due to their durability and decorative appearance. Although this advantage makes granite a popular building material it may cause an increase in radiation dosage to occupants.

It is likely that granite countertops used in luxury buildings could variably increase the radiation dose above the normal natural background dose that comes from soil and other building materials, resulting in potential risk to consumers. For buildings constructed on normal soils, both the subsoil and its released radon gas generate radiation dose for occupants^[6]. Assessments using indoor measurements indicated that some granite slabs could increase the indoor radon concentration by about 40 Bq/m³ (1 pCi/L), with higher concentrations for more elevated slabs^[7].

Radon and its progenies in air are the main contributors to the radiation dose of the public. On considering the global average total effective dose (2.4 mSv) to the public, about 60% of this dose is related to radon exposure *via* inhalation^[8]. Epidemiological studies show a clear link between exposure to radon in air and lung cancer^[9], where the lifetime risk of lung cancer mortality from radon exposure of 150 Bq/m³ in air is about 2.3%.

The United States Environmental Protection Agency (USEPA) has established an action level of 148 Bq/m³ for radon in residential indoor air^[10]. Similarly, the International Commission on Radiological Protection (ICRP) recommends an action level for radon in indoor air of dwellings that is higher than 200 Bq/m³ (5.4 pCi/L)^[11].

Granite countertops from local sources used for decoration in the new buildings of King Abdulaziz University (KAU), may result in increased dose to occupants. The granite is used in both office rooms and in most corridors, where the floors and wall-parts are decorated with granite countertops. At corridor intersections, the entire walls are decorated with granite slabs. However, evaluating the actual radiation dose to occupants of the new buildings is an objective.

The aim of this article is to address the question posed by the occupants as to whether the granite countertops significantly increase exposure dose rate to occupants of the new buildings due to radon gas emanating from the granite slabs into the indoor air. The present study was designed to answer this enquiry by providing the appropriate radiological data.

The following protocol was designed to achieve the aim of this study:

- a). Measuring the activity concentration of radon in the indoor air of the old and new buildings of KAU.

- b). Measuring the activity concentration of radon in the outdoor atmosphere of KAU campus.
- c). Estimating the radiation dose rate and annual effective dose to occupants due to radon inhalation, based on the obtained results.
- d). Assessing the potential risk due to radon inhalation (usually risk of lung cancer mortality due to radon inhalation).
- e). Comparing the estimates of doses to health-based values for radiation safety published by authoritative organizations concerned with the protection of public health, such as the ICRP, the World Health Organization (WHO) and USEPA.

Materials and Methods

Equipment

Radon measurement instrument (RAD7) (DURRIDGE Company, Inc., Billerica, MA, USA), is an advanced, portable and easy to use radon measurement system. It contains an internal solid-state alpha detector. The instrument can be used in different modes, using the relevant accessories, for different applications such as measuring radon gas concentration in air, water and soil.

For quality control purposes of radon gas measurements in the atmosphere, the RAD7 instrument is sent periodically to the factory for calibration as instructed by the manufacturer.

Radon Measurements in Air (Indoor and Outdoor)

The activity concentration of radon was measured in air by following the standard operating procedure of the instrument manual (www.durridge.com). Briefly, the instrument was connected to the appropriate accessories (inlet air filter, drying station, dry-stick and a printer), and fixed at the site of interest at 1 m above the floor and at equal distance from the sidewalls. The RAD7 instrument is controlled through the CAPTURE software and a four-key menu driven interface. The four keys allow to look at the commands and operate the instrument to collect the required data. Owing to the diurnal variation of radon releases, the measurement period was 24 hours. After the counting period, the result of radon activity concentration is automatically

printed in a unit of Bq/m³ of air, with the statistical error in 2 σ level. The new buildings were fully closed, while the air exchange systems and ventilation fans were running 24 hours. Radon concentration of the outside air was measured as inside the buildings except that the instrument was fixed at a site protected from both fast winds and direct sunlight.

