Journal of Environmental Science and Technology

ISSN 1994-7887

OPEN ACCESS Journal of Environmental Science and Technology

ISSN 1994-7887
DOI: 10.3923/jest.2016.238.245

Research Article
Gamma Spectroscopic Analysis and Associated Radiation Hazards Parameters of Cement Used in Saudi Arabia

[1]S. Alashrah and [1,2]A. El-Taher

[1]Department of Physics, Faculty of Science, Qassim University, Buraydah 51452, Saudi Arabia
[2]Department of Physics, Faculty of Science, Al-Azhar University, Assuit 71452, Egypt

Abstract
This study is concerned with the environmental impact of the cement industry in Saudi Arabia. The activity concentrations of natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K in raw materials used in Qassim cement factory in addition to final product from Qassim cement and other factories in Saudi Arabia were measured using gamma-ray spectrometer employing a NaI (Tl) detector. The average activity concentrations for ^{226}Ra, ^{232}Th and ^{40}K radionuclides in raw materials were 13.5, 12 and 122.3 Bq kg^{-1}, respectively. In addition, their activity concentrations in Qassim cement product were 11.2, 10 and 117.1 Bq kg^{-1}. The activity concentration of Riyadh, Yamamah, Hail and North region cement were measured. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the raw materials and final product were matched among the reported data from different countries. The average values of the activity concentrations were lower than the corresponding international values documented by United Nations Scientific Commnitee on the Effect of Atonic Radiations (UNSCEAR) publications. The radium equivalent activity (Raeq) and the external hazard index (Hex) were calculated to estimate the radiation hazard for people living in home made of cement. Moreover, the absorbed dose rate in air (D) in each sample was evaluated. All the materials studied are satisfactory for use as building materials as limited by the Organization of Economic Co-operation and Development (OECD) criterion. The consequences acquired show no significant of radiological risk when Qassim cement is used.

Key words: Natural radioactivity, cement, raw materials, radiation hazards

Received: December 02, 2015 Accepted: January 22, 2016 Published: February 15, 2016

Citation: S. Alashrah and A. El-Taher, 2016. Gamma spectroscopic analysis and associated radiation hazards parameters of cement used in Saudi Arabia. J. Environ. Sci. Technol., 9: 238-245.

Corresponding Author: S. Alashrah, Department of Physics, Faculty of Science, Qassim University, Buraydah, 51452, Kingdom of Saudi Arabia

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Continuously, human are exposed to natural radiation resulting mainly from the cosmic rays and the terrestrial natural radionuclides. The source of these radionuclide's are the earth's crust. Natural radionuclides are present in rocks, air, water and minerals (El-Taher, 2012; El-Taher and Alashrah, 2015). Naturally Occurring Radioactive Materials (NORMs) include all natural radionuclides such as uranium isotopes (^{234}U and ^{238}U), radium isotopes (^{226}Ra, ^{228}Ra), thorium (^{232}Th), radon (^{220}Rn) and potassium-40 (^{40}K). Furthermore, there is a noticeably higher radiation doses to man present in Technologically Enhanced Naturally Occurring Radioactive Material (TENORM), resulting from human industrial activities such as production of building material, cement and concrete (Popic *et al*., 2011; Landsberger *et al*., 2013).

Building materials obtained from rock and soils include natural radionuclide's like radium (^{226}Ra), thorium (^{232}Th) and potassium (^{40}K) (Kadum *et al*., 2013). Therefore, the level of radioactivity in the building materials should be measured for assessment the radiological hazards. In addition, it should be measured precisely for founding the accepted radiation levels (National guidelines) (Kadum *et al*., 2013). The absorbed dose rate in air resulting from the cosmic radiation at the sea level is estimated by 30 nG h^{-1} (Kadum *et al*., 2013). The assessment of radioactivity of radionuclides in the building materials is being essential. Concrete is the main construction materials. It is prepared from natural sources (e.g., rock and soil) and waste products (e.g., phosphogypsum, alum shale, coal fly ash, oil shale ash, some rare minerals, certain slugs, etc.). Furthermore, it is made of industry products like power plants, phosphate fertilizer and oil industry (Kadum *et al*., 2013). Workers expose to radiation, specifically in mines and at manufacturing sites. In addition, the populations are exposed to indoor radiation since they consume around 80% inside offices and homes (Mollah *et al*., 1996; Paredes *et al*., 1987; El-Taher and Alashrah, 2015). The concentrations of radionuclides in raw cement materials and processed cement materials change with a geological source and geo-chemical features. Therefore, the radioactivity in cement is important to assess the radiological hazard to person health.

