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Radiation dose estimation and mass attenuation coefficients of cement samples used in Turkey

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ABSTRACT

Different cement samples commonly used in building construction in Turkey have been analyzed for natural radioactivity using gamma-ray spectrometry. The mean activity concentrations observed in the cement samples were 52, 40 and 324 Bq kg^{-1} for ^{226}Ra, ^{232}Th and ^{40}K, respectively. The measured activity concentrations for these radionuclides were compared with the reported data of other countries and world average limits. The radiological hazard parameters such as radium equivalent activities (Ra_{eq}), gamma index (I_γ) and alpha index (I_α) indices as well as terrestrial absorbed dose and annual effective dose rate were calculated and compared with the international data. The Ra_{eq} values of cement are lower than the limit of 370 Bq kg^{-1}, equivalent to a gamma dose of 1.5 mSv y^{-1}. Moreover, the mass attenuation coefficients were determined experimentally and calculated theoretically using XCOM in some cement samples. Also, chemical compositions analyses of the cement samples were investigated.

1. Introduction

Materials derived from rock and soil contain mainly natural radionuclides of the uranium (^{238}U) and thorium (^{232}Th) series, and ^{40}K. In the uranium series, the decay chain segment starting from radium (^{226}Ra) is radiological the most important and, therefore, reference is often made to radium instead of uranium. Naturally occurring radionuclides in building materials are sources of external and internal radiation exposure in dwellings. The external exposure is caused by direct gamma radiation. The internal radiation exposure, affecting the respiratory tract, is due to radon and its daughters which emanate from building materials, water, soil and beneath the earth [1]. The worldwide mean concentrations in the building materials are given as follows: ^{226}Ra (50 Bq kg^{-1}), ^{232}Th (50 Bq kg^{-1}) and ^{40}K (500 Bq kg^{-1}) [2].

Knowledge of basic radiological parameters such as radioactive contents and attenuations coefficients in building materials is important in the assessment of possible radiation exposure to the population as most people spend about 80% of their life inside houses and offices [3]. This knowledge is essential for the development of standards and guidelines for the use of these materials.

The mass attenuation coefficients are determined by performing transmission experiment in narrow beam geometry. Theoretical values for the mass attenuation coefficients are calculated by XCOM program which was developed by Berger and Hubbell [4] for calculating mass attenuation coefficients or photon interaction cross-section for any element, compound or mixture at energies 1 keV to 100 GeV. There are some earlier works in studying mass attenuation in building materials [5,6].

Cement that is commonly used in building materials is considered as one of the basic industries which play an important role in the economy of Turkey. The main objectives of the present study were to determine natural (^{226}Ra, ^{232}Th and ^{40}K) radioactivity levels and mass attenuation coefficients, and to estimate the radiological hazards associated with natural radioactivity from cement samples used in building materials in Turkey. Although there is a publication giving the activity concentration results in some cement samples used as building materials in Turkey [7], in the current paper we present the activity concentration results in the cement samples in region scale giving the mass attenuation coefficients and chemical analysis. The results obtained in the present study are also compared with the corresponding results available in some other countries of the world.

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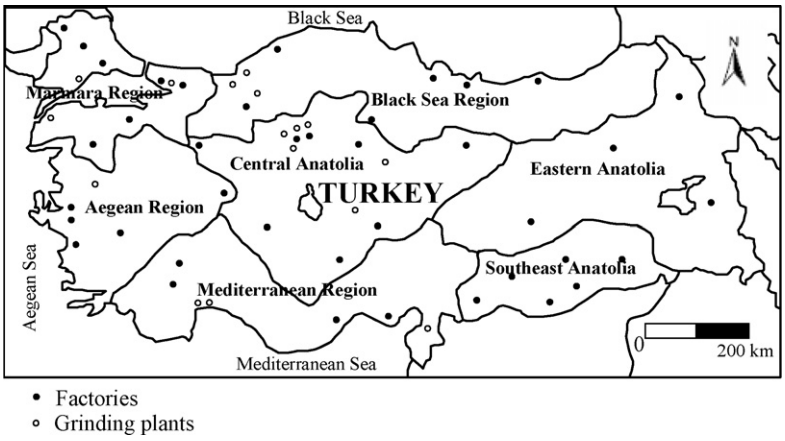

Fig. 1. Map of the sampling sites in Turkey.

