EXPOSURE TO RADIATION FROM THE NATURAL RADIOACTIVITY IN JORDANIAN BUILDING MATERIALS

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Received January 25 2005, amended July 4 2005, accepted July 9 2005

The natural radioactivity due to the presence of $^{226}$Ra, $^{232}$Th and $^{40}$K in selected building materials used in Jordanian building constructions has been measured using gamma-ray spectrometer with a Hyper Pure germanium detector. The average activity concentrations observed in different building materials ranged from $27.7 \pm 7.5$ to $70.4 \pm 2.8$, $5.9 \pm 0.67$ to $32.9 \pm 3.9$ and $30.8 \pm 0.87$ to $58.5 \pm 1.5$ for $^{226}$Ra, $^{232}$Th and $^{40}$K, respectively. The activity concentrations of $^{226}$Ra measured in fine aggregates was found to be among the highest values obtained in this work. The ranges of the calculated Ra-equivalent were found to be lower than those values recommended for construction materials ($370 \text{ Bq kg}^{-1}$). The average internal and external hazard indices were found to be $<1$. The average of the calculated annual gonadal equivalent dose was found to be $198 \mu\text{Sv y}^{-1}$. Results indicate no significant radiological hazards arise from using such materials in building construction.

INTRODUCTION

Most of the environmental radiation contribution comes from radionuclides which are members of the natural radioactive series and $^{40}$K(1,2). In the last two decades, considerable attention has been focused on low level exposure arising from naturally occurring radionuclides, particularly $^{226}$Ra, $^{232}$Th and $^{40}$K. They account for very significant fractions of radiation dose received by man(3–5). The worldwide average annual effective dose from natural sources is estimated to be 2.4 mSv, of which $\sim 1.1 \text{ mSv}$ is due to the basic background radiation and 1.3 mSv is due to exposure to radon$^6$. It had been observed that $^{226}$Ra, $^{232}$Th and $^{40}$K are present in building materials(7–9). Generally, dose contributions from building materials to the doses in dwellings are small compared to those from underlying bedrock and soil(10). However, several articles have identified building materials as the major contributors. This is true when the materials are either made from the radioactive industry with products such as fly ash and slag(11,12). In addition $^{226}$Ra and $^{232}$Th can also increase the concentrations of $^{222}$Rn and $^{220}$Rn and their daughters in the building. It is well known that the inhalation of radon isotopes and their short-lived progeny leads to internal exposure, thus, radon may be considered the major source of radiation disease.

Gonads were considered by the UNSCEAR as organs of interest for dosimetry purposes(6). According to the Recommendations of the International Commission on Radiological Protections, the weighting factor for the gonads is 0.2(13). This relatively high factor represents the radiation sensitivity of the gonads due to the risk of mutagenesis. Thus, there should be continued efforts to minimize the gonadal dose to the general population.

There are a few data on the radioactivity of building materials in Jordan(9,14), therefore, there is need to investigate the radioactivity levels of the building materials such as sand, hard stones, aggregates and cement used in building constructions. In Jordan, the determination of the radioactivity levels of building materials is important because of the living environment in some sites and refugee camps. Because of the large population in the refugee camps and the small size of these camps, most of the people live in small rooms with low ceilings and are surrounded by a great amount of building materials. If the building materials contain high radioactivity, then the radiological hazards on people may not be insignificant.

To minimise the exposure of the population to ionising radiation, there is need to control and limit the content of radioactive materials in constructions. The objective of the present study is to determine the specific activity of $^{226}$Ra, $^{232}$Th and $^{40}$K in several types of building materials used in Jordan from natural resources. The results of this study are compared with results from previous local studies and other countries of the world.

MATERIALS AND METHODS

Activity concentrations of natural radionuclides ($^{226}$Ra, $^{232}$Th and $^{40}$K), measured for each sample separately using appropriate gamma lines then averaged over the number of samples, were determined in the samples collected from different types of building materials (Table 1). The samples were obtained from different construction sites in Jordan. Hard rock (dimension-stone) samples consist mainly

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of limestone (quarried from three different sites in Jordan, namely Ajloon, Ma'an and Hallabat). Fine and coarse aggregates are mainly composed of crushed calcareous materials of limestone and dolomitic rocks. Also, building materials contain sand (which consists of silica) and marble (the commercial name of any cut and polished rocks, e.g. granite). Powder samples such as sand and fine aggregate were sieved, while hard samples (stones, coarse aggregate and marble) were crushed and sieved to remove the larger-size grains; then all samples were dried at 70°C for 16 h. Each of the dried samples was then packed and sealed using a Marrinelli beaker and stored for at least 4 weeks to reach a secular equilibrium between $^{226}\text{Ra}$ and $^{232}\text{Th}$ and their progenies. The radioactivity of the samples was measured using a gamma-ray spectrometer based on a Hyper Pure germanium detector connected to sufficient electronics; for more details on the system used see Al-Jundi(3).

