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Study of the Different Modes of the External Exposure to the Terrestrial Gamma Rays at Seila Area, Southeastern Desert, Egypt

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Abstract

Uranium activity concentration in the granitic rocks at a studied location at Seila area ranged between 161 and 2778 (Bq/kg) with an average of 1163 (Bq/kg). Several modes and configurations were suggested to evaluate the effective dose rates received externally by the workers exposed to the gamma rays emitted from the studied granites. Precisely described exposure configurations can prevent any undesired overestimation of the effective doses received by the workers. Using such configurations reduced the estimated effective dose rate from 1.12 to almost its half value, 0.58 (µSv/h). However, all modes of exposure to the terrestrial gamma rays at Seila area result in occupational effective doses which are below the recommended limits. It is unlikely that the transport of the granitic rocks from Seila area causes any considerable exposures to the occupants or to the environment.

Keywords: Granitic rocks; Gamma rays; Radioactive material; Monzogranite; Radiometric measurements; Uranium

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Introduction

All minerals and raw materials contain radionuclides of natural origin. The most important for the purposes of radiation protection are the radionuclides in the ^{238}U and ^{232}Th decay series and the non-series radioactive element ^{40}K. For most human activities involving minerals and raw materials, the levels of exposure to these radionuclides are not significantly greater than normal background levels and are not of concern for radiation protection. However, certain work activities can give rise to significantly enhanced exposures that may need to be controlled by regulations [1]. Material giving rise to these enhanced exposures has become known as naturally occurring radioactive material (NORM). Uranium exploration and mining include several activities that give rise to the enhanced exposures to ionizing radiation. Seila area, southeastern Desert of Egypt is located between latitudes 22°13′48′′-22°18′36′′N and longitudes 36°10′12′-36°1836′′E. The younger granite at Seila area is represented by Gabal Qash Amir, Gabal El Seila and isolated granite stocks. These rocks are affected by ENE-WSW shear zones and sub-parallel fault system dipping 50°-70° to the south and extending about 9 km, with thicknesses between 2 to 40 m. The ENE-WSW trend was intersected by the N-S sinestral strike slip and dip slip fault systems. Shear zones and fault systems are filled with quartz veins, fine grained granite and basic dykes. The ENE-WSW shear zones display radioactive anomaly along the sheared fine grained granite and basic dykes. Generally, these rocks are pale pink slightly leucocratic, medium to coarse grained, cavernous and exfoliated monzogranite and they include U-bearing minerals such as biotite, zircon and muscovite [2]. These minerals have enhanced concentrations of the terrestrial radioactive elements; ^{238}U, ^{232}Th and ^{40}K [3]. The Egyptian nuclear materials authority (NMA) established some of projects to explore the radioactive elements in Egypt. One of them was established at Seila area. So, the radioactive exposure of workers in this project from terrestrial radioactive elements; uranium, thorium and potassium should be evaluated. In this study, the author suggests some modes and configurations to evaluate the external effective doses from the gamma rays received by the workers at Seila area during exploration of uranium and handling the rock samples collected from this area.

Field Works and Measurements

Among several locations chosen by the Nuclear Materials

Authority NMA for uranium exploration development at Seila area, the one at Lat. 22°17'55.95", Long. 36°14'8.76" is the subject of this study **(Figure 1).** This location represents a vertical face cutting the fractured granite. The area of the face is almost 3.5 × 3.5 m^2.

Radiometric measurements

A grid pattern containing 12 points was demonstrated on the granitic face for radiometric measurements **(Figure 2)**. The spacing between the vertical lines is 1.5 m while the spacing between the horizontal lines is 1m. Radiometric measurements were carried out at the chosen spots on the grid pattern using RS-230 BGO (Bismuth Germanate Oxide) Super-Spec portable radiation detector. This spectrometer has high accuracy (Probable measurement errors about 5%) in full assay capability with data in K%, eU (ppm) and eTh (ppm) while no radioactive sources required for proper operation. The detector is a product of an independent private company (Radiation Solutions Inc. Mississauga, Ontario, Canada). The values of eU and eTh in ppm as well as K in percent were converted to activity concentrations, (Bq/kg), using the conversion factors given by the International Atomic Energy Agency IAEA [4]. The activity concentration of a sample containing 1 ppm by weight of eU yields is 12.35 (Bq/kg) of ^{238}U, 1 ppm of eTh yields 4.06 (Bq/kg) of ^{232}Th and 1% of K yields 313 (Bq/kg) of ^{40}K.

