Specific Activity of $^{226}\text{Ra}$, $^{232}\text{Th}$ and $^{40}\text{K}$ for Assessment of Radiation Hazards from Building Materials Commonly Used in Upper Egypt

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**Abstract:** In this paper, the specific activity of natural radionuclides ($^{226}\text{Ra}$, $^{232}\text{Th}$, and $^{40}\text{K}$) in some building materials, soil, sand, redbrick, clay brick, limestone, alabaster and marble commonly used in Upper Egypt is presented. Measurements were done by using gamma spectrometry (NaI (Tl) 3″ x 3″). Concentrations of natural radionuclides ($C_{\text{Ra}}$, $C_{\text{Th}}$, and $C_{\text{K}}$), radium equivalent ($R_{\text{aeq}}$), external hazard index ($H_{\text{ex}}$), the specific dose rates in door ($D$) and the annual effective dose ($DE$) due to gamma radiation from building materials was calculated. Concentrations of natural radionuclides ($^{226}\text{Ra}$ and $^{232}\text{Th}$) are in usual range and below maximal permitted values. The lowest value of ($H_{\text{ex}}$) is 0.15 for sand while the highest one is 0.5 for Redbrick. The ranges of ($DE$) are between 0.9 and 3.5 $\mu\text{Sv}/\text{y}$, it is below maximal permitted values, so that examined materials can be used for construction of new buildings (for interior and external works) as well as for covering of pavements, floors, etc.

**Key words:** Building materials, activity concentration index, dose rate, annual effective dose

**Yukarı Mısır Bölgesinde Yaygın Olarak Kullanılan Yapı Malzemelerindeki Radyasyon Riskinin Değerlendirilmesi Açısından $^{226}\text{Ra}$, $^{232}\text{Th}$ ve $^{40}\text{K}$’ın Özgül Aktivitelerinin Belirlenmesi**

**Özet:** Yukarı Mısır bölgesinde yaygın olarak kullanılan toprak, kum, kızıl tümla, kilili tümla, kireç taş, kaynak taşı ve mermer gibi bazı yapı malzemelerinde bulunan doğal radyoçekirdeklerin ($^{226}\text{Ra}$, $^{232}\text{Th}$ ve $^{40}\text{K}$) özgül aktiviteleri bu makalede sunulmaktadır. Ölçümler 3″ x 3″ NaI (Tl) gamma spektrometresi kullanarak yapılmıştır. Yapı malzemelerinden gelen gama radyasyonu ölçülecek, doğal radyoçekirdek yoğunlukları ($C_{\text{Ra}}$, $C_{\text{Th}}$, ve $C_{\text{K}}$), radium eşdeğer dozu ($R_{\text{aeq}}$), harici risk indisi ($H_{\text{ex}}$), bina içi özgül doz oranları ($D$) ve yıllık etkin doz ($DE$) değerleri hesaplanmıştır. Doğal radyoçekirdek ($^{226}\text{Ra}$ ve $^{232}\text{Th}$) yoğunlukları olağan sınırlar içerisinde ve izin verilen en büyük değerlerin altında durdu. En küçük $H_{\text{ex}}$ değeri 0.15 (kum için) iken, en büyük ise 0,5’dir (kızıl tümla için). $DE$ parametresi 0,9 $\mu\text{Sv}/\text{y}$ – 3,5 $\mu\text{Sv}/\text{y}$ aralığındadır ve izin verilen en büyük değerin altında olduğundan, incelenen materyallerin, taban, tavan, vb. yerlerin kaplanmasında kullanılmasının yanı sıra yeni yapının iç ve dış kısımlarında da kullanılması uygundu.