A set of indoor and outdoor measurements for radon concentration were obtained covering various sites distributed throughout the buildings to be representative of the study area. The reported indoor radon concentration values are based on equilibrium with air change rate inside the buildings. The likely sources for the measured indoor radon concentrations are,

- a) Radon emanation from granite countertops.
- b) Radon contribution from other sources in the building materials.
- c) Radon emanation from the subsoil in the ground floor.
- d) Radon from the outer atmosphere due to air change.

The measured outdoor radon emanates from outer soil and is diluted by wind action. The difference between radon concentration in the new and old buildings is attributed to the use of granite countertops.

Dose Due to Radon

To calculate the annual effective dose, H_E , due to radon inhalation inside the buildings, which corresponds to the value of the radon concentration, the following equation^[8] was used:

$$H_E = C_{Rn} \times Eq \times T \times 9 \text{ nSv(Bq h/m}^3\text{)}$$

Where

C_{Rn} = the radon concentration, in Bq/m³.

Eq = the indoor equilibrium factor between radon and radon progenies (equals 0.4 in closed spaces, but under the air change equilibrium condition, this factor may be less and is difficult to estimate, therefore 0.4 was considered the maximum value).

T = the annual exposure time to this concentration in hours. Following UNSCEAR Report^[11], the annual indoor occupancy time fraction is 0.8 (7008 h/y) and the occupancy office time,

where the occupants are exposed to extra dose due to granite countertops is assumed to be equal to 8 hours/day and 22 working days/month and 10.5 months/year; this means 1848 h/y. The recommended dose conversion factor is the value 9 nSv(Bq h/m³).

Using this equation, inhalation of 1 Bq/m³ of indoor radon causes an effective dose of about 25.23 μ Sv, and the annual effective dose due to inhalation of an extra 1 Bq/m³ of indoor radon during office time causes an extra effective dose of about 6.65 μ Sv. The extra dose relates to the difference in average radon concentration between traditional buildings (old buildings) and the new buildings with extensive use of granite countertops for decoration.

The above equation is also used to calculate the annual effective dose due to the inhalation of outside air radon. The annual exposure time fraction to this concentration is assumed to be 0.2 (1752 h/y) and the value 0.6 is the equilibrium factor^[8]. Based on these assumptions, inhalation of 1 Bq/m³ of outdoor radon causes an effective dose of about 9.46 μ Sv.

Lung Cancer Risk Due to Radon Inhalation

Following BEIRVI^[12] report, a risk of lung cancer mortality due to lifetime exposure to air-radon at an activity level of 1 Bq/m³ was estimated. This value is based on risk projections predicted from previous studies of several workers. Accordingly, a risk projection of 1.3×10^{-4} per unit concentration in air (1 Bq/m³) was developed. The value was for a mixed population of smokers and nonsmokers. However, the value 1.3×10^{-4} is used in this work for nonsmokers, to estimate the excess risk of lung cancer mortality that could be attributed to radon gas inhalation, considering the lifetime inhalation of a certain average concentration and the occupancy time fraction of each concentration.

Results

Radon Measurements in Air

The data in Table 1 show that the activity concentration of radon inside the new buildings, where granite countertops are extensively used for decoration of entrances, corridors and some office rooms, varied within a narrow range (7.8 to 20.7 Bq/m³), with an average value of 11.2 ± 4.9 Bq/m³. The outdoor radon concentration was much lower (less than 5.4 Bq/m³). Table 2 shows the radon measurement results inside

the old buildings. The activity concentration of indoor radon inside the old buildings also varied in a narrow range (6.3 to 13.8 Bq/m³), with an average value of about 8.8 ± 4.8 Bq/m³. The obtained results of Tables 1 and 2 are summarized in Table 3. Table 4 shows a summary of the present indoor radon concentration values together with some examples of other international values.

