The annual effective dose of granite rock samples using alpha track detector

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ABSTRACT
Radon concentration and annual effective dose for granite samples collected from Abu Rusheid area, South Eastern Desert, Egypt, were measured using passive technique with CR-39. It is important to assess the possible health hazard for the studied area. The values of radon concentration varied from 881.5 to 22,629 Bq m\(^{-3}\). The values of radon concentration varied from 881.5 to 22,629 Bq m\(^{-3}\). The annual effective dose was ranged from 22.24 to 570.9 mSv y\(^{-1}\) with mean value 129.2 mSv y\(^{-1}\). The values of radon concentration and annual effective dose are higher than the values of the world average due to the presence of high radium content in these samples so that the samples are not safe to be used as construction materials.

KEYWORDS
Rocks; dose; radon; CR-39; passive technique

Research Highlights
- Radon exhalation rate measurements for material may be used as building materials must be recorded.
- Closed-can technique as a tool to measurement of radon gas concentration and exhalation rate.
- The manuscript contains information about the radon level of some granite rock in the eastern desert of Egypt.
- The handling of high radioactive materials must be controlled in working area.
- It is concluded in the results that the granite rocks from the area under study can not be used as construction materials.

1. Introduction
Radon has become one of the most important tools that scientists have been using in the uranium minerals and building materials as a tracer (Saad, 2008). Uranium exists in all types of rocks, soils, sand, and water. \(^{226}\)Ra and \(^{222}\)Rn are decay products of uranium in the uranium decay series. The previous studies have shown that radon and its daughters cause health problems for humans. It is mainly linked to lung cancer. The second reason for lung cancer after smoking is radon and its daughters (IARC, 2004). Assessment of radium concentration and radon flux escape to our atmosphere must be known to make sure that radiological hazards and risks to human health from soil and building materials are under control (Bala, Kumar, & Mehra, 2017). Over the last few decades, researchers have become more interested in the effect of natural radiation activity. Therefore, they have to pay attention to the radon gas as it contributes to more than half of the natural ionizing radiation dose coming from radon and its progenies (Choudhary, 2014). Alpha particles produced by the natural decay of radon products \(^{218}\)Po and \(^{214}\)Po interact with lung cells, causing damage to DNA (Yousef et al., 2016).

There are three main processes that occur to the radon from the moment it is generated from the atom of radium into soil deposits until it reaches our atmosphere: (1) emanation: the way radon comes out of the soil grains into the interstitial spaces and depends on the grains properties, interstitial space properties, temperature, and pressure; (2) migration: a distance traveled by the radon since reaching the inter-distances until it reaches the surface of the earth and is done in two ways (transportation and diffusion); and (3) exhalation: is the process by which radon enters our atmosphere. The process by which the radon in the pore will enter the atmosphere is called exhalation. The exhalation of radon depends on the presence of radium content in the materials. Assessment of radon concentration in the atmosphere and air is necessary to protect the population from the increment of exposure to radiation, for instance from lung cancer risk. Radon exhalates out of any natural material that contains a percentage of uranium. Normally, natural materials are used as building materials such as rocks, soil, and clay; many factors may affect the radon exhalation process, these are radium content, water, porosity, permeability, and temperature (Nazoroff & Nero, 1988). Radon measurement methods can be classified into two parts: (1) active: in which an air sample can be drawn using a sized pump on a filter paper or detector and (2) passive: if the methods of measurement depend on the normal diffusion of radon without the need for a pump (Nastro, Carni, Vitale, Lamonac, & Vasile, 2018).
Radon exhalation rate from rock samples which may be utilized as developing materials must be controlled to understand the danger of radon gas, inhalation for a long period leads to health problems, particularly lung cancer (Tawfiq & Jaleel, 2015). The area under investigation is located about 90 km southwest of Marsa Alam on the Red Sea coastal plain, in the South Eastern Desert of Egypt. It is limited by latitudes 24° 37′ 25″ and 24° 38′ 17″ N and longitude 45° 30′ and 34° 46′ 29″ E.

In this paper, we aimed to study radon concentration, exhalation rate, and annual effective dose of granite rock samples, in order to assess the possible health hazard in the studied area, because granite rock is used as building material.

1. Detailed geology and location of the studied area

Twenty-six cataclastic rock samples were collected from Abu Rushied area, the study area was divided into two sections: north area and south area separated by distance about 400 m, the separation distance between two stations is nearly ranged from 150 to 200 m (Figure 1a). The detailed geologic map of the study area (3.0 km²) is characterized by low-to-moderate topography. The tectonostratigraphic sequence of the Precambrian rocks unit of the studied area (Figure 1b) is arranged as follows: (a) ophiolitic mélange, consisting of ultramafic rocks and layered metagabbros set in metasediment matrix; (b) cataclastic rocks, consisting of protomylonites, mylonites, ultramylonites, and silicified ultramylonites; (c) mylonitic granites; and (d) post-granite dykes and veins (Saleh et al., 2012). The cataclastic (mylonites) rocks are frequently dissected by pegmatite and quartz veins, which are usually concordant with the foliation planes. The altered rock acquires reddish to yellowish color due to staining with iron solutions. Some pyrite crystals were removed leaving vugs filled with quartz, carbonates, and U-minerals. Columbite-tantalite occurs abundantly as disseminated minute grains or as single crystal and aggregates visible by naked eyes.

