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ESTIMATION OF NATURAL RADIONUCLIDES OF THE ROCKS OF ABU KHURUQ RING COMPLEX, EGYPT

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The naturally occurring radionuclides (radium, thorium, potassium and radon) were investigated in the alkaline rocks of Abu Khuruq Ring, southern Eastern Desert, Egypt. High-Resolution Germanium detector was used for the detection of ^{40}K, ^{232}Th, and ^{226}Ra (Canberra, GR4020 model) while ^{222}Rn concentration was measured by Alpha-Guard Saphymo GmbH system, model PQ 2000 (AG). Positive correlation was observed between effective radium content and radon concentrations pointing to the strong linear dependency between both contents in the studied rocks. The average values of activity concentration of ^{40}K, ^{232}Th, ^{226}Ra, and ^{222}Rn were little more than the suggested level by a factor of 1.38%, 3.16%, 2.09%, and 1.16%, respectively. Significant variations were observed between radiological hazards parameters, e.g., the mean value of annual effective dose (0.55 mSv y^{-1}) was more than the global reference value of 0.41 mSv y^{-1} by a factor of 1.34. The calculated average value of gamma index was 0.90, whereas the calculated average value of alpha index was 0.37. H_{ex}, H_{in} and Ra_{eq} showed less average values than the standard values of unity and 370 Bq kg^{-1}, respectively.

KEYWORDS: Alpha-Guard; HPGe; Radon; alkaline rock; Abu Khuruq

1. INTRODUCTION

The majority of the materials existing on the surface of the earth consist of a detectable quantity of naturally occurring radioactive materials (NORM), including thorium, uranium, and by-products. Materials having high quantity of NORM are generally carcinogenic in nature [1]. Gamma radiation which comes from the radionuclides ^{40}K, ^{232}Th, and ^{238}U series and their decay products are characterized by their half-lives and are the main external source of exposure to radiations. Therefore, it is important to detect and estimate the radioactive elements in materials used in daily lives for radiation protection of the environment.

The natural radionuclides (^{40}K, ^{232}Th and ^{226}Ra) are prone to external exposure because of gamma ray emission and to internal exposure because of radon and its daughter products. Radionuclides are found in scattered proportions in the environment [1]. External hazard occurs by the direct contact with γ-ray radiation, whereas internal hazard is caused by α-particles that enter the human body when thoron (^{220}Rn), radon (^{222}Rn), and their products are inhaled. These elements have short life span but get deposited on the tissues of the respiratory tract [2]. The radioactive materials thoron ($T_{1/2}$: 56 s) and radon ($T_{1/2}$: 3.82 days) are formed from the disintegration of ^{224}Ra and ^{226}Ra, respectively, which are formed from ^{238}U and ^{232}Th decay. The exhalation process is important in the fraction of outdoor and indoor quantity of radon [3-4].

The presence of radioactive elements like Ra, U and Th is common in any type of rocks. Few types of granite have more of radioactive elements that depend on the characteristics of its original molten rock [5]. This behavior can be correlated to fractional crystallization and the partial melting of magma. This helps Th and U to converge in the liquid phase and convert into silica-rich phases. Therefore, igneous rocks having granite are rich in Th and U (mean values: 61.5 Bq kg^{-1} (15 ppm) of Th and 62 Bq kg^{-1} (5 ppm) of U), as compared to the crust of the earth (average values: 29.52 Bq kg^{-1} (7.2 ppm) for Th and 22.32 Bq kg^{-1} (1.8 ppm) for U [6]. The continental crust's upper portion has a mean value of 43.05 Bq kg^{-1} (10.5 ppm) for Th and 33.48 Bq kg^{-1} (2.7 ppm) for U [7]. In comparison, basaltic rocks or rocks having ultramafic composition contain 1.24 Bq kg^{-1} (0.1 ppm) of U and 0.82 Bq kg^{-1} (0.2 ppm) of Th [8]. Thus, the radiological impact of these elements can be assessed by exploring the concentrations of natural radioisotopes and their distributions in rocks [9]. Moreover, it is essential to determine radionuclide concentration in building materials for examining its radiation effect on human health and for managing these types of rocks.

This study aimed to estimate the activity concentrations of the examined radioisotopes (Radium-226, Thorum-232 and Potassium-40) in the alkaline rocks collected from the Abu Khuruq ring complex; to increase awareness and mitigate possible hazards from radon concentration emitted from this area.

2. MATERIAL AND METHODS

2.1 General description of the Geology of Abu Khuruq area

The late Cretaceous (89 Ma) Abu Khuruq ring in the southern portion of the Eastern Desert (Figure 1) is located between latitudes 24°00′10″ and 24°03′15″ N and longitudes 33°54′50″ and 33°58′ E. It is the youngest Ring Complex in Egypt [10]. The outcrop occupies about 14.5 km2 from north to south.

