# Assessment of Natural Radioactivity Levels and Associated Radiation Hazards of Building Materials used in Saudi Arabia

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**Abstract**: In order to assess the radiological hazards to human health in a living environment, the level of natural radionuclides ($^{226}Ra$, $^{232}Th$ and $^{40}K$) present in various building materials available in Saudi Arabia (Jeddah city) analayzed using Gamma-ray spectrometry. The results showed that the activity concentration of $^{226}Ra$ ,$^{232}Th$ and $^{40}K$ was between 12.6 Bq/kg (Brick- clay) –31.5 Bq/kg (Granite), 9.2Bq/kg (Brick-clay) - 27.2Bq/kg (Granite) and 114.4Bq/kg (Brick-clay) –534.7Bq/kg (Granite), respectively. The radiological hazard parameters radium equivalent activity, gamma index, absorbed dose rate and the annual exposure rate, were calculated to assess the radiation hazards associated with Saudian buildings. All studied samples are lower than world average limits. The results are compared with the published data of other countries and with the world average limits. The measurements help in the development of standards and guidelines for the use and management of building materials.

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## 1. Introduction

Almost every building material contains $^{226}Ra$,$^{232}Th$, their progenies and $^{40}K$ radionuclides, these radioactive elements can be found in almost all types of rocks and soils from which building materials are produced (Turhan., 2008). The worldwide average concentrations in the soil are given as follows: $^{226}Ra$ (32 $Bq.kg^{-1}$ ), $^{232}Th$ (45 $Bq.kg^{-1}$ ) and $^{40}K$ (420 $Bq.kg^{-1}$ ) and in building materials $^{226}Ra$ (50 $Bq.kg^{-1}$),$^{232}Th$ (50 $Bq.kg^{-1}$ ) and $^{40}K$ (500 $Bq.kg^{-1}$) UNSCEAR.,1993,2000. Therefore, the building materials are one of main sources of exposure to humans exposure to gamma - ray from natural radionuclides occurs outdoors and indoors UNSCEAR.,2000). So, measurement of activity concentration of natural radionuclides in building materials is important in the assessment of population exposures as most individuals spend 80% of their time indoor exposure to low level radiation may lead to somatic infirmities, like cancer and genetic defects such as mutation and chromo some aberrations (Mustonen., 1979). In massive houses made of brick, concrete or stone, the gamma-rays emitted outdoors are efficiently absorbed by the walls and the indoor absorbed dose rate depends mainly on the activity concentrations of the natural radionuclides in the building materials. So, knowledge of the dose received from natural radioactivity, is very important in the discussion of effect on health (UNSCEAR, 2000).

The great interest expressed worldwide in natural radiation exposure has led to extensive surveys to determine the specific activity of building materials in many countries (Mantazul *et al*., 1998; Xinwei, 2004; Yasir *et al*., 2007; Medhat, 2009; Nabil *et al*., 2010). This interest reflects the magnitude of the total exposure of the public due to indoor radiation arising from the usage of various types of building materials. In Saudi Arabia, modern buildings are constructed from soil and rock based materials such as sands, cements, bricks, Concrete and Granite. The rapid physical development of the country especially in the last 20 years, has also increased the demand for such materials and there is no standards and guidelines with regard to acceptable levels of radioactivity in building materials. So, the aim objectivities of this work are to quantify the presence of natural radionuclides in the most commonly used building materials in Saudi Arabia and to estimate the radiological hazards associated with the natural radioactivity levels of these materials.

## 2. Materials and methods

### 2.1 Materials

The samples investigated were some common building materials, local products and sourced from hardware shops in Saudi Arabia (Jeddah city). Among the selected materials used were bricks (red and clay), Gravel, sands (terrestrial and ex-mining), gypsum, concrete, soil, limestone and Granite.