2. Materials and methods

2.1. Sampling

In this study, six different cement types named CEM I: Portland cement, CEM II: Portland-composite cement, CEM IV: pozzolanic cement, CEM V: composite cement, SDC: sulphate resistant cement and BPC: white cement were used which were the most common and standardized to TS EN 197-1 [8].

Ninety-six cement samples were collected from a number of factories and grinding plants in different regions of Turkey as shown in Fig. 1.

2.2. Chemical analysis

EDXRF spectrometer (Epsilon5, PANalytical, Almelo, the Netherlands) was used for chemical analysis of cement samples. The cement samples were dried for 4 h at 105 °C to evaporate any remaining water. The pellets were pressed with a hydraulic press applying a pressure of 7 tones during 20 s. The resulting pellets have a diameter of 40 mm and a uniform mass of 500 ± 3 mg.

2.3. Radioactivity measurements

Each sample was homogenized and dried in a temperature controlled furnace at 105 °C for 24 h to remove moisture, and sieved through a 2 mm mesh. About 150 g of samples were sealed in gas tight, radon impermeable, cylindrical polyethylene plastic containers (5.5 cm diameter and 5 cm height) for gamma activity analysis. Before measurements, the containers were kept sealed for 4 weeks in order to reach the equilibrium of ^{226}Ra and its short lived progeny.

Gamma spectrometry measurements were conducted with a coaxial HPGe detector of 15% relative efficiency and a resolution of 1.9 keV at the 1332 keV gamma of ^{60}Co (Canberra, GC 1519 model). The detector was shielded in a 10 cm thick lead well internally lined with 2 mm Cu foils. The spectrum analysis was performed using computer software Genie 2000 obtained from Canberra. A performance test using the certified reference samples (IAEA-375, IAEA, Vienna) of known activities was conducted for checking the efficiency calibration of the system. The specific activities of these samples were in accordance with their certified values within errors not exceeding 10%. The quality assurance of the measurements was carried out by periodical efficiency and energy calibration and repeated sample measurement. The counting time for each sample was selected to be 50,000 s to obtain the gamma-spectrum with good statistics. To determine the background distribution in the environment around the detector, an empty container was counted in the same manner and in the same geometry as the samples. The background spectra were used to correct the net peak area of gamma rays of the measured isotopes [9,10].

The gamma-ray transitions of energies 351.9 keV (^{214}Pb) and 609.3 keV (^{214}Bi) were used to determine the activity concentration of the ^{226}Ra series. The gamma-ray lines at 911.1 keV (^{228}Ac) and 583.1 keV (^{208}Tl) were used to determine the activity concentration of the ^{232}Th series. The activity concentrations of ^{40}K were measured directly through the gamma line emission at 1460.8 keV.

The activity concentrations for the natural radionuclides in the measured samples were computed using the following relation:

$$C = \frac{N}{\varepsilon P M t}\ (\mathrm{Bq\,kg^{-1}}) \quad (1)$$

where N is the net counting rate of the gamma ray, ε is the photo peak efficiency of the used detector, P is the absolute transition of gamma decay, t is the counting time in seconds and M the weight of the dried sample in kilogram.

2.4. Mass attenuation measurements

In narrow beam geometry with the standard gamma-point sources placed one after the other at a distance of 20 cm from the end cap of the detector as shown in Fig. 2, the number of counts reaching the detector with and without the samples under study was recorded for a counting time of 10,000 s. The samples were irradiated by photons emitted from ^{109}Cd, ^{57}Co, ^{133}Ba, ^{54}Mn, ^{137}Cs, ^{60}Co and ^{22}Na radioactive sources in the energy range from 81

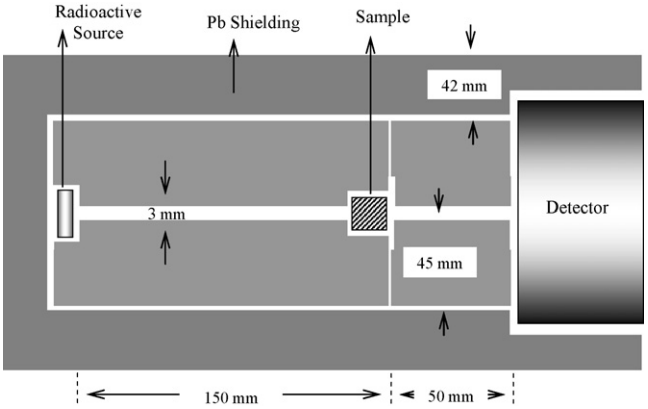

Fig. 2. Experimental setup for measuring mass attenuation coefficients.