The ring is formed of discontinuous ring dykes, cones, sheets, and bodies of the type of stock [11]. Its center consists of alkaline trachyte and alkaline rhyolite porphyry rocks. The outer rings are composed of alkaline gabbro (syenogabbro, essexite) and syenites rocks. The latter consists of quartz syenite, syenite, nepheline syenite, and nepheline-bearing pegmatites. A major ring fracture isolates the outer ring, i.e., quartz syenite, and syenite and nepheline syenite. The alkaline rocks of Abu Khuruq consist of minerals rich in K and Na, including alkali pyroxenes, feldspathoids, and a part of alkali amphiboles. All these rocks occur normally in the plate tectonic settings and have similarities with rifting and/or extensional tectonics [12].

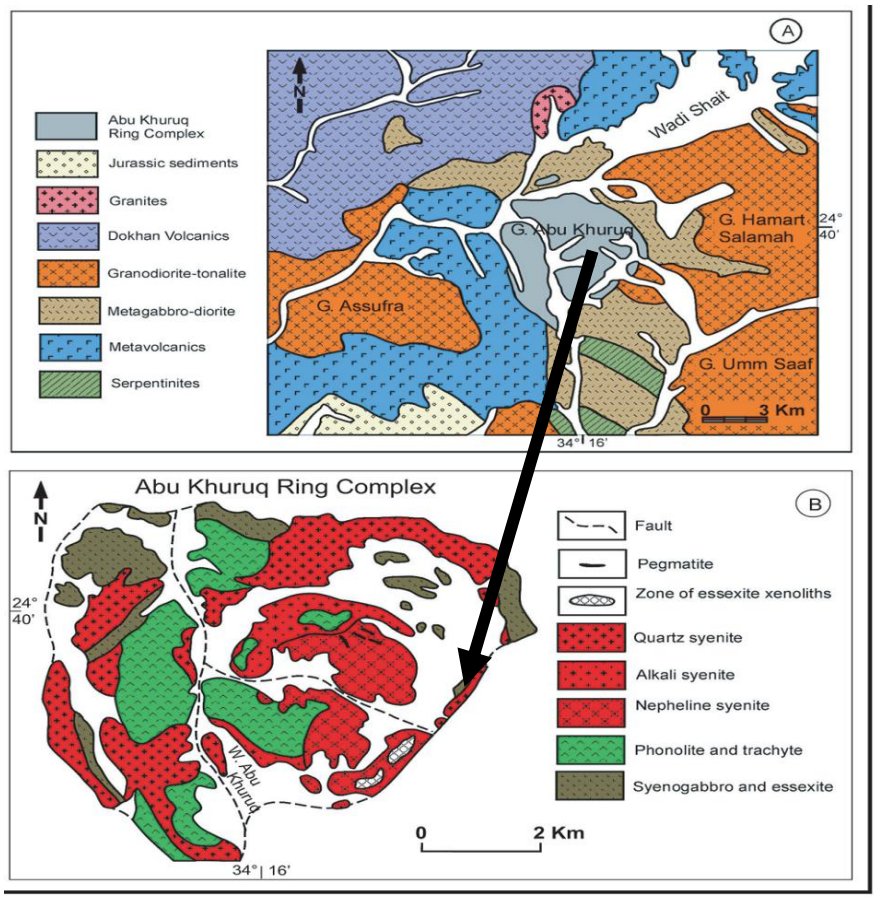

Figure1. *Geological map of the Abu Khuruq area location, south Eastern Desert, Egypt; B. A detailed geological map of the Abu Khuruq ring complex [10].*

2.2 Sample Preparation

Twenty granitic rock samples were clustered from the Abu Khuruq Alkaline Ring Complex during the winter of 2013 and 2014. These samples included all types of granitic rocks found in the area. Each sample was grinded into a fine powder, sieved using a mesh of size 200 μm, dried for more than 3 hours at 120 °C (for dehumidification), weighed and finally placed in a sealed plastic container measuring 95 mm in length, 80 mm in height and 0.5 mm in thickness. To ensure that the radon is airtight, each container was plastered tightly in the neck of the container with a vinyl tape. Containers were saved for 30 days or more to ensure secular equilibrium among ^{226}Ra, ^{222}Rn and their progenies.