### 2.2 Sample treatment

A total of 45 samples from different building materials used in Jeddah, Saudi Arabia were collected from local markets and construction sites and prepared for the natural radioactivity measurement, so, the calculated activity concentration values represent the average of five measurements of each building material . The samples were broken into small parts using a manual hammer and then crushed into homogenized material of particle size 1 mm using a grinder machine. Samples are dried in oven at 110 °C for 6 hours and then sieved and packed in plastic containers. The activities of natural radionuclides ($^{226}$Ra, $^{232}$Th and $^{40}$K) in the building material samples has been determined by a gamma – rays spectrometrey Na(Tl) detector of 3 X 3 inch crystal dimentions, coupled with1024 microcomputer multichannel analyzer. The detector has the following characteristics, peak efficiency 1.2 X$10^{-5}$ at 1332 kev and resolution: 7.5 for 662 kev. The $^{226}$Ra activities were estimated from$^{214}$Pb (351.9 keV) and $^{214}$Bi (609.3keV ).The Gamma-ray energies of $^{212}$Pb (238.6 keV),$^{228}$ Ac (911 keV) were used to measure the concentration of $^{232}$Th, while the $^{40}$K activity was determined from the 1460.7 keV emission. The sample was sealed and the measurements were made one month later to assure secular equilibrium between the $^{226}$Ra and its daughters.

**2.3 Natural specific activity measurement**

The activity concentrations of the natural radionuclides in the measured samples were computed using the following relation (Noorddin, 1999; El-Taher, 2011):

$A_S$ (Bq $kg^{-1}$) = $C_a$ / ε $P_r$ Ms ………………. (1)

Where $C_a$ is the net gamma counting rate (counts per second), ε the detector efficiency of the specific γ–ray, $P_r$ the absolute transition probability of Gamma–decay and Ms the mass of the sample (kg).

**2.4.Radiation hazard index**

**2.4.1 Radium- equivalent activity index**

To assess the radiological hazard of the building materials used, it is useful to calculate an index called the radium equivalent activity ($Ra_{eq}$), defined according to the estimation that 1 Bq.$kg^{-1}$ of $^{226}$Ra,0.7 Bq.$kg^{-1}$ of $^{232}$Th and 13 Bq.$kg^{-1}$ of $^{40}$K produce the same -ray dose (Berekta & Mathew, 1985). This index $Ra_{eq}$ is given as (UNSCEAR, 1982):

$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K$ ----------- ( 2)

Where, $A_{Ra}$, $A_{Th}$ and $A_K$ are specific activities of $^{226}$Ra,$^{232}$Th and $^{40}$K,respectively, in Bq.$kg^{-1}$ .The maximum value of $Ra_{eq}$ in building materials must be less than 370 Bq.$kg^{-1}$for safe use i.e., to keep the external dose below1.5mSv.$y^{-1}$ (UNSCEAR, 1993).

**2.4.2 Representative level index ($I_r$ )**

Representative level index ($I_r$ ) is used to estimate the level of γ -radiation hazard associated with the natural radionuclides in specific building materials. The value is calculated using the formula derived by the European Commission (EC), NAE-OECD (1979):

$I_r = C_{Ra}/150 + C_{Th}/100 + C_K/1500 \leq 1$ --------- (3)

where $C_{Ra}$, $C_{Th}$ and $C_K$ (in Bq/kg) are the concentration of $^{226}$Ra, $^{232}$Th, and $^{40}$K, respectively.

**2.4.3 Internal hazard index**

The internal exposure to radon and its progeny produced is quantified by an internal hazard index ($H_{in}$) which can be defined as (UNSCEAR., 1988):

$H_{in} = A_{Ra}/185 + A_{Th}/259 + A_K/4810$ ---------- (4)

For safe use of a material in construction of dwelling, $H_{in}$ should be less than unity (Berekta & Mathew., 1985).

**2.4.4 Absorbed gamma dose rate and annual effective dose**

The absorbed dose rate in air is due to gamma ray emission from the isotopes $^{226}$Ra $^{232}$Th and $^{40}$K inside the building materials. It can be defined in units of nGy $h^{-1}$ using the following formula (UNSCEAR., 1993):

D(nGy$h^{-1}$) = $\sum_i Ri \times Ai$ ------- (4)

where Ai (Bq $kg^{-1}$) are the mean activities of $^{226}$Ra,$^{232}$Th and $^{40}$K , Ri (nGy.$h^{-1}$ per Bq$kg^{-1}$ ) their corresponding dose factor. According to an EC(1999) report, the dose conversion coefficients were calculated for Bulk materials as 0.92 ,1.1 and 0.08 nGy$h^{-1}$per Bq$kg^{-1}$ and for Superficial materials as 0.12 ,0.14 and 0.009 nGy$h^{-1}$per Bq$kg^{-1}$ for $^{226}$Ra ,$^{232}$Th and $^{40}$k respectively, using the standard room model with Dimensions of 4m ×5m× 2.8m. The worldwide average value of the absorbed gamma dose rate is 55 nGy$h^{-1}$.