**Anahtar kelimeler:** Yapı malzemeleri, aktivite yoğunluk indisi, doz oranı, yıllık etkin doz

1. **Introduction**

The exposure of human beings to ionizing radiation from natural sources is a continuing and inescapable feature of life on earth. There are two main contributors to natural radiation exposures: high-energy cosmic ray particles incident on the earth's atmosphere and radioactive nuclides that originated in the earth's crust and are present everywhere in the environment, including the human body itself.
It is well known that radioactive nuclides in the uranium and Thorium decay chains do occur with varying degrees of concentration in the earth’s crust. While radioactive nuclides such as radium (226Ra), radon (222Rn) and bismuth (214Bi) are the product in the decay chain of uranium (238U), other radioactive nuclides, such as actinium (228Ac), bismuth (212Bi) and lead (212Pb) do occur in the decay chain of the thorium element (232Th). In addition, the radionuclide (40K) does also occur in construction materials.

These radioactive elements can be found almost in all types of building materials containing naturally occurring radionuclides are the main source of exposure. The knowledge of natural radioactivity in these materials is then important for determining the amount of public exposure because people spend most of their time (about 80%) indoors [1]. Furthermore, knowledge of this radioactivity is useful in setting the standards and national guidelines in regard to the international recommendations and in assessing the associated radiation hazard.

The population-weighted average of indoor absorbed dose rate in air from terrestrial sources of radioactivity is estimated to be 84 nGyh⁻¹ [2]. Elevated indoor external dose rates may arise from high activities of radionuclides in building materials. Large-scale surveys of concentrations of radioisotopes in construction materials were summarized by the United Nations Scientific Committee on the Effects of Atomic Radiation [3]. Consequently, this study was undertaken with the purpose of determining radioactivity in some Egyptian building materials and to assess the annual effective dose to the Egyptian population due to external gamma ray exposure in dwellings typical of Upper Egypt.

2. Materials and Methods

2.1. Sample Description and Preparation

A total of 43 samples of 7 different buildings materials six samples from each type (sand, redbrick, clay brick, limestone, alabaster and marble) while seven samples from soil were collected for the measurements of activity concentrations from Qena and Assiut governments in Upper Egypt. The materials were obtained from suppliers or gathered directly in demolished houses or buildings under construction. A brief description of these building materials follows.

Sand is a granular material made up of fine rock particles. The most common constituent of sand is silica (silicon dioxide, or SiO₂), usually in the form of quartz. The composition of sand varies according to local rock sources and conditions. Bricks may be made from clay, shale, soft slate, and calcium silicate. Limestone rocks are sedimentary rocks that are made from the mineral calcite, which comes from the beds of evaporated seas and lakes and from seashells.

Each sample was dried in an oven at about 110 °C to ensure that moisture was completely removed. The samples were crushed, homogenized and sieved through a 200 μm, which is the optimum size enriched in heavy minerals. Weighed samples were placed in polyethylene beaker, of 350-cm³ volumes each. The beakers were completely
sealed for 4 weeks to reach secular equilibrium where the rate of decay of the progeny becomes equal to that of the parent (radium and thorium) within the volume and the progeny will also remain in the sample [4, 5].

2.2. Instrumentation and Calibration

Activity measurements were performed by gamma ray spectrometer, employing a scintillation detector (3” x 3”). It is hermetically sealed assembly, which includes a NaI (TI) crystal, coupled to PC-MCA Canberra Accuspes. To reduce gamma ray background, a cylindrical lead shield (100 mm thick) with a fixed bottom and movable cover shielded the detector. The lead shield contains an inner concentric cylinder of copper (0.3 mm thick) in order to absorb X-rays generated in the lead. In order to determine the background distribution in the environment around the detector, an empty sealed beaker was counted in the same manner and in the same geometry as the samples. The measurement time of activity or background was 43200s. The background spectra were used to correct the net peak area of gamma rays of measured isotopes. A dedicated software program [6], from Canberra has carried out the online analysis of each measured gamma ray spectrum. The $^{232}\text{Th}$ concentration was determined from the average concentrations of $^{212}\text{Pb}$ (238.6 keV,) and $^{228}\text{Ac}$ (911.1 keV) in the samples, and that of $^{226}\text{Ra}$ was determined from the average concentrations of the $^{214}\text{Pb}$ (351.9 keV) and $^{214}\text{Bi}$ (609.3 keV and 1764.5 keV) decay products. While the gamma line for $^{40}\text{K}$ is (1460.6 keV). The minimum detectable activity (MDA) was 25.2 Bqkg$^{-1}$ for $^{40}\text{K}$, 6.5 Bqkg$^{-1}$ for $^{226}\text{Ra}$ and 5.7 Bqkg$^{-1}$ for $^{232}\text{Th}$. All procedures and efficiency calibration are described in previous publications [7].