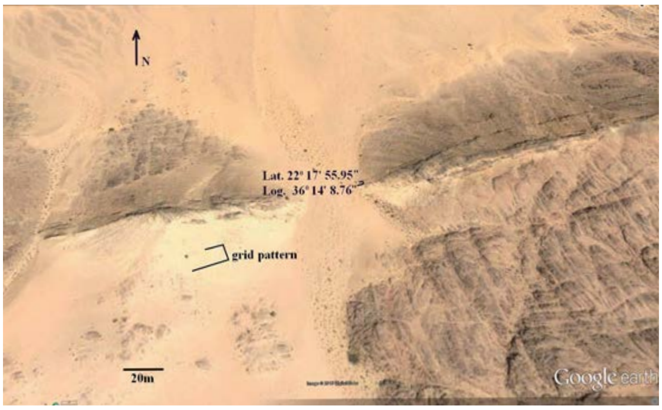

Figure 1 Location of the studied U-exploration site at Seila area.

Figure 2 A grid pattern on the vertical granitic face to investigate the concentrations of U, Th and K. The picture was taken looking east.

Measurements of dose equivalent rate

The RDS-100 survey-meter, ALNOR, Turku, Finland, was used for measuring the gamma equivalent dose rate. This detector can detect gamma rays in the energy range of 50 kev to 3 Mev and equivalent dose rate measurements range 0.05 (µSv/h)-99.99 (mSv/h). It contains Geiger Muller tube calibrated against a ^{60}Co γ-source of activity 7.4 × 10^8 Bq at the national institute of standards and technology (NIST). Measurements were achieved at the chosen locations on six lines parallel to the studied granitic face. These lines were at distances 0.5, 2.5, 5, 7.5,10 and 12.5 m from the face.

Results and Discussion

Concentration of the radionuclides

Darnley defined the "uraniferous granites" as those containing at least twice the Clarke value (4 ppm U), hence, they would contain 8 ppm or more, regardless of the presence of associated U-mineralization or not [5]. Accordingly, the data in **Table 1** clarified that the studied granite face at Seila area can be considered uraniferous granites. U-content varies between 13 and 224.9 with an average value of 94.16 ppm. It seems that U-content varies from the higher values at the north of the grid pattern (N line) to the lower values at the south (S line) and from upwards (first line) to downwards (fourth line). However, the rock samples were collected in cloth bags and loaded on a truck to be transported to NMA branch at Inchas. **Table 2** represents the concentration of U, Th and K in the rock samples on the truck at six points. Comparing the average values of the studied measurements in **Tables 1 and 2,** It is clear that the data of U and Th were affected by the physical condition of the rocks. U-content decreased from 94.16 ppm in the local bedrock at the studied granitic face to only 32.16 ppm in the crushed rock samples on the truck, while Th-content decreased from 8.93 to 6.08 ppm. This conclusion suggests an intercomparison between all the radiometric survey meters and devices to check the reproducibility of the measurements.

Absorbed dose rate D and equivalent dose rate H

The absorbed dose rate D (nGy/h) at 1 m due to the exposure to gamma rays emitted from the studied granitic face at Seila area is calculated according to the formula [6].

$$D=0.462\ A_U+0.604\ A_{Th}+0.0417\ A_K \qquad (1)$$

Where A_U, A_{Th} and A_K are the mean activities of ^{238}U, ^{232}Th and ^{40}K in (Bq/kg), respectively

The workers of the NMA at Seila area are all adults. Consequently, the conversion factor from the absorbed dose rate D (nGy) to the equivalent dose rate H (nSv/h) equals unity. **Table 3** represents the activity concentrations (Bq/kg) of ^{238}U, ^{232}Th and ^{40}K. The values of the equivalent dose rate H (µSv/h) using **Equation 1** and the relevant conversion factor are shown in **Table 3.** The equivalent dose rate H varies between 0.14 and 1.38 with an average of 0.61 (µSv/h). Indeed, **Table 3** represents the value of H at 1 m from

Table 1 The eU, eTh and K contents in the studied granite face located at Seila area.