The annual effective dose rate is calculated by applying the dose conversion factor of 0.7Sv$Gy^{-1}$ with an indoor occupancy factor of 0.8 (UNSCEAR, 1993; 2000):

$D_{eff}$ (mSv/y) = D(nGy$h^{-1}$) ×(0.7Sv/Gy ×8760h/year ×0.8) ×$10^{-6}$ ------(5)

Where 8,766 hrs is the number of hours in 1 year . Taking into account the indoor exposure, D(nGy$h^{-1}$) ~ 80 nGy$h^{-1}$ to terrestrial gamma-rays for the case of a typical masonry, Eq. (5) gives $D_{eff}$ (mSv/y) = 0.39 mSv$y^{-1}$ as the annual effective dose for individuals indoors, the recommended upper limit is 1 mSv$y^{-1}$ (ICRP,1990).

## 3. Results and Discussion

**3.1 Activity concentration**

The range and mean values of activity concentrations for $^{226}$Ra, $^{232}$Th and $^{40}$K in various building materials used in Saudi Arabia are presented in Table 1. From these results, it can be seen that the lowest mean value of the $^{226}$Ra concentration is 12.6 Bq $kg^{-1}$ measured in gravel, whereas the highest mean value for the same radionuclide is 31.5 Bq $kg^{-1}$ measured in granite. The lowest mean value of $^{232}$Th is 8.6 Bq kg-

$^{1}$ recorded in Gypsum and the highest mean value is 27.2Bq $kg^{-1}$ measured in granite .The lowest mean value for $^{40}K$ is 114.4 Bq $kg^{-1}$ recorded in Brik (clay) and the highest mean value is 534.7 $Bqkg^{-1}$ measured in granite, Generally, the average concentration of natural radionuclides in the samples under syudying are lower than the world average (50 Bq / kg for $^{226}Ra$ and $^{232}Th$ and 500 Bq / kg for $^{40}K$) present in building materials except for $^{40}K$ in Granite. However, the values of all natural radionuclides in most of the samples are close or slightly above the world average value of soils (25 Bq/kg for $^{226}Ra$ and $^{232}Th$, and 370 Bq/kg for $^{40}K$) (UNSCEAR,1982). Figure 1 shows comparison between the mean activity concentration of $^{226}Ra$ ,$^{232}Th$ and $^{40}K$ in building under investigation.

**Table 1. The range and mean activity concentration of $^{226}Ra$, $^{232}Th$ and $^{40}k$ Radionuclides in some building materials used in Saudi Arabia**

| Material | Activity concentration(Bq/Kg) | | |
|---|---|---|---|
| | $^{226}Ra$ | $^{232}Th$ | $^{40}K$ |
| Brick (Clay) | (10.8-32.3)<br>15.3±0.4 | (3.4-18.7)<br>9.2±0.4 | (45.7-170.6)<br>114.4±1.3 |
| Brick(Red) | (17.8-38.5)<br>27.4±0.8 | (11.7-27.3)<br>21.3±0.7 | (212.5-318.5)<br>278.5±3.2 |
| Gravel | (5.8-21.6)<br>12.6±0.6 | (8.6-21.6)<br>13.4±0.6 | (145.2-178.3)<br>157.5±2.4 |
| Sand | (14.8-32.4)<br>22.6±0.5 | (16.3-28.4)<br>20.7±0.6 | (132-189.7)<br>171.9±2.8 |
| Gypsum | (13.8-24.5)<br>22.34±0.7 | (8.7-13.2)<br>8.6±0.3 | (109.7-273.4)<br>224.9±3.2 |
| Concrete | (9.7-32.5)<br>21.7±0.6 | (10.6-21.6)<br>16.1±0.5 | (145.6-362.3)<br>226.2±2.6 |
| Soil | (11-26.5)<br>17.3±0.5 | (8.6-22.4)<br>12.9±0.4 | (173.1-356.6)<br>286.8±3.8 |
| Limestone | (12.7-23.4)<br>18.4±0.6 | (8.6-18.3)<br>13.6±0.5 | (85.8-198.6)<br>136.5±1.7 |
| Granite | (29.4-45.2)<br>31.5±0.8 | (15.4-35.2)<br>27.2±0.7 | (326.4-820.5)<br>534.7±3.6 |

