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Calculation of the Indoor Radon Concentrations and their Effective Doses Due to the Public Use of Some Egyptian Albite Granites

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Abstract: This work calculates the indoor radon gas concentrations assuming an exact configuration of radon diffusion. Albite granitic rocks from Abu-Rusheid, Abu-Dabbab, Um Naggat and Nuweibi areas at the Southeastern Desert of Egypt were assumed to be used as slabs of a thickness 2cm, 3cm, 5cm or 10cm to cover the walls and floors inside the buildings.
Assuming a ventilation rate of unity, the average values of the radon concentrations in the air inside a building uses one of the studied rocks were found to be much lower than the worldwide average of (40Bq/m^3). The higher indoor radon concentrations were obtained for the Abu-Rusheid samples to have average values of 2.39 (Bq/m^3), 2cm slabs, and 3.56 (Bq/m^3), 3cm slabs, for the walls and 1.28 (Bq/m^3), 5cm slabs 2.28 (Bq/m^3), 10cm slabs, for the floors. The maximum of total radon concentrations were 5.6 and 8.9 (Bq/m^3) for the 2cm walls&5cm floors combination and the 3cm walls&10cm floors combination, respectively.
The maximum internal annual effective dose received from radon due to the use of the studied rocks was 0.22 (mSv/year) indicting safe emanation of radon gas from the studied rocks. The external annual effective doses received by the public members should use these rocks must be estimated.
Keywords: Radon, Flux density, Indoor, Effective dose.

1 Introduction

Radon is a radioactive gas that is known to be the second leading cause of lung cancer after smoking [1]. As a decay product of uranium series, radon appears everywhere in nature and occurs in substantial concentrations especially in buildings. Hence, the major exposure of the population to radon takes place at home.
Concrete, brick, gypsum, stone, and other structural building materials have long been recognized as a source of radon in residential and other buildings [2]. Given their low emission rates of radon and the potential for entry of radon into occupied areas to be impeded by surface finishes (for example, paint, wall covering and flooring), most structural building materials have been thought to make a negligible contribution to radon exposures inside a structure [3-5]. However, with the increased use of natural rocks as a functional and ornamental feature inside homes, such as a Kitchen or bath countertop, it is important to determine whether these natural stones can be a meaningful source of radon in indoor environments.
During the last decades radon flux for different rocks has been reported to range from 0.01 to 13.5 Bq.m^{-2}.h^{-1} among ~500 samples of structural and unidentified granite building materials obtained from several nations of Africa, Asia, and the Middle East [6-19]. A good agreement was found between the predicted indoor radon concentration determined from whole-slab radon flux characterized using the grid sampling approach (2.1 Bq.m^{-3}) and a full-chamber test (1.2 Bq.m^{-3}) applied to a granite countertop that was cut and finished for use in a home [2].
The ongoing development projects at Abu Rusheid, Abu Dabbab, Um Naggat and Nuweibi areas at the Southeastern Desert of Egypt put an eye on the potential public use of the rocks at these areas as decorative materials for wall covering or floors. Besides, the activity concentrations of the terrestrial radionulclides; ^{238}U, ^{232}Th, ^{226}Ra and ^{40}K had been determined to be higher than the worldwide averages [20]. This questions the probable radiation exposures received by the members of public as a result of any use of the studied rocks.
In this study, the flux densities of radon gas emanating from the suggested slabs derived from the albite granites at Abu Rusheid, Abu Dabbab, Um Naggat and Nuweibi areas are calculated along with the additional indoor radon concentrations.

2 Calculations

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2.1 Radon Flux Density

In building materials with high radium levels, the radon diffusion from these materials may become of major importance. Radon flux J_s from a slab of thickness t (m) into the surrounding air is calculated using the equation [21]:

$$J = {}^{226}Ra\ \lambda_{Rn}\ f\ \rho\ L\ \tanh(t/2L)\quad (Bq\ m^{-2}\ s^{-1}) \qquad (1)$$

where;
J= radon flux from the decorative slab, (Bq m^{-2} s^{-1}),
^{226}Ra = activity concentration of radium, (Bq/kg),
λ_{Rn}= decay constant of ^{222}Rn, s^{-1},
ρ = density of the rock, 2700 kg/m^3,
t= thickness of the decorative slab, 2cm, 3cm, wall covering, 5cm, 10cm, floors,
L = diffusion length, =.068m [22] while f = emanation coefficient of the studied rock and is calculated as follows [23]:

$$f=(4/{}^{226}Ra)+0.005 \qquad (2)$$

This study employs the radium activity concentration in 33 samples collected from the albite granites at Abu Rusheid, Abu Dabbab, Um Naggat and Nuweibi areas, Figure 1 & Table 1 [24].