2. Materials and methods

About 250–300 g of mylonitic rock samples collected from the area under study was crushed to fine powder about 200 mesh and sealed in stainless container of 5 cm in depth. A piece CR-39 (1 cm ×1 cm) was fixed on the top of the can at 10.5 cm height (Figure 2). The samples were sealed for 30 days. The exposed detectors were etched using 6.25 N (NaOH) solution at 70°C for 8 h using water bath, an optical microscope at 640× magnification was used for counting.

2.1. Radon gas concentration calculation

To measure the radon activity concentration (Bq m⁻³), the following equation was used (Lamonaca, Nastro, Nastro, & Grimaldi, 2014; Yousef, El-Farrash, Abu Ela, & Merza, 2015):

\[ C_{Rn} = \frac{\rho K T}{T} \]

where \( \rho \) represents the track density (tracks cm⁻²) resulting in the surface of CR-39, \( K \) is the diffusion constant and depends on the geometry of the cup \((a\text{-tracks cm}^{-2} \text{ d}^{-1} \text{ [Bq m}^{-3}]^{-1})\). \( T \) is the exposure time (day).

Figure 1. (a) The google earth color image map showing the location of the collected rock samples of the Abu Rusheid area. (b) Detailed geologic map of Abu Rusheid area, South Eastern Desert, Egypt, after (Saleh et al., 2012), showing the structural lines as well as the investigated sites and the different rock types constitute the project area. (Oph. M: Ophiolitic mélange; My: cataclastic; P: proto; U: ultra; S: silicified; Grt: granite; Qz: quartz and W.dep: Wadi deposits). A: Lower hemisphere stereographic projection of fractures and the inferred stress tensor; B: rose diagram for fracture strikes; and C: orientations of the induced (σ3) axes.
2.2. Radon exhalation rate measurements

The best method to measure the integrated radon exhalation rate in terms of area is obtained from the expression (Yousef et al., 2015):

\[
E_A = \frac{CV\lambda}{A[T_e + \frac{1}{\lambda}(e^{-\lambda T} - 1)]} \tag{2}
\]

where \( E_A \) is the radon exhalation rate (Bq m\(^{-2}\) h\(^{-1}\)), \( V \) is the effective volume (m\(^3\)), \( \lambda \) is the radon decay constant (h\(^{-1}\)), and \( A \) is the surface area of the can (m\(^2\)), since the detector received a variable level of radon exposure. Consequently, the effective exposure time \((T_e)\) needs to be determined, \( T_e \) is related to the active exposure time \( T \) and \( \lambda \) for \(^{222}\)Rn with the relation:

\[
T_e = T - \frac{1}{\lambda}(1 - e^{-\lambda T}) \tag{3}
\]

2.3. Annual effective dose

The mathematical expression used to calculate the effective annual dose in (mSv) is as follows:

\[
H_E = C_{Rn} \times D \times F \times H \times T \tag{4}
\]

where \( C_{Rn} \) is the mean radon concentration, \( F \) is indoor equilibrium factor (=0.4), \( T \) is the indoor occupancy time \( 24 \times 365 = 8760 \) h, \( H \) is the occupancy factor which is equal to (0.8), and \( D \) is the dose.
results that $C_{Rn}$ has the highest value in sample (14 in the northern part and 22 in the southern part). Figure 3 shows the clear difference between radon concentrations of samples under study. The radon exhalation rate in Bq m$^{-2}$ h$^{-1}$ varies from 0.72 sample (19) to 18.38 sample (14) with an average value of 6.27.

Figure 4 demonstrates the correlation of the estimated Rn concentration with exhalation rate. The values of working level varied from 0.10 to 2.45 WL and estimated annual effective dose rate from 22.24 to 570.90 mSv y$^{-1}$ as represented in Table 1, which is higher than the normal background level value of 1.10 mSv y$^{-1}$ as quoted by UNSCEAR (2000). Therefore, we can conclude that the mylonitic rock samples from Abu Rushied area cause health hazards in terms of radon emanation to public when it is used as a building material or for workers dealing with these samples in that area.