**3.2 Radiation hazards**

As shown in Table 2, the result of the hazard parameters indicates that:-

1- The radium equivalent activity $Ra_{eq}$ for all selected materials, the highest value (111.6 Bq/kg) is observed in Granite, while the lowest value (37.3 Bq/kg) is found in Brick-clay. However, the maximum $Ra_{eq}$ values recorded are still lower than the maximum values (370 Bq/kg) suggested for building material (UNSCEAR,1982). Therefore , we can recommend those materials for contractures.

2- For representative level index ($I_{\gamma}$), the maximum suggested value is 1. Any value less than 1 shows that the external radiation dose within the building is less than the maximum suggested dose. Gamma index for the investigated materials are ranged from 0.27(Brick-clay) to 0.84 (Granite).

3- For the internal hazard index( $H_{in}$), If the maximum concentration of radium is half that of the normal acceptable limit, then $H_{in}$ will be less than 1.0 (Berekta & Mathew, 1985). For the safe use of a material in the construction of dwellings, $H_{in}$ should be less than unity. The calculated values of $H_{in}$ range from 0.14(Brick-clay) to 0.39 (Granite).

4- The estimated indoor absorbed dose rate ($nGyh^{-1}$) varied from 12.4 (Granite) to 70.92 (Brik-red). Brick-red and Sand exceed the recommended upper limit $55nGyh^{-1}$. Figure 2 shows comparison between Radium equivalent activity (Bq/Kg) and absorbed dose rate (nGy/h) for building materials under investigation.

5- The values of the annual effective dose, varied from 0.06 (Granite) to 0.35(Brick-red). The recommended upper limit of 1 $mSvy^{-1}$ is not exceeded. In general the dwellers inside the building are not supposed to acquire any radiological complication.

The recommended maximum levels of radium equivalents for building materials to be used for homes is < 370 Bq $kg^{-1}$ and for industries is 370-740 Bq $kg^{-1}$. Therefore, all the materials examined are acceptable for use as building materials as defined by the OECD criterion.

**Table 2. The average values of radiation hazard parameters for building materials used in Saudi Arabia**

| Material | $Re_{aq}$ (Bq/Kg) | Representative level index ($I_{\gamma}$) | Internal index $H_{in}$ | Absorbed dose ($nGyh^{-1}$) | Annual effective dose ($mSvy^{-1}$) |
|---|---|---|---|---|---|
| Brick(Clay) | 37.3 | 0.27 | 0.14 | 33.35 | 0.16 |
| Brick(Red) | 79.3 | 0.58 | 0.29 | 70.92 | 0.35 |
| Gravel | 43.9 | 0.32 | 0.15 | 38.93 | 0.19 |
| Sand | 65.4 | 0.48 | 0.25 | 59.42 | 0.29 |
| Gypsum | 51.9 | 0.38 | 0.20 | 48.01 | 0.24 |
| Soil | 62.1 | 0.44 | 0.20 | 53.05 | 0.26 |
| Concrete | 57.8 | 0.46 | 0.23 | 55.77 | 0.27 |
| Limestone | 48.4 | 0.34 | 0.18 | 42.81 | 0.21 |
| Granite | 111.6 | 0.84 | 0.39 | 12.40 | 0.06 |

Finally, the specific activities of $^{226}Ra$ ,$^{232}Th$ and $^{40}K$ and the $Ra_{eq}$ activity for selected building materials in this work are compared with those obtained in other regions of the world as shown in Table 3.This table shows that the average activity concentrations of $^{226}Ra$ ,$^{232}Th$ and $^{40}K$ in this work is in agreement with other studies. It is clear that the radioactivity in building materials varied from one country to another or even there are variations in the radium equivalent activities of different materials within the same type of materials, this depends on nature of the region from which samples are collected. The results may be important from the point of view of selecting suitable materials for use in building construction. The variations in radium equivalent activities may suggest that it is advisable to monitor the radioactivity levels of materials from a new source before adopting it for using as a building material (Xinwei., 2004).