2.2 Indoor Radon Concentrations

The United Nations Scientific Committee on The Atomic Radiation, UNSCEAR, proposed a reference house which encloses an air volume of 250 m^3, wall area 450 m^2 and floor area of 100m^2 [21]. The indoor radon concentration due the use of the studied rocks is calculated using the formula [21]:

$$C_{Rn} = (J \times S_B/V) / \lambda_v \qquad (Bq/m^3) \qquad (3)$$

where,
$C_{Rn:}$ is the indoor radon activity concentration in a reference house (Bq m^{-3}),
J: is the flux density of radon from a building element (Bq m^{-2} h^{-1}),
S_B: is the emanating surface area (450m^2), walls, (100m^2), floors,
V: is the volume of the reference house (250m^3),
λ_v : is the ventilation rate chosen at (1 h^{-1}).

Table 1: Radium activity concentrations (Bq/kg) of 33 rock samples from four different areas at the Southeastern Desert, Egypt [24].

Abu Rusheid		**Abu Dabbab**		**Um Naggat**		**Nuweibi**	
Sample code	**^{226}Ra (Bq/kg)**	**Sample code**	**^{226}Ra (Bq/kg)**	**Sample code**	**^{226}Ra (Bq/kg)**	**Sample code**	**^{226}Ra (Bq/kg)**
Rsh 1	**214.8**	Dab 1	97.4	UNg 1	844.5	Nwb 1	96.5
Rsh 2	262.7	Dab 2	**86.6**	UNg 2	725.7	Nwb 2	83.9
Rsh 3	521.7	Dab 3	97.1	UNg 3	514.9	Nwb 3	**110**
Rsh 4	341.0	Dab 4	122.2	UNg 4	345.3	Nwb 4	81.0
Rsh 5	**1300**	Dab 5	102.9	UNg 5	**1017**	Nwb 5	75.9
Rsh 6	872.9	Dab 6	88.1	UNg 6	150.7	Nwb 6	63.2
Rsh 7	555.2	Dab 7	**146.7**	UNg 7	447.0	Nwb 7	49.7
Rsh 8	497.2			UNg 8	**118.2**	Nwb 8	**41.5**
Rsh 9	634.5					Nwb 9	71.0
Ave.	**577.8**	**Ave.**	**105.8**	**Ave.**	**520.4**	**Ave.**	**74.8**

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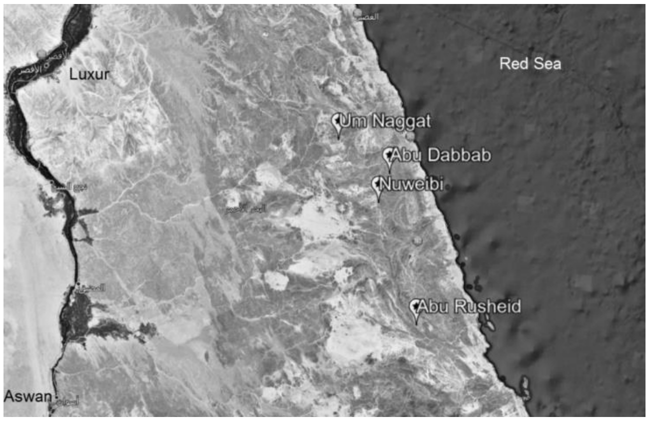

Fig.1: Locations of the chosen four areas at the Southeastern Desert, Egypt, Googleearth [24].