Table 1. Radon concentration, exhalation rate, annual effective dose, and the working level for the studied samples.

| Sample no. | North part | South part |
|------------|------------|------------|
| 1          | 1825.00 ± 75.59 | 1359.00 ± 75.80 |
| 2          | 2409.94 ± 89.85 | 1672.00 ± 75.50 |
| 3          | 5605.51 ± 74.29 | 5571.27 ± 74.84 |
| 4          | 6488.69 ± 74.97 | 4039.00 ± 74.56 |
| 5          | 5472.00 ± 74.80 | 3392.00 ± 74.74 |
| 6          | 4689.80 ± 74.49 | 2858.00 ± 74.81 |
| 7          | 5220.00 ± 74.18 | 22,629.00 ± 6.90 |
| 8          | 5328.20 ± 73.97 | 22,629.00 ± 6.90 |
| 9          | 2659.80 ± 74.80 | 15,810.00 ± 15.48 |
| 10         | 4171.00 ± 64.05 | 2589.00 ± 74.74 |
| 11         | 6702.00 ± 74.22 | 5927.29 ± 74.09 |
| 12         | 5092.03 ± 73.91 | 3392.00 ± 74.74 |
| 13         | 5092.03 ± 73.91 | 3392.00 ± 74.74 |
| 14         | 4171.00 ± 64.05 | 2589.00 ± 74.74 |
| 15         | 1825.00 ± 75.59 | 1359.00 ± 75.80 |
| 16         | 2409.94 ± 89.85 | 1672.00 ± 75.50 |
| 17         | 5605.51 ± 74.29 | 5571.27 ± 74.84 |
| 18         | 6488.69 ± 74.97 | 4039.00 ± 74.56 |
| 19         | 5472.00 ± 74.80 | 3392.00 ± 74.74 |
| 20         | 4689.80 ± 74.49 | 2858.00 ± 74.81 |
| 21         | 5220.00 ± 74.18 | 22,629.00 ± 6.90 |
| 22         | 5328.20 ± 73.97 | 22,629.00 ± 6.90 |
| 23         | 2659.80 ± 74.80 | 15,810.00 ± 15.48 |
| 24         | 4171.00 ± 64.05 | 2589.00 ± 74.74 |
| 25         | 6702.00 ± 74.22 | 5927.29 ± 74.09 |
| 26         | 5092.03 ± 73.91 | 3392.00 ± 74.74 |
| Average    | 5121.05 ± 70.04 | 3429.00 ± 69.00 |

Figure 3. The relationship between the sample number and Rn concentration for northern and southern part samples.
The variation of surface exhalation rate and annual effective dose with radon concentration are plotted in Figures 4 and 5, respectively; these figures indicate the positive correlation factor of 1 and 1. Finally, the average values of the exhalation rate results, obtained in the current study, are compared with those reported in the literature as given in Table 2.

4. Conclusions

It is clear from the results for the region under study that the average values of radon concentration varied from 881.50 to 22,629.00 Bq m⁻³, the average radon exhalation rate varied from 0.72 to 18.38 Bq m⁻² h⁻¹, and average annual effective dose varied from 22.24 to 570.90 mSv y⁻¹. Overall values of radon concentration are higher than the recommended limit. The International Commission on Radiological Protection recommended a radon concentration range from 200 to 600 and 500 to 1500 Bq m⁻³ for public and occupation, respectively, and the effective annual dose is higher than the world average value of 1.1 and 20 mSv y⁻¹, for public and occupation, respectively (Gupta, Mahur, & Verma, 2011). For this reason, the granite rocks from the area under study can not be used as construction materials because they will cause

| Country                          | \( C_{\text{Rn}} \) (Bq m⁻³) | \( E_x \) (Bq m⁻² h⁻¹) | \( H_{\text{E}} \) (mSv y⁻¹) | References                           |
|----------------------------------|-------------------------------|------------------------|-------------------------------|--------------------------------------|
| Egypt                            | 136.19                        | 0.088                  | 26.65                         | Shoeib and Thabayneh (2014)          |
| Egypt                            | 845                           | 1.089                  | 26.65                         | Yousef et al. (2015)                 |
| Palestine                        | 322.16                        | 0.59                   | 8.12                          | Shoqvar, Dwaikat, and Saffarini (2013) |
| Palestine                        | 246                           | 1.46                   | –                             | Dabayneh (2008)                     |
| Saudi Arabia                     | –                             | 0.72                   | –                             | Al Jarallah, Abu Jarad, and Rehman (2001) |
| Canada                           | 3.5                           | 30–42                  | –                             | Chen, Naureen, and Abu Atiya (2010)  |
| Portugal                         | –                             | 88–653                 | –                             | Pereira et al. (2017)               |
| Romania (soil)                   | 20–500                        | Up to 80               | –                             | Costantin et al. (2013)             |
| Iran                             | –                             | 0.06–0.28              | –                             | Bavaregin et al. (2013)             |
| South Africa (mine tailings)     | –                             | 0.12                   | –                             | Ongori, Lindsay, Newman, and Maleka (2015) |
| Egypt, Abu Rusheid area, South Eastern Desert (Granite) | 5121.05 | 1.83 | 129.20 | Current study |

The variation of surface exhalation rate and annual effective dose with radon concentration are plotted in Figures 4 and 5, respectively; these figures indicate the positive correlation factor of 1 and 1. Finally, the average values of the exhalation rate results, obtained in the current study, are compared with those reported in the literature as given in Table 2.
some radon risk level in buildings that use these rocks. A strong correlation has been found between the radon surface exhalation rate, annual effective dose with radon concentration.

Disclosure statement

No potential conflict of interest was reported by the authors.

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