## RESULTS AND DISCUSSION

Table 1 shows the mean activity concentrations of $^{226}\text{Ra}$, $^{232}\text{Th}$ and $^{40}\text{K}$, averaged over the number of samples, in the selected building materials investigated in this work. $^{226}\text{Ra}$ content in fine aggregate and coarse aggregate samples are about a factor of two higher than that in marble samples, whereas the mean activity concentrations of $^{232}\text{Th}$ are about the same for all types of materials used in this work except for sand. The average contents for the radionuclide of $^{226}\text{Ra}$, $^{232}\text{Th}$, and $^{40}\text{K}$ were 42.3 ± 1.7, 12.9 ± 8.7, 39.1 ± 9.5 Bq kg$^{-1}$, respectively, all the values are much lower than the world averages for building materials: $^{226}\text{Ra}$: 50 Bq kg$^{-1}$, $^{232}\text{Th}$: 50 Bq kg$^{-1}$, $^{40}\text{K}$: 500 Bq kg$^{-1}$. Moreover, the average values obtained in this study are lower than those reported by other researchers in the world. The natural radioactivity of the raw materials and products of the cement industry in Hungary has been measured by Gallyas and Török(7). The average concentration of $^{232}\text{Th}$, $^{226}\text{Ra}$ and $^{40}\text{K}$ that was reported by them varied within the following intervals 0.6–199, 0.6–228 and 7–709 Bq kg$^{-1}$, respectively. Typical activities measured in some building materials of Kenya were in the ranges 50–1500 Bq kg$^{-1}$ for $^{40}\text{K}$, 5–200 Bq kg$^{-1}$ for $^{226}\text{Ra}$ and 5–300 Bq kg$^{-1}$ for $^{232}\text{Th}$(15).

A common index called the radium equivalent activity ($R_{\text{aeq}}$) was used by Beretka and Mathew(16) to compare the radiological effects of building materials containing $\text{Ra}$, $\text{Th}$ and $\text{K}$; this index is based on the estimation that 370 Bq kg$^{-1}$ of $^{226}\text{Ra}$, 259 Bq kg$^{-1}$ of $^{232}\text{Th}$ and 4810 Bq kg$^{-1}$ of $^{40}\text{K}$ produce the same gamma-ray dose rates, and therefore $R_{\text{aeq}}$ can be written as:

$$R_{\text{aeq}} = C_{\text{Ra}} + 1.43 C_{\text{Th}} + 0.077 C_{\text{K}},$$

where $C_{\text{Ra}}$, $C_{\text{Th}}$, and $C_{\text{K}}$ are the specific activity concentrations of $^{226}\text{Ra}$, $^{232}\text{Th}$ and $^{40}\text{K}$ in Bq kg$^{-1}$, respectively. The calculated $R_{\text{aeq}}$ values obtained in this study were shown in Table 1. The highest $R_{\text{aeq}}$ reported in this study was for fine aggregates followed by that for coarse aggregates while the lowest reported value was for marble. It is obvious that there are variations in the radium equivalent activities of different materials, and this may ascribed to the different origins of these materials; moreover, it is suggested here that it is advisable to monitor the radioactivity levels of materials from a new source before using it as a building material. However, the average $R_{\text{aeq}}$ found in this study was found to be much lower than the values recommended by Somlai et al(17). Somlai et al(17) have recommended the use of construction materials with an average $R_{\text{aeq}}$ value of <370 Bq kg$^{-1}$ for dwellings. So those materials used in Jordanian buildings do not pose a significant radiological hazard when used for such construction. The annual gonadal equivalent dose (AGED) for the resident of a house built using a material with given activity concentrations of $^{232}\text{Th}$, $^{226}\text{Ra}$ and $^{40}\text{K}$ was calculated using the following equation(18):

$$D(\mu\text{Sv y}^{-1}) = 3.09 C_{\text{Ra}} + 4.18 C_{\text{Th}} + 0.314 C_{\text{K}},$$

where $C_{\text{Ra}}$, $C_{\text{Th}}$, and $C_{\text{K}}$ are defined in the above text. This model considers a house to be a cavity with