Effective Dose Rate and Risk Due to Radon

The obtained average radon concentration is used to calculate the average effective dose rate (Table 5). In addition, the probability of lung cancer mortality due to lifetime exposure to radon is estimated and presented in Table 5. Generally, the estimation of lung cancer mortality due to exposure to radon has a large number

Table 1. Indoor and outdoor radon levels of the new building.

Site	Specifications		Level	²²² Rn concentration, Bq/m ³
	Floor	Walls		
Main Corridor	Red and white granite	1.25 m height of red granite	0*	8.4 ± 3.0
				11.8 ± 4.9
			1	9.9 ± 3.5
				10.2 ± 3.5
			2	9.2 ± 3.4
				11.1 ± 4.1
			3	10.4 ± 3.3
				12.6 ± 4.6
4	12.6 ± 4.2			
	10.7 ± 3.5			
Corridors	Red and white granite	1.25 m height of red granite	0	9.5 ± 3.3
				10.6 ± 4.6
			1	16.3 ± 5.4**
				11.6 ± 5.1
			2	12.3 ± 3.3
				10.3 ± 3.7
	3	9.2 ± 3.3		
		10.5 ± 3.3		
	4	15.8 ± 3.9**		
		11.2 ± 3.3		
	Pottery tiles	1.25 m height pottery tiles	0	11.2 ± 5.3
				10.2 ± 4.1
11.8 ± 4.2				
8.2 ± 4.6				
8.3 ± 3.4				
11.2 ± 2.4				
Offices	Concrete	Concrete	0	8.3 ± 3.4
	Pottery tiles			11.2 ± 2.4
	White granite	Concrete	1	20.7 ± 4.9**
				11.3 ± 5.0
	Red and white granite	Concrete	2	8.2 ± 1.8
	White granite			9.9 ± 2.7
	Red and white granite	Concrete	3	13.9 ± 5.2**
	White granite			11.5 ± 3.7
White granite	Concrete	4	10.6 ± 3.4	
White granite			7.8 ± 3.3	
Wide Yard	Red and white granite	Red granite	1	14.9 ± 4.8**
				10.4 ± 3.7
Car Park	Concrete	Concrete	0	13.9 ± 5.1
				9.7 ± 2.0
Open Air	Concrete	Open area	0	9.1 ± 4.4
				9.6 ± 2.1
				5.4 ± 2.7
				3.8 ± 2.5
				4.1 ± 2.4

* 0 level = ground level; ** Closed places of slow air change
Abbr: ²²²Rn: Radon

Table 2. Radon levels inside the old building.

Site	Specifications		Level	²²² Rn Concentration, Bq/m ³		
	Floor	Walls				
Entrance	Brown granite	Concrete	0 (Ground Floor)	10.4 ± 4.3 11.8 ± 4.9		
Corridors	Marble	Concrete	0	7.4 ± 4.5 8.2 ± 4.2 7.9 ± 4.3		
				1	6.3 ± 2.2 7.1 ± 4.2 7.4 ± 4.2	
			Offices	Concrete	0	9.8 ± 4.3 13.8 ± 6.8 9.5 ± 4.1
						1

Abbr: ²²²Rn: Radon

Table 3. Comparison between the indoor radon concentration in new and old buildings.

Site	Radon Concentration, Bq/m ³				Percent Increase
	New Building		Old Building		
	Average	Range	Average	Range	
Indoor	11.2 ± 4.9	7.8 - 20.7	8.8 ± 4.8	6.3 - 13.8	27.3
Outdoor	4.4 ± 2.8	3.8 - 5.4	4.4 ± 2.8	3.8 - 5.4	00.0

Table 4. Comparison between the present indoor radon concentration values and some other international values.

