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Natural Radioactivity in Building Materials from Kirkuk City of Iraq

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Abstract: The natural radioactivity concentrations in 10 samples from different raw and construction materials in Kirkuk city of Iraq were measured using a hyper purity germanium (HPGe) detector. The determined average values of the specific activity were 38.68 Bq/kg (^{226}Ra), 11.84 Bq/kg (^{232}Th), and 169.98 Bq/kg (^{40}K). The results have been compared with the acceptable worldwide average values and with those obtained in some other countries. Additionally, the calculated radiological hazard parameters have also been calculated. The radium equivalent activity Raeq was 85.008 Bq/kg, the absorbed gamma dose rate D was 40.517 nGy/h, the annual effective dose rate AEDE outdoor and indoor were 0.051 and 0.198 respectively, the external hazard Hex was 0.220, the internal hazard Hin was 0.298, and the Gamma radiation representative level Index Iγ was 0.633. There are some materials which have values slightly higher than the internationally allowable values.

Keywords: Natural radioactivity, Building materials, Radiation pollution, HPGe detector.

1 Introduction

Raw and construction materials such as cement, sand, marbles, etc. cause radiation pollution due to their natural radionuclide content. From the radiological point of view, the most important primordial radionuclides are of ^{238}U-series ($t_{1/2} = 4.47\times10^9$ years), ^{232}Th-series ($t_{1/2} = 1.41\times10^{10}$ years) and non-series ^{40}K ($t_{1/2} = 1.28\times10^9$ years) [1]. All these can be sources of both internal and external radiation exposure. Internal exposure occurs through the inhalation of radon gas, and external exposure occurs through the emission of penetrating gamma rays [2]. In general, the average annual effective dose to an individual resulting from natural background radiation is estimated to be 2.4 mSv [3].

Inspection of the level of radioactive levels in building materials is important for assessment of the exposure to natural radiation. Varied studies regarding building materials have been conducted in the literature, for example, in the Brazil [4], Ireland [2], European Union [5], Latvia [6], Palestine [7], Algeria [8], Saudi Arabia [9], Turkey [10], Iran [11], and Iraq [12].

The paper aims to measure the specific activity of the naturally occurring radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) found in commonly used building materials in Kirkuk-Iraq, and to evaluate the associated potential health hazards.

2 Experimental Section

2.1 Experimental procedures

Ten samples of raw and construction materials were collected from Kirkuk city of Iraq. The collected samples were mixed, sieved with 0.2 mm mesh, and dried. The samples were packed and left for at least 4 weeks to ensure that radioactive equilibrium between radon and its decay products.

All samples were analyzed using a low background HPGe detector of the crystal of 50 mm diameter with acquisition time 7200s. Energy calibration and detection efficiency have been conducted each week to ensure that they were stable during the research period as part of quality control procedures. These two parameters of the detector were carried out by using the mixed radionuclide source (^{241}Am, ^{109}Cd, ^{57}Co, ^{60}Co, and ^{137}Cs); energy (59.5, 88,122, 1173, 1332 and 6616 keV, respectively) of mass 441.0 g, volume 450.0 ± 4.5 cm^3, and density 0.98± 0.01 g/cm^3.

2.2 Calculations

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The specific activity of the radionuclides was obtained using [13],

$$A(Bq/kg) = \frac{Counts/sec}{\varepsilon \times I_\gamma \times m(kg)} \quad (1)$$

Where ε is the gamma peak efficiency and I_γ is the gamma intensity of the corresponding peak [14].

The Ra_{eq} index is a convenient index compared with the specific activities of samples containing different activity concentrations of ^{226}Ra, ^{232}Th. and ^{40}K [15],

$$Ra_{eq}(Bq/kg) = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (2)$$

The external exposure from natural radiation of radionuclides can be determined in terms of the absorbed gamma dose rate (D) as follows [16-18],

$$D(nGy\,h^{-1}) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \quad (3)$$

The H_{ex} used to evaluate a potential hazard which is associated with non-radiological and radiological effects, and is given by [19, 20],

$$H_{ex} = \left(\frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810}\right) \le 1 \quad (4)$$

The internal exposure to radon and its daughter progenies is quantified by the internal hazard index (H_{in}). It is given by [21-22],

$$H_{in} = \left(\frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810}\right) \le 1 \quad (5)$$

The I_γ is used to estimate the level of gamma radiation associated with different concentrations of some specific radionuclides, can be defined as follows [23]:

$$I_\gamma = \left(\frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500}\right) \quad (6)$$

The I_γ can be used to estimate the level of γ radiation hazard associated with the natural radionuclide in the materials. Its value must be less than unity in order to keep the radiation hazard safe.

