

Assessment of Natural Radioactivity Levels and Radiological Hazards of Cement in Iraq

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Abstract: Eight samples of cement were collected from different commercial factories (Al-Koufa, Al-Basra, Al-Najaf and Kerkouk factories) located in Iraq. They were analyzed using a gamma ray spectroscopy system. The activity concentrations of ²²⁶Ra, ²³²Th and ⁴⁰K were ranged from 5.8 to 43.17 Bq kg⁻¹, from 0.99 to 55.79 Bq kg⁻¹ and from 53.28 to 185.34 Bq kg⁻¹, respectively. The potential radiological hazards were assessed by calculating the radium equivalent activity (Ra_{eq}), the indoor absorbed gamma dose rate (D), the annual effective dose equivalent (AEDE), the alpha index (I_α), the gamma index (I_γ), and the external hazard (H_{ex}) and internal hazard (H_{in}) indices. The highest value of Ra_{eq} is estimated of 101.36 Bq kg⁻¹, which is significantly less than the upper limit of 370 Bq kg⁻¹. The estimated maximum value of the absorbed gamma dose rate of 54.71 nGy h⁻¹ is within the world average value of 55 nGy h⁻¹, and the annual effective dose equivalent in the studied samples were 0.05 (outdoor), 0.18 (indoor) mSv y⁻¹, which is lower than the recommended limit reported in the UNSCEAR (2000). The values of the hazard indices were below the recommended levels; therefore, the study shows that the measured radioactivity for cement does not pose as significant source of radiation hazard and is safe for use in the construction of dwellings.

Keywords: Gamma Ray Spectroscopy, Building Materials, Hazard Index

1. Introduction

The human population is always exposed to ionizing radiation due to background radiation. The main source of background radiation is naturally occurring radioactive materials (NORM). The natural radioactivity in soil and building materials mainly comes from uranium (²³⁸U) series, thorium (²³²Th) series and a radioactive isotope of potassium (⁴⁰K) (These radionuclides can be found almost in all types of rocks, sand, cement and gypsum from which building materials are produced) [1-3]. All of these natural sources of radioactivity can be sources of both internal and external radiation exposure. Internal exposure occurs through the inhalation of radon gas and its progeny, which emit alpha particles, are the most significant radionuclides that diffuse from building materials into the indoor environments. The radionuclide ²²⁶Ra, with a half-life of 1600 years [4], is a source of the radioactive inert gas radon (²²²Rn), which emits alpha and beta particles, followed by gamma radiation. And external exposure occurs through the emission of penetrating

gamma rays from radioactive sources. Therefore, it is important to measure the radioactivity levels in the built-up areas to assess the radiological consequences [5, 6]. It is known that the cement is a large part of most buildings and as most people spending approximately 80% of their lifetimes surrounded by building materials at home and/or at the office [7]. Therefore, it is important to know the radioactivity in building materials, especially the cement to estimate radiation risks to human health

The knowledge of the radioactivity present in construction materials helps to assess the possible radiological hazards to human health and develop the standards and guidelines for the use and management of these materials.

In this study, the concentrations of natural radionuclides were measured in 8 samples of cement from national commercial factories in Iraq, by means of gamma ray spectrometry, with the aim of assessing the radiological hazards due to external gamma ray exposure in dwellings.

The potential radiological hazards associated with these materials were assessed by calculating the radium equivalent activity (Ra_{eq}), the indoor absorbed gamma dose rate (D), the annual effective dose equivalent (AEDE), the activity utilization index, the external hazard (H_{ex}), the gamma index (I_γ), internal hazard (H_{in}) and the alpha index (I_α) indices.

2. Laboratory Measurements

2.1. Sampling

Eight samples of cement (the common building material) were collected from eight different commercial factories located in Iraq. The sampling locations were chosen according to the factories. Four locations in the district were chosen for this investigation, Al-Koufa, Al-Basra, Al-Najaf and Kerkouk. The cement samples were taken directly from the factories in these governorates that was studied in its natural form. Each sample was properly marked and coded according to its origin and the location of the sampling site. The collected samples were dried in an oven at 80°C for 8 hours to remove the moisture from the samples. Approximately 500g of each sample was sealed into a Marinelli beaker and stored for a period of 30 days at room temperature to allow secular equilibrium between ^{226}Ra and its progeny species to be achieved prior to gamma spectroscopy [8].