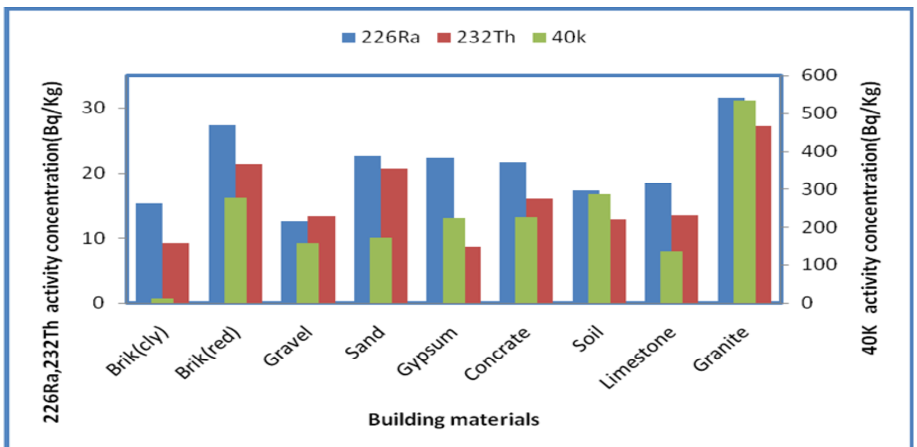


**Fig.1 Comparison between the mean activity concentration of $^{226}Ra$ ,$^{232}Th$ and $^{40}K$ in building materials used in Saudi Arabia**

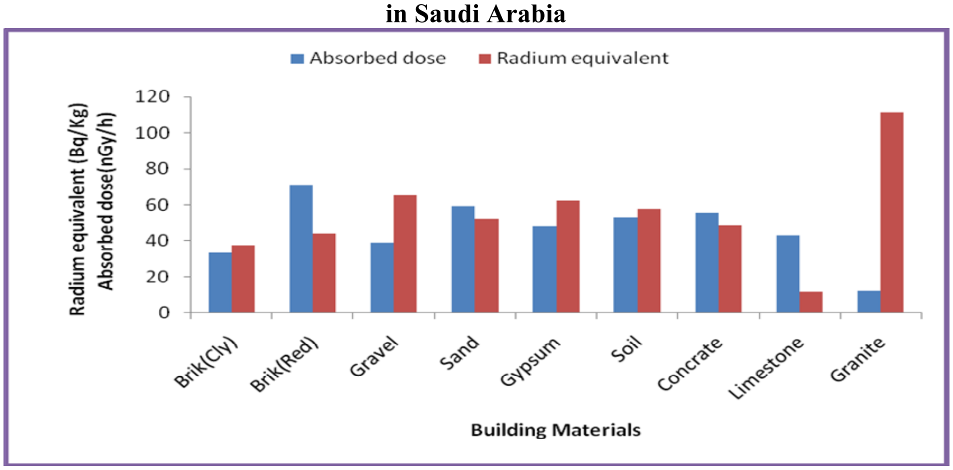


**Fig. 2 Comparison between Radium equivalent activity (Bq/Kg) and Absorbed dose rate (nGy/h) for building materials used in Saudi Arabia**

