Dirasat, Pure Sciences, Volume **34**, No. **1**, 2007

Radioactive Contents in Construction Materials Used in Jordanian Buildings

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ABSTRACT

Radionuclides in construction materials of different types and origins used for building in Jordan were investigated by gamma spectroscopy. The activity concentrations of ^{40}K, ^{238}U and ^{232}Th were measured in marble, limestone, granite, fine lime, ceramic, bricks, and concrete using High Purity Ge (HPGe) spectrometer. Results indicate that granite has the maximum average activity concentrations of 39.3±2.2 Bq/kg, 53.64±3.22Bq/kg and 786±33.03Bq/kg for ^{238}U, ^{232}Th and ^{40}K, respectively, exceeding the typical world averages for ^{232}Th and ^{40}K which have the values of 50Bq/kg and 500Bq/kg, respectively. Self absorption correction was made through the calculation of the attenuation coefficients at different gamma energies. These results are in an increase in the activities of all materials. Radium equivalent Ra_{eq} activities and hazard indices, H_{ex} and H_{in}, were also calculated to assess the radiation hazards of the above mentioned materials. It has been found that all materials have Ra_{eq} well below the world average limit which is measured to be 370Bq/kg.

Keywords: Gamma Spectroscopy, Building Materials, Radiation Contents, Attenuation Coefficients, Radium Equivalent Activity, Radiation Hazards.

1. INTRODUCTION

Over the last two decades, considerable interest has been devoted to radioactivity in the environment; due to its impact on a wide range of fields that are directly related to human existence, such as health, agriculture, water and many other fields. The most important radionuclides, which constitute the major source of naturally occurring radioactive material in the environment, exist in the earth crust (Eisenbud, 1987). Among those present in building raw materials are ^{40}K, ^{238}U with uranium series isotopes, and ^{232}Th with thorium series isotopes. Building materials contribute to environmental radioactivity through emission of gamma-radiation, mainly from the above mentioned radionuclides and their progenies, and also by releasing the noble gas radon. Concentration of ^{226}Ra (the daughter isotope of ^{238}U) is, however, crucial because its daughter isotope is ^{222}Rn that easily penetrates into places of permanent residence for people. In fact, the presence of ^{222}Rn isotope and its daughter isotopes in the air of a dwelling results in the risk of internal contamination. When ^{222}Rn gas is breathed into lungs, it causes internal irradiation by means of the strongly ionizing of alpha particles (Steger and Grun, 1999). It has also been reported (Durrance, 1986) that gamma ray, emitted from the above-mentioned radionuclides and from other artificial radiation sources, can seriously cause a great deal of damage to human body. Therefore, knowledge of radionuclides concentrations in a given building material enables us to assess any possible radiological hazards to people by the use of such materials and helps for developing standards concerning the use of building materials (Nazaroff and Nero, 1988; Mollah, et al., 1986; Khan et al., 2002).

In Jordan, several building materials are available in the local market. Most of these materials are made from rocks and soils that are extracted from earth's crust. Therefore, it is reasonable to believe that such building materials have their own radionuclides, and that a dwelling built up from materials that have a high concentrations of radionuclides will act as a radioactive

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Received on 15/2/2006 and Accepted for Publication on 8/10/2006.

incubator. Hence, nationwide surveys have been carried out in most countries (Hizem et al., 2005; Pavlidou et al., 2006) to determine the level of radiation content in building materials, so as to compile data for any possible radiological hazards. However, little attempts (Ahmad et al., 1997; Awadallah, 2003; Khataibeh et al., 1997) have been made to investigate the radiation content in building materials that are used in Jordan. This motivated the authors to carry out a series of experiments to determine the level of radioactive radiation in building materials.

The objective of the present paper is to determine the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in some building materials before and after self-absorption correction. The obtained data, without self-absorption correction, has also been used to calculate the Radium equivalent Ra_{eq} activities and hazard indices in an attempt to decide whether the materials under investigation are acceptable according to the OECD criteria (OECD, 1979).

2. EXPERIMENTAL SETUP

Samples of construction materials were collected and marked according to the origin / location and classified into three groups. First group contains the materials that are extracted from their sites and used directly in buildings without any changes in their structures. The second group, however, consists of building materials that are made up of some components mixed together and processed before final molding as building materials (Awadallah, 2003). Concrete samples with certain mixing ratios of their raws were prepared at the laboratory and identified as a third group of building materials. Specifications of samples of the above-mentioned groups are given in Table (1). Sample geometries were formulated to be compatible with the detector system design. Solid materials were cut into slices of known thickness and areas covering the cap of the detector. The samples under study were kept in plastic containers for almost a month to achieve secular equilibrium between the series parents and the subsequent daughters following radon in the decay sequence.

Since the collected samples are of different densities, the internal attenuation of the emitted radiation has to be taken into account. Based on the narrow beam method (Lowenthal et al., 2001), the attenuation coefficients of the samples were measured using a multiple gamma-radiation source, as shown in Figure 1. This source was made by joining several point sources of different radionuclides with different energy lines (^{133}Ba at 302.71 keV, and 355.86 keV; ^{137}Cs at 661.62 keV; ^{60}Co at 1173.23 keV and 1332.51 keV and ^{22}Na at 1274.54 keV, supplied by EG&G Ortec, USA). The resulting collimated beam of gamma radiation was directed to penetrate the stacked material slices (placed between the beam and the detector) towards the detector. After counting 15 minutes, the top slice was carefully removed and the measurements were repeated until the last one.

Investigation of the radiation contents of the samples has been carried out using the same setup, but after removing the radiation source. Slices were stacked sequentially one by one on the top of the detector cap, and counting was performed for at least 12 hours for each material. The same procedures were performed for the rest of the slices of the same material until all slices were counted.

Radiometric analysis was performed using two High Purity Germanium (HPGe) detectors supplied by EG&G Ortec, at the Radiation Measurements Laboratory (RML) of Al-Balqa' Applied University. One of these detectors is n-type gamma-x ray (GMX) detector, operated at 3500V, with useful energy range of 3 keV - 10 MeV, and a standard energy resolution of 2.02 keV and a relative efficiency of 56.9% both at 1.33 MeV of ^{60}Co. The other detector is a p-type well (GWL) detector, operated at 1500V, with useful energy range of 10 keV - 10 MeV, and a standard energy resolution of 2.09 keV at 1.33 MeV of ^{60}Co. The "Gamma Vision- 5.0" software was used for analysis, and the systems were energy and efficiency calibrated using the standard source "soil-6" from the IAEA. The calibration source used was a petri-dish of 9 cm in diameter and 1cm in thickness.

3. RESULTS AND DISCUSSION

The investigation of the natural radioactive series was based on measuring the activity concentration of their daughters in each sample. Some members of the uranium series, thorium series and ^{40}K, were studied and are listed in Table (2). In the present study, daughters were selected based on the most clean, strong and distinguishable lines in the gamma spectra.