2.3 The Gamma Radiation Measurement

The radioisotopes were examined in the Nuclear Lab, Physics Department, Faculty of Science, Assiut University using a high purity germanium detector (HPGe) (Canberra, GR4020 model). Its relative efficiency was about 40%, with an energy resolution of 2 keV (FWHM) for the gamma-rays of 1.332 MeV using ^{60}Co transition. A lead shield (Model 747E, Canberra) was used for shielding the detector, and the DSA-1000 (Canberra, USA) was utilized for acquisition of data. ^{60}Co and ^{137}Cs point sources were used for calibration of energy of the detection system. Further, efficiency calibration was done using Canberra's Geometry Composer, Lab SOCS software. It was used as an alternative source for each sample for optimizing the containers' physical dimensions. This improved the radiation detection capacity of HPGe detector. The measuring time depends on the radionuclide concentration in the measured samples. The spectra were analyzed automatically by GENIE-2000 software [13].

The concentration of ^{226}Ra specific activity was estimated by using the transition lines of energies 609.31, 1120.3 and 1764.5 keV for ^{214}Bi and 295.2 and 351.9 keV for ^{214}Pb. Using the transition gamma lines of energies 209.25, 338.32, 968.97 and 911.2 keV for ^{228}Ac, ^{212}Pb emissGammaions at 238.63 keV and ^{208}Ti emissions at 583.19 and 2614 keV gamma lines, the specific activity concentration of ^{232}Th was computed, while the transition line 1460.8 keV was the only one used to assess the specific activity concentration of ^{40}K.

2.4 Radon measurement

An Alpha- Guard (Saphymo GmbH system, model PQ 2000, AG) is used to analyze radon concentration (Bqm^{-3}) in the rock samples. It operates in the manner of a chamber for pulse ionization, mounted with an emanation container with an Alpha-Pump (AP) (Genitron, Germany) operated at a particularly low flow rate of 0.05 Lmin^{-1}.of. The temporary radon (^{222}Rn) concentrations were recorded in the intervals of one-min for an overall time period of 20 min. The concentration became stable after showing an initial increment. The average values of the final stabilization were considered here as the actual concentration of radon. Contribution of thoron (^{220}Rn, $T_{1/2}$= 55 s) at this low flow rate was negligible [14].

3. RESULTS AND DISCUSSION

3.1 Activity Concentrations of Radioisotopes in the Investigated Samples

The estimated concentration of ^{40}K, ^{226}Ra, and ^{232}Th in the investigated rocks are shown in Figure 2. In the samples, ^{40}K, ^{226}Ra, and ^{232}Th showed the highest specific activities at 1170±25.10 Bq kg^{-1}, 322.4±10.53 Bq kg^{-1}, and 530.5±17.76 Bq kg^{-1}, respectively. The lowest values for the three radionuclides were 17.1±1.47 Bq kg^{-1}, 4.46±0.59 Bq kg^{-1}, and 3.44±0.60 Bq kg^{-1}, respectively. ^{40}K showed a mean value of 554.88±15.20 Bq kg^{-1}, whereas ^{226}Ra and ^{232}Th showed mean values of 73.27±2.55 Bq $kg^{-1}$and 95.04±3.89 Bq kg^{-1}, respectively. The estimated mean values are distinctly higher than the global mean values of 400, 35, and 30 Bq kg^{-1} by 1.38, 2.09, and 3.16 factors, respectively [1]. Figure (3 - a to d) represents the contour maps of the activity concentrations of the examined radioisotopes (^{40}K, ^{226}Ra, ^{232}Th, and ^{222}Rn), where the highest concentrations were recorded close to the center of the ring.

In the rock samples, the mean concentration of radon was 350.28 Bq m^{-3} while its concentration range was 26.5 Bq m^{-3} to 2044 Bq m^{-3}. The mean concentration of radon is extremely higher than the worldwide mean of 40 Bq m^{-3} [1] and is more than the suggested level of reference, i.e., 200–300 Bq m^{-3} [16] by about 1.16–1.75 times. The maximum radon gas content was recorded close to the center of the ring (2044 Bq m^{-3}) as shown in Figure (3-d), while the minimum was the host rock (gabbro) (37 Bq m^{-3}). Uranium mineralization in Abu Khuruq is confined to the accessory minerals bearing uranium (zircon, allanite, etc.). The radon concentration at Abu Khuruq ring is high, possibly because the rocks are alkaline, i.e., phonolite, trachyte, syeno-gabbro, nepheline syenite, essexite, and quartz syenite, and the pegmatites bearing nepheline with high total radiation (counts). However, radon is most commonly generated close to the site of uranium, its ultimate long-lived parent. The highest level of radon concentration was recorded in the nepheline syenite (Sample No. AB 15F) rich in dark xenoliths (2044Bq/m^3).