Country	Rn Concentration, Bq/m ³		Reference
	Average	Range	
Saudi Arabia	11.2	7.8 - 20.7	The present study
Saudi Arabia	54.6	12.0 - 125.6	[22]
Brazil	61	12 - 920	[16]
Egypt	43	9.9 - 76.1	[21]
Vietnam	10	4.0 - 27	[19]
Cyprus	11	2 - 134	[20]
Sweden	--	100 - 5000	[23]
Palestine	117	26 - 611	[24]

Table 5. The average effective dose rate and the estimated risk of lung cancer mortality due to radon inhalation.

	Average Radon Concentration, Bq/m ³	Annual Effective Dose, mSv	Risk
Outdoor	4.4	0.042	11.4 x 10 ⁻⁵
Indoor	8.8	0.222	91.5 x 10 ⁻⁵
Extra Dose	2.4	0.016	6.6 x 10 ⁻⁵

of unavoidable uncertainties due to uncertainties in parameter estimates such as the averages used for occupancy factors, radon/radon daughters' equilibrium factors and radon concentration.

Discussion

No explicit difference was found in radon concentration between sites of the same characteristics in the different levels, including the ground level (Table 1). For example, the main corridors of the different levels have undistinguishable differences in indoor radon concentration. This is the case with any of the other sites (corridors, offices or laboratories). The radon concentration in the atmosphere of the ground levels was almost the same as that of the other levels indicating that the effect of subsoil source of radon is insignificant. The narrow range of variation in indoor radon concentration may be related to its migration inside the buildings, and is assumed to be in equilibrium with the air change rate. Lower air-change rate sites, such as closed rooms, stair-rooms and closed terminals of corridors, showed significantly higher values due to local radon accumulation (Table 1). Usually, lower radon concentrations with little variation is reported for outdoor radon levels due to the dilution by the wind action.

The data in Table 3 indicates that about a 27.3% increase in average indoor radon concentration of the new buildings attributable to the granite countertops. Variations in indoor radon concentration have been reported by many workers^[13-16]. The average indoor radon concentration is still significantly lower than the global average concentration of 40 Bq/m³^[17], despite the extensive use of granite. In addition, the radon concentrations in all buildings were found to be far below the USEPA recommended action level of 148 Bq/m³^[18] and no samples exceeded or were close to the action limit of 74 Bq/m³. This may be related to the measurement conditions. The global average value is based on the standard measurement conditions (measurement inside closed chambers), whereas measurements in this study were conducted under continuous air change condition inside the buildings (the typical conditions under which the occupants spend their business time). The present data is comparable with data of other workers^[19,20]. The outdoor radon levels (3.8 to 5.4 Bq/m³) were below the limit value of global average of 10 Bq/m³^[8]. The average indoor radon level was about 2.5 times higher than that of the outdoors. Sarrou and Pashalidis^[20] reported a factor of 1.5 in low level data, and a factor of

5 by other workers^[16,21] in higher level data, indicating the effect of radon emanation and radon change rates on this factor.

The location of Jeddah City at the Eastern Red Sea Coast may have some contribution to lowering the outdoor radon levels due to the radon-depleted air coming from the sea. This factor, together with the indoor measurement condition (indoor air change) contributed to lowering the indoor radon concentration. Another local study^[22] indicated an average indoor radon concentration of 54.6 Bq/m³. This higher value relates to different factors such as the measurement conditions, where the measurements were carried out in closed chambers (no air change) of town homes located in a high natural background radiation area away from the sea. The average outdoor radon concentration in the latter area was 10.3 Bq/m³, which is consistent with the global average value. The reported average radon levels inside dwellings in Pocos de Caldas, Brazil was 61 Bq/m³^[16], which is much higher than the present data due to the higher background radiation of that plateau, but very low compared to indoor radon values reported by other workers^[23], ranging from 100 to 5000 Bq/m³. The WHO recommended a reference limit value of 100 Bq/m³ for indoor radon, otherwise remediation projects should be planned. Such projects may include aeration and/or development of building codes requiring radon prevention actions when designing new buildings. Fortunately, with regard to indoor radon, the present data indicated no need for special restrictions. Average indoor radon values ranging from 1 to 100 Bq/m³ were reported in some European countries^[25].

