Assessment of terrestrial gamma radiation doses for some Egyptian granite samples

A. M. El Arabi, N. K. Ahmed, K. Salahel Din


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Abstract

External exposures of population to ionising radiation due to naturally occurring radionuclides in sixty-three granite samples from three different locations in south eastern desert of Egypt were considered in this article. Average outdoor gamma dose rates in air were 190, 290 and 330 nGy h\(^{-1}\) for Elba, Qash Amir and Hamra Dome granites, respectively. The corresponding doses in indoor air are 270, 400 and 470 nGy h\(^{-1}\), respectively. These average values give rise to annual effective dose (outdoor, indoor and in total) 0.24, 1.4 and 1.6 mSv for Elba granite. For Qash Amir and Hamra Dome granites the corresponding values were 0.35, 2 and 2.3 mSv and 0.41, 2.3 and 2.7 mSv, respectively.

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INTRODUCTION
It has been established that human exposure to radioactivity comes mainly from natural sources. The natural radiation to which the general public is exposed consists of two components, namely, internal exposure and external exposure. Internal exposure is due to the inhalation of radon gas in the air and the intake of traces of radionuclides in food and drinking water. External exposure arises from terrestrial gamma rays and cosmic radiation incident on the earth's surface. In fact, only about 15% of the total effective dose is derived from cosmic radiation and about 0.6% is attributable to cosmogenic radionuclides. The members of the radioactive decay chains of $^{232}$Th (14%), $^{235}$U and $^{238}$U (55.8%), along with $^{40}$K (13.8%) are responsible for the main contributions to the dose from natural radiation, while a more than 0.3% is due to the effect of $^{87}$Rb$^1$.

Many natural rocks contain radioactive elements such as $^{238}$U, $^{226}$Ra, $^{232}$Th and $^{40}$K. Although these radionuclides are widely distributed, their concentrations depend on geological and geographical conditions and as such they vary from place to place$^2$. The concentration of natural radionuclides in the rock varies considerably, depending on the rock formation and lithologic character$^3$. Higher radiation levels are associated with igneous rocks, such as granite, and lower levels with sedimentary rocks. There are exceptions, however, as some shales and phosphate rocks have relatively high content of radionuclides$^4$.

Granites are mainly consisting of coarse grains of quartz, potassium feldspar and sodium feldspar, other common minerals such as mica and hornblende. Typical granites are chemically composed of 75% silica, 12% aluminum, less than 5% potassium oxide, less than 5% soda, as well as by lime, iron, magnesia, and titania in smaller quantities$^5$. In terms of natural radioactivity, granites exhibit an enhanced elemental concentration of uranium (U) and thorium (Th) compared with the very low abundance of these elements observed in the mantle and the crust of the Earth. Geologists provide an explanation of this behaviour in the course of partial melting and fractional crystallisation of magma, which enables U and Th to be concentrated in the liquid phase and become incorporated into the more silica-rich products. For this reason, igneous rocks of granitic composition are strongly enriched in U and Th (on an average 5 ppm of U and 15 ppm of Th), compared with rocks of basaltic or ultramafic composition (<1 ppm of U)$^6$.

Since granite was widely used as building material and because radiation exposure of the population can be increased appreciably by the use of building materials containing above-normal levels of natural radioactivity, it is, therefore, important to
measure the concentration of radionuclides in rocks used as building materials for assessing the radiological risks to human health\(^8\).

The objective of the present study is to determine the external doses due to \(^{226}\)Ra, \(^{232}\)Th and \(^{40}\)K for granites under investigation and compared the data with international recommended values.

**EXPERIMENTAL METHOD**

Sixty-three granite rocks from Gabel Elba, Gabel Qash Amir and Gabel Hamra Dome in Elba protective area, south eastern desert of Egypt, have been collected randomly and measured by gamma-ray spectroscopic analysis. The granite rocks were crushed and pulverised, dried in an oven at 105°C and sieved through a 200 mesh, which is the optimum size enriched in heavy mineral. The prepared samples were transferred to radon-impermeable plastic containers of almost uniform size (5.5 cm diameter × 7.5 cm height), weighed and sealed for four weeks before measurement to reach secular equilibrium between \(^{226}\)Ra and \(^{232}\)Th and their decay products (assumption that \(^{232}\)Th and \(^{228}\)Th are in equilibrium). The spectrometer consists of 3 × 3 inch NaI(Tl), S-1212-I model, with a 1024 microcomputer multichannel analyser, 5510 ORTEC Norland. The detector has a peak gamma-ray efficiency of 1.2 × 10\(^{-5}\) at 1332 keV, and energy resolution of 7.5% at 662 keV\(^9\).