<table>
<thead>
<tr>
<th>Materials</th>
<th>Number of samples</th>
<th>$^{226}\text{Ra}$</th>
<th>$^{232}\text{Th}$</th>
<th>$^{40}\text{K}$</th>
<th>$^{226}\text{Ra}_{\text{aeq}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine aggregates</td>
<td>8</td>
<td>70.4 ± 2.8</td>
<td>14.8 ± 1.6</td>
<td>58.5 ± 1.43</td>
<td>123.2</td>
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<tr>
<td>Coarse aggregate</td>
<td>8</td>
<td>68.1 ± 12</td>
<td>12.8 ± 2.3</td>
<td>34.3 ± 9.8</td>
<td>117.9</td>
</tr>
<tr>
<td>Sand (silica)</td>
<td>10</td>
<td>31.9 ± 2.8</td>
<td>32.9 ± 3.9</td>
<td>38.8 ± 4.3</td>
<td>86.22</td>
</tr>
<tr>
<td>Marble (granite)</td>
<td>8</td>
<td>28.7 ± 3.9</td>
<td>6.22 ± 0.3</td>
<td>42.3 ± 1.4</td>
<td>54.96</td>
</tr>
<tr>
<td>Hard rock Desert</td>
<td>6</td>
<td>37.4 ± 7.9</td>
<td>9.52 ± 3.3</td>
<td>30.8 ± 0.87</td>
<td>70.70</td>
</tr>
<tr>
<td>Hard rock Halabat</td>
<td>6</td>
<td>27.7 ± 5.3</td>
<td>5.90 ± 0.67</td>
<td>38.6 ± 4.5</td>
<td>53.20</td>
</tr>
<tr>
<td>Hard rock Ajloun</td>
<td>6</td>
<td>34.4 ± 8.7</td>
<td>7.85 ± 1.9</td>
<td>31.9 ± 4.2</td>
<td>64.70</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>42.3 ± 1.7</td>
<td>12.9 ± 8.7</td>
<td>39.1 ± 9.5</td>
<td>82.00</td>
</tr>
</tbody>
</table>
infinitely thick walls, which makes it possible to compare AGED of a house containing concentrations of $^{232}$Th, $^{226}$Ra and $^{40}$K equal with the world average values in soil (25, 25, and 370 Bq kg$^{-1}$, respectively) with those obtained using a given material. Table 2 presents the average values of external and internal indices, and the calculated AGED of building materials subjected to this study. The average values of $I_{in}$ and $I_{ex}$ are $<$1, as required by the safe standards set by different authorities. The average AGED value is much less than the world average values for soil (0.298 mSv y$^{-1}$). Results presented in Table 2 indicate that the commonly used building materials, which are examined in this work, could be used in building construction without exceeding the proposed radioactivity criterion level. Thus, by using such building materials, buildings could work as shields for residents against terrestrial radiation. In fact, the ratio of the AGED values obtained in this study to the world average values is 66%. This means that buildings in Jordan shield and shut out $\sim$34% of terrestrial radiation.

Table 3 compares the reported values of radium equivalent activities for selected building materials obtained locally and in other countries of the world with those determined in this study. As shown in this table, the Ra$_{eq}$ varies from one country to another. Although, the Ra$_{eq}$ values of Jordanian building materials measured in this work are significantly higher than those figures obtained by Amrani and Tahtat$^{(19)}$, yet, they are still much lower than those values reported from Syria and Sri Lanka. Moreover, our values are much lower than the limit set in the Organization for Economic Cooperation and Development (OECD) report (370 Bq kg$^{-1}$)$^{(20)}$.

CONCLUSIONS

The activity concentrations of natural raw materials of some Jordanian building materials used in Jordan were determined using gamma-ray spectrometry. The radium concentrations in hard rock (Halabat), marble and sand are among the lowest measured values. The activity concentrations of $^{232}$Th measured in sand was the highest measured value compared to those of other building materials. Values of 0.28 and 0.5 were found to be the average of external and internal hazard indices of the selected building materials studied in this work. The activity concentrations of these materials produced an average radium equivalent activity of 82, which is less than that recommended by OECD (370 Bq kg$^{-1}$). The average of the calculated AGED was found to be 198 mSv y$^{-1}$. The average value obtained in this study was much less than the world average value (298 mSv y$^{-1}$) reported in OECD report$^{(20)}$.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of the deanship of scientific research at the Hashemite University and Dr. A. Al-Malabeh for invaluable discussions.

REFERENCES

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Table 2. The average values of annual gonadal equivalent dose (AGED) and hazard indices of Jordanian building materials.

<table>
<thead>
<tr>
<th>Hazard indices</th>
<th>Internal indices</th>
<th>External indices</th>
<th>AGED ($\mu$Sv y$^{-1}$)</th>
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</thead>
<tbody>
<tr>
<td>Average value</td>
<td>0.50</td>
<td>0.28</td>
<td>198</td>
</tr>
</tbody>
</table>

Table 3. Comparison of $^{226}$Ra$_{eq}$ (Bq kg$^{-1}$) values of sand in this study with those from other local and world studies.

<table>
<thead>
<tr>
<th>Country</th>
<th>Number of samples</th>
<th>Ra$_{eq}$</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pakistan</td>
<td>Rawalpindi and Islamabad</td>
<td>15</td>
<td>62</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>Different sectors</td>
<td>24</td>
<td>183</td>
</tr>
<tr>
<td>Algeria</td>
<td>Whole country</td>
<td>12</td>
<td>28</td>
</tr>
<tr>
<td>India</td>
<td>Different parts of country</td>
<td>2</td>
<td>84</td>
</tr>
<tr>
<td>Australia</td>
<td>Victoria</td>
<td>3</td>
<td>70</td>
</tr>
<tr>
<td>Syria</td>
<td>Whole country</td>
<td>9</td>
<td>130</td>
</tr>
<tr>
<td>Jordan</td>
<td>Whole country</td>
<td>73</td>
<td>60</td>
</tr>
<tr>
<td>Jordan</td>
<td>Whole country</td>
<td>10</td>
<td>82</td>
</tr>
</tbody>
</table>

JORDANIAN BUILDING MATERIALS: NATURAL RADIOACTIVITY EXPOSURE