3.1 Radioactive Contents

Direct measurements of the activity of ^{238}U is not possible owing to the fact that it emits a weak (0.064%)

γ-ray. Therefore, the activity of any of the γ-emitting daughters nuclides of ^{238}U could be used, since they are in secular equilibrium with their precursor. As the studied samples are in secular equilibrium, so; ^{226}Ra (186.21 keV), ^{214}Bi (609.30 keV), ^{214}Pb (295.20 keV) and ^{214}Pb (351.90 keV) nuclides were used to calculate the activity of ^{238}U. Following the assumption suggested by Papachristodoulou et al., (2003), the activity of ^{238}U (as measured from its ^{226}Ra daughter) is calculated using the formula:

$$A(^{226}\mathrm{Ra}, 186.21) = \frac{\varepsilon(186.21) \times I(^{226}\mathrm{Ra}, 186.21)}{\varepsilon(609.30) \times I(^{214}\mathrm{Bi}, 609.30)} \times A(^{214}\mathrm{Bi}, 609.30) \quad (1)$$

Where $I(^{A}X, E_\gamma)$ and $\varepsilon(E_\gamma)$ are the emission probability and detection efficiency for the energy E_γ measured in keV of γ-ray. The same procedures were also used for the calculation of ^{238}U activity using the nuclides ^{214}Pb-1 (295.20 keV) and ^{214}Pb-2 (351.90 keV). It was reported in literature, (Durrance, 1986), that under secular equilibrium the activities of the daughters in a decay series are equal to that of the parent. Therefore, in the present study, the ^{238}U activity (taken as that of ^{226}Ra) is the average of the three values of ^{214}Bi, ^{214}Pb-1 and ^{214}Pb-2 obtained above.

Figure (2) shows the activity concentrations of the uranium daughters in the studied construction materials. For each material, the activities of the four daughters are so close, and the differences are within experimental errors. Such close activity concentrations are expected under the conditions of secular equilibrium. The average activity concentrations of the ^{238}U daughters ranged from 2.8 ± 0.2 Bq/kg in marble up to 39.3 ± 2.2 Bq/kg in granite. Uranium concentration in most of the samples does not exceed 15 Bq/kg. However, ceramic and granite are relatively the most populated with uranium. But still, their activities are less than the corresponding world average of 50 Bq/kg (NEA-OECD, 1979).

Following the same procedures used for the calculation of ^{238}U activity, the ^{232}Th activity concentration has been obtained from the nuclides ^{208}Tl (583.14keV) and ^{228}Ac (911.07keV). Extremely lower concentration of thorium (as measured from its ^{208}Tl and ^{228}Ac daughters) is seen in most of the studied samples as shown in Figure (3). The low-activity group of materials ranges from limestone, with an average of 0.67 ± 0.03 Bq/kg, up to concrete with 4.13 ± 0.24 Bq/kg. An obvious exception is seen for ceramic and granite samples, which scored activity concentrations of 28.24 ± 1.47 Bq/kg and 53.64 ± 3.22 Bq/kg, respectively. Since some of the measured values are extremely small, the Minimum Detectable Activities (MDAs) were calculated using the Currie method (Currie, 1968), and the obtained values are given in Table (3), to demonstrate the credibility of the relatively low levels of activity concentrations in the studied samples (Pavlidou et al., 2006). However, granite and ceramic are exceptions where granite exceeds the typical world average value of 50 Bq/kg for thorium (NEA-OECD, 1979).

The activity concentration of ^{40}K, in the studied sample, shows a distribution similar to that of thorium as it is evident from Figure (4). Meanwhile, limestone keeps the lowest activity with 3.74 ± 0.16 Bq/kg. Ceramic and granite score the highest concentrations, with 413.47 ± 24.35 Bq/kg and 786 ± 33.03 Bq/kg, respectively. It is clear that the activity concentration of ^{40}K in the studied samples is within the typical world average value of 500 Bq/kg except for granite (NEA-OECD, 1979). It is noteworthy that a strong correlation between ^{232}Th and ^{40}K were found for all the studied materials, as shown in Figure (5). However, less significant correlation of R=0.79 was found between ^{238}U and ^{232}Th, and R= 0.78 was found between ^{238}U and K-40. The reason behind such close correlation between ^{232}Th and ^{40}K is unknown and work in that direction is in progress.

It is mentioned earlier that the first group of building materials: limestone, marble and granite are extracted from different regions of earth crust and are used directly in building works. Figures (6-8) show the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in different types of limestone, marble and granite samples, respectively, that are available in the local market. Figure (6) shows that the activity concentration of ^{238}U is the highest with a value of 25.74 ± 1.81 Bq/kg in the Samek type of limestone. Meanwhile, the activity concentration of ^{40}K has a maximum value of 5.32± 0.43 Bq/kg for Azraq, with a minimum value of 0.78 ± 0.06 Bq/kg for Ma'an type of limestone. It is observed from the same figure that ^{232}Th has the least concentration, and even the highest value is relatively low compared to that of ^{238}U and ^{40}K in the same sample. In marble samples, the situation is a little bit different as it is clear from Figure (7). Almost ^{40}K radionuclide is the dominant with maximum and minimum values of 39.82± 2.81 and 2.79 ± 0.18 Bq/kg

for Elegenti and Karara marble types, respectively. ^{238}U has a maximum concentration of 4.36± 0.32 Bq/kg in Hallabat sample with a minimum of 1.79 ± 0.13 Bq/kg in both Elegenti and Rosa marble samples. The relatively low activity of ^{232}Th is obvious and is less than 1 Bq/kg for all types of marble samples.

Our earlier results indicate that granite is the most radiation-populated sample in comparison with all the studied construction materials. Figure (8) shows the variation in activity concentrations for the different types of granite. The average activity concentrations of ^{238}U and ^{232}Th are 44.2 ± 2.6 Bq/kg with a standard deviation of 24.4 Bq/kg; and 45.6 ± 3.2 Bq/kg with a standard deviation of 41.7 Bq/kg, respectively. For all types of granite, ^{40}K highly dominates all present radionuclides, with an average around 1007.2 ± 57.4 Bq/kg with a standard deviation of 331.1 Bq/kg. The activity concentrations of Palmoral type of granite show the highest values, with different orders of magnitude, in uranium, thorium and potassium.

3.2 Self Absorption Correction

Density variation of the samples under investigation requires self-absorption correction of the activities. This was made through the calculation of the linear attenuation coefficient μ for each material at the different energy lines under study. The multiple γ-radiation source (mentioned in the experimental setup) was used to obtain the attenuation coefficient μ. Different numbers of slices, and hence different thicknesses, of the studied materials were placed between the source and the detector, and ratios of the numbers of counts were taken. Figure (9) shows a plot of the number of counts versus the sample thickness, and the slope of the resulting straight line gives the linear attenuation coefficient. To calculate μ at any other energy E, an empirical formula ($\mu = CE^{-B}$) was suggested, where C and B are constants found by a semi-log plot of μ against E, yielding B = - 0.44, while C shows material dependent values (Awadallah, 2003). This was further used to calculate μ for the studied energy lines as listed in table (4).

Using the obtained values of μ, self-absorption correction for each material was made using the formula (Gilmore and Hemingway, 1995):

$$A = \frac{A_o \mu x}{1 - e^{-\mu x}} \qquad (2)$$

Where x is the sample thickness given in Table (4).

Based on that, Figure (10) shows the activity concentrations with corrected self-absorption of ^{238}U of the studied construction materials. Bricks and fine lime show up as the highest ones populated among the lower activity group of materials. Meanwhile, ceramic and granite keep their position in the higher activity group, although with reverse order.