Table 1
Chemical compounds of the cement samples.

Chemical compounds	Unit	Minimum	Maximum	Mean
Na_2O	%	ND	2.11	1.23
MgO	%	ND	3.71	1.70
Al_2O_3	%	7.69	15.5	11.9
SiO_2	%	25.9	43.8	35.1
SO_3	%	2.57	6.19	4.16
K_2O	%	0.33	1.58	0.99
CaO	%	30.9	56.3	42.0
TiO_2	%	0.11	0.92	0.39
V_2O_5	ppm	59	473	185
Cr_2O_3	ppm	32	501	150
MnO	ppm	42	3900	1010
Fe_2O_3	%	0.18	4.87	2.59
NiO	ppm	ND	307	63
CuO	ppm	5	179	39
ZnO	ppm	5	398	87
Rb	ppm	ND	86	36
SrO	ppm	356	1480	785
ZrO_2	ppm	ND	240	124
BaO	ppm	239	1770	789
La_2O_3	ppm	ND	136	58
CeO	ppm	ND	198	80
PbO	ppm	ND	164	26
Th[a]	ppm	2.8	28.3	10
U[a]	ppm	1.1	8.4	4.2

ND: not detectable.
[a] Calculated values.

to 1332.5 keV. For each energy, the measurements for all samples were carried out four times. The measurements were performed by using gamma spectrometry with a high purity Ge detector of 55% relative efficiency and resolution 1.9 keV at the 1332 keV gamma of ^{60}Co (Ortec, GEM55P4 model).

3. Results and discussions

The chemical composition of the cement samples is summarized in Table 1. As the U and Th elemental concentrations (mg/kg) are below the detection limit of the system used, the activity concentrations of ^{226}Ra and ^{232}Th (Bq kg^{-1}) are measured using gamma spectrometry. Then, elemental concentrations of U and Th were calculated using ^{226}Ra and ^{232}Th activity concentrations, respectively [11]. Calculated values are presented in Table 1 in units of ppm.

Since Th and U elements are considered because of radioactive toxicity, it is important to check if they are above the international levels or not. Permissible concentrations of Th and U in the building materials should not exceed the internationally accepted levels of 20 and 10 mg/kg, respectively [12]. The mean obtained values for Th and U are within the international accepted values in general. The Th/U ratio in the lithosphere is taken equal to 3 [13]. This ratio approximately equals to 3 in the cement samples.

The specific activities of the natural radionuclides of the ^{226}Ra, ^{232}Th and ^{40}K were determined by using gamma-ray spectroscopy in 96 different cement samples collected from suppliers, grinding plants and factories in Turkey. The measured minimum, maximum and mean activity concentration values, together with the statistical uncertainty (1σ) and standard deviation (SD), of the above natural radionuclides are presented for the different regions in Table 2. The activity levels for ^{226}Ra, ^{232}Th and ^{40}K in all cement samples ranged from 14 ± 1 to 103 ± 9 Bq kg^{-1} with a mean of 52 ± 22 Bq kg^{-1}, 11 ± 1 to 113 ± 10 Bq kg^{-1} with a mean of 40 ± 20 Bq kg^{-1} and 82 ± 3 to 695 ± 30 Bq kg^{-1} with a mean of 324 ± 120 Bq kg^{-1}, respectively. The world's mean values of ^{226}Ra, ^{232}Th and ^{40}K are 50, 50 and 500 Bq kg^{-1}, respectively [2]. The mean of ^{232}Th and ^{40}K observed in this study was significantly lower than the world's mean values, whereas the mean concentration of ^{226}Ra was comparable with the world's mean value of 50 Bq kg^{-1}.

As could be seen from Table 2, while the highest mean activity of ^{226}Ra was determined in the Mediterranean region, the region of Southeast Anatolia showed the lowest mean concentration of ^{232}Th. The activity concentrations of radionuclide ^{40}K were found to be minimum in the Mediterranean (82 ± 3 Bq kg^{-1}) and maximum in the Black Sea (695 ± 28 Bq kg^{-1}) areas.