The activity of \(^{226}\)Ra was measured by 351.92 keV (35.1%) photopeak emitted from \(^{214}\)Pb and 609.32 keV (44.6%) photopeak in turn from \(^{214}\)Bi. The activity of \(^{232}\)Th was extracted by 911.16 keV (26.6%) and 2614 keV (35.8%) gamma rays emitted from \(^{228}\)Ac and \(^{208}\)Tl, respectively. \(^{40}\)K was determined by measuring its single peak at 1460.8 keV (10.67%).

The activity concentrations of \(^{226}\)Ra, \(^{232}\)Th and \(^{40}\)K were calculated using the following relation\(^{10}\).

\[
A = \frac{\text{NCPS}}{\text{EP} \times \epsilon(E) \times M}
\]

where \(A\) activity of radionuclide (Bq kg\(^{-1}\)), NCPS net counts per seconds in the energy window of interest; EP emission probability of the gamma line; \(\epsilon(E)\) absolute peak efficiency at gamma energy \(E\) and mass \(M\) of the sample (kg).
CALCULATION OF EXTERNAL EXPOSURE DUE TO NATURALLY OCCURRING RADIONUCLIDES IN GRANITES UNDER INVESTIGATIONS

The quantities commonly used for estimating the external exposure to population from terrestrial radionuclides are external absorbed dose rate in air and the annual effective dose rate. If the natural gamma sources are uniformly distributed in the ground, dose rate at 1 m above the ground surface are calculated using the method introduced and revised by many authors\textsuperscript{(11–13)}. From the activity concentrations of $^{226}\text{Ra}$, $^{232}\text{Th}$ and $^{40}\text{K}$ and using the relevant conversion factor, one can calculate the external absorbed dose rate in outdoor and indoor air and annual effective doses.

**External absorbed dose rate in outdoor air**

The external absorbed dose rates $D$, in outdoor air at 1 m above the ground level, to the population can be calculated from activities of terrestrial radionuclides according to the following formula\textsuperscript{(14)}:

$$D = A_{Ei} \times C_F$$

where $A_{Ei}$ is the activity concentration (Bq kg\textsuperscript{-1}), and $C_F$ is the dose conversion factor (absorbed dose rate in air per unit activity per unit mass, is in units of nGy h\textsuperscript{-1} per Bq kg\textsuperscript{-1}). Dose conversion factors have been extensively calculated during the last 40 years by many researchers. In the present work, the considered dose rate conversion factors for $^{226}\text{Ra}$, $^{232}\text{Th}$ and $^{40}\text{K}$ are those determined by Quindos \textit{et al.}\textsuperscript{(13)}, where $C_{\text{Ra}} = 0.4551$, $C_{\text{Th}} = 0.5835$ and $C_{\text{K}} = 0.0429$.

**External absorbed dose rate in indoor air**

Since granite is extensively used as construction material of dwelling, it is important to estimate its contribution to indoor exposure. Considering the indoor contribution is 1.4 times higher than outdoor dose\textsuperscript{(4)}, the indoor dose rate was calculated as well:

$$D_{\text{indoor}} = D_{\text{outdoor}} \times 1.4$$

**Annual effective dose**
In estimating the effective dose in any environment, the two factors of importance are the conversion factor from $\text{Gy h}^{-1}$ to $\text{Sv h}^{-1}$ and the occupancy factor. The former gives the equivalent human dose in $\text{Sv y}^{-1}$ from the absorbed dose rate in air ($\text{Gy h}^{-1}$), while the latter gives the fraction of the time that an individual is exposed to the outdoor radiation. In the recent\textsuperscript{[15,4]} reports, a value of 0.7 was used for the conversion factor from absorbed dose in air to effective dose received by adults, and 0.8 for the indoor occupancy factor, implying that 20% of time is spent outdoor, on an average, around the world. Therefore, the annual effective doses outdoors and indoors received by adults can be estimated as follows:

$$\text{Outdoors: } D_{\text{out}} \times \text{Gy h}^{-1} \times 8760 \text{h}$$
$$\quad \times 0.7 \text{Sv Gy}^{-1} \times 0.2$$

$$\text{Indoors: } D_{\text{in}} \times \text{Gy h}^{-1} \times 8760 \text{h}$$
$$\quad \times 0.7 \text{Sv Gy}^{-1} \times 0.8$$

RESULTS AND DISCUSSION

Table 1 is a summary result of activity concentrations of $^{226}\text{Ra}$, $^{232}\text{Th}$ and $^{40}\text{K}$ beside outdoor and indoor dose rates for granites under study. From the table it can be seen that: The notably high obtained activity levels and in turn resulting doses for the studied granites may be related to the natural geological formation of these granites such as:

- According to the world average values of outdoor and indoor dose rates are 59 and 84 $\text{nGy h}^{-1}$, respectively, mentioned in UNSCEAR report\textsuperscript{[4]}. The average outdoor and indoor dose rates values for Elba granites are three times higher than the world average. Whereas the corresponding values for Qash Amir and Hamra Dome granites are five and six times higher than the world average, respectively.

