Journal of Radiation Research and Applied Sciences 8 (2015) 17–25

HOSTED BY

ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Journal of Radiation Research and Applied Sciences

journal homepage: http://www.elsevier.com/locate/jrras

The assessment of natural radioactivity and its associated radiological hazards and dose parameters in granite samples from South Sinai, Egypt

D.A.E. Darwish [a], K.T.M. Abul-Nasr [a], A.M. El-Khayatt [b,c,*]

[a] Physics Department, Faculty of Science, Suez Canal University, Ismailia, Egypt

[b] Department of Physics, College of Science, Al Imam Mohammad Ibn Saud Islamic University (IMSIU), Saudi Arabia

[c] Reactor Physics Department, Nuclear Research Center, Atomic Energy Authority, P.O. Box 13759, Cairo, Egypt

ARTICLE INFO

Article history:
Received 3 September 2014
Accepted 22 October 2014
Available online 8 November 2014

Keywords:
Natural radioactivity
HPGe detector
Granite
Radiological hazards
Dose parameters

ABSTRACT

Gamma ray spectra of natural radioactivity from ^{238}U- and ^{232}Th series and from ^{40}K of eight (representing 40 collected samples) granite samples collected from Saint Katherine region, South Sinai, Egypt, had been measured using a gamma-ray spectrometer with an HPGe detector. The results reported in the present article include: Specific activities (A) of ^{226}Ra, ^{232}Th and ^{40}K radionuclides, Radium equivalent activities (Ra_{eq}), external and internal hazard indices (H_{ext}, H_{int}), external and internal level indices (I_γ, I_α), activity utilization index (I), exposure rate (ER) and other important parameters to the subject. The results have been presented in table graphs with the permissible maximum limits.

1. Introduction

Granite is widely used as a building material in the construction of homes. It contains the natural radionuclides ^{238}U, ^{232}Th and their progenies together with ^{40}K. This assures the importance of the assessment of radiation levels and the related radiological hazards to which the population might be exposed. Nearly in all nations, scientists probed since long time ago and are still probing the earth's crust and for a long time in the future to measure the radiation levels and quantify the hazards and doses affecting people, animals, plants and all kinds of life. In the present work, we are taking our share with other scientists in the world to arrive to a decision of building homes free of radiation.

2. Experimental steps

2.1. Sample collection and preparation

Total 40 granite samples were collected from eight locations of an area of ($2 \times 4 = 8$ km^2) south to Saint Katherine Monastery,

* *Corresponding author*. Reactor Physics Department, Nuclear Research Center, Atomic Energy Authority, P.O. Box 13759, Cairo, Egypt. Tel.: +20 966 504942745; fax: +20 966 12586922.

E-mail addresses: ahmed_el_khayatt@yahoo.com, aelkhayatt@gmail.com (A.M. El-Khayatt).

Peer review under responsibility of The Egyptian Society of Radiation Sciences and Applications.

http://dx.doi.org/10.1016/j.jrras.2014.10.003

South Sinai Governorate, Egypt. Five granite samples were taken from each location. The following steps were performed in the preparation: the samples were: mixed, pulverized, sieved to >1 mm grain size, stirred to become homogeneous, dried at 110 °C for 48 h to have dry mass samples. Finally, eight granite samples representing the eight locations are obtained. The 8 samples were weighed and sealed in polyethylene containers for 30 days for the short lived members of ^{222}Rn and ^{220}Rn series to reach a secular equilibrium.

2.2. *Energy and efficiency calibrations*

The calibration of the gamma ray detection system always includes two stages the energy and the efficiency calibrations. The energy calibration converts channel numbers to γ-ray energy in MeV and the efficiency calibration aimed to determine the gamma ray counting efficiencies over the full energy range of measurement.

The energy and efficiency calibrations of the detection system were performed using a set of high quality certified reference sources (IAEA, RG-set) with density similar to the densities of the measured samples. For calibrations, the reference source was placed in the same place as the samples when measuring their γ-ray spectra. For energy calibration, the amplifier gain has been adjusted to measure γ-rays in the energy range of 100 keV up to 2600 keV.

2.3. *Gamma-ray spectra measurements*

A high purity vertical HPGe detector (p-type with a relative efficiency of 25% and peak to Compton ratio of 54:1) was used for measuring the γ-ray spectra of the granite samples. The energy resolution (FWHM) of the detector was 1.9 keV at the 1332 keV γ-ray line of ^{60}Co source. The detector was coupled to a Canberra data acquisition system applying a Genie-2000 analysis software, version 3.0, with many functions including peak area determination, background subtraction together with both γ-ray energy and radionuclide identification. The HPGe detector was shielded with a lead cylinder of 10 cm thickness internally lined with 2 mm thick copper cylinder to absorb lead X-rays. The Sample containers were placed one at a time on the top of the detector (under the shield) for counting during an accumulation time of 80,000 s. All measurements were corrected for background radiation and backscattering.

The activity of ^{40}K has been calculated from its γ-ray line of energy 1460.8 keV. The activities of the decay products ^{214}Pb and ^{214}Bi were taken to represent ^{226}Ra using the γ-ray lines of energies 295.2 keV and 351.9 keV from ^{214}Pb and the 609.3 keV and the 1764.5 keV from ^{214}Bi while the specific activity of ^{232}Th has been calculated using γ-ray lines of energies 338.4 keV and the 911.2 from ^{228}Ac, the 727.3 keV from ^{212}Bi and the 583.2 keV from ^{208}Tl decay products (Debertin & Helmer, 1988).