The activity concentrations of ^{232}Th, before and after correction, are shown in Figure (11). The maximum and minimum change in the activity concentrations is observed to occur in bricks and in both concrete and limestone, respectively. The activity concentrations in granite and ceramic increased, nearly in the same rate, keeping their position and order in all materials' distribution, relative to the uncorrected activity concentrations. The self-absorption corrected activity concentrations of ^{40}K in the studied samples are plotted in Figure (12). It is clear that marble, ceramic and granite make a noticeable jump, relative to the materials in the uncorrected distribution. Meanwhile, the raise in concrete is relatively small which may be attributed to its relatively smaller attenuation coefficient.

3.3 Radium Equivalent Activity

The building materials act as sources of radiation and also as shields against outdoor radiation that are absorbed by walls. Nevertheless, in dwellings, the main factor that affects the indoor-absorbed dose is the activity concentrations of natural radionuclides present in the used building materials. To account for the radiation hazards associated with ^{40}K, ^{226}Ra and ^{232}Th, an index known as radium equivalent activity Ra_{eq} has been introduced by (Beretaka and Mathew, 1985; El-Arabi, 2005; Veiga et al., 2006). According to these authors, 1 Bq/kg of ^{226}Ra, 0.7 Bq/kg of ^{232}Th and 13Bq/kg of ^{40}K, produce the same gamma dose rate. This may be represented as:

$$Ra_{eq} = A(^{226}Ra) + 1.43\ A(^{232}Th) + 0.077\ A(^{40}K) \qquad (3)$$

Where $A(^{226}Ra)$, $A(^{232}Th)$ and $A(^{40}K)$ are the activities of ^{226}Ra, ^{232}Th and ^{40}K, respectively, in Bq/kg. This is a widely used radiological hazard index and according to Somlai et al. (1998), construction materials with an average Ra_{eq} value of less than 370 Bq/kg may be used for dwellings. In the present study, ceramic has an average activity of ^{226}Ra, ^{232}Th, and ^{40}K that equals 32.6,

28.3, and 413.5 Bq/kg, respectively. Substituting these values in the above equation yields Ra_{eq} value of 104.9 Bq/kg. The obtained values of Ra_{eq} of other samples are depicted in Figure (13). It is clear that all the samples have Ra_{eq} well below the limit of 370Bq/kg that is set by the Organization for Economic Cooperation and Development (OECD) countries (Khan et al., 2002).

3.4 Hazard Indices

It was reported (Abbady et al., 2006) that the upper limit of radiation dose arising from building materials is 1.5 $mSvy^{-1}$. For limiting the radiation dose to the said value, Hewamanna et al. (2001) suggested a model considering a wall of finite thickness and the existence of windows and doors. This model may be written as:

$$H_{ex} = A(^{226}Ra)/740 + 1.43\ A(^{232}Th)/520 + 0.077\ A(^{40}K)/9620 \quad (4)$$

where $A(^{226}Ra)$, $A(^{232}Th)$ and $A(^{40}K)$ are the activities of ^{226}Ra, ^{232}Th and ^{40}K, respectively, in Bq/kg. The value of this index must be less than one for the radiation hazard in order to be negligible. The obtained values of H_{ex} for the samples under consideration are found to be, as given in Figure (14), less than unity which meets the ICRP (1977) requirements.

The internal exposure to radon and its short lived daughters is dangerous to the respiratory system (Ahmad, 2005). Therefore, it is noteworthy to calculate the internal hazard index H_{in} which was suggested by Krieger (1981), and is given by:

$$H_{in} = A(^{226}Ra)/185 + 1.43\ A(^{232}Th)/259 + 0.077\ A(^{40}K)/4810. \quad (5)$$

For the safe use of materials under investigation, H_{in} should be less than unity (Abbady et al., 2006). Indeed, the average calculated values of H_{in}, as given in Figure 14, were less than unity and agrees fairly well with those reported in literature (Ahmad, 2005).

4. CONCLUSION

Radiometric analysis of different construction materials that are available in the Jordanian market has been performed using HPGe spectrometer; the following conclusions were drawn:

Granite has the maximum average activity concentration exceeding the typical world average value for both ^{232}Th and ^{40}K, but still lower than that of granite materials reported in literature (UMSHPS, 2003).

Materials of high elemental concentration of radionuclides and of large rate of self-absorption lower the hazards, as it is evident from the activity concentrations of ceramic and granite samples before and after self-absorption correction.

The estimated average values of Ra_{eq} activities are less than that of the world average limit. Accordingly, construction materials available in the local market may be safely used in buildings and they don't pose significant radiation hazards. The calculated values of the external and internal hazard indices are in support of this conclusion.

Table (1): Specifications of the Groups of Collected Samples.

Group-1

Sample code	Material	Type	Origin	No. of Slices	Dimensions LWT(mm)
851	**Marble-1**	Rosa	Italy	11	120x 100x 14
852	**Marble-2**	Karara	Turkey	11	120x 100x 14
853	**Marble-3**	Hallabat	Jordan	10	120x 100x 14
990	**Marble-4**	Suprano	Turkey	6	80x 80x 30
991	**Marble-5**	Calcutta	Greece	6	80x 80x 30
992	**Marble-6**	Eleganti	Spain	9	80x 80x 20
846	**Limestone-1**	Red	Qatrana	12	100x 100x 14
847	**Limestone-2**	Rweished	Rweished	12	100x 100x 14
848	**Limestone-3**	Azraq	Azraq	12	100x 100x 14
849	**Limestone-4**	Samek	Amman	12	100x 100x 14
850	**Limestone-5**	Sat'h	Ma'an	12	100x 100x 14

966	**Granite-1**	Black	S.Africa	9	80x 80x 21
967	**Granite-2**	Ratwa	Jordan	6	80x 79x 30
968	**Granite-3**	Salmon	Italy	6	80x 80x 29
969	**Granite-4**	Palmoral	Italy	6	80x 80x 28
970	**Granite-5**	Pornio	Spain	6	80x 80x 29
971	**Granite-6**	Paltech	Fenland	6	80x 79x 30
972	**Granite-7**	Brown	S.Arabia	6	81x 80x 30
878	**Fine lime**	Sand	Jordan	1	(D = 87) x 70

Group– 2.

Sample code	Material	Type	Origin	No. of Slices	Dimensions LWT (mm)
927	**Bricks-1**	Ribs	Local	6	100x 100x 30
928	**Bricks-2**	Ribs	Local	6	100x 100x 30
929	**Bricks-3**	10 cm	Local	6	100x 100x 30
977	**Ceramic-1**	Floors	Spain	20	80x 81x 9
978	**Ceramic-2**	Walls	Spain	6	80x 81x 10
979	**Ceramic-3**	Walls	China	6	80x 80x 8
982	**Ceramic-4**	Walls	Local	6	80x 80x 7

Group- 3.