2.2. Radionuclide Analysis

The activity concentrations of ^{238}U , ^{232}Th and ^{40}K of the collected samples were measured using gamma spectrometry system. These measurements were occurred at Iraq- the Ministry of Science & Technology. The Gamma spectrometry system consist of High-Purity Germanium (HPGe) detector with an efficiency of (40%) and resolution 2 keV at 1.332 MeV gamma ray photo peak of ^{60}Co source, the data are collected using digital spectrum analyzer (DSA-2000). Calibration and efficiency of the system was carried out using multi-gamma ray standard sources (MGS-5 Canberra, activity 1.1 μCi , made in 2004) of Marinelli Beaker geometry. The analysis samples were conducted by dedicated software programme (Genie-2000, USA). Each sample was measured for one hour [9].

3. Estimation of Radiation Hazard Indicators

To assess the excess gamma radiation originating from building materials, several hazard indices have been suggested by a number of investigators; these calculations include the absorbed gamma dose rate in the indoor environment and the corresponding annual effective dose equivalent, the radium equivalent activity, the external and internal hazard indices, the alpha index (internal index) and the gamma activity concentration (gamma index). In the present study, the aforementioned hazard indicators were

estimated for individuals living in domestic dwellings and for individuals at the workplace to evaluate the potential radiation risks arising from the use of the studied building materials.

3.1. Assessment of the Radium Equivalent Activity (Ra_{eq})

The relative concentrations of ^{226}Ra , ^{232}Th and ^{40}K are not uniform in environmental media. Accordingly, the distributions of the ^{226}Ra , ^{232}Th and ^{40}K radionuclides were not found to be uniform in the studied building materials. A non-uniform distribution of radioactivity in materials containing Ra, Th and K can be modelled using a general index Ra_{eq} (radium equivalent activity), Ra_{eq} was computed using Eq (1) [10, 11].

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (1)$$

Where A_{Ra} , A_{Th} and A_K (in Bq kg^{-1}) are the activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K , respectively. Eq (1) is based on the assumption that 1 Bq kg^{-1} of ^{238}U , 0.7 Bq kg^{-1} of ^{232}Th and 13 Bq kg^{-1} of ^{40}K produce the same gamma-ray dose rates [10].

3.2. Absorbed Gamma Dose Rate (D)

The outdoor absorbed dose rate (nGy h^{-1}) in air from terrestrial gamma radiation at 1 m above the ground is calculated after applying the conversion factors (in nGy h^{-1} per Bq kg^{-1}) to transform the specific activities A_{Ra} , A_{Th} and A_K into the absorbed dose rate according to the formula provided by UNSCEAR and European Commission [12, 13].

$$D (\text{nGy h}^{-1}) = 0.5A_{Ra} + 0.75A_{Th} + 0.05A_K \quad (2)$$

3.3. Annual Effective Dose Equivalent (AEDE)

To estimate the annual effective dose rate, it is necessary to use the conversion coefficient from the absorbed dose in air to the effective dose (0.7 Sv Gy^{-1}) and the outdoor and indoor occupancy factor 0.2 and 0.8, respectively, proposed by UNSCEAR [14]. Therefore, the effective dose rate is determined as follows [12]:

$$\text{Outdoor: } (\text{mSv y}^{-1}) = D (\text{nGy h}^{-1}) \times 8760\text{h} \times 0.2 \times 0.7 \text{ Sv Gy}^{-1} \times 10^{-6} \quad (3)$$

$$\text{Indoor: } (\text{mSv y}^{-1}) = D (\text{nGy h}^{-1}) \times 8760\text{h} \times 0.8 \times 0.7 \text{ Sv Gy}^{-1} \times 10^{-6} \quad (4)$$

Where D is the dose rate in nGy h^{-1} .