**Table 3.Comparison between the activity Concentrations and $Ra_{eq}$ in our building materials with those of other Countries.**

| Material | Country | Activity Concentration (Bq/Kg) | | | Raeq | Reference |
|---|---|---|---|---|---|---|
| | | 226Ra | 232Th | 40K | | |
| Brik(Cly) | Iraq | 59 | 12 | 934 | 146 | Hussain et al, 2010 |
| | Bangladesh | 29 | 53 | 292 | 127 | Mantazul *et al.,* 1998 |
| | Malyzia | 32 | 31 | 488 | 114 | Yasir *et al.,* 2007 |
| | Egypt | 30 | 21 | 289 | 82 | Medhat, 2009 |
| | Algeria | 65 | 51 | 675 | 190 | Amrani&Tahtat, 2001 |
| | Saudi Arabia | 26 | 15 | 234 | 58 | Present work |
| Brik (red) | Malyziya | 33 | 24 | 443 | 101 | Yasir *et al.,* 2007 |
| | Iraq (Najaf) | 120 | 15 | 978 | 215 | Hussain et al ,2010 |
| | Saudi Arabia | 27 | 21 | 279 | 79 | Present work |
| Grvel | Egyept | 13 | 23 | 193 | 65 | El-Taher 2011 |
| | Pakistan | 33 | 32 | 57 | 83 | Iqbal *et al.,* 2000 |
| | Bangladesh | 25 | 55 | 228 | 21 | Mantazul *et al.,* 1998 |
| | Saudi Arabia | 13 | 13 | 158 | 44 | Present work |
| Sand | Malyziya | 27 | 22 | 581 | 90 | Yasir *et al.,* 2007 |
| | India | 9 | 52 | 66 | 84 | Kumar *et al.,* 2003 |
| | Pakstan | 20 | 29 | 383 | 91 | Faheem *et al.,* 2008 |
| | Egypt | 33 | 27 | 385 | 101 | Medhat 2010 |
| | China | 41 | 22 | 303 | 95 | Xinwei, 2004 |
| | Saudi Arabia | 23 | 21 | 172 | 65 | Present work |
| Gypsum | Egypt | 39 | 25 | 226 | 92 | Medhat 2009 |
| | India | 8 | ------ | 27 | 10 | Kumar *et al.,* 2003 |
| | Saudi Arabia | 22 | 9 | 225 | 52 | Present work |
| Concrate | Malyzeya | 25 | 22 | 324 | 84 | Yasir *et al.,* 2007 |
| | Saudi Arabia | 22 | 16 | 226 | 62 | Present work |
| Soil | Malyzeya | 30 | 26 | 479 | 104 | Yasir *et al.,* 2007 |
| | Bangladesh | 21 | 38 | 464 | 112 | Mantazul *et al.,* 1998 |
| | Eygept | 16 | 7 | 102 | 28 | El-Taher 2011 |
| | Saudi Arabia | 17 | 13 | 287 | 58 | Present work |
| Limestone | Egypt | 17 | 10 | 280 | 53 | Medhat 2009 |
| | China | 22 | 15 | 83 | 50 | Xinwei2004 |
| | India | 74 | ---- | 65 | 79 | Kumar *et al.,* 2003 |
| | Saudi Arabia | 18 | 14 | 137 | 48 | Present work |
| Granite | Japan | 34 | 54 | 856 | 173 | Nabil *et al.,* 2010 |
| | Egypt | 65 | 60 | 920 | 221 | Medhat 2009 |
| | Saudi Arabia | 32 | 27 | 535 | 112 | Present work |

## 4. Conclusion

The natural radioactivity and radiological hazard parameters of some building materials commonly used in Saudi Arabia were assessed by gamma ray spectrometry. The concentration values for $^{226}$Ra,$^{232}$Th and $^{40}$K have been found to lie within the ranges of 12.6 to 31.5, 9.2 to 27.2 and 114.4 to 534.7Bq $kg^{-1}$, respectively. The lowest $^{226}$Ra concentration was found in gravel and the highest in granite. The lowest $^{232}$Th was found in Brick(clay) and the highest in granite. The lowest $^{40}$K concentration was found in Brick and the highest in granite. The average concentrations for $^{226}$Ra (21 $Bqkg^{-1}$), $^{232}$Th (16Bq $kg^{-1}$) and $^{40}$K (225 Bq $kg^{-1}$) in these samples of building materials are lower than the corresponding typical world averages of 50, 50 and 500 Bq $kg^{-1}$ respectively. Moreover, the calculated radiation hazard indexes are also not exceeding the maximum suggested values. Therefore, the use of these materials in construction of dwellings is considered to be safe for inhabitants.

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