- The average outdoor dose rate for Elba granites is six times higher than Egypt reference value, 32 $\text{nGy h}^{-1}\text{(4)}$, whereas the corresponding values for Qash Amir and Hamra Dome granites are nine and ten times higher than Egypt reference value. The difference between the obtained values and prior Egypt range, 8–93 $\text{nGy h}^{-1}\text{(4)}$, is that the prior work did not include samples from the area under study.
• In case of Gabel Elba, the high activity may be related to the presence of accessory minerals such as zircon, uranium-bearing mineral davidite (Fe, La, U, Ca)6 (Ti, Fe)15 (O,OH)36 and rare earth mineral cerianite (Ce, Th) O2\(^{16}\).

• Presence of both primary, uraninite UO\(_2\), and secondary uranium mineral, uranophane and beta-uranophane Ca (UO)\(_2\) (SiO\(_3\))\(_2\) (OH)\(_2\) O . 5 H\(_2\)O in Qash Amir granites\(^{17}\).

• Wide spread concentration of accessory minerals such as allnite, zircon and sphene in Hamra Dome granites\(^{17}\).

Table 1.

Activity concentration of natural radionuclides beside the external doses for granite samples under study.

<table>
<thead>
<tr>
<th>Area</th>
<th>Gabel Elba</th>
<th>Gabel Qash Amir</th>
<th>Gabel Hamra Dome</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^{226})Ra activity concentration range, Bq kg(^{-1})</td>
<td>55 ± 6.8–378 ± 18</td>
<td>60.7 ± 8.4–886 ± 33</td>
<td>71.8 ± 8.2–547 ± 28</td>
</tr>
<tr>
<td>(^{232})Th activity concentration range, Bq kg(^{-1})</td>
<td>41.3 ± 5.9–153.6 ± 11.3</td>
<td>47.6 ± 7.5–292 ± 18.5</td>
<td>96 ± 10.3–399 ± 24</td>
</tr>
<tr>
<td>(^{40})K activity concentration range, Bq kg(^{-1})</td>
<td>398 ± 25–2285 ± 60</td>
<td>349 ± 28 –1878 ± 64.2</td>
<td>368 ± 24.1– 1768 ± 53</td>
</tr>
<tr>
<td>Outdoor air absorbed dose rate range, nGy h(^{-1})</td>
<td>70–340</td>
<td>90–610</td>
<td>100–490</td>
</tr>
<tr>
<td>Outdoor air absorbed dose rate mean, nGy h(^{-1})</td>
<td>190</td>
<td>290</td>
<td>330</td>
</tr>
<tr>
<td>Indoor air absorbed dose rate range, nGy h(^{-1})</td>
<td>100–470</td>
<td>120–860</td>
<td>140–690</td>
</tr>
<tr>
<td>Indoor air absorbed dose rate mean, nGy h(^{-1})</td>
<td>270</td>
<td>400</td>
<td>470</td>
</tr>
</tbody>
</table>

The average values of annual effective doses received by adults in comparison with world average are shown in Table 2. From the table it is evident that, the annual effective dose values are much higher than world average 0.48 mSv\(^{4}\). The total annual effective dose of Elba granites is more than three times world average, whereas the
corresponding values of Qash Amir and Hamra Dome granites are approximately five and six times higher than the world average, respectively.

Table 2.
Average values of annual effective doses in comparison with world average.

<table>
<thead>
<tr>
<th>Location</th>
<th>Annual effective dose equivalent mSv</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Outdoor</td>
</tr>
<tr>
<td>Gabel Elba</td>
<td>0.24</td>
</tr>
<tr>
<td>Gabel Qash Amir</td>
<td>0.35</td>
</tr>
<tr>
<td>Gabel Hamra Dome</td>
<td>0.41</td>
</tr>
<tr>
<td>Worlda</td>
<td>0.07</td>
</tr>
</tbody>
</table>

a Values reported in UNSCEAR (2000) report.

According to the obtained results we can recommend to avoid the use of these granites as building and interior decorative materials of dwelling without radioactivity control.

CONCLUSION

In view of worldwide concern about radioactivity content of construction materials, measurements of natural radioactivity due to $^{226}$Ra, $^{232}$Th and $^{40}$K and resulting external exposure to population for 63 granite samples from Gabel Elba, Gabel Qash Amir and Gabel Hamra Dome, south eastern desert of Egypt, have been carried out. The average dose rates values for outdoor and indoor air for Elba granites are found to be three times higher than the world average. Whereas, the corresponding average values for Qash Amir and Hamra Dome granites are five and six times higher than the world average, respectively. Total annual effective doses of 1.6, 2.3 and 2.7 mSv were obtained for Elba, Qash Amir and Hamra Dome granites, respectively. These values are much higher than the world average of 0.48 mSv y$^{-1}$. Thus, this information is an important alert for the local people to avoid the use of these granites in the construction of dwelling without radioactivity control.
REFERENCES


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