3.4. Hazard Indices

3.4.1. Hazard Indices for External Gamma Radiation (H_{ex} & I_γ)

For the assessment of excess gamma radiation, to assess gamma radiation for building materials, two indices were used in this paper. The hazard index for the external gamma radiation dose from building materials as given below [10]:

$$H_{ex} = A_{Ra}/370 + A_{Th}/259 + A_K/4810 \quad (5)$$

The value of Hex should be below 1 to ensure the safe use of building materials, which corresponds to the upper limit of Raeq (370 Bq kg⁻¹). The European Commission (EC) proposed an index called the gamma index (I_γ) to verify whether the guidelines of EC for building material usage are met. I_γ is calculated using the following formula [13]:

$$I_{\gamma} = A_{Ra} / 300 + A_{Th} / 200 + A_K / 3000 \leq 1 \quad (6)$$

3.4.2. Hazard Indices for Internal Alpha Radiation (Hin & Ia)

Internal exposure arises from the intake of terrestrial radionuclides by inhalation and ingestion. Doses by inhalation result from the presence in air of dust particles containing radionuclides of the ²³⁸U and ²³²Th decay chains. The dominant components of inhalation exposure are the short-lived decay products of radon (²²²Rn). In addition to the external hazard, radon and its short-lived products are also hazardous to the respiratory organs. To assess the internal exposure to ²²²Rn gas and its daughter products the internal hazard index has been defined by the following formula [10]:

$$H_{in} = A_{Ra} / 185 + A_{Th} / 259 + A_K / 4810 \quad (7)$$

This quantity should be less than unity for the safe use of materials in the construction of buildings. Excess alpha radiation caused by the inhalation of radon liberated from building materials can be estimated using the alpha index (I_α), which has been defined by the following formula [14]:

$$I_{\alpha} = A_{Ra} / 200 \leq 1 \quad (8)$$

4. Results & Discussion

The results obtained for the activity concentrations of ²²⁶Ra, ²³²Th and ⁴⁰K in the eight various cement samples are presented in Table 1. They were analysed by gamma-ray spectrometry system and ranged from 5.8 to 43.17 Bq kg⁻¹, with an average value 24.25 Bq kg⁻¹ for ²²⁶Ra, from 0.99 to 55.79 Bq kg⁻¹, with an average value 25.41 Bq kg⁻¹ for ²³²Th and from 53.28 to 185.34 Bq kg⁻¹, with an average value 93.17 Bq kg⁻¹ for ⁴⁰K.

Table 1. The radioactivity concentrations of ²²⁶Ra, ²³²Th and ⁴⁰K radionuclides in cement samples.

Sample Code	Sample Name	Radioactivity Concentration (Bq Kg ⁻¹)			Raeq (Bq Kg ⁻¹)
		²²⁶ Ra	²³² Th	⁴⁰ K	
CEM1	Kerkuk 1	9.43 ± 0.52	54.31 ± 7.75	185.34 ± 11.03	101.36
CEM2	Kerkuk 2	10.16 ± 0.66	26.07 ± 0.93	177.82 ± 10.11	61.13
CEM3	Basra 1	40.91 ± 4.65	2.03 ± 0.44	70.32 ± 6.4	49.23
CEM4	Basra 2	34.66 ± 3.54	0.99 ± 0.26	66.97 ± 6.12	41.23
CEM5	Najaf 1	42.85 ± 1.47	5.92 ± 0.71	56.34 ± 6.7	55.65
CEM6	Najaf 2	43.17 ± 1.32	5.74 ± 0.56	53.28 ± 6.03	55.48
CEM7	Kuffa 1	7.03 ± 0.46	52.43 ± 1.22	63.74 ± 5.89	86.91
CEM8	Kuffa 2	5.8 ± 0.55	55.79 ± 1.32	71.53 ± 6.09	91.09
	Average	24.25 ± 1.45	25.41 ± 1.65	93.17 ± 7.30	67.76

The calculated values of the radium equivalent activities (R_{eq}) for all the samples of cements are presented in Table 1 based on Eq.1. The highest value of R_{eq} estimated in CEM1 is 101.36 Bq kg⁻¹, which is significantly less than the upper limit of 370 Bq kg⁻¹ [10] and thus does not pose any radiological hazard when used for the construction of buildings. Figure 2 is shown the values of the radium equivalent activity in cement samples.