The ^{226}Ra, ^{232}Th and ^{40}K activity concentrations measured in the cements types of CEM I, CEM II, CEM IV and CEM V, as well as SDC and BPC are shown in Table 2. The mean activity of ^{226}Ra in CEM V composite cement samples was higher than the world mean value, while the mean activities of ^{232}Th and ^{40}K were lower than the world quoted values. BPC white cement samples showed the lowest ^{226}Ra, ^{232}Th and ^{40}K activity concentration values and these values were lower than reported world's mean values [2].

Some experimental values presented for reported data of other countries are given for comparison in Table 3. While the ^{226}Ra mean activity concentration for cement samples was higher than the concentration for Iran, Norway, Austria, Finland, Italy, Netherlands, Pakistan, India, Japan, Algeria, Jordon, Tunisia and Cameroon, it was consistent with the value of Australia. For ^{232}Th activity concentrations, the observed value was higher than for Iran, Norway, Austria, Finland, Netherlands, Pakistan, India, Japan, Algeria, Greece, Ireland, Egypt, Jordon, Tunisia and Cameroon but lower than Malaysia, Italy, Australia, Brazil and Bangladesh. Moreover, our value is con-

Table 2
Activity concentrations (Bq kg^{-1}) of ^{226}Ra, ^{232}Th and ^{40}K in cement samples according to the different regions and types.

	^{226}Ra			^{232}Th			^{40}K		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Region									
Marmara	24 ± 1	80 ± 4	51 ± 16	16 ± 1	69 ± 5	37 ± 15	119 ± 5	453 ± 23	296 ± 110
Aegean	27 ± 2	102 ± 9	68 ± 23	31 ± 2	113 ± 10	51 ± 29	165 ± 6	624 ± 25	353 ± 160
Mediterranean	31 ± 2	101 ± 8	71 ± 24	22 ± 1	110 ± 9	56 ± 27	82 ± 3	467 ± 18	327 ± 130
Black Sea	14 ± 1	80 ± 4	44 ± 20	25 ± 1	62 ± 3	37 ± 10	163 ± 6	695 ± 28	361 ± 160
Central Anatolia	14 ± 1	87 ± 3	50 ± 22	25 ± 1	46 ± 3	34 ± 7	264 ± 9	433 ± 18	324 ± 60
Eastern Anatolia	27 ± 2	54 ± 3	38 ± 11	17 ± 1	37 ± 2	25 ± 7	167 ± 7	299 ± 13	253 ± 52
Southern Anatolia	30 ± 2	47 ± 3	36 ± 7	11 ± 1	44 ± 4	25 ± 12	139 ± 5	529 ± 21	312 ± 140
Types									
CEM I	14 ± 1	77 ± 5	47 ± 20	18 ± 1	67 ± 5	35 ± 14	119 ± 5	529 ± 21	306 ± 110
CEM II	25 ± 2	89 ± 6	48 ± 17	17 ± 1	83 ± 6	37 ± 14	137 ± 5	695 ± 26	320 ± 110
CEM IV	14 ± 1	102 ± 9	52 ± 26	11 ± 1	113 ± 10	45 ± 31	208 ± 8	769 ± 28	391 ± 150
CEM V	71 ± 5	101 ± 8	85 ± 11	34 ± 3	69 ± 5	45 ± 14	304 ± 12	445 ± 17	368 ± 50
SDC	25 ± 2	95 ± 8	47 ± 28	16 ± 1	110 ± 9	48 ± 37	163 ± 6	285 ± 9	211 ± 50
BPC	31 ± 2	60 ± 4	44 ± 12	22 ± 2	48 ± 4	33 ± 10	82 ± 3	381 ± 12	194 ± 120

The quoted errors are the standard deviations.

Table 3
Comparison of mean activity concentrations (Bq kg^{-1}) with published results in cement samples from different countries.