The γ-ray spectra of the samples were measured twice at two different laboratories; the first one is our Lab at The Physics Department, Faculty of science, Suez Canal University, Ismailia, Egypt and the other lab at the Egyptian Atomic Energy Authority (EAEA), Cairo, Egypt. A good agreement between both measurements was obtained. The detection system specifications that mentioned in this section for our lab.

Table 1 – Annual effective dose equivalent (AEDE) in three types of dwellings (Hewamanna et al., 2001).

Type of dwellings	AEDE (mSv yr^{-1})
Block houses	0.44
Concrete houses	0.47
Stone houses	0.52

Table 2 – Average values of *F* for different organs or tissues (El-Gamal et al., 2007).

Organ or tissue	F
Lungs	0.64
Ovaries	0.58
Bone marrow	0.69
Testes	0.82
Whole body	0.68

3. Calculations of activities, hazard indices and dose parameters

In the calculations carried out in this section, we used the symbols: A_{Ra}, A_{Th} and A_K to represent the activity concentrations of ^{226}Ra for (^{238}U), ^{232}Th and ^{40}K radionuclides respectively.

3.1. *Specific activity or activity concentration (A) in (Bq kg^{-1})*

The activity concentration A_i of any γ-ray line taken to represent this parameter for the ^{226}Ra, ^{232}Th and ^{40}K radionuclides has been calculated using the relation (Amrani & Tahtat, 2001):

$$A_i(\mathrm{Bq\ kg^{-1}}) = \frac{C_i}{\varepsilon(E) \times t \times m}. \tag{1}$$

where C_i is the net peak area after subtraction of background of the γ-ray line at energy *E*, $\varepsilon(E)$ is the detector efficiency of such γ-ray line, *t* is the time of measurement in seconds and *m*

Table 3 – Gamma factors for the investigated radionuclides (Nemeth, 2000; Saito et al., 1998).

Radionuclide (A_i)	Gamma factor (F_i), nSv h^{-1}/Bq kg^{-1}
K-40	0.048
U-238 + daughters	0.490
Ra-226	0.486
Pb-214	0.540
Bi-214	0.432
Th-232 + daughters	0.670
Ac-228	0.319
Tl-208	0.367
Bi-212	0.024
Pb-212	0.024

Table 4 – Specific activity, radium equivalent, hazard, radiation level and activity utilization indices of the granite samples.

Sample number	Specific activity (A), Bq kg^{-1}			(Ra_{eq}), Bq kg^{-1}	The hazard indices			The level indices		Activity utilization index
	^{238}U	^{232}Th	^{40}K		(H_{ext})[a]	(H_{ext})[b]	(H_{int})	I_γ	I_α	I
G1	22.93 ± 2.37	41.26 ± 2.75	1102.4 ± 15.71	165.89	0.45	0.22	0.51	0.7	0.1	1.4
G2	58.54 ± 4.46	75.50 ± 4.73	1248.9 ± 24.47	262.14	0.71	0.35	0.86	1	0.3	1.91
G3	67.99 ± 4.59	121.13 ± 6.02	1194.3 ± 25.33	332.17	0.9	0.44	1.08	1.2	0.3	2.32
G4	66.81 ± 2.03	87.17 ± 2.18	1322.9 ± 11.15	292.52	0.79	0.39	0.97	1.1	0.3	2.1
G5	28.45 ± 3.09	30.70 ± 2.82	1317 ± 25.61	173.31	0.47	0.23	0.54	0.7	0.1	1.49
G6	85.92 ± 0.73	118.11 ± 7.8	1165.7 ± 38.22	343.66	0.93	0.46	1.16	1.3	0.4	2.29
G7	23.30 ± 3.01	26.09 ± 3.06	1202.3 ± 22.47	152.89	0.41	0.20	0.48	0.6	0.1	1.34
G8	17.19 ± 0.68	26.97 ± 2.15	940.6 ± 12.53	128.18	0.35	0.18	0.39	0.5	0.1	1.11
Min	17.19	26.09	940.6	152.8	0.35	0.18	0.39	0.5	0.1	1.11
Max	85.92	121.13	1322.9	343.6	0.93	0.46	1.16	1.3	0.4	2.32
Average	46.39	65.76	1186.45	231	0.62	0.31	0.74	0.9	0.3	1.74
The permissible maximum value	33	45	420	370	1	1	1	0.5	1	2

[a] Calculated by Eq. (3) (without doors and windows).
[b] Calculated by Eq. (4) (with doors and windows).

is the mass of the sample in kg. The world accepted criteria of A for ^{226}Ra, ^{232}Th and ^{40}K are 35, 35 and 370 Bq kg^{-1}, respectively.

3.2. *Radium equivalent activity (Ra_{eq})*

The exposure due to γ-radiation is usually defined in terms of radium equivalent activity Ra_{eq} is given by Eq. (2) (Beretka & Mathew, 1985):

$$Ra_{eq}\,(\mathrm{Bq\,kg^{-1}}) = A_{Ra} + 1.43A_{Th} + 0.077A_K. \tag{2}$$

The above equation is based on the assumption that 370 Bq kg^{-1} of ^{226}Ra, 259 Bq kg^{-1} of ^{232}Th, and 4810 Bq kg^{-1} of ^{40}K produce the same gamma-ray dose rate. The radium equivalent is related to both the external γ-dose and the internal α-dose from radon and its progeny. The permissible maximum value of the radium equivalent activity is 370 Bq kg^{-1}, which corresponds to an effective dose of 1 mSv yr^{-1} for to the inhabitants of dwellings (UNSCEAR, 2000).