The radionuclides concentrations can be estimated by the average outdoor conversion coefficient from absorbed dose rate in the air and the average annual effective dose equivalent (AEDE). According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000) reports [16], a value of 0.7 Sv/Gy was used for the conversion coefficient from the absorbed dose in the air to the effective dose received by adults, and 0.2 for the outdoor occupancy factor. The components of the annual effective dose in mSv/y are determined as follows [23],

$$AEDE_{out} = \text{Dose Rate}\left(\frac{nGy}{h}\right) \times 0.7\left(\frac{Sv}{Gy}\right) \times 0.2 \times 8760(h/y) \times 10^{-6} \quad (7)$$

$$AEDE_{in} = \text{Dose Rate}\,(nGy/h) \times 0.7\,(Sv/Gy) \times 0.8 \times 8760(h/y) \times 10^{-6} \quad (8)$$

The corresponding worldwide values are 0.08 and 0.42 mSv respectively.

3 Results and Discussion

The specific activities (Bq/kg) of ^{226}Ra, ^{232}Th and ^{40}K radionuclides for the studied samples are listed in Table 1 and illustrated in the Figs. 1-3. For ^{226}Ra, the highest value is obtained in sample B4 (81.8 Bq/kg), the minimum value was obtained in sample B10. The highest value of ^{232}Th was 29.8 Bq/kg with an average of 11.84 Bq/kg. The specific activity of ^{40}K was ranged from 11.2 Bq/kg (sample B9) to 530.0 Bq/kg (sample B4), with an average value of 196.98 Bq/kg. These differences were also attributable to the differences in the origin of the samples under investigation. The differences are significant in all samples, but all were lower than the worldwide average value given by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 1993) [1]. The obtained average values fall within the range of corresponding world values and other published results mentioned in Table 2.

Table 1. Specific activities (Bq/kg) of ^{226}Ra, ^{232}Th and ^{40}K for the studied samples.

Sample	Code	^{226}Ra Bq/kg	^{232}Th Bq/kg	^{40}K Bq/kg
Turkish Brick	B1	31.8	18.8	344.4
Iraqi Brick	B2	42.6	15.0	270.0
Turkish ceramic	B3	55.2	29.8	237.0
Iranian ceramic	B4	81.8	19.6	530.0
Spanish ceramic	B5	32.4	14.5	251.2
Portland Iraqi cement 1	B6	27.6	6.6	101.0
Portland Iraqi cement 2	B7	32.8	7.0	120.2
Portland Iraqi cement 3	B8	46.6	7.1	91.2
Turkish Marble	B9	36.0	BDL	11.2
Iraqi gypsum	B10	BDL	BDL	13.6
Average		38.68	11.84	196.98
Worldwide Average Value		50	50	500

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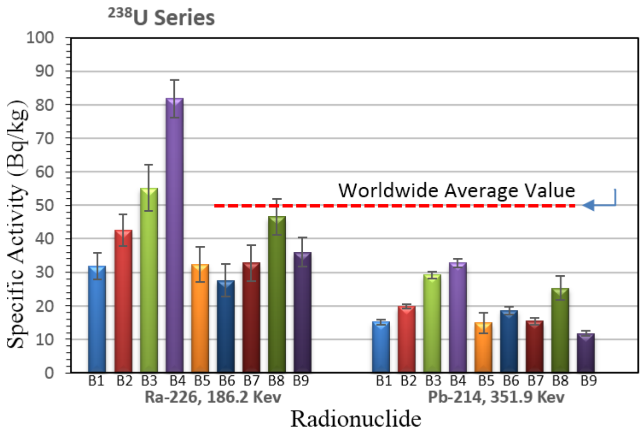

Figure 1. Comparison of the specific activity of ^{238}U-series for the investigated samples with the worldwide average value [1].

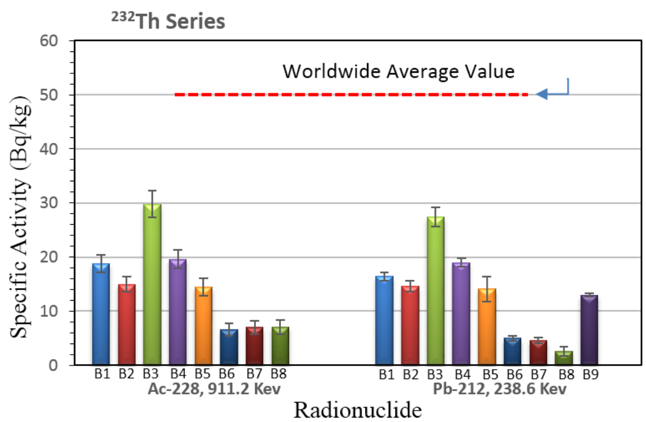

Figure 2. Comparison of the specific activity of ^{232}Th for the investigated samples with the worldwide average value [1].