3. Results and Discussion

Activity concentrations of $^{226}\text{Ra}$, $^{232}\text{Th}$ and $^{40}\text{K}$ in controlled samples of building materials are shown in Table 1.

<table>
<thead>
<tr>
<th>Sample Name</th>
<th>Number Of samples</th>
<th>$^{226}\text{Ra}$ A in (Bqkg$^{-1}$)</th>
<th>$^{232}\text{Th}$ A in (Bqkg$^{-1}$)</th>
<th>$^{40}\text{K}$ A in( Bqkg$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil</td>
<td>7</td>
<td>31±2 to 40±2</td>
<td>52±3 to 61±3</td>
<td>149±7 to 210±11</td>
</tr>
<tr>
<td>Sand</td>
<td>6</td>
<td>11±1 to 29±1</td>
<td>17±1 to 70 ±4</td>
<td>144±7 to155 ±8</td>
</tr>
<tr>
<td>Redbrick</td>
<td>6</td>
<td>54±3 to 65±3</td>
<td>65±3 to 81±4</td>
<td>285±14 to 376±19</td>
</tr>
<tr>
<td>Clay brick</td>
<td>6</td>
<td>16±1 to 52±3</td>
<td>30±2 to 89±5</td>
<td>167±8 to228±14</td>
</tr>
<tr>
<td>Limestone</td>
<td>6</td>
<td>23±1 to 74±3</td>
<td>17±2 to 51±3</td>
<td>115±10 to 135±13</td>
</tr>
<tr>
<td>Alabaster</td>
<td>6</td>
<td>29±2 to 38 ±2</td>
<td>8.4±1 to 13±1</td>
<td>121±13 to 156±14</td>
</tr>
<tr>
<td>Marble</td>
<td>6</td>
<td>32±2 to 51± 4</td>
<td>10±1 to 14±1</td>
<td>124±12 to 178±17</td>
</tr>
</tbody>
</table>

From Table 1, it can be seen that $^{40}\text{K}$ always contributes to the most specific activity compared to $^{226}\text{Ra}$ and $^{232}\text{Th}$. For different samples, the largest activity of $^{226}\text{Ra}$ is 74± 3 Bqkg$^{-1}$ for limestone, it is five times greater than that of the lowest value 11±1 Bq kg$^{-1}$ found in sand. $^{232}\text{Th}$ is in the wide range from 8.4±1 Bqkg$^{-1}$ in alabaster up to 89±5
Bq kg\(^{-1}\) in clay bricks. Concentration of \(^{40}\)K values ranges from 115±10 Bq kg\(^{-1}\) in limestone to 376±19 Bq kg\(^{-1}\) in redbrick. Thus activities in redbrick were higher than in other building materials. This may suggest that it is advisable to monitor the radioactivity levels of materials from a new source before adopting it for use as a building material. We can say that, all materials under investigation would not present a significant radiological hazard when it is used in building constructions.