3.3. *External hazard index (H_{ext})*

Some authors proposed a model for a room in the house where the inhabitants live with infinitely thick walls without windows and doors and calculated H_{ext} using the following relation (Model I) (UNSCEAR, 2000):

$$H_{ext} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \le 1. \tag{3}$$

Other authors modified such model to a room with windows and doors and calculated H_{ext} using the following equation (Model II) (Oktay, Şule, & Mahmut, 2011):

$$H_{ext} = \frac{A_{Ra}}{740} + \frac{A_{Th}}{518} + \frac{A_K}{9620} \le 1. \tag{4}$$

where the three factors of Eq. (4) are decreased to half their values in Eq. (3).

In model II the presence of doors and windows will cause some kind of ventilation in the room which will decrease the exposure of inhabitants to radiation and decrease all kinds of doses (ICRP 106, 2008).

The value of this index must be less than unity in order to keep the radiation hazard insignificant. The prime objective of this index is to limit the radiation dose to the accepted dose limit of 1 mSv yr^{-1} (Hewamanna, Sumithrarachchi, Mahawatte, & Nanayakkara, 2001).

3.4. *Internal hazard index (H_{int})*

Inhalation of alpha particles emitted from the short-lived radionuclides (radon ^{222}Rn, the daughter product of ^{226}Ra) and thoron (^{220}Rn, the daughter product of ^{224}Ra) is also hazardous to the respiratory organs. This hazard can be controlled by the internal hazard index (H_{int}), which is given by the following Eq. (Righi & Bruzzi, 2006):

$$H_{int} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \le 1. \tag{5}$$

For the safe use of a certain building material in the construction of dwellings, the index (H_{int}) should be less than unity.

3.5. *External (γ-radioactivity) level index I_γ*

This index is also known as the representative level index and was calculated from the following relation (El-Gamal, Nasr, & El-Taher, 2007; NEA-OECD, 1979):

$$I_\gamma = \frac{A_{Ra}}{300} + \frac{A_{Th}}{200} + \frac{A_K}{3000} \le 1. \tag{6}$$

The OECD group of experts suggested some criteria for a definition of different levels of to be (representative, first enhanced, second enhanced) (NEA-OECD, 1979). $I_\gamma = 1$ as an upper limit, $I_\gamma \le 1$ corresponds to 0.3 mSv y^{-1}, $I_\gamma \le 3$

corresponds to 1 mSv yr^{-1}. Concerning different building materials, the ranges of I_γ are:

- Materials used in bulk amounts like bricks: $I_\gamma \le 0.5$ to $I_\gamma \le 1$
- Superficial and other materials: $I_\gamma \le 0.2$ to $I_\gamma \le 6$

3.6. *Internal (α-radioactivity) level index I_α*

The excess alpha radiation due to radon inhalation originating from building materials is estimated using the relation below (El-Galy, El Mezayn, Said, El Mowafy, & Mohamed, 2008):

$$I_\alpha = \frac{A_{Ra}}{200} \le 1. \tag{7}$$

I_α should be lower than the maximum permissible value of $I_\alpha = 1$, which corresponds to 200 Bq kg^{-1}. For alpha radiation and taking into consideration that a building material with Ra concentration lower than 200 Bq kg^{-1} could not cause indoor radon concentration higher than 200 Bq m^{-3}.

3.7. *Activity utilization index (I)*

In massive houses made of different building materials such as stone, bricks, concrete or granite, the factor that mainly affects the indoor absorbed dose is the activity concentrations of natural radionuclides in those materials, while radiation emitted by sources outdoors is efficiently absorbed by the walls. Consequently, dose rates in air indoors will be elevated according to the concentrations of naturally occurring radionuclides present in construction materials. This index has been calculated using the following relation (Orgun et al., 2007):

$$I = \frac{A_U}{50} f_U + \frac{A_{Th}}{50} f_{Th} + \frac{A_k}{500} f_K \le 2. \tag{8}$$

where f_U, f_{Th} and f_K are fractional percentages to the total dose rate from ^{238}U, ^{232}Th and ^{40}K, respectively. $f_U = 8.09\%$, $f_{Th} = 47.98\%$, and $f_K = 43.92\%$.

3.8. *Exposure rate (ER)*

The exposure rate was calculated using the following relation (Akhtar, Tufail, Ashraf, Mohsin, & Iqbal, 2005):

$$ER\ (\mu R\ h^{-1}) = 1.90 A_{Ra} + 2.82 A_{Th} + 0179 A_K \tag{9}$$

3.9. *Dose rate (DR) and its relation with (ER)*

The dose rate was calculated using the following two relations (O'Brien & Sanna, 1976):

$$\begin{aligned} DR\ (mrem\ yr^{-1}) &= 8.33 ER(\mu R\ h^{-1}) \\ DR\ (mSv\ yr^{-1}) &= 0.0833 ER(\mu R\ h^{-1}) \end{aligned} \tag{10}$$

3.10. *Annual dose equivalent (ADE) at 1 m from a radioactive source*

This dose parameter has been calculated applying the following relation (Nemeth, 2000; Saito, Petoussi-Henss, & Zankl, 1998):

$$ADE\ (nSv) = \sum_{i=0}^{k} F_i A_i t k. \tag{11}$$

where: F_i is the γ-conversion factor in nSv h^{-1}/Bq kg^{-1}, A_i is the specific activities of the detected radiations in Bq kg^{-1}, $t = 8$ h (the working hours per day) and k is the working days per year ($k = 1, 2, \ldots, 365$) (Table 1).