Point No.	eU ppm	eTh ppm	K %
N1	155.7	13.1	3.9
N2	224.9	15.7	4.1
N3	222.9	15.6	4
N4	59.7	3.4	1.5
M1	102.3	6.2	2.1
M2	93.9	6.1	2.9
M3	74.6	4.4	3.2
M4	47.4	11.3	3.5
W1	46.5	16.6	4
W2	42.6	4.3	2.3
W3	46.4	3.5	2.2
W4	13	6.9	3.5
Ave.	94.16	8.93	3.1

Table 2 The eU, eTh and K contents in the rock samples at six points on the truck.

Point No.	eU ppm	eTh ppm	K %
1	16.3	6.2	6.2
2	19.2	5.9	5.9
3	57.1	6.6	6.6
4	21.5	6.2	6.2
5	33.33	6.5	6.5
6	45.5	5.1	5.1
Ave.	32.16	6.08	6.08

Table 3 Activity concentration of the radionuclides ^{238}U, ^{232}Th and ^{40}K (Bq/kg) and the equivalent dose rate H (µSv/h) at 1m from the surface of the studied granites at Seila area.

Point No.	^{238}U (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)	H (µSv/h)
N1	1923	53.19	1221	0.98
N2	2778	63.74	1283	1.38
N3	2753	63.34	1252	1.37
N4	737	13.80	470	0.37
M1	1263	25.17	657	0.63
M2	1160	24.77	908	0.59
M3	921	17.86	1002	0.48
M4	585	45.88	1096	0.35
W1	574	67.40	1252	0.36
W2	526	17.46	720	0.29
W3	573	14.21	689	0.31
W4	161	28.01	1096	0.14
Ave.	1163	36.24	970	0.61

each point on the studied granitic face. Alternatively, the survey meter located at 1 m from the granitic face receives gamma rays emitted from each point on the whole area of the face and replies a value representing the average value of H. **Figure 3** represents the gradient of the measured equivalent dose rate H (µSv/h) with the distance from the granitic face. Fitting the measured data suggests an exponential gradient of H with the distance x from the studied granitic face according to the relation:

$$H=0.0907+1.3e^{-x/6.98} \quad (2)$$

where H is the equivalent dose rate (µSv/h) and x is distance (m). From **Equation 2,** the equivalent dose rate at 1 m from the granitic face is 1.22 (µSv/h) which is almost twice the average value obtained in **Table 3.** This is because the equivalent dose rate measured by the survey meter collects gamma rays from not only the studied granitic rock face but also from the surrounding rock walls and the remnants of the rock samples on the ground **(Figure 3)**. **Equation 2** can be interpreted at two extreme values of the distance X. The first value of X is assumed at infinity. Mathematically, this value eliminates the second term in **Equation 2** and the value of H equals 0.0907 ± 0.012 (µSv/h). Physically, this value is set as the average background of the equivalent dose rate due to the gamma rays received down into the northern neighboring Wadi at a distance far enough from the studied granitic face, X=50 m. However, the average background of the equivalent dose rate measured at the western neighboring Wadi was found to be 0.08 ± 0.012 (µSv/h) [7]. The other value of x represents the contact between the survey meter and the granitic face (X=0). The average value of the equivalent dose rate H is calculated at (X=0) from **Equation 2** to have the value of 1.39 (µSv/h).

Effective dose rate and its different modes

The effective dose rate E (µSv/h) due to the terrestrial gamma rays is calculated according to the **equation [8]**

$$E= \sum H\, w_T \quad (3)$$

Where H is the equivalent dose rate (µSv/h) and w_T is the organ or tissue weighting factor **(Table 4).**

The equivalent dose rate H is assumed constant at a specific distance from the studied granitic face. Accordingly, **Equation 3** becomes:

$$E= H \sum w_T \quad (4)$$

Standing mode: The "Standing" mode is described as a worker stands before the rocks to study its mineral composition or takes its picture at any distance, etc. This mode represents a whole body radiation. So, the summation in **Equation 4** is unity as shown in