Figure 4 clearly indicates that the linear correlation coefficient between effective radium content and radon concentrations was 0.72; pointing to the strong linear dependency between both contents in the studied rocks.

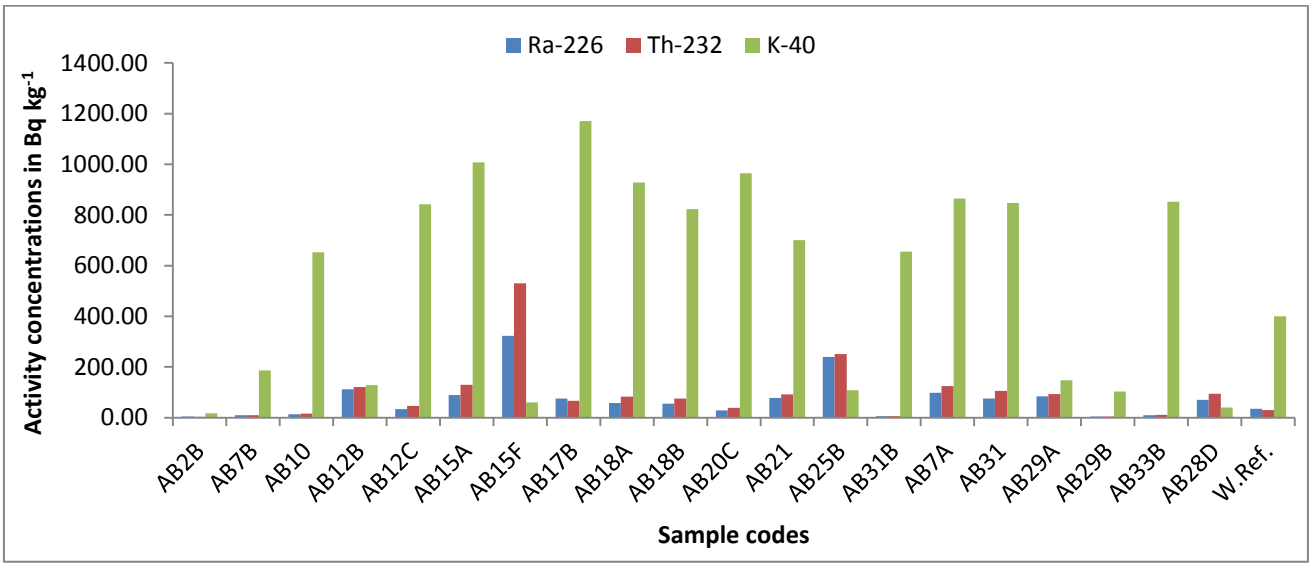

Figure 2. *Activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in Bq Kg^{-1} with their world reference*