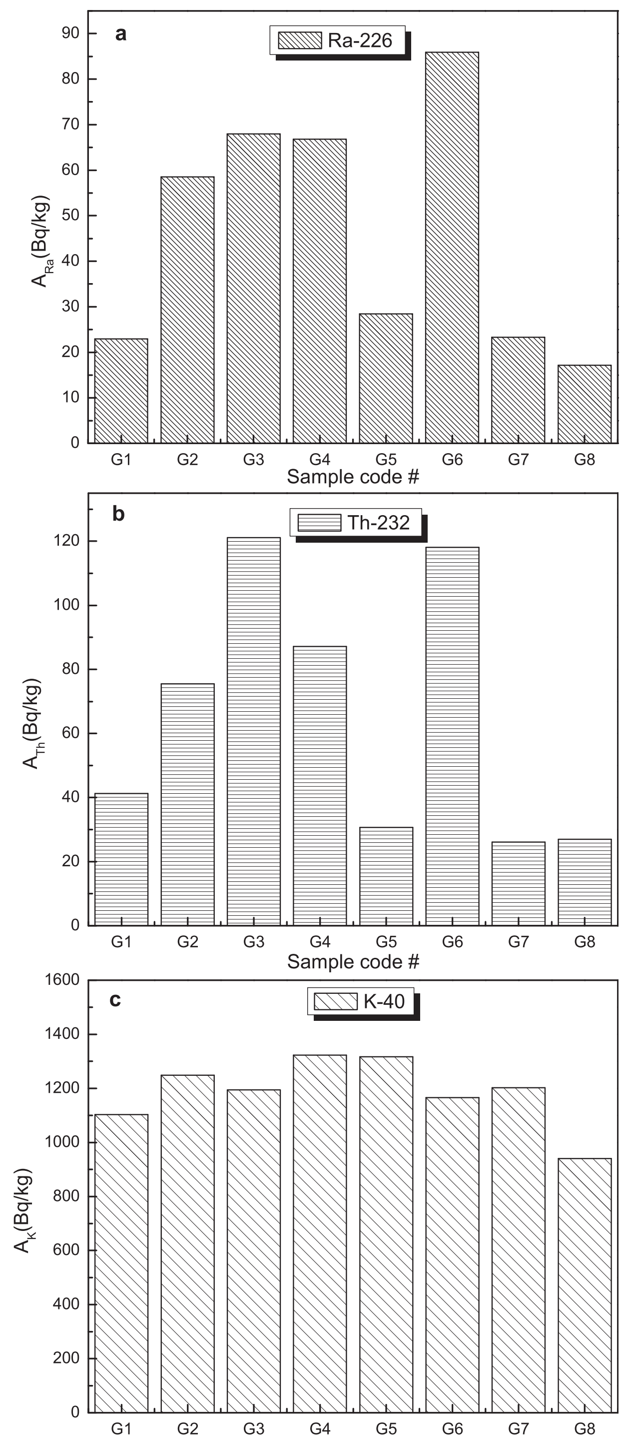

Fig. 1 – Histograms for the measured specific activities of ^{226}Ra (a), ^{232}Th (b), and ^{40}K (c).

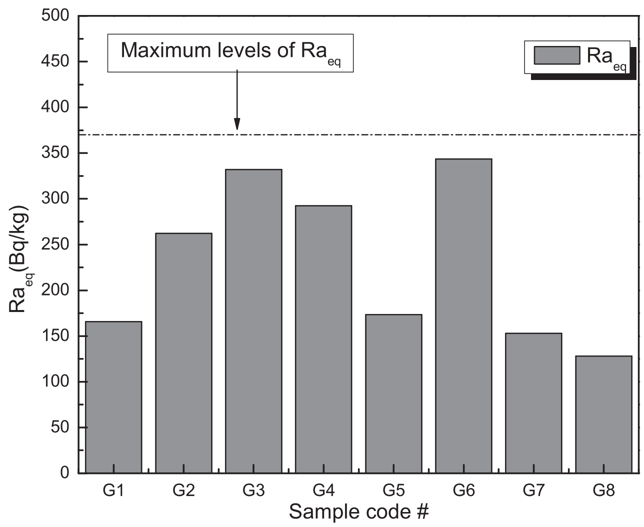

Fig. 2 – The measured values of Ra_{eq} in Bq kg^{-1}.

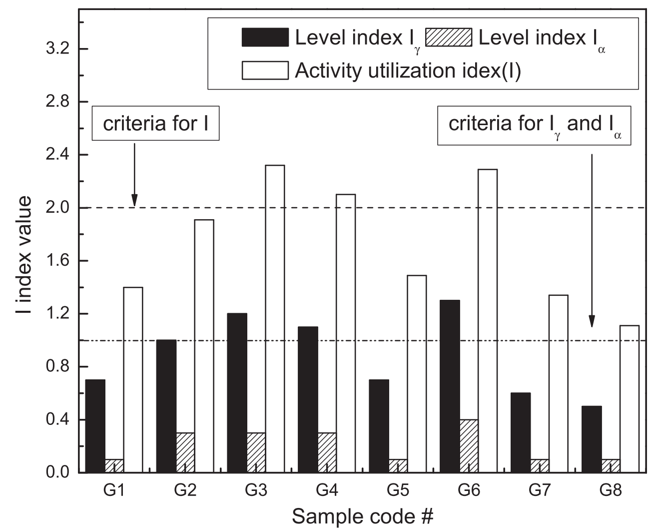

Fig. 4 – External (γ-radioactivity) and internal (α-radioactivity) level indices and activity utilization index.