Sample code	Material	Mixture (%)					No. of Slices	Slice dimensions [Diam.xThick.] (mm)
		Silicon Sand	Lime Sand	Cement	Coarse			
					D* (cm)	Qty %		
926	**Concrete-1**	-	60	40	-	-	8	86 x 14
954	**Concrete-1**	65	-	35	-	-	10	86 x 14
955	**Concrete-3**	34	33	33	-	-	10	86 x 13
960	**Concrete-4**	42	-	25	0.5	33	8	86 x 13
961	**Concrete-5**	44	-	28	1.0	28	6	86 x 21
962	**Concrete-6**	42	-	28	2.0	30	7	86 x 20
973	**Concrete-7**	42	-	27	3.0	31	7	87 x 23

D*= coarse diameter, D= diameter, T = thickness, L= length.

Table (2): The Daughters Used in Series Investigation.

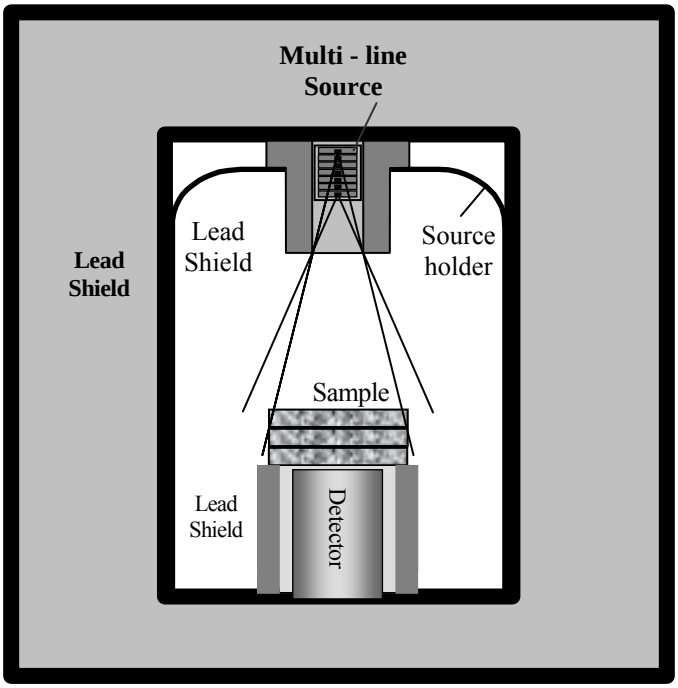
Series	Nuclide	Energy(keV)	Half-Life
U-238	Ra-226	186.21	1600 Yrs
	Pb-214-1	295.20	26.8 Min
	Pb-214-2	351.90	26.8 Min
	Bi-214	609.30	19.9 Min
Th-232	Ac-228	911.07	6.13 Hrs
	Tl-208	583.14	3.1 Min
K-40	K-40	1460.75	$1.28\ 10^9$

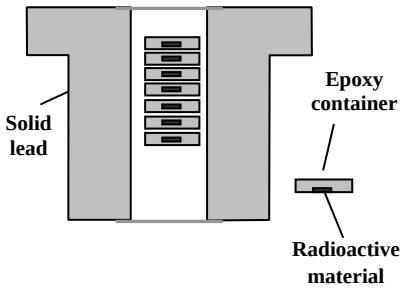
Table (3): Minimum Detectable Activities of the ^{232}Th Daughters.

Material	Tl-208		Ac-228	
	Activity (Bq/kg)	MDA (Bq/kg)	Activity (Bq/kg)	MDA (Bq/kg)
Limestone	0.80	0.06	0.53	0.16
Marble	1.09	0.04	0.77	0.12
Fine lime	0.83	0.06	1.28	0.16
Bricks	1.31	0.10	0.90	0.35
Concrete	4.11	0.02	4.15	0.07
Ceramic	29.73	0.05	26.74	0.14
Granite	54.95	0.02	52.34	0.06

Table (4): Linear Attenuation Coefficients (in m^{-1}) at Different Energy Lines (Awadallah, 2003).

Sample	Thickness (cm)	Density (g/cm^3)	Energy (keV)					
			295.2	351.9	583.1	609.3	911.1	1460.8
Ceramic	3.4	2.31	21.5 ± 0.7	20.6 ± 0.9	18.0 ± 0.6	17.0 ± 0.5	13.0 ± 0.9	10.2 ± 0.8
Limestone	7.0	2.51	27.8 ± 0.8	25.7 ± 0.9	20.6 ± 0.8	20.2 ± 0.7	16.9 ± 0.8	13.8 ± 0.7
Marble	12.2	2.58	27.8 ± 0.8	25.7 ± 0.8	20.6 ± 0.8	20.2 ± 0.8	16.9 ± 0.7	13.8 ± 0.7
Bricks	9.0	1.90	24.0 ± 0.7	22.2 ± 0.8	17.7 ± 0.6	17.3 ± 0.6	14.5 ± 0.6	11.7 ± 0.8
Concrete	11.8	1.87	20.9 ± 0.5	19.4 ± 0.8	15.5 ± 0.4	15.2 ± 0.8	12.7 ± 0.7	10.3 ± 0.5
Granite	19.7	2.68	29.2 ± 0.9	27.1 ± 0.9	22.1 ± 0.8	21.7 ± 0.8	18.4 ± 0.5	15.1 ± 0.6
Fine lime	7.0	1.88	22.4 ± 0.8	23.5 ± 0.5	18.8 ± 0.6	18.5 ± 0.6	15.5 ± 0.5	12.6 ± 0.5





(a)

Fig. 1.
(a) Detecting system setup.
(b) Multi-line point source.

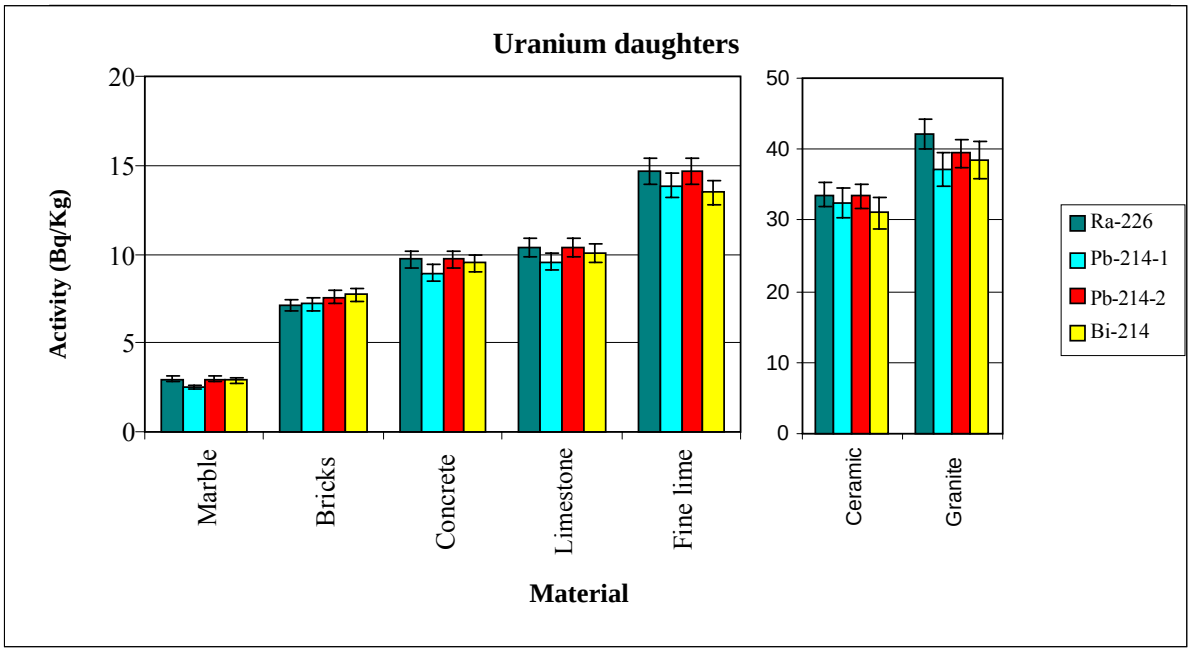


Fig.2. Activity concentrations of the ^{238}U daughters.