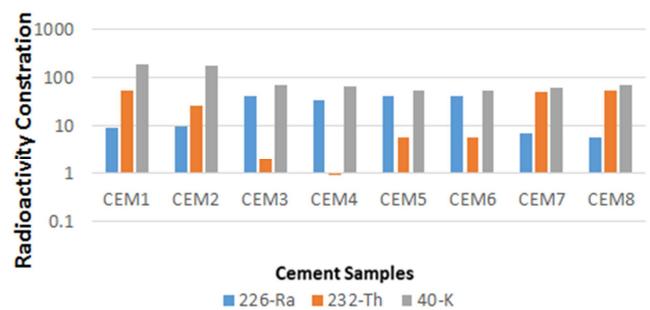


Figure 2. The values of radium equivalent activity in cement samples.

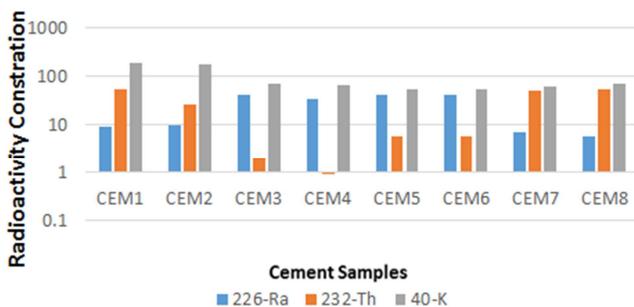


Figure 1. The radioactivity concentrations of ²²⁶Ra, ²³²Th and ⁴⁰K radionuclides in cement samples.

Table 2 is shown the value of the gamma dose rate (D) in air for the cement samples. Where the maximum gamma dose rate is 54.71 nGy h⁻¹ in CEM1 sample, while the minimum value found in CEM4 was approximately 21.42 nGy h⁻¹. The estimated mean value of D in the studied samples is 35.84 nGy h⁻¹, which is within the world average indoor absorbed gamma dose rate of 55 nGy h⁻¹ [12]. Figure 3 is shown the values of the absorbed dose rate with cement samples. The estimated mean value of the annual effective

dose equivalent (AEDE) which are presented in Table 2, based on Eq. 3 and Eq.4 were 0.05 (outdoor), 0.18 (indoor) mSv y⁻¹, respectively, are below the recommended limits for annual effective dose of the 1 mSv y⁻¹ approved by the

International Commission on Radiological Protection (ICRP) as the maximum annual dose to the members of the public [12]. Figure 4 is shown the various samples of cement along with the annual effective dose rate and hazard indices.

Table 2. The calculated values of absorbed dose rate, annual effective dose, alpha index, gamma index and hazard index, in sample.

Sample Code	Sample Name	(D) (nGy h ⁻¹)	(AEDE) (mSv y ⁻¹)		Hazard Index		Alpha Index	Gamma Index I _γ
			outdoor	indoor	H _{ex}	H _{in}	I _α	
CEM1	Kerkuk 1	54.71	0.07	0.27	0.27	0.30	0.05	0.36
CEM2	Kerkuk 2	33.52	0.04	0.16	0.17	0.19	0.05	0.22
CEM3	Basra 1	25.49	0.03	0.13	0.13	0.24	0.20	0.17
CEM4	Basra 2	21.42	0.03	0.11	0.11	0.21	0.17	0.14
CEM5	Najaf 1	28.68	0.04	0.14	0.15	0.27	0.21	0.19
CEM6	Najaf 2	28.55	0.04	0.14	0.15	0.27	0.22	0.19
CEM7	Kuffa 1	46.02	0.06	0.23	0.23	0.25	0.04	0.31
CEM8	Kuffa 2	48.32	0.06	0.24	0.25	0.26	0.03	0.32
Average		35.84	0.05	0.18	0.18	0.25	0.97	0.24

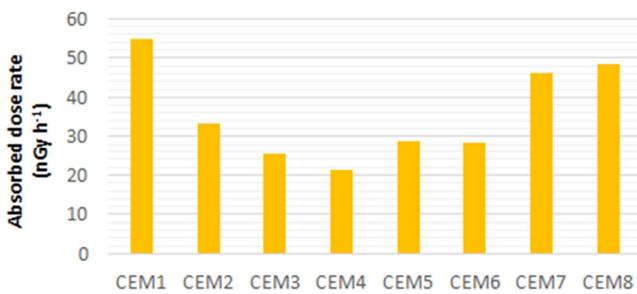


Figure 3. The values of the absorbed dose rate in the cement samples.