3.11. *Air absorbed gamma dose rate (D_{air})*

The absorbed gamma dose rate in air 1 m above the ground surface for the uniform distribution of radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) was computed on the basis of provided guide lines (Hewamanna et al., 2001; Oktay et al., 2011). The conversion factors used to compute absorbed gamma dose rate in air (D_{air}) per unit activity concentration in (1 Bq kg^{-1}) are 0.462 for ^{226}Ra, 0.621 for ^{232}Th, and 0.0417 for ^{40}K. Such dose parameter was calculated applying the following relation (Arafa, 2004):

$$D_{air}\left(\mathrm{nGy\ h^{-1}}\right) = 0.462A_{Ra} + 0.621A_{Th} + 0.0417A_{K}. \tag{12}$$

The population-weighted values give an absorbed dose rate in air outdoor from terrestrial gamma radiation a value of 57 nGy h^{-1}.

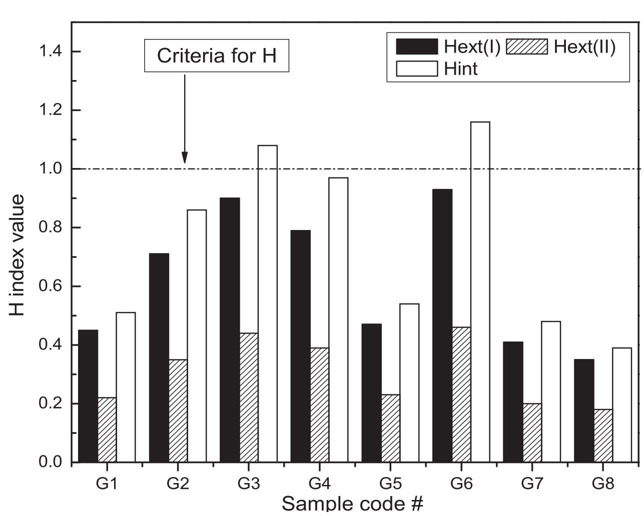

Fig. 3 – External (γ-radioactivity) and internal (α-radioactivity) hazard indices.

3.12. *Annual effective dose equivalent (AEDE)*

To estimate the AEDE the conversion factor (0.7 Sv Gy^{-1}) from absorbed dose rate in air in nGy h^{-1} to effective dose rate in mSv yr^{-1} is used with outdoor occupancy factor of 0.2 and indoor occupancy factor of 0.8. The AEDE was calculated using the following formulae (UNSCEAR, 2000):

$$\mathrm{AEDE(Indoor)}\left(\mathrm{mSv\ yr^{-1}}\right) = D_{air}\left(\mathrm{nGy\ h^{-1}}\right) \times 8766\ \mathrm{h} \times 0.8 \times 0.7\ \mathrm{Sv\ Gy^{-1}} \times 10^{-6} \tag{13}$$

$$\mathrm{AEDE(outdoor)}\left(\mathrm{mSv\ yr^{-1}}\right) = D_{air}\left(\mathrm{nGy\ h^{-1}}\right) \times 8766\ \mathrm{h} \times 0.2 \times 0.7\ \mathrm{Sv\ Gy^{-1}} \times 10^{-6} \tag{14}$$

These indices measure the risk of stochastic and deterministic effects in the irradiated individuals. The recommended value of the annual effective dose equivalent is 0.48 mSv yr^{-1} and the criterion of the total annual effective dose equivalent (indoors + outdoors) should be less than 1 mSv yr^{-1} (UNSCEAR, 2000) (Table 2).

3.13. *Effective dose rate (D_{organ}) to different body organs and tissues*

The effective dose rate delivered to a particular organ can be calculated using the following relation (O'Brien & Sanna, 1976):

$$D_{organ}\left(\mathrm{mSv\ yr^{-1}}\right) = \mathrm{AEDE} \times f \tag{15}$$

where f is the conversion factor of organ dose from air dose. The energies of interest in the present work, is 0.2–3 MeV f is almost independent of energy. The average values of f for various organs and tissues are given in Table 3. Using these f values, D_{organ} was calculated by applying Eq. (15) (El-Gamal et al., 2007).

Table 5 – The Calculated values of different exposure and dose parameters of the studied samples.

Exp. or Dose parameter	Sample numbers								
	G1	G2	G3	G4	G5	G6	G7	G8	Criteria
(a) Exposure									
ER ($\mu R\ h^{-1}$)	357	547	684	609	376	704	333	227	600
(b) Dose ($mSv\ yr^{-1}$)									
DR	29	45	57	50	31	58	27	23	50
D_{air}[a]	82	98	156	140	87	161	77	64	57
AEDE indoor	0.40	0.49	0.77	0.69	0.43	0.79	0.38	0.31	0.48
AEDE outdoor	0.10	0.12	0.19	0.17	0.11	0.20	0.09	0.08	0.48
(c) D_{organ} ($mSv\ yr^{-1}$)									
Lungs indoor	0.26	0.39	0.49	0.44	0.27	0.51	0.24	0.19	0.64
Lungs outdoor	0.06	0.09	0.12	0.11	0.06	0.127	0.06	0.05	0.64
Ovaries indoor	0.23	0.36	0.45	0.40	0.25	0.46	0.22	0.18	0.58
Ovaries outdoor	0.06	0.09	0.11	0.1	0.06	0.11	0.05	0.05	0.58
Bone marrow indoor	0.28	0.43	0.53	0.47	0.29	0.55	0.26	0.21	0.69
Bone marrow outdoor	0.07	0.11	0.13	0.12	0.07	0.13	0.06	0.05	0.69
Testes indoor	0.33	0.51	0.63	0.56	0.35	0.65	0.31	0.25	0.82
Testes outdoor	0.08	0.13	0.16	0.14	0.09	0.16	0.08	0.07	0.82
Whole body indoor	0.27	0.42	0.52	0.47	0.29	0.54	0.26	0.21	0.68
Whole body outdoor	0.07	0.11	0.13	0.12	0.07	0.13	0.06	0.05	0.68
AGDE	0.58	0.88	1	0.98	0.62	1.11	0.55	0.11	1
ELCR	0.52	1.40	0.43	0.66	0.69	0.43	0.60	0.28	0.29

[a] ($nGy\ h^{-1}$).