3 Results and Discussion

3.1 Radon Flux

Equation 1 describes the competition between the physical parameters which affect the radon flux from the studied rocks; the radium specific activity ^{226}Ra, the emanation coefficient f and the diffusion length L at the chosen thickness t. The radon flux J is directly proportional to all these parameters. Fortunately, the rocks are all albite granites and have the values for ρ and L. Accordingly, the only varying parameter is the radium activity concentration ^{226}Ra along with the emanation coefficient f which depends on ^{226}Ra as formulated in Equation 2. Figure 2 represents the variation of the radon flux J using the average values of the radium activity concentrations in the studied rocks from Abu Rusheid, Abu Dabbab, Um Naggat and Nuweibi areas at the thickness of a slab in the range 1-10cm. At a glance, Figure 2 shows that the variation of J over t distributed the results about radon flux density J over two sets; the lower one includes the rocks that have ^{226}Ra around 100 (Bq/kg), Abu Dabbab and Nuweibi, and the upper having values near 550 (Bq/kg), Abu Rusheid and Um Naggat.

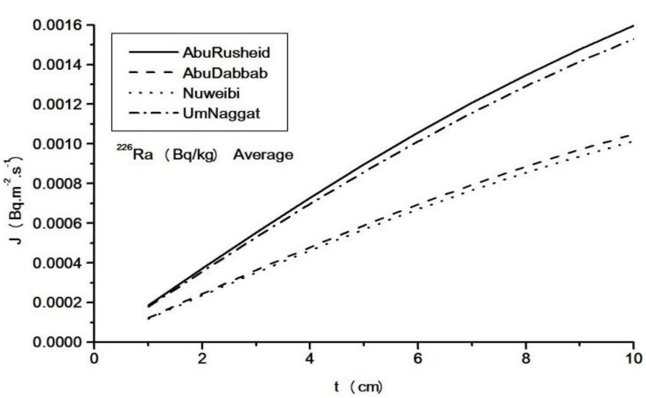

Fig.2: Variation of radon flux density J with the thickness t of the slabs from the studied rocks at the average values of the radium specific activity.

The members of public use the natural rocks as decorative materials in a suitable configuration. This study suggests the use of the rocks from Abu Rusheid, Abu Dabbab, Um Naggat and Nuweibi areas as slabs of thickness t equals 2 and 3cm for wall covering and t equals 5 and 10cm for the floors. Table (2) represents the minimum; maximum and average values of the radon flux J ($Bq.m^{-2}.s^{-1}$) from the slabs at the suggested thicknesses derived from the rocks at the studied areas.

Table 2: Radon flux density J from the slabs of different thicknesses t derived from the rocks at four areas at the Southeastern Desert, Egypt.

	J ($Bq.m^{-2}.s^{-1}$) x10^{-4}			
	2cm	**3cm**	**5cm**	**10cm**
Abu Rusheid				
Min. (1)	2.72	4.04	6.56	11.7
Max. (5)	5.63	8.37	13.6	24.1
Ave.	3.69	5.49	8.90	15.8
Abu Dabbab				
Min. (2)	2.38	3.53	5.73	10.2
Max. (7)	2.54	3.77	6.12	10.9
Ave.	2.43	3.61	5.85	10.4
Um Naggat				
Min. (8)	2.46	3.66	5.93	10.6
Max. (5)	4.87	7.24	11.7	20.9
Ave.	3.54	5.26	8.53	15.2
Nuweibi				
Min. (8)	2.26	3.35	5.44	9.68
Max. (3)	2.44	3.63	5.88	10.5
Ave.	3.29	4.89	7.92	14.1

The values of the radon flux range from $2.26x10^{-4}$ ($Bq.m^{-2}.s^{-1}$), 2cm slab, Nuweibi rocks to $2.41x10^{-3}$ ($Bq.m^{-2}.s^{-1}$), 10cm slab, Abu Rusheid rocks. Radon flux from ~3cm slabs was measured to lie in the range $7.71x10^{-4}$-0.064 ($Bq.m^{-2}.s^{-1}$) [25]. In comparison, radon flux was determined for 53 different samples of drywall, tile and granite available on the Canadian market for interior home decoration. The radon flux ranged from non-detectable to 3.51 ($Bq.m^{-2}.s^{-1}$). Slate tiles and granite slabs had relatively higher radon flux than other decorative materials, such as ceramic or porcelain tiles. The average radon flux was $3.47x10^{-4}$ ($Bq.m^{-2}.s^{-1}$) for slate tiles and $4.86x10^{-4}$ ($Bq.m^{-2}.s^{-1}$) for granite slabs of various types and origins. Granites used in the United States emanated up to $4.32x10^{-4}$ ($Bq.m^{-2}.s^{-1}$) [26].