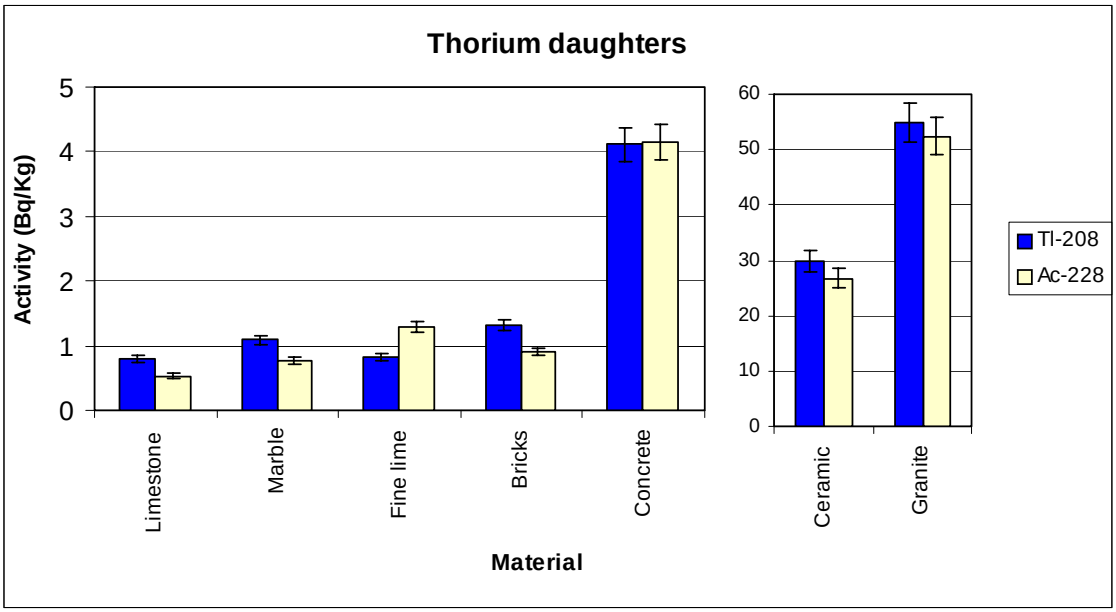


Fig.3. Activity concentrations of ^{232}Th daughters.

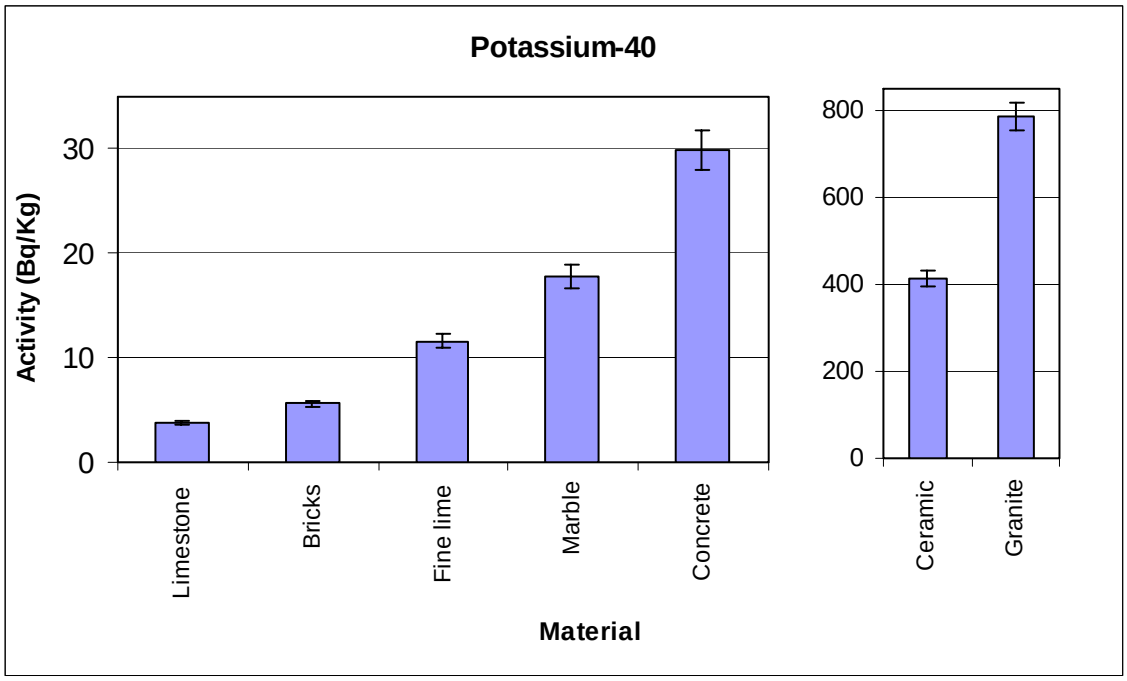


Fig.4. Activity concentrations of ^{40}K.

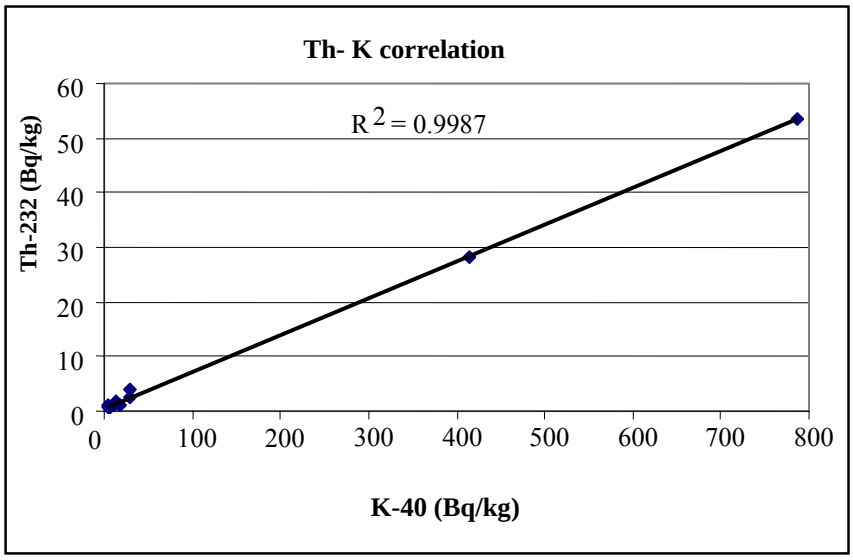


Fig.5. Correlation between ^{40}K and ^{232}Th.