Countries	^{226}Ra	^{232}Th	^{40}K	References
Norway	30	19	259	[20]
Malaysia	81	59	204	[21]
Austria	27	14	210	[22]
Finland	40	20	251	[23]
Italy	46	42	316	[24]
Australia	52	48	115	[15]
Netherlands	27	19	230	[25]
Brazil	62	59	564	[26]
Jordon	46	12	201	[27]
India	37	24	432	[28]
Japan	36	21	139	[29]
Algeria	41	27	422	[30]
Pakistan	26	29	273	[31]
Greece	92	31	310	[32]
Ireland	66	11	130	[33]
Egypt	35	19	93	[34]
Tunisia	22	10	176	[35]
Bangladesh	61	80	1133	[36]
China	57	37	173	[37]
Iran	31	12	121	[38]
Cameroon	27	15	277	[39]
Mean	45	30	287	
Turkey	52	40	324	Present study

sistent with the value of China. The mean activity concentration value of ^{40}K was 324 Bq kg^{-1}. This value was in the range of the value for Greece (310 Bq kg^{-1}), but it was higher than for Iran, Norway, Malaysia, Austria, Finland, Italy, Australia, Netherlands, Pakistan, Japan, Greece, Ireland, Tunisia, China, Egyptian, Iran, Jordon, Cameroon and lower than for Brazil, India, Bangladesh and Algeria.

The distribution of ^{226}Ra, ^{232}Th and ^{40}K in cements was not uniform. Uniformity with respect to exposure to radiation was defined in terms of radium equivalent activity (Ra_{eq}) in Bq kg^{-1} to compare the specific activity of materials containing different amounts of ^{226}Ra, ^{232}Th and ^{40}K [14]. The radium equivalent activity was calculated through the following relation [15]:

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_K \quad (2)$$

where C_{Ra}, C_{Th} and C_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1}, respectively.

The mean calculated Ra_{eq} values are shown in Table 4 for the different cement types and the regions where they were collected. The minimum (62 Bq kg^{-1}) and the maximum (312 Bq kg^{-1}) values of Ra_{eq} were found in SDC and CEM IV cement types in the Marmara and Aegean regions, respectively. The mean Ra_{eq} values of all the measured samples were almost three times lower than the limit value of 370 Bq kg^{-1} recommended by Organization for Economic Cooperation and Development [16].

Number of indices dealing with the assessment of the excess gamma radiation arising from building materials such as external and internal hazard indices and gamma-concentration indices has been proposed by several investigators [1,15–17]. In this study, the gamma index (I_γ) was calculated as proposed by the European Commission [1]:

$$I_\gamma = \frac{C_{Ra}}{300} + \frac{C_{Th}}{200} + \frac{C_K}{3000} \quad (3)$$

where C_{Ra}, C_{Th} and C_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1}, respectively. The mean values of I_γ calculated from the measured activity concentration of ^{226}Ra, ^{232}Th and ^{40}K are presented in Table 4 for different cement types and the regions where they were collected. The mean calculated values of I_γ for the studied samples values varied in the range between 0.37–0.64 for types of cement and 0.34–0.65 for the regions which were less than the critical value of unity.

So far, several alpha indices have been proposed to assess the exposure level due to radon inhalation originating from building materials [1]. The alpha index was determined by the following formula:

$$I_\alpha = \frac{C_{Ra}}{200\,(\text{Bq kg}^{-1})} \quad (4)$$

where C_{Ra} (Bq kg^{-1}) is the activity concentration of ^{226}Ra assumed in equilibrium with ^{238}U. The recommended exemption and upper level of ^{226}Ra activity concentrations in building materials are 100 and 200 Bq kg^{-1}, respectively, as suggested by ICRP [18]. These considerations are reflected in the alpha index. The recommended upper limit concentration of ^{226}Ra is 200 Bq kg^{-1}, for which $I_\alpha = 1$. The mean computed I_α values for the studied cement samples are given in Table 4 for the different cement types and the regions where they were collected. The values of I_α ranged from 0.07 to 0.51, with the mean value of 0.26. For the safe use of a material in the construction of dwellings, I_α should be less than unity. The mean calculated values were less than unity.

There is concern that some of the buildings will cause excessive radiation doses to the total body due to gamma rays emitted by ^{214}Pb and ^{214}Bi progeny of ^{226}Ra and ^{232}Th decay chains, and ^{40}K also contributes to the total body radiation dose. The absorbed dose rate in indoor air due to gamma-ray emission from activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K was estimated using the following formula provided by UNSCEAR [19] and EC [1]. In the UNSCEAR

Table 4
Radium equivalent activity, gamma and alpha indices, the dose rate, and annual effective dose for the different regions and cement types.