It should be noted that the maximum value of J is obtained for Abu Rusheid rocks to have only 15% of the reported value of 0.016 ($Bq.m^{-2}.s^{-1}$) of the rocks that have only a radium activity ^{226}Ra of 40 ($Bq.kg^{-1}$) while the studied rocks from Abu Rusheid reached a ^{226}Ra of 1300 ($Bq.kg^{-1}$). Returning to Equation 1, the reported rocks have one meter diffusion length L while the Abu Rusheid rocks as albite granites have a value of only 6.8cm [22].

3.2 Indoor Radon Combinations

Table 3 represents the minimum, maximum and average values of the additional indoor radon concentration C_{Rn} inside a reference house with its walls covered by slabs of thickness 2cm or 3cm no matter what is the material on the floor and the additional C_{Rn} if only the floors in the house used the studied rocks in the form of slabs of thickness 5cm or 10cm. All the average values of C_{Rn} are much below the worldwide indoor average concentration of 40 (Bq/m^3). The maximum values are recognized for the rocks from Abu Rusheid and Um Naggat as they have the high values of radium activity concentrations.

Figure 4 shows the effect of the ratio (S/V) on the indoor radon concentrations. This ratio increased the concentration from the walls although the chosen thickness for the slabs lies in the range 0.5-3.5cm while it decreased the concentration emanating from the floors at the thickness in the range 4-10cm. Analysis showed that even if an entire floor was covered with a material having a radon flux of 3.47x10^{-3} (Bq.m^{-2}.s^{-1}), it would contribute only 18 Bq m^{-3} to a tightly sealed house with an air ventilation rate λ_v of 0.3 (h^{-1}). At the chosen thickness 1-10cm, the slabs can't keep the radon inside their pores but they emanate the gas into the surrounding environment. This makes the ratio (S/V) a more reliable key to control the indoor radon concentrations.

The situation that a reference house uses the studied rocks for wall covering and floors was estimated. Among four combinations, this study chooses two combinations; the lower combination that uses slabs of 2cm for walls with slabs of 5cm for floors and the upper combination that uses slabs of 3cm for walls with slabs of 10cm for floors. The total additional radon concentration C^t_{Rn} for a combination is the sum of the radon from walls and the radon from the floors of this combination. Table (4) represents the minimum, maximum and average values of the total radon concentration C^t_{Rn} from the lower and the upper combinations.

Table 3: Radon activity concentration C_{Rn} resulting from the slabs used as wall covers or floors.

	C_{Rn} (Bq/m^3)			
	walls		**floors**	
	2cm	**3cm**	**5cm**	**10cm**
Abu Rusheid				
Min. (1)	1.76	2.62	0.94	1.68
Max. (5)	3.65	5.42	1.95	3.48
Ave.	2.39	3.56	1.28	2.28
Abu Dabbab				
Min. (2)	1.54	2.29	0.82	1.47
Max. (7)	1.64	2.44	0.88	1.57
Ave.	1.57	2.34	0.84	1.50
Um Naggat				
Min. (8)	1.60	2.37	0.85	1.52
Max. (5)	3.16	4.69	1.69	3.01
Ave.	2.29	3.41	1.23	2.19
Nuweibi				
Min. (8)	1.46	2.17	0.78	1.39
Max. (3)	1.58	2.35	0.85	1.51
	2.13	3.17	1.14	2.03

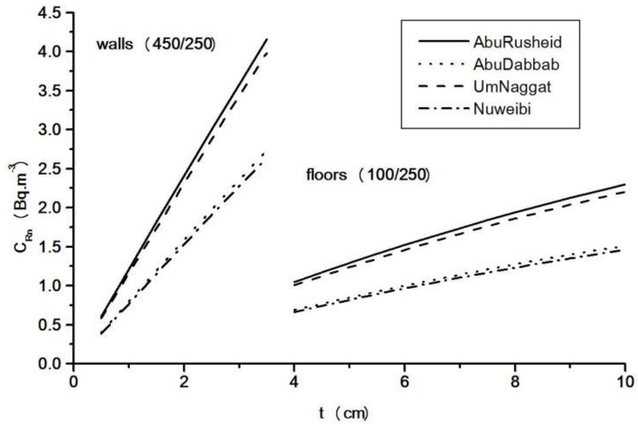

Fig. 3: Comparison between the effect the thickness of the slabs t and the ration (S/V) on the indoor radon concentration.