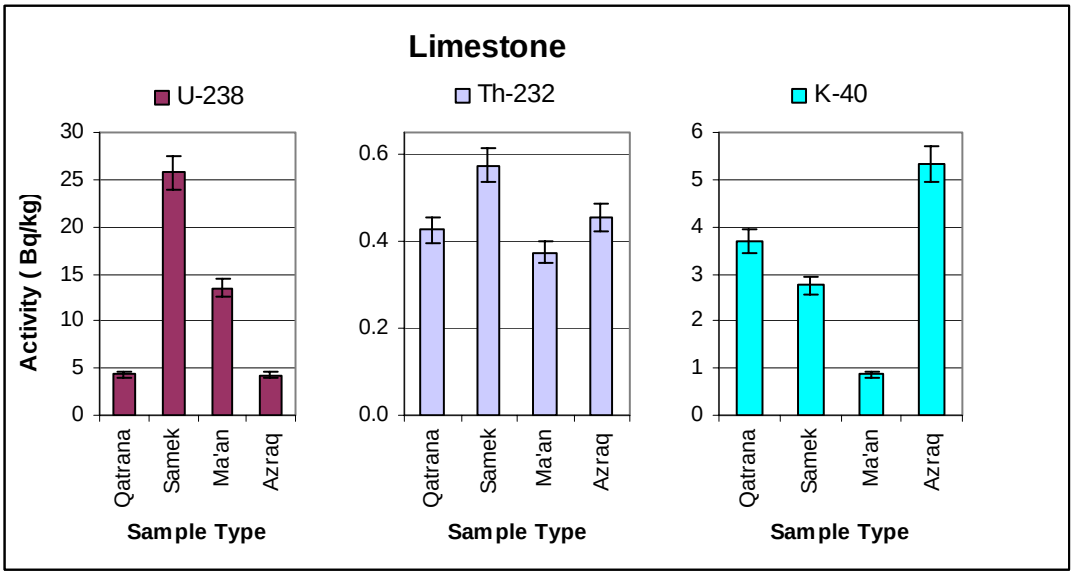


Fig.6. Activity concentrations of different radionuclides in limestone samples.

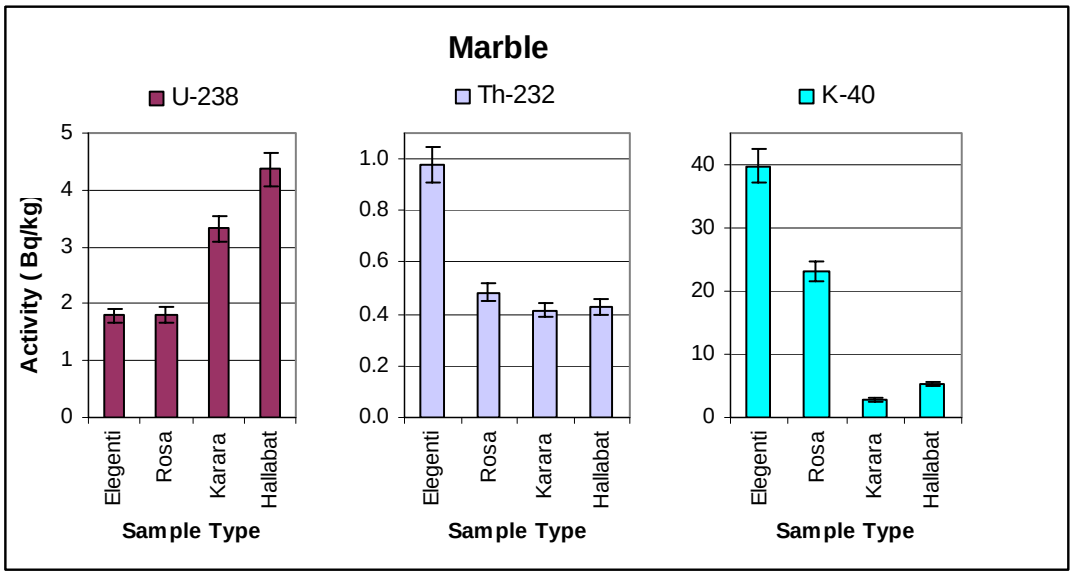


Fig. 7. Activity concentrations of different radionuclides in marble.

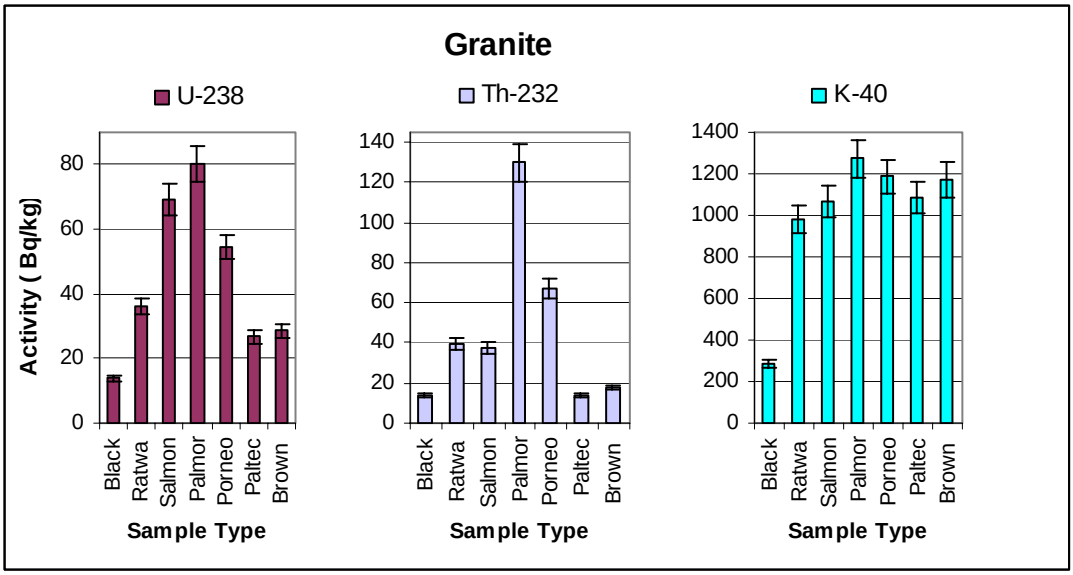
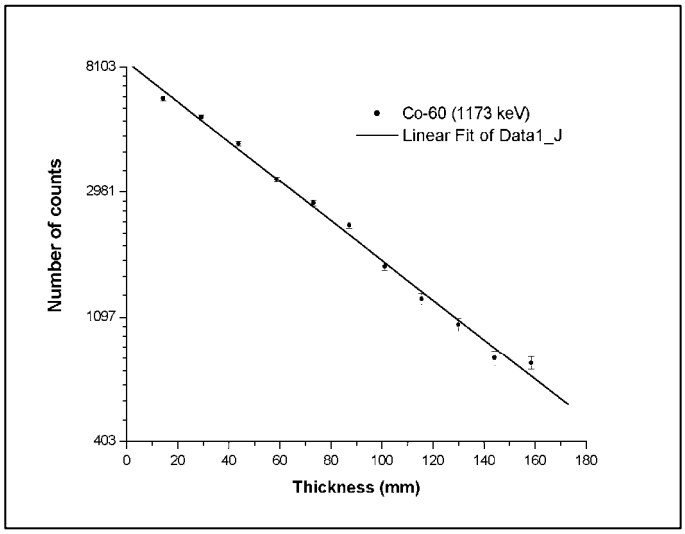


Fig. 8. Activity concentrations of different radionuclides in granite.