3.14. *The annual gonadal dose equivalent (AGDE) for a resident of a house*

The gonads, the active bone marrow and the bone surface cells are considered to be the organs of importance. The annual gonadal dose equivalent (AGDE) due to the specific activities of ^{226}Ra, ^{232}Th and ^{40}K was calculated using the following relation (Arafa, 2004).

$$\mathrm{AGDE}(\mu Sv\ yr^{-1}) = 3.09A_{Ra} + 418A_{Th} + 0.031A_K. \quad (16)$$

The world averages of AGDE of a house containing activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K are 35, 35 and 370 $mSv\ yr^{-1}$, respectively. The standard UNSCEAR value for AGED is 300 $mSv\ yr^{-1}$.

3.15. *Excess lifetime cancer risk (ELCR) in $mSv\ yr^{-1}$*

This gives the probability of developing cancer over a lifetime at a given exposure level. The ELCR has been calculated using the following equation (Arafa, 2004):

$$\mathrm{ELCR}\ (mSv\ yr^{-1}) = \mathrm{AEDE} \times \mathrm{DL} \times \mathrm{RF}. \quad (17)$$

where DL is the duration of life (70 years average) and RF is the risk factor (Sv) i.e. fatal cancer risk per Sievert. For stochastic effects, the ICRP 106 used a value of RF = 0.05 for the public.

3.16. *Clark value $^{232}Th/^{238}U$ concentration ratio*

This ratio will give an indication that the samples collected from a certain region have either higher or lower uranium concentration to be economic for uranium mining and extraction (UNSCEAR, 2000). The Clark value values of our samples are listed in Table 6.

3.17. *Isotopic activity ratios*

Among the same series the isotopic activity ratios between a parent and a daughter or a daughter and another daughter gives the indication if there is an equilibrium or not in that series. The equilibrium is achieved if $^{226}Ra/^{214}Pb = 1$ and $^{214}Pb/^{214}Bi = 1$ for ^{238}U series and $^{212}Pb/^{212}Bi = 1$ for ^{232}Th series (Carvalho, Anjos, Veiga, & Macario, 2011). The presence of secular equilibrium for all measured samples are tested by calculating the isotopic activity ratio as mentioned in Table 6.

4. Results and discussion

The measured specific activities, radium equivalent activities together with hazard indices, radiation level indices and activity utilization indices of the granite samples are presented in Table 4 together with the permissible maximum value or criteria for easy comparison.

It is clear from Table 4 that the specific activities of ^{226}Ra varied from 17.2 $Bq\ kg^{-1}$ to 85.9 $Bq\ kg^{-1}$ with an average 46.4 $Bq\ kg^{-1}$. The samples G1, G5, G7 and G8 have values below the criteria 35 $Bq\ kg^{-1}$. For ^{232}Th, although the samples G5, G7 and G8 have values below the permissible maximum value 35 $Bq\ kg^{-1}$, the average of specific activities is 65.8, which is nearly twice the permissible maximum value. In case of ^{40}K, the specific activities of are ranged from 940.6 to 1323 $Bq\ kg^{-1}$

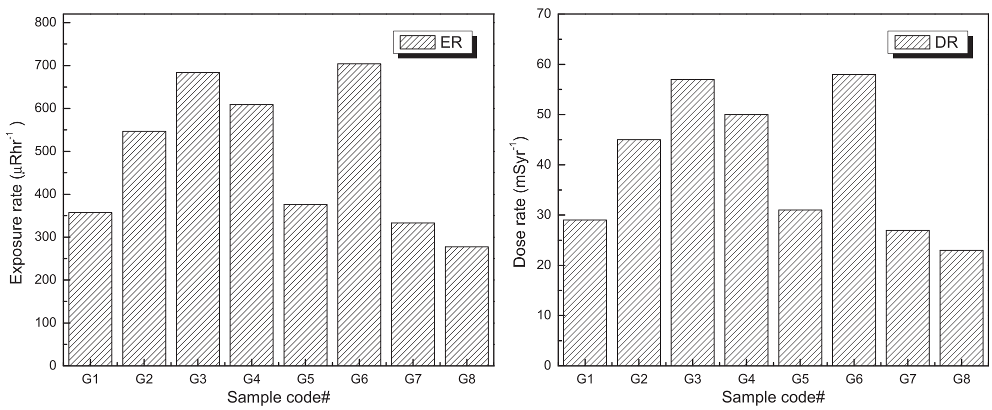

Fig. 5 – Exposure and dose rates in (μR h^{-1}) and (mSv yr^{-1}), respectively.

with an average of 1186.4, which is 3 times higher than the set limit 370 Bq kg^{-1}. The specific activates of ^{40}K are about 11 times higher than ^{232}Th and 15 times higher than ^{238}U. This shows that the largest contribution to the total activity comes from ^{40}K in the study region.

In addition, the obtained results showed that the Ra_{eq} of all samples have values less than the permissible maximum value 370 Bq kg^{-1}. As well as the hazard, level and activity utilization indices have values, which are less than the permissible maximum value too.

The results in Table 4 are graphed on the histograms shown in Figs. 1–4. Fig. 1 shows the measured specific activities of ^{226}Ra, ^{232}Th and ^{40}K. From the first look to (a) and (b) of Fig. 1 it can be observed that samples G1, G5, G7 and G8 have values less than the set limits while other samples show high values in (a), (b) and (c). Fig. 2 represent the R_{eq} of the studied samples and it is clear that all samples have values lower than the permissible maximum limit.