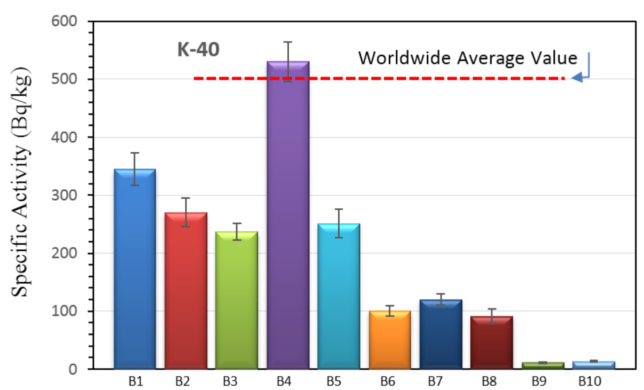

Figure 3. Comparison of the specific activity of ^{40}K for the investigated samples with the worldwide average value [1].

Table 2. The natural radioactivity levels in the studied samples compared with those of other countries.

Country	Specific Activity Bq/kg		
	^{226}Ra	^{232}Th	^{40}K
Brazil [4]	5.7-111	3.5-1256	11-1823
Ireland [2]	<1-139	<1-56.9	4.1-1281
European Union [5]	0-1000	1-258	0-3200
Latvia [6]	5.6-40	2.3-87	25-810
Palestine [7]	18.6-151.2	28.8-211	400-1256.8
Algeria [8]	12-65	7-51	36-675
Saudi Arabia [9]	0.36-32.4	0.10-32	0.68-897.1
Turkey [10]	18-143	5-66	142-540
Iran [11]	26-38	24-36	100-152
Iraq [12]	18.7-346	6.1-160	19.08-1182.14
Worldwide Average Value [1]	50	50	500
Our Study	27.6-81.8	6.6-29.8	11.2-530

The obtained radiological hazard indices are listed in Table 3. The Ra_{eq} for the samples was between 33.851 Bq/kg in sample B3 to 183.092 Bq/kg in sample B1 with an average value of 85.008 Bq/kg. All values were within and less the permissible limits of 370 Bq/kg [24-25].

The calculated absorbed gamma dose rate D varied from 16.224 to 87.079 nGy/h with an average value of 40.517 nGy/h. The value of sample B1 (Turkish brick) was higher than the international recommended value 55 nGy/h [24-25].

The calculated external hazard indexes (H_{ex}) varied from 0.088 (sample B3) to 0.475 (sample B1) with an average value of the 0.220. The calculated average values were less than 1. The internal exposure by radon and its progeny was controlled by the internal hazard index (H_{in}). The H_{in} ranged between 0.123 (sample B3) and 0.649 (sample B1) with an average value of the 0.298. The average values were less than 1.

The obtained I_γ values for all the samples were presented in Table 3. The values were ranged from 0.252 (sample B1) to 1.359 (sample B3) with an average of 0.633. All the obtained values were lower than 1.

The calculated indoor and outdoor AEDE values are also displayed in Table 3. The maximum of outdoor and indoor effective dose were obtained in sample B1: 0.110 and 0.427, respectively. It can be seen that the values of Turkish brick were higher than the corresponding worldwide recommended values of 0.08 and 0.42 mSv, respectively [25].

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Table 3. The obtained radiological hazard indices of the investigated samples. (RV: Recommended values)

Sample	Ra_{eq} (Bq/Kg)	D (nGy/h)	H_{ex}	H_{in}	I_γ	AEDE (mSv/y)	
						Out	In
B1	183.092	87.079	0.475	0.649	1.359	0.110	0.427
B2	115.665	55.117	0.300	0.411	0.860	0.069	0.270
B3	33.851	16.224	0.088	0.123	0.252	0.020	0.079
B4	47.692	22.719	0.124	0.178	0.352	0.028	0.111
B5	106.316	51.013	0.274	0.342	0.806	0.064	0.250
B6	56.207	26.762	0.147	0.218	0.412	0.033	0.131
B7	69.425	32.840	0.178	0.225	0.519	0.041	0.161
B8	46.647	22.110	0.120	0.161	0.346	0.027	0.108
B9	81.805	39.505	0.214	0.296	0.614	0.050	0.193
B10	109.382	51.801	0.282	0.374	0.813	0.065	0.254
Average	85.008	40.517	0.220	0.298	0.633	0.051	0.198
RV	370	55	≤1	≤1	≤1	0.08	0.42

4 Conclusion

Most of the specific activities (Bq/kg) of ^{226}Ra, ^{232}Th and ^{40}K radioisotopes for the studied samples were lower than the world average values with some exceptions which were described in figures and tables of this study. The averages values of the calculated radiological hazard parameters: the obtained radiation hazard levels such as: the radium equivalent (Ra_{eq}), the absorbed gamma dose rate (D), the external (H_{ex}) and the internal (H_{in}) hazard index, the radioactivity level index (I_γ) and the indoor and outdoor annual effective dose equivalent (AEDE) were within or near the limit of the international recommended values. It can be seen from the study that all the investigated samples expect for Turkish brick don't have any significant radiological risk.

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