	Ra_{eq} (Bq kg^{-1})	I_γ	I_α	D (nGy h^{-1})	AED (mSv y^{-1})
Region					
Marmara	127 ± 42	0.45 ± 0.15	0.25 ± 0.08	111 ± 36	0.55 ± 0.18
Aegean	168 ± 72	0.60 ± 0.26	0.34 ± 0.12	147 ± 61	0.72 ± 0.30
Mediterranean	176 ± 64	0.65 ± 0.23	0.37 ± 0.12	153 ± 54	0.75 ± 0.27
Black Sea	125 ± 33	0.45 ± 0.12	0.22 ± 0.10	110 ± 30	0.54 ± 0.15
Central Anatolia	124 ± 34	0.46 ± 0.12	0.24 ± 0.10	109 ± 29	0.54 ± 0.15
Eastern Anatolia	93 ± 10	0.34 ± 0.04	0.19 ± 0.06	83 ± 9	0.41 ± 0.04
Southern Anatolia	96 ± 32	0.35 ± 0.12	0.18 ± 0.03	86 ± 28	0.42 ± 0.14
Types					
CEM I	121 ± 39	0.43 ± 0.14	0.23 ± 0.10	106 ± 34	0.52 ± 0.17
CEM II	126 ± 37	0.46 ± 0.13	0.24 ± 0.09	110 ± 32	0.54 ± 0.16
CEM IV	146 ± 77	0.52 ± 0.27	0.26 ± 0.13	129 ± 65	0.63 ± 0.32
CEM V	181 ± 25	0.64 ± 0.09	0.43 ± 0.05	159 ± 21	0.78 ± 0.10
SDC	132 ± 83	0.46 ± 0.28	0.23 ± 0.14	113 ± 68	0.55 ± 0.33
BPC	106 ± 32	0.37 ± 0.12	0.22 ± 0.06	92 ± 28	0.45 ± 0.14

The quoted errors are the standard deviations.

Table 5
Comparison of mass attenuation coefficients in the cement samples with theoretical and experimental values.

Energy (keV)	Present study		Medhat [5]	
	Experimental ($cm^2\ g^{-1}$)	Theoretical ($cm^2\ g^{-1}$)	Experimental ($cm^2\ g^{-1}$)	Theoretical ($cm^2\ g^{-1}$)
81	0.232–0.267 ± 0.004	0.239–0.260		
88	0.200–0.238 ± 0.006	0.218–0.234		
122	0.162–0.182 ± 0.007	0.166–0.173		
136	0.149–0.165 ± 0.007	0.155–0.160		
276	0.106–0.119 ± 0.003	0.109–0.113		
302	0.100–0.112 ± 0.002	0.105–0.109		
356	0.095–0.104 ± 0.002	0.098–0.101	0.078	0.098
383	0.092–0.101 ± 0.001	0.095–0.098		
511	0.080–0.092 ± 0.002	0.084–0.087		
661	0.073–0.079 ± 0.001	0.075–0.077	0.062	0.077
834	0.064–0.073 ± 0.001	0.067–0.069		
1173	0.054–0.063 ± 0.001	0.057–0.059	0.051	0.057
1275	0.052–0.059 ± 0.003	0.055–0.056		
1332	0.050–0.054 ± 0.001	0.053–0.055	0.052	0.054

and the European Commissions reports, the dose conversion coefficients were calculated for the standard room centre. Dimensions of the room were 4 m × 5 m × 2.8 m. Thicknesses of walls, floor and ceiling and density of the structures were 20 cm and 2350 kg m^{-3} (concrete), respectively.

$$D = \alpha C_{Ra} + \beta C_{Th} + \gamma C_K \quad (5)$$

where α, β and γ are the dose rates per unit activity concentrations of Ra, Th and K (nGy h^{-1}/Bq kg^{-1}); C_{Ra}, C_{Th} and C_K are the activity concentrations of Ra, Th and K (Bq kg^{-1}), respectively. The values of α, β and γ were taken to be 0.92, 1.1 and 0.08, respectively [1].

The absorbed dose rates in indoor air calculated from the measured activities in cement samples are also given in Table 4 (column 5) for the different cement types and the regions where they were collected. The absorbed dose rate in indoor air was found to vary from 55 to 268 nGy h^{-1} with a mean of 117 nGy h^{-1}. It was observed that the mean value was higher than the world mean populated-weight value of 84 nGy h^{-1}. Results presented in Table 4 shows that the maximum and the minimum absorbed dose rates in air were delivered by CEM V and BPC, respectively.