Linear Fit for Data1_J on linearized scales.
y scale (Y) = A + B * x scale (X)

A	9.0402	0.04202
B	-0.01493	8.06E-04

Fig.9. Linear fitting and fitting analysis of the above plot.

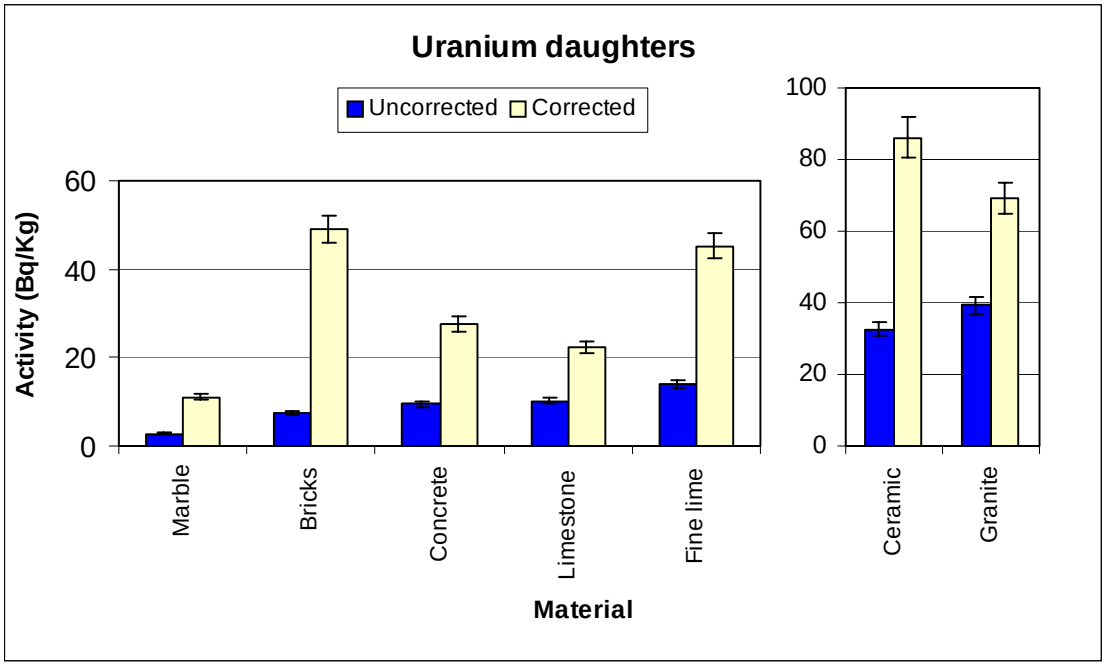


Fig.10. Average activity concentrations of ^{238}U before and after self-absorption correction.

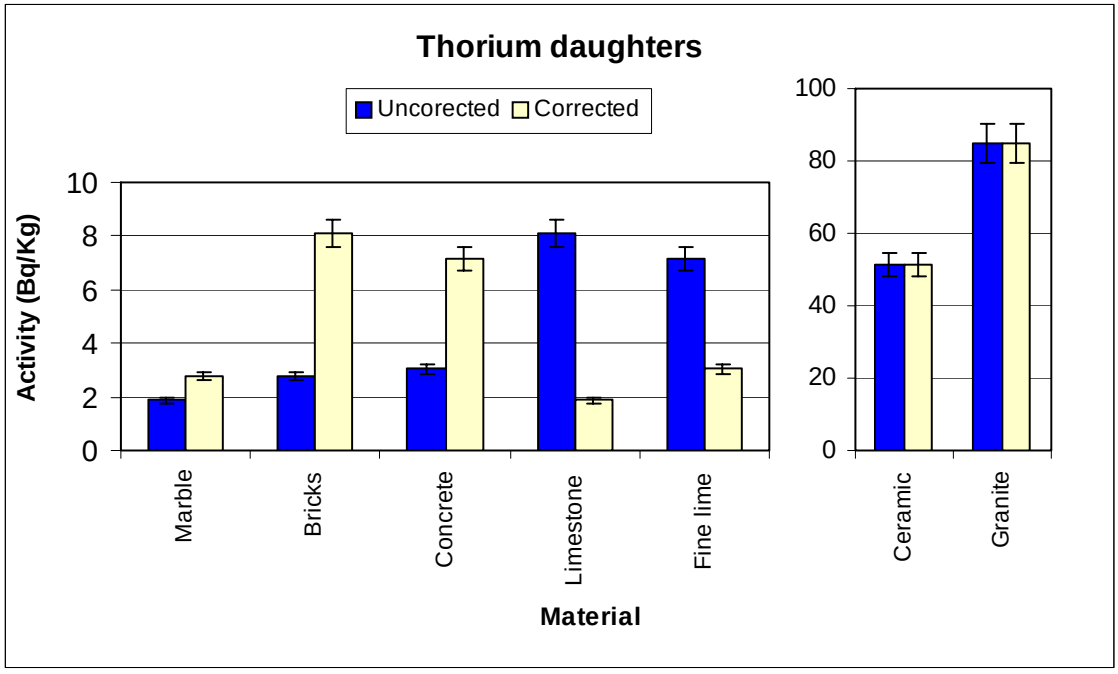


Fig.11. Average activity concentrations of ^{232}Th before and after self-absorption correction.

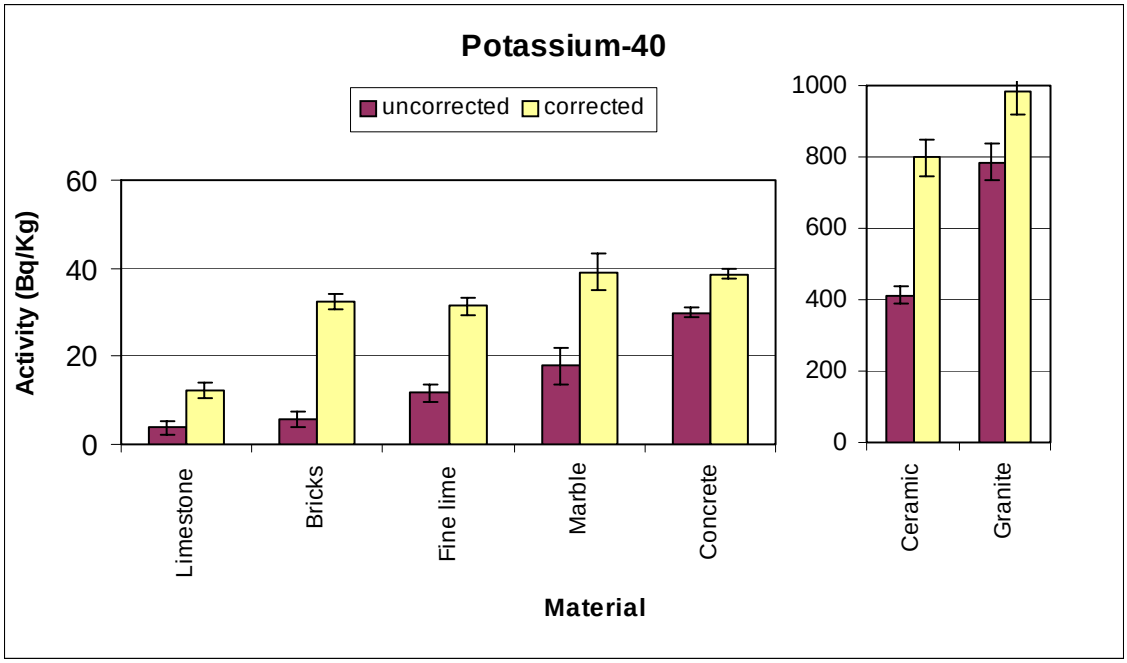


Fig.12. Activity concentrations of ^{40}K before and after self absorption correction.