3.1. Radium Equivalent Activity and External Hazard Index

\(^{226}\)Ra, \(^{232}\)Th and \(^{40}\)K are non-uniformly distributed in building materials. In order to compare the specific activity of materials containing different amounts of \(^{226}\)Ra, \(^{232}\)Th and \(^{40}\)K, the radium equivalent activity \(Ra_{eq}\) is used as defined by the following expression [8]:

\[
Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_{K}
\]

(1)

Where \(A_{Ra}\), \(A_{Th}\) and \(A_{K}\) are the mean activity in Bq kg\(^{-1}\) of \(^{226}\)Ra, \(^{232}\)Th and \(^{40}\)K, respectively. Eq. (1) is based on the fact 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 equivalent. Column 2 of Table 2 summarizes the \(Ra_{eq}\) results for all the samples studied. These values range from 65 Bq kg\(^{-1}\) in Alabaster to 187 Bq kg\(^{-1}\) in redbrick. Thus, all materials will not present a significant radiological hazard when they are used in building constructions. However, from the results (\(Ra_{eq}\)), there is no considerably in the different materials and in the same type of material collected from different areas.

While the external hazard index (\(H_{ex}\)): is given by the following equation [9]:

\[
H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_{K}}{4810} \leq 1
\]

(2)

Where \(C_{Ra}\), \(C_{Th}\) and \(C_{K}\) are the concentration in Bq kg\(^{-1}\) of radium, thorium and potassium, respectively. This index must be less than unity so that the annual effective dose due to radioactivity in the material will be less or equal to 1.5 mSv. As indicated in Table 2, it appears that investigated materials meet this criterion.

3.2. Absorbed Dose, Activity Concentration Index and Annual Effective Dose Rate

For materials containing naturally occurring radioactive materials such as \(^{226}\)Ra, \(^{232}\)Th and \(^{40}\)K, the absorbed dose rate \(D_o\) can be defined if the radionuclide concentrations are known. It can be obtained in units of nGy h\(^{-1}\) using the formula:

\[
D_o = 0.00333C_{Ra200} + 0.005 C_{Th} + 0.000333C_{K}
\]

(3)

Where \(C_{Ra}\), \(C_{Th}\) and \(C_{K}\) are the concentration in (Bq kg\(^{-1}\)) of radium, thorium and potassium respectively. Column 4 of Table 2 gives the results for absorbed dose rate in
air for building materials under investigation. We notice that redbricks show the highest value (0.7 nGy h⁻¹), whereas the lowest value is found in sand (0.2 nGy h⁻¹).

Table 2: Range of Radium equivalent activity $Ra_{eq}$, external hazard index $H_{ex}$, absorbed dose rate $D_o$, and annual effective dose $DE$ in building materials under investigation.

<table>
<thead>
<tr>
<th>Sample name</th>
<th>$Ra_{eq}$ (Bq kg⁻¹)</th>
<th>$H_{ex}$</th>
<th>Dose rate $D_o$ (nGy h⁻¹)</th>
<th>Annual Effective Dose $DE$ (μSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil</td>
<td>116.6 to 143.7</td>
<td>0.32 to 0.40</td>
<td>0.41 to 0.48</td>
<td>2.0 to 2.5</td>
</tr>
<tr>
<td>Sand</td>
<td>52.5 to 140.8</td>
<td>0.15 to 0.37</td>
<td>0.2 to 0.5</td>
<td>0.9 to 2.4</td>
</tr>
<tr>
<td>Redbrick</td>
<td>169.7 to 203.9</td>
<td>0.32 to 0.38</td>
<td>0.6 to 0.7</td>
<td>2.4 to 3.5</td>
</tr>
<tr>
<td>Clay brick</td>
<td>77.8 to 201.6</td>
<td>0.2 to 0.5</td>
<td>0.28 to 0.7</td>
<td>1.3 to 3.5</td>
</tr>
<tr>
<td>Limestone</td>
<td>66.8 to 118.1</td>
<td>0.2 to 0.3</td>
<td>0.3 to 0.4</td>
<td>1.0 to 2.0</td>
</tr>
<tr>
<td>Alabaster</td>
<td>59.3 to 70.3</td>
<td>0.1 to 0.2</td>
<td>0.18 to 0.25</td>
<td>0.9 to 1.2</td>
</tr>
<tr>
<td>Marble</td>
<td>59.8 to 79.8</td>
<td>0.16 to 0.22</td>
<td>0.21 to 0.28</td>
<td>1.0 to 1.4</td>
</tr>
</tbody>
</table>