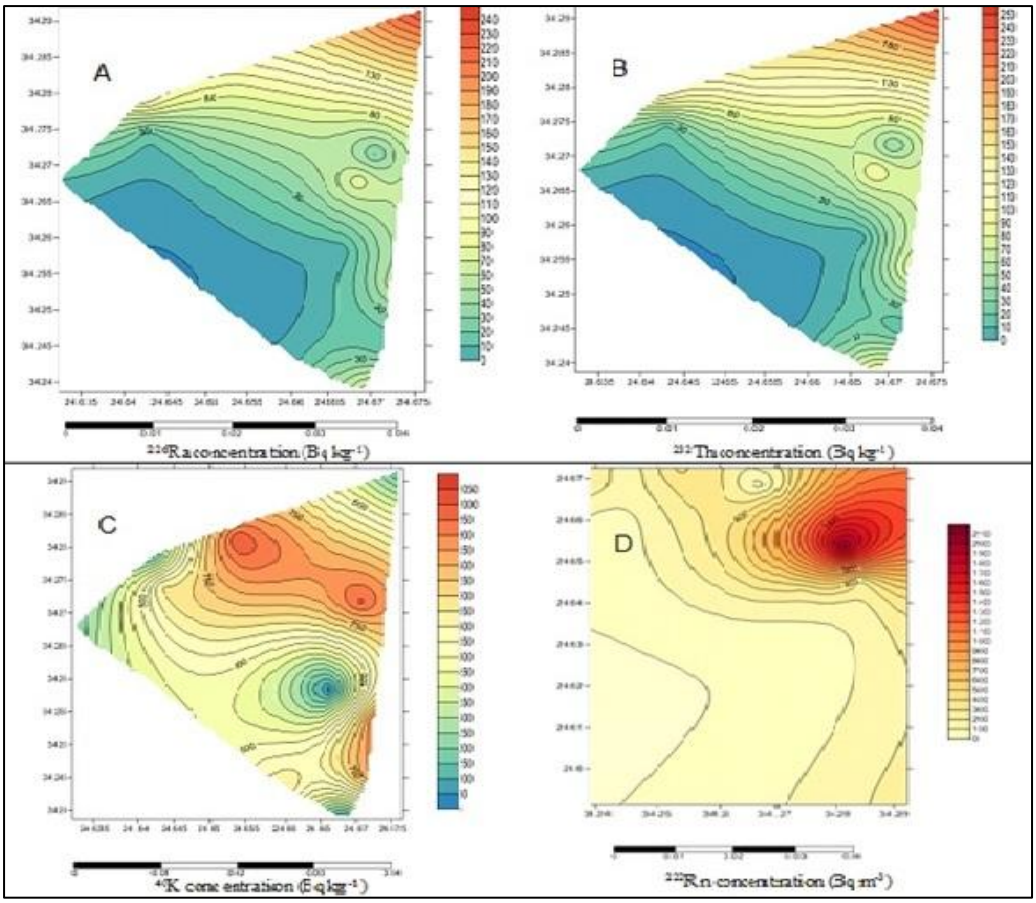

Figure 3. *Contour maps for the activity concentration of the examined radioisotopes ^{226}Ra (a), ^{232}Th (b), ^{40}K (d) and ^{222}Rn (d)*

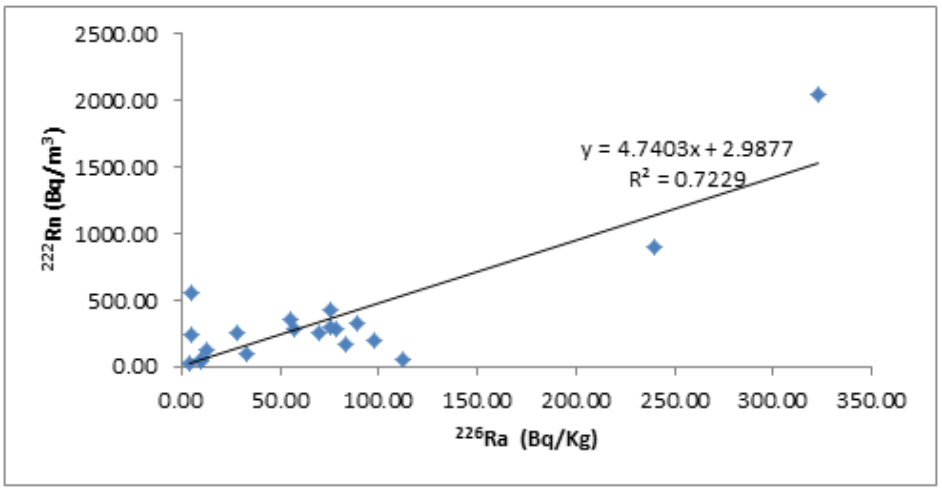

Figure *4. The relation between radium and radon concentrations*

3.2 Radiological hazard parameters

3.2.1 Radium Equivalent Activity Ra_{eq}

Globally, granitic rocks are utilized as decorative materials and superior building materials in homes and other construction works. It is, therefore, essential to assess the level of natural radioactivity associated with them.
Several radiation hazard indices have estimated the radiological hazards caused by γ-rays emitted from ^{40}K, ^{226}Ra, and ^{232}Th. In general, any Ra_{eq} concentration exceeding 370 Bq Kg^{-1} may elevate radiation hazards. In our study, radiation equivalent activity was estimated and expressed in Bq kg^{-1} and is represented as Ra_{eq}. It is given by Xinwei et al. [17].

$$\boldsymbol{Ra_{eq}(Bq\ kg^{-1}) = AC_{Ra} + 1.43AC_{Th} + 0.077AC_{K}} \qquad (1)$$

where $AC_{K,}$ AC_{Ra}, and AC_{Th}, denote the specific activities of ^{40}K, ^{226}Ra, and ^{232}Th, respectively.
The obtained Ra_{eq} values ranged from 10.94 to 1085.62 Bq kg^{-1} and had a mean value of 251.89 Bq kg^{-1}. The sample (AB15F) with the highest concentrations of ^{232}Th and ^{226}Ra showed the highest value of 1085.62Bq kg^{-1}. All the Ra_{eq} values were within the recommended level of 370 Bq kg^{-1}[18], except for samples (AB15F and AB25B). These values are comparatively lower than the accepted maximum value for construction materials (350 Bq kg^{-1}) [19]. This indicates the safe use of the rocks of Abu Khuruq with a particular care for the locations of samples AB15F and AB25B.