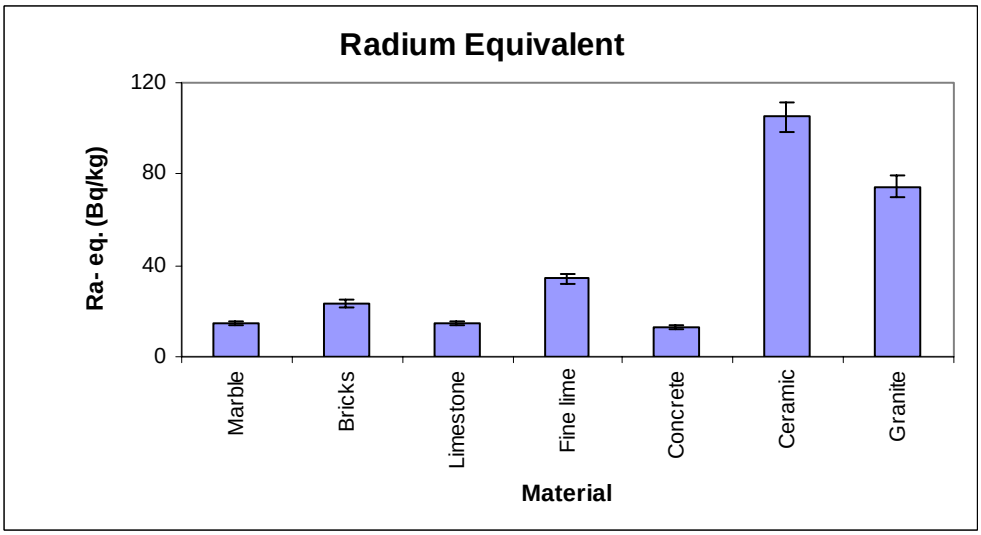


Figure 13. Radium equivalent of the studied construction materials without self-absorption correction.

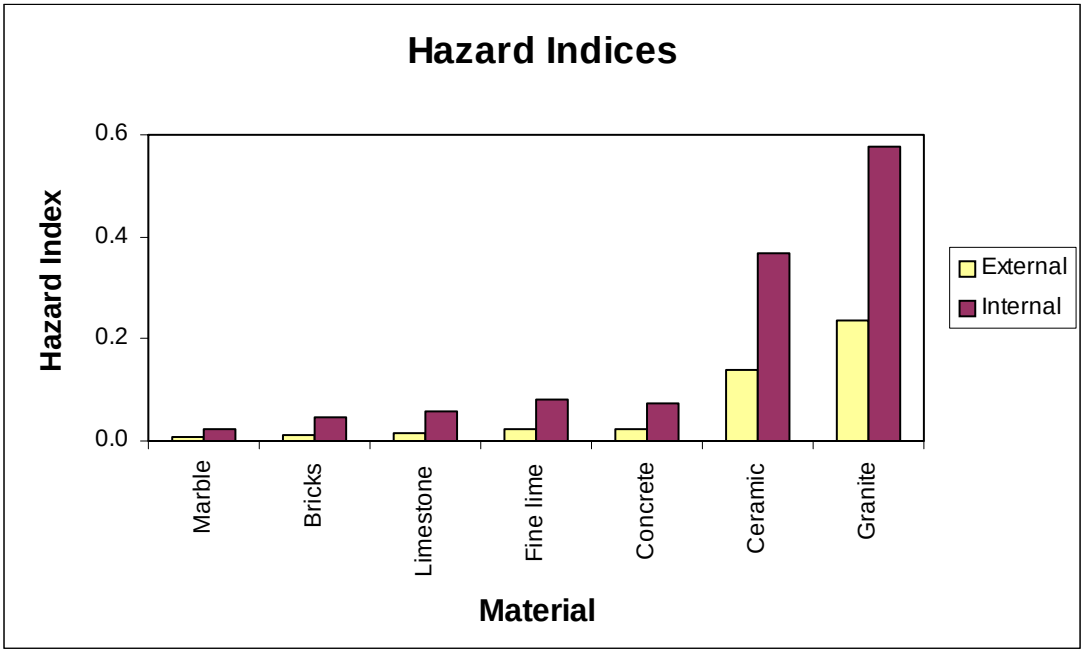


Figure 14. External and internal hazard indices of the studied samples without self-absorption correction.

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المحتوى الإشعاعي في مواد البناء المستخدمة في الأردن

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ملخـص

تمت دراسة المحتوى الإشعاعي لأنواع مختلفة من مواد البناء المستخدمة في الأردن بواسطة مطيافية جاما؛ إذ تم قياس تركيز نشاطية نويدات البوتاسيوم-40 واليورانيوم - 238 والثوريوم-232، في كل من الرخام، حجر البناء، الجرانيت، رمل البناء، السيراميك، الطوب والخرسانة، باستخدام مطياف الجرمانيوم عالي النقاوة. وتشير النتائج إلى أن الجرانيت لديه أعلى معدل لتركيز النشاطية ويبلغ 39.3 ± 2.2 بيكرل/كغم، 53.64 ± 3.22 بيكرل/كغم و786 ± 33.03 بيكرل/كغم لكل من اليورانيوم-238 والثوريوم-232 والبوتاسيوم-40، على الترتيب، وبذلك يتجاوز المعدلات العالمية المعروفة للثوريوم والبوتاسيوم وهي 50 بيكرل/كغم و500 بيكرل /كغم، على الترتيب. ويأخذ الامتصاص الداخلي لأشعة جاما في الاعتبار، تم تصحيح النتائج بحساب معاملات توهين أشعة جاما بطاقات مختلفة في العينات المدروسة، ونتج عن ذلك زيادة في نشاطية كل المواد. كما تم أيضا حساب النشاطية المكافئة للراديوم ومعاملي الخطورة الخارجي والداخلي، لتقييم الخطورة الإشعاعية للمواد المذكورة. وقد وجد أن النشاط الإشعاعي لجميع المواد يقع تحت الحد العالمي البالغ 370 بيكرل/كغم.

* مختبر القياسات الإشعاعية، قسم العلوم الأساسية، كلية الأمير عبد الله بن غازي للعلوم وتكنولوجيا المعلومات، جامعة البلقاء التطبيقية، السلط، الأردن. تاريخ استلام البحث 2006/2/15، وتاريخ قبوله 2006/10/8.