The results are shown in Table 2 and these values were used to calculate annual effective doses, $DE$, due to gamma radiation from building materials was calculated as [10]:

$$DE = 0.7 \text{Sv Gy}^{-1} \cdot 7000 \text{ h} \cdot D_o$$  \hspace{1cm} (4)

Where $D_o$ must be taken in μGy h⁻¹ and 0.7 Sv Gy⁻¹ is effective absorbed dose conversion factor and 7000 h is annual exposure time. Results are presented in Table 2 and the $DE$ values are between 0.6 and 2.8 μSv y⁻¹. According to Ref. [2], the annual effective dose of these samples doesn't exceed the average worldwide exposure of 2.4 mSv due to natural sources. Table 3 shows the average radionuclide concentrations and radium equivalent activities $Ra_{eq}$ in building materials from other investigations for comparison.

Table 3: Comparison of activity and radium equivalent activities $Ra_{eq}$ in building materials used in Upper Egypt with those of other countries.

<table>
<thead>
<tr>
<th>Material</th>
<th>Country</th>
<th>Activity (Bq kg⁻¹)</th>
<th>$Ra_{eq}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>Algeria</td>
<td>$^{238}$U 12±1 $^{232}$Th 7±1 $^{40}$K 74±7</td>
<td>28±2.1</td>
</tr>
<tr>
<td></td>
<td>Bangladesh</td>
<td>$^{238}$U 14.53±1.8 $^{232}$Th 34.78±2.4 $^{40}$K 303.11±14.9</td>
<td>87.52±3.8</td>
</tr>
<tr>
<td></td>
<td>Brazil</td>
<td>$^{238}$U 10.2 $^{232}$Th 12.6 $^{40}$K 51</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>Egypt</td>
<td>$^{238}$U 9.2 $^{232}$Th 3.3 $^{40}$K 47.3</td>
<td>16.6</td>
</tr>
<tr>
<td></td>
<td>Greece</td>
<td>$^{238}$U 18±7 $^{232}$Th 17±10 $^{40}$K 367±20.4</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>India</td>
<td>$^{238}$U 9.4 $^{232}$Th 52.05 $^{40}$K 65.5</td>
<td>84.15</td>
</tr>
<tr>
<td></td>
<td>Kuwait</td>
<td>$^{238}$U 7.9±0.7 $^{232}$Th 7.2±0.3 $^{40}$K 360±14</td>
<td>45.4</td>
</tr>
<tr>
<td></td>
<td>Malaysia</td>
<td>$^{238}$U 60±3 $^{232}$Th 13±2 $^{40}$K 750±53</td>
<td>136±33</td>
</tr>
<tr>
<td></td>
<td>Pakistan</td>
<td>$^{238}$U 25.1 $^{232}$Th 14.6 $^{40}$K 188.1</td>
<td>60.5</td>
</tr>
</tbody>
</table>
From the comparison of activity and radium equivalent activities Ra\textsubscript{eq} in building materials used in Upper Egypt with those of other countries in Table 3, it is clear that our results are in average among other results.

### 4. Conclusions

The average value of the concentrations for $^{226}$Ra, $^{232}$Th and $^{40}$K in investigated samples have been found to lie within the range $17 \pm 1 – 79 \pm 4$, $17 \pm 1 – 115 \pm 6$, $95 \pm 5 – 376 \pm 19$ Bq kg\textsuperscript{-1}, respectively. The lowest $^{226}$Ra and $^{232}$Th activities were found in Sand and the highest in Redbrick. The lowest $^{40}$K activity was found in limestone and the highest in redbricks. The absorbed dose rate in door was found to vary from 0.19 to 0.57 nGyh\textsuperscript{-1}, and the corresponding annual effective dose ranging from 0.9 to 3.5 μSvy\textsuperscript{-1} is lower than the value 1.5 mSv yr\textsuperscript{-1} set in the OECD report [24].

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### References