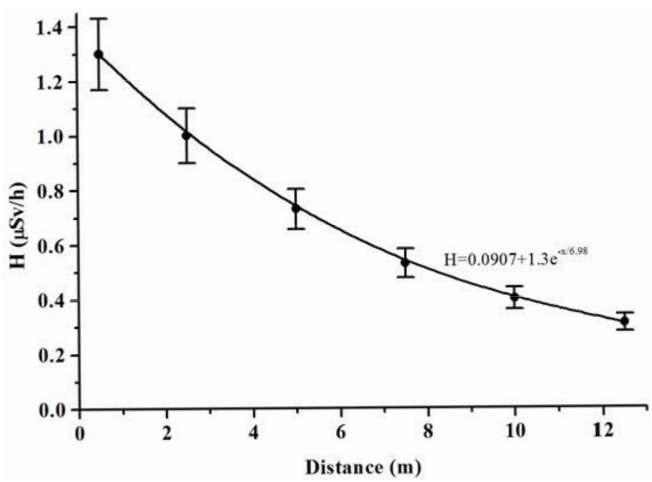

Figure 3 Variation of the average values of the measured equivalent dose rate H (µSv/h) with the distance from the granitic face at Seila area.

Table 4. Accordingly, the effective dose rate E equals numerically the equivalent dose rate H and **Equation 2** tends to the form:

$$Es = 0.0907 + 1.3\ e^{-x/6.98} \quad (5)$$

Where Es is the effective dose rate for the standing mode. **Equation 5** applies to the standing mode all over the studied area from the contact with the granitic face (X=0, Es=1.39 μSv/h) to the distance at (X=12.5, Es=0.31 μSv/h). These values are much below the recommended occupational effective dose rate of 10 (μSv/h) [8].

Carrying mode: The "carrying" mode represents the carrying of the rock samples in the bags to load on the truck. Three configurations are classified as carrying mode **(Figure 4).** The Right hand-Left hand (R-L) configuration represents the exposure to the nearest organs; bone and gonads ($\sum w_T=0.09$). The "Hug" configuration represents the exposure to colon, lung, stomach, breast, bladder, oesophagus, small intestine, liver, heart, kidney and gonads ($\sum w_T=0.71$). The "shoulder" configuration represents the exposure of bone-marrow, thyroid, brain, eye and salivary glands ($\sum w_T=0.19$). It is clear that the Hug configuration is the most risky one as it includes the exposure of most organs in the human body. The suggested configurations were exercised at the vicinity of the studied granitic face which means that the worker who carries a bag receives a total effective dose rate E which is the summation of the Standing mode Es as a component and the other component Ec resulting from carrying the bag i. e:

$$E = Es + Ec \quad (6)$$

Where E is the total effective dose rate (μSv/h), Es is the effective dose rate resulting from the Standing mode (μSv/h) and Ec is the effective dose rate from carrying the sample bags (μSv/h).

The effective dose rate from the carrying mode is calculated as follows:

$$Ec = H_g \sum W_T \quad (7)$$

Where H_g is net equivalent dose rate (μSv/h) measured in contact with each of random twelve bags during moving to the truck and $\sum W_T$ has the values 0.09, 0.71 and 0.19 for the different carrying configurations as clarified above. The cloth bags containing the rock samples and the truck were located at 12.5 m from the granitic face i.e. H=0.31 (μSv/h). This value should be subtracted from the direct contact reading H_D of the survey meter to obtain H_g. Accordingly, **Equation 6** becomes:

$$E = 0.31 + H_g \sum W_T \quad (8)$$

In this study the author equates the probability of the three carrying configurations to calculate the total effective dose rate E. **Table 5** represents the values of H_g, Ec for the three suggested carrying configurations and E during the loading of rock samples bags at Seila area. From **Table 5,** all values of the effective doses; Ec or E are much below the recommended dose rate [8]. The importance of the definition of E as proposed by **(Equation 6)** is that it relates the contact reading of any radioactive sample H to the resulting biological effect (w_T) through a precisely described configuration to prevent any undesired overestimation of the

Table 4 Recommended tissue weighting factors.

Tissue	W_T	$\sum W_T$
Bone-marrow (red), Colon, Lung, Stomach, Breast, Remainder tissues	0.12	0.72
Gonads	0.08	0.08
Bladder, Oesophagus, Liver, Thyroid	0.04	0.16
Bone surface, Brain, Salivary glands, Skin	0.01	0.04
Total		**1.00**

Figure 4 Three configurations suggested to the carrying mode.