3.2.2 Absorbed Dose Rates (D_R) and Annual Effective Dose Rates (AEDR)

Based on the formulas initiated by UNSCEAR [1] and EC [20], the D_R of indoor air (D_R in nGy h^{-1}) and the corresponding AEDR in mSv y^{-1} due to γ-rays emission from ^{40}K, ^{226}Ra, and ^{232}Th were estimated. The European Commission and UNSCEAR reports suggest that the coefficient of dose conversion is determined for the center of a standard room (dimensions 4 m × 5 m × 2.8 m and 3 cm thicknesses of granitic tiles of 2600 kg m^{-3} density covering all walls of the room). The D_R was determined using Eq. 2 as provided in UNSCEAR [1] and EC [20].

$$\mathbf{D_R[nGyh^{-1}] = 0.436AC_{Ra} + 0.599AC_{Th} + 0.041AC_{K}} \quad (2)$$

Thus, the AEDR in mSv y^{-1} due to γ-rays from the studied rock samples were computed as

$$\mathbf{AEDR[mSvy^{-1}]} = \boldsymbol{D_R}\mathbf{(nGy\ h^{-1}) \times 8766\ h \times 0.8 \times 0.7 SvGy^{-1} \times 10^{-6}} \qquad (\mathbf{3})$$

where the indoor occupancy factor is 0.8, the conversion coefficient obtained from the absorbed dose in air (Gy) to effective dose in Sv is 0.7 Sv Gy^{-1}, and the annual time in hours as suggested by UNSEAR [1] is 8766 h.

Table 1 shows the obtained indoor D_R and the AEDR of the investigated samples. The mean value of D_R was 112.01 nGy h^{-1}, while it ranged from 4.83 to 460.83 nGy h^{-1}. Here, it should be noted that the global mean value of D_R is 84 nGy h^{-1} [1], which is lower than the obtained mean D_R. The AEDR values ranged from 0.02 to 2.26 mSv y^{-1}. Its mean value of 0.55 mSv y^{-1} is lower than the dose criterion of 1 mSv y^{-1} [16, 21] but slightly higher than the global mean value of 0.41 mSv y^{-1}, as in UNSEAR [1].

3.2.3 External Hazard Index (H_{ex})

The H_{ex} reflects external exposure or the external risks of gamma rays radiated from natural radionuclides. It is presented as follows UNSCEAR [1]:

$$\mathbf{H_{ex}} = \frac{\mathbf{AC_{Ra}}}{\mathbf{370}} + \frac{\mathbf{AC_{Th}}}{\mathbf{259}} + \frac{\mathbf{AC_K}}{\mathbf{4810}} \leq \mathbf{1} \qquad (\mathbf{4})$$

To avoid the external risks of gamma-rays (reflecting a neglected external exposure), it is essential that H_{ex} must be less than unity (= 370 Bq kg^{-1}) (the upper limit of Ra_{eq} criterion).

Table 1 presents the estimated H_{ex} values for the collected samples. The table shows that H_{ex} varies in each sample, and its average value (0.68) is lower than unity (the recommended safety limit).

3.2.4 Internal Hazard Index (H_{in})

The internal exposure of the human body to radon and its related elements poses radiological hazards to internal organs and can be examined by H_{in}, as shown below:

$$\mathbf{H_{in}} = \frac{\mathbf{AC_{Ra}}}{\mathbf{185}} + \frac{\mathbf{AC_{Th}}}{\mathbf{259}} + \frac{\mathbf{AC_K}}{\mathbf{4810}} \leq \mathbf{1} \qquad (\mathbf{5})$$

Table (1) shows the varied values of H_{in} in the studied samples. It is obvious that the average value of H_{in} (0.88) does not go beyond unity.

The values of H_{in} and H_{ex} estimated for the Abu Khuruq samples were below the permissible limit of unity. Hence, the uses of these rocks have no immediate negative health implications, but a warning should be given against long-term cumulative effects.

3.2.5 Alpha and Gamma Indices (I_α & I_γ)

The alpha index (Iα) estimates radon inhalation for radon emitted from building materials [21-24]. This index is determined through the specific activity concentration of ^{226}R, AC_{Ra} which is in Bq kg^{-1}

$$\mathbf{I_\alpha = \frac{AC_{Ra}}{200 Bq\ kg^{-1}}} \qquad (6)$$

where AC_{Ra} is the activity concentration of the alpha emitter ^{226}Ra (Bq kg^{-1}). If the activity concentations of radium in a construction material exceeds 200 Bq kg^{-1}, radon exhalation from a material may have an adverse effect of increase of indoor radon concentrations more than the recommended reference value of 200 Bq m^{-3} [24,25]; thus, the recommended safe limit is less than or equal to unity.