All samples have hazard indices less than the set limit of >1 with the internal Hazard indices H_{int} slightly higher than the set limit as shown in Fig. 3. H_{int} is the cause of harmful effects to the lungs due to the internal contact of α-particles of a higher ionization power to the sensitive tissues of the lungs and other parts of the respiratory system. Fig. 4 showed that the activity utilization index of all samples are less than the set limit except that of G3, G4 and G6.

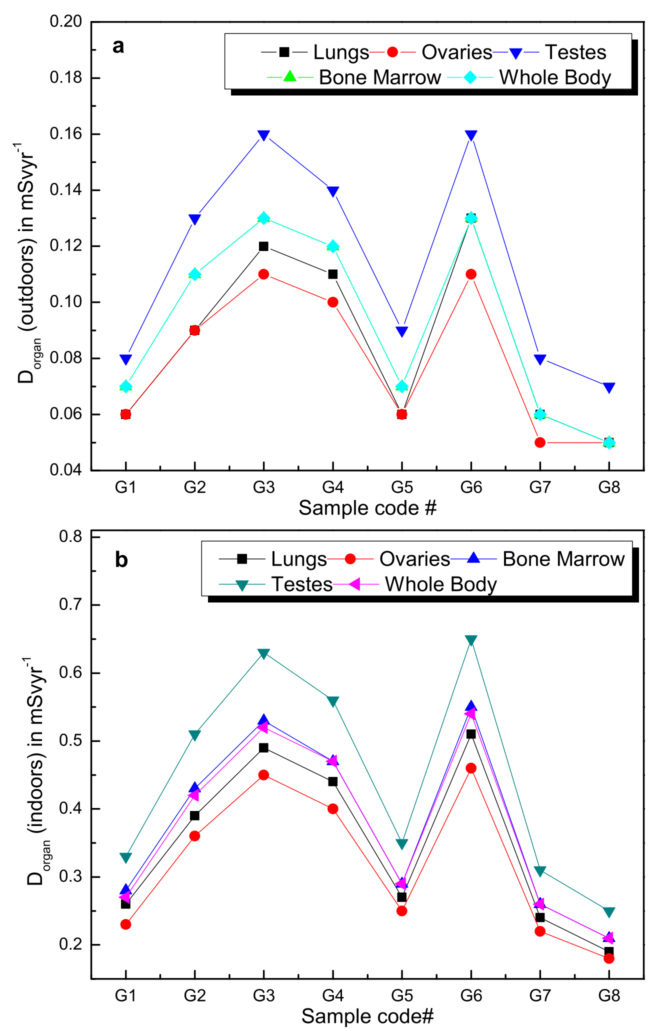

Fig. 7 – Effective dose rate (D_{organ}) to different body organs and tissues for both (a) outdoors (20% of time) and (b) indoors (80% of time).

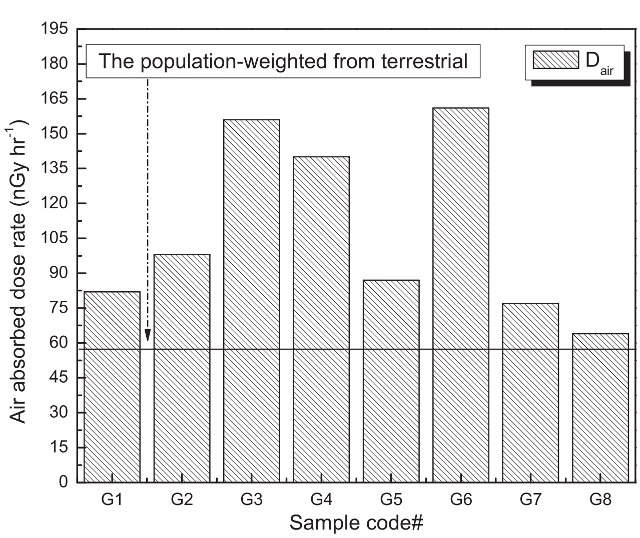

Fig. 6 – Air absorbed dose rate in (nGy h^{-1}).

Table 6 – Clark values, isotopic activity ratios and ppm contents.

The parameter		G1	G2	G3	G4	G5	G6	G7	G8
The Clark value		5.53	3.97	5.48	4.01	3.32	4.23	3.44	4.82
Isotopic activity ratios	$\frac{^{226}Ra}{^{214}Pb}=1$	0.98	0.99	0.98	0.98	0.99	0.99	0.98	0.98
	$\frac{^{214}Pb}{^{214}Bi}=1$	0.98	0.99	0.99	0.98	0.98	0.99	0.99	0.99
	$\frac{^{212}Bi}{^{212}Pb}=1$	0.98	0.99	0.99	0.98	0.99	0.98	0.98	0.99
The content in (ppm) of ^{238}U		1.84	4.70	5.46	5.37	2.29	6.90	1.87	3.72
The content in (ppm) of ^{232}Th		10.19	18.65	29.92	21.53	7.58	29.17	6.44	6.66
The content in (ppm) of ^{40}K		4.26	4.82	4.61	5.11	5.09	4.50	4.64	4.58

On the other hand, different calculated exposure and dose parameters are listed in Table 5 and some of them are graphed in histograms of Figs. 5–7. In all cases the AEDE indoors have higher values than outdoors as listed in Table 5. Except for G6 AGDE and ELCR for all samples show less or equal doses than set limit.

Concerning exposure rate, Fig. 5(a), we observed that while G3 and G6 have higher values than the maximum limit and G4 has a comparable value, the rest samples have values less than the criterion of 600 $\mu R\ h^{-1}$ of ER. As well as Fig. 5(b) shows that G3 and G4 samples have values for dose rate, DR, higher than the maximum permissible limits (50 mSv yr^{-1}).