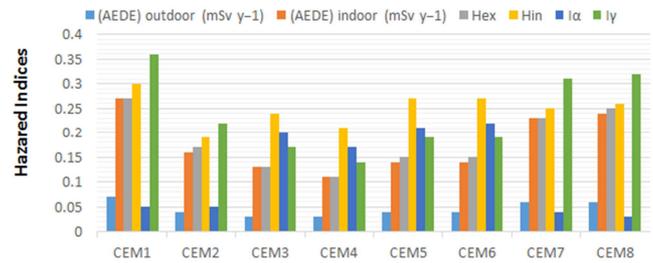


Figure 4. The values of AEDE (outdoor), AEDE (indoor), Hex, Hin, alpha index and gamma index in the cement samples.

In this study, the results of Hex based on Eq. (5) are given in Table 2. The values (Shows in Figure 4) range from 0.11 to 0.27, which means that all of them are below the recommended level of 1. The values of Hin based on Eq. (7) are presented in table 2. From the table, it can be seen that the values range from 0.19 to 0.30, which means that all of them are below the recommended level of 1 [10].

The computed values of the alpha and gamma indices (I_α and I_γ) are also given from Table 2. The highest values (Shows in Figure 4) of I_α and I_γ are 0.22 and 0.36, respectively, the obtained values of I_α and I_γ in the present study are lower than the recommended values of 1 [13].

In Table 3, the mean values of the activity concentrations of ²²⁶Ra, ²³²Th and ⁴⁰K and the radium equivalent activities (Raeq) determined in the current study for the cement samples are compared with other countries. The activity levels vary from one country to another, which can be attributed to differences in the contents of radioactive minerals and in the geological, geochemical and geographical origins of the raw materials, among other factors. This fact is important to consider in the section of suitable materials for use in building construction, especially those that exhibit large variations in their activities.

Table 3. Comparison of mean radioactivity concentrations of ²²⁶Ra, ²³²Th and ⁴⁰K and Raeq activity (Bq kg⁻¹) in cement samples with some other countries of the world.

Country	Radioactivity Concentration (Bq kg ⁻¹)		
	²²⁶ Ra	²³² Th	⁴⁰ K
Present study	24.25	25.41	93.17
Bangladesh [16]	61.1 ± 0.8	79.9 ± 1.2	1132.6 ± 17.3
China [17]	68.3 ± 3.6	51.7 ± 5.4	173.8 ± 8.6
Egypt [18]	134 ± 67	88 ± 35	416 ± 162
Pakistan [19]	37 ± 3	28 ± 3	200 ± 14
Turkey [20]	49.8 ± 5.8	17.3 ± 2.2	246.2 ± 20.8
Vietnam [21]	39.86±17.43	39.86±17.43	243.5±62.2
India [22]	54±13	65±10	440±91

5. Conclusion

Gamma ray spectrometry was used to determine the radioactivity concentrations of ²²⁶Ra, ²³²Th and ⁴⁰K in the

studied samples of cement from the cement factories, Iraq. The results show that the activity concentrations of ²²⁶Ra, ²³²Th and ⁴⁰K were in the range of the typical world value. The radium equivalent activity, absorbed gamma dose rate in indoor air and the corresponding annual effective dose

equivalent, the external and internal hazard indices, the alpha index (internal index) and the gamma activity concentration (gamma index) of the radiological parameters were calculated to qualify and quantify the radiological hazard associated with the studied cement. Hence, it is concluded that the radiological parameters obtained are normal and within the recommended limits. Therefore, the use of this cement samples under investigation in the construction of dwellings is considered to be safe for inhabitants.

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