To estimate the annual effective dose, it must be taken into account: (a) the conversion coefficient (0.7 Sv Gy^{-1}) from absorbed dose in air to effective dose and (b) the indoor occupancy factor (~80% for Turkish population). Therefore, the effective dose rate in mSv y^{-1} unit was estimated by the following formula:

$$\text{AED (mSv y}^{-1}) = D(\text{nGy h}^{-1}) \times 8760\ \text{h y}^{-1} \times 0.7 \times 0.8 \times 10^{-6} \quad (6)$$

The calculated values for the annual effective dose ranged from 0.27 to 1.32 mSv, with a mean value of 0.57 mSv. The corresponding annual effective dose rate from CEM I, CEM II, CEM IV, CEM V, SDC and BPC was lower than the dose criterion of 1 mSv y^{-1}.

The experimental and theoretical mass attenuation coefficients (μ/ρ) for different types of cement samples were determined for the sources such as 81.0, 88.0, 122.1, 136.5, 276.4, 302.8, 356.0, 383.8, 511, 661.6, 834.8, 1173.2, 1274.5 and 1332.5 keV. The results are shown in Table 5. Clearly, there are slight differences between the results of mass attenuation coefficients in different types of cement samples at the same energies; these may be due to the compositional variation and density among the different types of cement samples. It is evident from Table 5 that the experimental results are consistent with the theoretical data within the experimental errors. The theoretical data were calculated using the mixture rule which is standard practice to assuming that the contribution of each element to the attenuation is additive, i.e. the attenuation coefficient of any substance is the sum of the appropriately weighted contributions from the individual atoms. The results were compared with the available literature [5]. Generally a good agreement was observed between the experimental values especially for high energies.

Mass attenuation coefficient is an important parameter for building materials since buildings absorb the external radiation in a certain degree, the radiation from the external sources and cosmic rays. Moreover, it is important to use the building materials having relatively higher mass attenuation coefficient for nuclear power plants since they might absorb the radiation in degree and prevent it to affect the outside environment. Using mass attenuation coefficients, the percent radiation absorption rates for ^{226}Ra (352 keV and 609 keV), ^{232}Th (583 and 911 keV), ^{137}Cs (661 keV) and ^{40}K (1460 keV) were estimated as follows: 22.7, 18.4, 18.7, 15.4, 17.8 and 12.3, respectively.

4. Conclusions

The activities of the natural radionuclides of the ^{226}Ra, ^{232}Th and ^{40}K in the cement samples collected from suppliers, grinding plants and factories in Turkey were measured by using the technique of gamma-ray spectroscopy with HPGe detector. The results may be useful in the assessment of the exposures and the radiation doses due to the natural radioactive element contents in cement samples. The mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were 52, 40 and 324 Bq kg^{-1}, respectively. The observed mean concentrations of ^{232}Th and ^{40}K in the samples are lower than the corresponding world typical values of 50 and 500 Bq kg^{-1}, respectively. However, the mean concentration of ^{226}Ra was a little higher when compared with the world's mean value of 50 Bq kg^{-1}.

Obtained values shows that the mean radium equivalent activity (Ra_{eq}), gamma index (I_γ), alpha index (I_α), the indoor absorbed dose rate (D) and annual effective dose rate (AED) in cement samples are 133 Bq kg^{-1}, 0.48, 0.26, 117 nGy h^{-1} and 0.57 mSv y^{-1}, respectively. In order to obtain more realistic effective dose assessment for Turkish population due to natural radionuclide content in construction materials, cement, brick and sand were also taken into account. The percentages of the building construction materials were estimated to be around 80, 4 and 16 for sand, brick and cement, respectively [40]. Taking into account these data, the mean absorbed dose rate and mean annual effective dose were estimated to be 106 nGy h^{-1} and 0.52 mSv y^{-1}, respectively. These values are lower than the recommended limits, hence, the use of these materials in the construction of dwellings is considered to be safe for the dwellers. A comparison of the concentrations obtained in this work with other parts of the world indicates that the radioactivity content of the cement samples is not significantly different. Also, mass attenuation coefficients were measured in cement samples. It could be concluded that the experimental results were consistent with the

theoretical data. The results of the present study will be valuable database for future estimations of the impact of radioactive pollution.

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