For the general public living permanently in Jeddah City, they will receive an annual effective dose estimated at 0.264 mSv due to outdoor and indoor radon. An extra dose of 0.016 mSv/y added to individuals working in the KAU new buildings due to granite countertops results in a total dose of 0.280 mSv/y. This means that the contribution of radon to the annual global average dose rate (2.4 mSv) is about 11.8%. Extra dose means the dose due to excess radon emanating from granite slabs, which is the difference in average indoor radon concentration between the old and new buildings.

The risk of lung cancer mortality for the public, posed by lifetime exposure based on the average radon concentration, is estimated at 102.9x10⁻⁵. It is estimated at 109.5x10⁻⁵ for a KAU employee due to extra dose from the granite countertops.

These values mean that for every 972 individuals living permanently in Jeddah city one person may develop a case of lung cancer due to radon; and for the occupants of KAU's new building, one lung cancer case may occur out of every 913 individuals. However, the contribution to the annual dose due to radon exposure from the countertops is very low owing to the continuous indoor air change.

Conclusion

Based on the obtained data the following conclusions can be drawn:

A slight increase in the average indoor radon concentration of the new buildings compared to that of the old buildings is due to the use of granite countertops, but still lower than the global average. The modest nature of the increase is attributed to the continuous air change inside the buildings.

The average outdoor radon level was less than the global average, may be due to the sea breeze with low radon content diluting the general air concentration of the cities located along seacoasts, like Jeddah city.

The minor difference between the average indoor and outdoor radon concentrations is attributed to the indoor air change.

Despite the slight increase in indoor radon concentration within the new buildings, the obtained data make it possible to declare that generally the radon concentration does not present significant radiological hazards for the occupants of the new buildings.

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Conflict of Interest

The authors have no conflict of interest.

Disclosure

None of the authors received any type of commercial support either in forms of compensation or financial for this study. They have no financial interest in any of the products or devices, or drugs mentioned in this article.

Ethical Approval

Obtained.

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تأثير الاستخدام المفرط للجرانيت في تكسية المباني الفاخرة على زيادة انبعاث غاز الرادون داخلها وتقدير المخاطر المحتملة على السكان

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المستخلص. لقد تم قياس تركيز غاز الرادون المشع داخل المباني الجديدة بجامعة الملك عبد العزيز لدراسة تأثير الاستخدام المفرط لأحجار الجرانيت في الزينة على معدل انبعاث هذا الغاز داخل المباني. لقد تم تنفيذ مجموعة من القياسات في مواقع مختلفة داخل وخارج المباني باستخدام جهاز قياس الرادون (راد-٧). ومن أجل المقارنة لقد تم قياس تركيز هذا الغاز داخل المباني القديمة كذلك، حيث لم يستخدم الجرانيت سوى عند المداخل الرئيسية فقط. لقد أفادت النتائج أن متوسط تركيز غاز الرادون كان $4,8 \pm 8,8$ و $4,9 \pm 11,2$ بيكرل/م^٣ من الهواء في المباني القديمة والجديدة، على الترتيب. كما أفادت النتائج أن تركيز هذا الغاز في الهواء الخارجي كان $2,8 \pm 4,4$ بيكرل/م^٣ من الهواء، حيث أن هذه القيم تقل عن المتوسط العالمي. لقد تم حساب متوسط الجرعة الإشعاعية السنوية المؤثرة للعاملين في المباني القديمة بـ $0,264$ ملي سيفرت وللعاملين في المباني الجديدة بـ $0,280$ ملي سيفرت وقد قدرت مخاطر الإصابة بسرطان الرئة التي بنيت على هذه القيم بـ $1,0 \times 10^{-2}, 9$ و $1,0 \times 10^{-1}, 5$ لشاغلي المباني القديمة والجديدة، على الترتيب. لقد تم مناقشة هذه النتائج بالتفصيل في هذا البحث.