The values of Iα varied from 0.02 to 1.61, and its average was 0.37, which is well within the recommended upper level. So, these rocks can be considered for use as construction materials.

Potential radiological hazards because of the use of granite samples as superficial building materials (decorative or covering) are assessed by gamma representative index (Iγ) as given in the below equation [20].

$$\mathbf{I_\gamma = \frac{AC_{Ra}}{300} + \frac{AC_{Th}}{200} + \frac{AC_K}{3000}} \qquad (7)$$

In case of popular materials with limited use, e.g. tiles, $I_\gamma \leq 2$ denotes an annual effective dose of ≤ 0.3 mSv, whereas $2 < I_\gamma \leq 6$ denotes a dose of ≤ 1 mSv [20].

The computed I_γ values of the studied samples are inserted in Table 1. Its values vary from 0.04 to 3.75 with a mean value of 0.90, which is within the acceptable limit of I<2 for materials with limited use (e.g., boards, tiles, etc.). This value denotes an indoor annual effective dose <0.3. So, the investigated rocks are safe for use as superficial materials in construction.

Table 1. The Radium equivalent, Absorbed Dose Rates , Annual Effective Dose rates, External Hazard Index, Internal Hazard Index and Alpha and Gamma Indices of the rocks of Abu Khuruq

Sample code	Ra_{eq} (Bq kg^{-1})	D_R (nGy h^{-1})	AEDR (msv y^{-1})	H_{ex} (Bq Kg^{-1})	H_{in} (Bq Kg^{-1})	I_α	I_γ
AB2B	10.94	4.83	0.02	0.03	0.04	0.02	0.04
AB7B	37.67	17.71	0.09	0.10	0.13	0.05	0.14
AB10	85.17	42.03	0.21	0.23	0.26	0.06	0.34
AB12B	294.57	126.52	0.62	0.79	1.10	0.56	1.01
AB12C	165.15	77.71	0.38	0.45	0.54	0.17	0.62
AB15A	352.92	158.88	0.78	0.95	1.19	0.45	1.28
AB15F	1085.62	460.83	2.26	2.93	3.80	1.61	3.75
AB17B	260.59	121.51	0.59	0.70	0.91	0.38	0.97
AB18A	246.83	113.14	0.55	0.67	0.82	0.29	0.91
AB18B	226.56	103.63	0.51	0.61	0.76	0.28	0.83
AB20C	157.88	75.72	0.37	0.43	0.50	0.14	0.61
AB21	263.99	118.54	0.58	0.71	0.92	0.39	0.95
AB25B	606.94	259.36	1.27	1.64	2.29	1.19	2.09
AB31B	63.50	32.88	0.16	0.17	0.18	0.03	0.26
AB7A	342.54	153.32	0.75	0.92	1.19	0.49	1.24
AB31	291.65	131.45	0.64	0.79	0.99	0.37	1.06
AB29A	228.59	98.58	0.48	0.62	0.84	0.42	0.79
AB29B	19.07	9.037	0.04	0.05	0.06	0.02	0.07
AB33B	90.09	45.96	0.22	0.24	0.27	0.05	0.37
AB28D	207.63	88.54	0.43	0.56	0.75	0.35	0.72
Min.	10.94	4.83	0.02	0.03	0.04	0.02	0.04
Max.	1085.62	460.83	2.26	2.93	3.80	1.61	3.75
Mean	251.89	112.01	0.55	0.68	0.88	0.37	0.90

3.4 Major oxides contents of rocks

The major element concentrations investigated in the studied rocks (Table 2) are SiO_2: 36.00–77.70% with a mean value of 57.05%; Al_2O_3: 10.40–21.20% with a mean value of 15.59%; Fe_2O_3: 0.94–20.95% with a mean value of

8.81%; CaO: 0.19–15.72% with a mean value of 5.29%; MgO: 0.01–9.30% with a mean value of 2.70%; Na_2O: 3.04–8.90% with a mean value of 5.25%; K_2O: 0.32–4.95% with a mean value of 2.87%; TiO_2: 0.07–5.32% with a mean value of 1.29%; MnO: 0.07–0.35% with a mean value of 0.18%; P_2O_5: 0.02–2.76 with a mean value of 0.36%; BaO: 0.01–0.14 with a mean value of 0.05%; and SrO:0. 01–0.09 with a mean value of 0.03%. Significant variation was noticed between the measured concentrations of major oxides due to the various redox conditions and other factors [33]. The ordering of elements based on their abundance was SiO_2>Al_2O_3>Fe_2O_3>CaO>Na_2O>K_2O>MgO>TiO_2>P_2O_5>MnO>BaO>Cr_2O.