For all samples, the calculated absorbed gamma dose rate in air 1 m above the ground surface, D_{air}, register higher values than the permissible maximum limit and G3 and G6 being have the highest values as shown in Fig. 6.

Fig 7 showed that the D_{org} values are less than the set limit but always indoors is higher than outdoors as expected. Also we can conclude that, the testes and ovaries have highest and lowest radiation sensitivity, respectively.

The Clark values of the granite samples together with isotopic activity ratios and radionuclide ppm contents are reported in Table 6. The Clark values indicate that ^{232}Th concentration is about 4.35 times higher than ^{238}U which means that this region is not economic for Uranium mining and extraction. Also ^{40}K has ppm contents lower than ^{232}Th and comparable with ^{238}U. The isotopic activity ratios have value of 0.99 for all samples indicating clearly that radioactive equilibrium has been fulfilled among the members of both ^{238}U and ^{232}Th series.

5. Conclusion

From the experimental and computational work on natural radioactivity of Egyptian granite samples, we can conclude the following;

1. The region from where we collected the granite samples in Saint Katherine area, South Sinai Governorate, Egypt contain ^{238}U, ^{232}Th and ^{40}K radionuclides with concentrations higher, comparable and lower than the set limits.
2. The radium equivalent activity is less than the world limit.
3. In general, the hazard indices, the level indices and the activity utilization indices are less than the world set criteria.
4. The Clark value is equal to about five which means that the region from where we took the granite samples is not economic for Uranium mining and extraction.

Acknowledgements

The authors would like to thank prof. Dr. I. S. Hassen for his help in providing granite samples and Dr. I. H. Khalifa for his help in grinding machine Geology Department, Faculty of Science, Suez Canal University Ismailia, Egypt.

We are happy also to the members of Nuclear Physics Department, NRC, Egyptian Atomic Energy Authority (EAEA), for their help during the γ-ray spectra measurements.

REFERENCES

Akhtar, N., Tufail, M., Ashraf, M., Mohsin, A., & Iqbal, M. (2005). Measurement of environmental radioactivity for estimation of radiation exposure from saline soil of Lahore, Pakistan. *Radiation Measurements, 39*(1), 11–14.

Amrani, D., & Tahtat, M. (2001). Natural radioactivity in Algerian building materials. *Applied Radiation and Isotopes, 54*, 687–689.

Arafa, W. (2004). Specific activity and hazards of granite samples collected from the Eastern Desert of Egypt. *Journal of Environmental Radioactivity, 75*, 315–327.

Beretka, J., & Mathew, P. J. (1985). Natural radioactivity of Australian building materials, industrial wastes and by-products. *Health and Physics, 48*, 87–95.

Carvalho, C., Anjos, R. M., Veiga, R., & Macario, K. (2011). Application of radiometric analysis in the study of provenance and transport processes of Brazilian coastal sediments. *Journal of Environmental Radioactivity, 102*, 185–192.

Debertin, K., & Helmer, R. G. (1988). *Spectrometry with semiconductor detectors*. North-Holland, Amsterdam.

El-Galy, M. M., El Mezayn, A. M., Said, A. F., El Mowafy, A. A., & Mohamed, M. S. (2008). Distribution and environmental impacts of some radionuclides in sedimentary rocks at Wadi Naseib area, southwest Sinai, Egypt. *Journal of Environmental Radioactivity, 99*, 1075–1082.

El-Gamal, A., Nasr, S., & El-Taher, A. (2007). Study of the spatial distribution of natural radioactivity in the upper Egypt Nile River sediments. *Radiation Measurements, 42*, 457–465.

Hewamanna, R., Sumithrarachchi, C. S., Mahawatte, P., & Nanayakkara, H. L. C. (2001). Natural radioactivity and gamma dose from Sri Lankan clay bricks used in building construction. *Applied Radiation and Isotopes, 54*(2), 365–369.

ICRP. (2008). Radiation dose to patients from radiopharmaceuticals – addendum 3 to ICRP Publication 53. ICRP Publication 106 *Annals of the ICRP, 38*, 1–2.

NEA-OECD, Nuclear Energy Agency. (1979). *Exposure to radiation from natural radioactivity n building materials*. Paris: OECD. Report by NEA group of experts.

Nemeth, C. (2000). Japan International Radiation protection.

O'Brien, K., & Sanna, R. (1976). The distribution of absorbed dose-rates in humans from exposure to environmental gamma rays. *Health and Physics, 30*(1), 71–78.

Oktay, B., Şule, K., & Mahmut, D. (2011). Assessments of natural radioactivity and radiological hazards in construction materials used in Elazig, Turkey. *Radiation Measurements, 46*, 153–158.

Orgun, Y., Altinsoy, N., Sahin, S. Y., Gungor, Y., Gultekin, A. H., Karaham, G., et al. (2007). Natural and anthropogenic radionuclide in rocks and beach sands from Ezine region, Western Anatolia, Turkey. *Applied Radiation and Isotopes, 65*, 739–747.

Righi, S., & Bruzzi, L. (2006). Natural radioactivity and radon exhalation in building materials used in Italian dwellings. *Journal of Environmental Radioactivity, 88*, 158–170.

Saito, K., Petoussi-Henss, N., & Zankl, M. (1998). Calculation of the effective dose and its variation from environmental gamma ray sources. *Health and Physics, 74*(6), 698–706.

UNSCEAR. (2000). *Effects of atomic radiation to the general assembly*. New York: United Nations Scientific Committee on the Effect of Atomic Radiation, United Nations.