The higher values of C^t_{Rn} appear for both the combinations of Um Naggat and Abu Rusheid rocks since the activity concentrations of radium reached 1017 and 1300 (Bq/kg), respectively. In fact, according to Equation 3, indoor radon concentration inherited the effects of all the physical parameters on the radon flux as discussed above.

3.3 Effective Doses

In order to evaluate the radiation hazards arising from the studied slabs as decorative materials, the effective doses received by the members of public, externally and internally should be estimated.

The annual internal effective dose received from radon gas is calculated as follows [21]:

$$E\ (\text{mSv/year}) = C^t_{Rn}\ (\text{Bq/m}^3) * 0.4 * 7000\ (\text{h/year}) * 9\ (\text{nSv Bq}^{-1}\ \text{m}^3\ \text{h}^{-1}) * 10^{-6} \quad (4)$$

Table 4 represents the values of the annual effective dose *E* (mSv/year) received by the members of public due to the use of the wall or floor slabs from the studied rocks. From the table, all values of *E* are below the worldwide value of ~1 (mSv/year) which corresponds to a radon concentration of 40 (Bq/m^3) [21]. Comparing with the maximum value 0.22 (mSv/year) due the upper combination of slabs from location #5 at Abu Rusheid area indicates an apparent safe radon emanation from all the studied rocks.

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Table 4: Total radon concentrations C^{t}_{Rn} from the two chosen combinations and the resulting annual effective dose *E*.

	C^{t}_{Rn} (Bq/m^3)		*E* (mSv/year)	
	lower 2cm, 5cm	upper 3cm, 10cm	lower 2cm, 5cm	upper 3cm, 10cm
Abu Rusheid				
Min. (1)	2.71	4.30	0.07	0.11
Max. (5)	5.60	8.90	0.14	0.22
Ave.	3.68	5.84	0.09	0.15
Abu Dabbab				
Min. (2)	2.37	3.76	0.06	0.09
Max. (7)	2.53	4.01	0.06	0.10
Ave.	2.42	3.84	0.06	0.10
Um Naggat				
Min. (8)	2.45	3.89	0.06	0.10
Max. (5)	4.85	7.70	0.12	0.19
Ave.	3.52	5.60	0.09	0.14
Nuweibi				
Min. (8)	2.24	3.57	0.06	0.09
Max. (3)	2.43	3.86	0.06	0.10
Ave.	3.27	5.20	0.08	0.13

In contrast, the external effective doses come from the radioactive series; ^{238}U and ^{232}Th and the non-series radioactive element ^{40}K. A natural building material of the activity concentrations 40, 33 and 400 (Bq/kg) of ^{238}U, ^{232}Th and ^{40}K, respectively, cause an external annual effective dose of 0.41(mSv) [21]. The studied rocks at Abu Rusheid, Abu Dabbab, Um Naggat and Nuweibi areas have much higher activities of ^{238}U, ^{232}Th and ^{40}K [20] which necessitates the estimation of the external effective doses from the studied rocks if used as decorative slabs.

4 Conclusions

The albite granites from Abu Rusheid and Um Naggat have high respective radium activity concentrations. The poor properties for radon gas diffusion of these rocks resulted in very low indoor radon concentrations having a maximum value ~9 (Bq/m^3). The area-to-volume ratio of the standard house proposed by the UNSCEAR may be employed as a controlling parameter for the indoor radon concentrations. Low values of the annual effective doses received by the public due the use of the studied rocks as decorative slabs indicates the safe emanation of radon gas from these granites. However, the external effective doses received from the slabs derived from the studied rocks should be estimated.

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