Table 2- Major oxides in the investigated rocks in %

Sample code	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	Cr_2O_3	TiO_2	MnO	P_2O_5	SrO	BaO
AB2B	46.90	19.10	9.22	8.85	8.91	3.84	0.43	0.01	0.70	0.11	0.10	0.04	0.01
AB7B	49.50	13.35	10.10	9.36	8.67	3.07	0.97	0.07	1.53	0.14	0.33	0.07	0.05
AB10	36.00	10.52	19.25	9.88	9.30	4.47	0.41	0.01	5.23	0.30	2.76	0.06	0.02
AB12B	57.70	18.40	5.64	2.39	0.72	7.49	4.27	0.01	0.63	0.14	0.18	0.04	0.07
AB12C	58.00	19.00	5.41	1.92	0.32	8.61	4.37	0.01	0.35	0.14	0.12	0.04	0.06
AB15A	63.80	12.10	9.90	0.93	0.12	6.78	4.19	0.01	0.62	0.30	0.06	0.01	0.03
AB15F	54.90	19.55	6.32	1.25	0.26	8.90	4.25	0.01	0.14	0.29	0.06	0.01	0.01
AB17B	77.70	13.25	0.94	0.19	0.14	3.56	3.34	0.01	0.07	0.03	0.02	0.01	0.07
AB18A	63.50	15.90	6.06	2.11	0.46	6.08	3.81	0.01	0.62	0.16	0.14	0.02	0.14
AB18B	64.00	14.60	3.52	3.50	0.42	5.61	4.95	0.01	0.55	0.12	0.05	0.01	0.06
AB20C	61.50	13.40	10.05	1.44	1.25	6.75	4.56	0.01	0.54	0.33	0.11	0.01	0.03
AB21	63.70	13.85	8.86	2.08	0.18	5.38	4.02	0.01	0.63	0.18	0.11	0.01	0.07
AB25B	70.50	10.40	7.05	1.56	0.16	4.26	4.08	0.01	0.37	0.12	0.02	0.01	0.01
AB31B	48.95	19.45	8.59	9.82	5.44	3.86	0.43	0.03	1.36	0.12	0.19	0.06	0.03
AB7A	67.90	13.45	4.44	1.95	0.01	4.79	5.02	0.01	0.41	0.07	0.02	0.01	0.01
AB31	57.60	18.30	6.22	2.99	0.94	7.01	4.11	0.01	0.76	0.14	0.21	0.05	0.09

AB29A	45.00	17.55	12.35	11.90	4.39	3.04	0.32	0.01	4.07	0.14	0.10	0.07	0.01
AB29B	49.00	21.20	8.99	10.30	3.29	3.95	0.55	0.01	1.82	0.10	0.45	0.09	0.03
AB33B	63.10	15.00	8.03	2.44	0.33	6.18	3.88	0.01	0.58	0.21	0.10	0.01	0.09
AB28D	42.14	13.02	20.95	15.72	4.72	0.00	0.00	0.00	2.10	0.35	0.00	0.00	0.00
Min	36.00	10.40	0.94	0.19	0.01	3.04	0.32	0.01	0.07	0.07	0.02	0.01	0.01
Max	77.70	21.20	20.95	15.72	9.30	8.90	4.95	0.07	5.32	0.35	2.76	0.09	0.14
Average	57.05	15.59	8.81	5.29	2.70	5.25	2.87	0.02	1.29	0.18	0.36	0.03	0.05
STDEV	11.82	3.51	5.51	5.07	3.47	2.23	1.93	0.02	1.56	0.09	0.78	0.03	0.04

4. CONCLUSION

The activity levels of natural radioisotopes, such as ^{40}K, ^{232}Th, ^{226}Ra, and ^{222}Rn in alkaline rocks samples from Abu Khruq ring complex were assessed by using different experimental techniquies.

Radiologically, a High Purity Germanium detector (HPGe) was considered to measure the mean concentrations of the investigated radionuclides in the rocks of Abu Khuruq, Egypt. Distinct variations are observed between the calculated radiological hazard indices compared to the worldwide average. Some indices showed greater values compared to the world average, e.g., D_R, AEDR, I_α, and I_γ. Hence, protective covering should be used when handling such rocks to prevent excessive exposure to radiation. The remaining indices showed lower values compared to the world average, e.g., H_{in}, H_{ex}, and Ra_{eq}. Thus, the uses of these materials have the least possibility of any immediate health complications, but caution should be taken against long-term cumulative effects.

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