Table 5 Equivalent dose rates H_D and H_g (μSv/h), the effective dose rate for the three carrying configurations Ec (μSv/h) and the total effective dose E (μSv/h) resulting from the loading of granitic rocks from Seila area.

Bag No.	H_D (μSv/h)	H_g (μSv/h)	Ec (μSv/h)			E (μSv/h)
			R-L	Hug	Shoulder	
1	1.07	0.76	0.38	0.85	0.45	0.56
2	0.82	0.51	0.36	0.67	0.41	0.48
3	0.71	0.40	0.35	0.59	0.39	0.44
4	1.00	0.69	0.37	0.80	0.44	0.54
5	0.98	0.67	0.37	0.79	0.44	0.53
6	0.69	0.38	0.34	0.58	0.38	0.44
7	0.88	0.57	0.36	0.71	0.42	0.50
8	0.76	0.45	0.35	0.63	0.40	0.46
9	1.12	0.81	0.38	0.89	0.46	0.58
10	0.67	0.36	0.34	0.57	0.38	0.43
11	0.88	0.57	0.36	0.71	0.42	0.50
12	0.90	0.59	0.36	0.73	0.42	0.50
Ave.	0.87	0.56	0.36	0.71	0.42	0.50

occupational exposures. For example, grab #9 yields a contact equivalent dose of 1.12 (µSv/h). This value gives an effective dose of 1.12 (µSv/h) if assuming whole body radiations. In contrast, using **Equation 6** the effective dose reduced to half its value 0.58 (µSv/h) **(Table 5).**

Transport mode: The "transport" mode includes both occupational exposure represented by the driver in the cabin of the truck and public exposure due to the passage of the truck in the surrounding environment carrying the granitic rocks in its box. To estimate the resulting effective doses due this carriage, the equivalent doses were measured inside the cabin of the truck and in contact with sides of its box before loading the sample bags **(Figure 5a)** and after loading **(Figure 5b).**These measurements were carried out at the NMA Field Center at Abu Ramad city located about 22 km to the east of Seila area. From the data projected on **(Figures 5a and 5b)** the additional equivalent dose rate at the driver in the cabin is 0.05 (µSv/h). Assuming whole body radiation for the driver results in an additional effective dose rate of only 0.05 (µSv/h). Assuming 2000 working hours per year, the annual effective dose is 0.1 (mSv). This is much below the recommended occupational dose rate which ranges between 1 and 6 (mSv/y) during the transportation of natural radioactive materials [9]. On the other hand, the additional equivalent dose rate in contact with the box of the truck is 0.15 (µSv/h). This is lower than the recommended limit of 6 (µSv/h) [9].

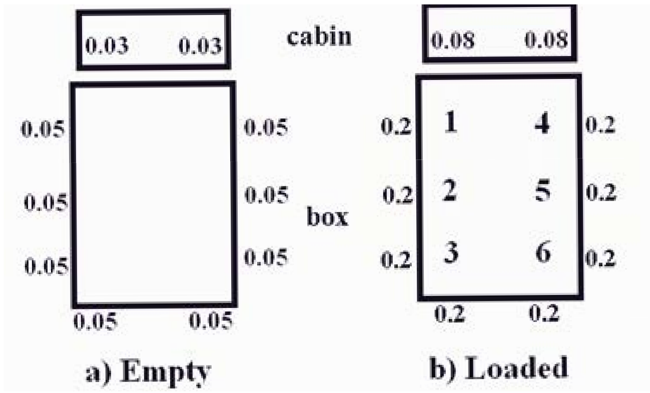

Figure 5 Comparison between the equivalent dose rates (µSv/h) in the cabin of the truck and in contact with sides of its box before and after loading the granitic rocks from Seila area. Big digits represent the six points measured for eU, eTh and K.

Conclusions

All modes of exposures to the terrestrial gamma rays at Seila area result in occupational effective doses which are below the recommended limits. Precisely described exposure configurations can prevent any undesired overestimation of the effective doses received by the workers. It is unlikely that the transport of the granitic rocks from Seila area causes any considerable exposures to the occupants or to the environment.

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