The has issued documents for the amount of accumulated doses by the individual throughout his live activities. The dose rate resulting from cosmic radiation is about 0.38 mSv $year^{-1}$ and to terrestrial radiation is about 0.45 mSv $year^{-1}$ (this rises by almost 20% for brick and cement materials). The exposures to water, food and air are about 1.5 mSv $year^{-1}$. Regarding to manmade, the estimating dose rate from x-rays diagnostics is about 0.4 mSv $year^{-1}$ and the exposure to the other factors is about 0.1 mSv $year^{-1}$. Thus, the total dose rate received by human is about 2.7 mSv $year^{-1}$ from natural and man-made radiation sources. Nearly all buildings in Saudi Arabia are constructed from cement blocks and cement concrete.There are many studies for determining radionuclide concentrations in building materials in many countries (Amrani and Tahtat, 2001). However, measurements of the radioactivity in these materials in Saudi Arabia are limited. The purpose of this study is to measure the natural radioactivity (^{226}Ra, ^{232}Th and ^{40}K) in raw and final products of cement used at the Qassim cement manufactory and other local manufactories in Saudi Arabia. Furthermore, the radiological parameters will be calculated. These parameters are radium equivalent activity Raeq, level index Iγr, external hazard index hex and absorbed dose rate. The results of activity concentration levels and the parameters are compared with similar studies obtained from different countries.

MATERIALS AND METHODS

Sampling and sample preparation: Fifty five samples of raw materials and final products were collected from Qassim, Riyadh Yamamah, Hail and North region of Saudi Arabia cement factories. Twenty five samples of raw materials were obtained from Limestone, Clay, Slag, Iron oxide and gypsum, which are the main raw materials used for cement. The rest samples (30 samples) were collected from cement factories as portland and white cement. Each sample was weighed as 1 kg and the sizes of the samples were 250 mL made of a polyethylene. An oven at about 110°C was used to dry the samples to remove the moisture completely. The samples were crushed and homogenized. Next, they were sieved through a 200 mesh. The containers were completely closed tightly for 4 weeks to ensure secular equilibrium. This step is necessary to ensure that radon gas is confined within the volume and the daughters will also remain in the sample.

Instrumentation and calibration: Gamma-spectrometric measurements were performed with NaI (Tl) detector. The measuring time for gamma-ray spectra ranged was 12 h. In order to find out the background radiation around the detector, an empty polystyrene container was used in the same method as the raw cement materials and final cement products samples. After subtraction of activity concentration of the background radiation from the activity concentration measurement, the values of the activity concentration was calculated (El-Taher, 2010, 2011; El-Taher and Madkour, 2011). The specific activity of ^{226}Ra was estimated from gamma-ray lines of ^{214}Bi at 609.3 keV, 1120.3 keV and 214 Pb at 351 keV. Furthermore, the specific activity of ^{232}Th was evaluated from gamma-ray lines of ^{228}Ac at 338.4, 911.1 and 968.9 keV. The specific activity of ^{40}K was determined directly from its 1460.8 keV gamma-ray line.

The activity concentration The activity concentration (activity per mass unit or specific activity) for each detected photo peak rely on the secular equilibrium. It means that the rate of decay of the radon daughters becomes equal to that of the parent. in the samples. The activity concentration in Bq kg^{-1} (A) in the environmental samples was obtained as Eq. 1:

$$A = \frac{Np}{e \times \eta \times m} \quad (1)$$

where, Np is (cps) sample-(cps) back ground, e is the abundance of the γ-peak in a radionuclide, η is the measured efficiency for each gamma-ray peak observed for the same number of channels either for the sample or the calibration source and m is sample mass in kilograms.

RESULTS AND DISCUSSION

Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K: The average values of specific activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K for all raw materials and final products used in the Qassim cement factory are presented in Table 1 and 2.

The radionuclide concentrations in all raw materials samples are below the world averages for building materials 50, 50 and 500 (Bq kg^{-1}) for ^{226}Ra, ^{232}Th and ^{40}K, respectively (UNNSCEAR., 2000; NEA-OECD., 1979). The ^{226}Ra activity concentrations in raw material samples was between 32.8±1.0 Bq kg^{-1} (slag) and 3.3±0.2 Bq kg^{-1} (gypsum and limestone) while ^{232}Th activity concentration was between 27.2±1.4 Bq kg^{-1} for the slag samples and 2.5±0.2 Bq kg^{-1} for limestone samples. However the ^{40}K activity concentration was between 285.1±12.9 Bq kg^{-1} for gypsum samples and 32.9±1.6 Bq kg^{-1} for limestone samples as shown in Table 1.

Table 2 shows the radionuclide concentrations of final products of Qassim, Riyadh, Hail, North region and Yamamah. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were below the world averages for building materials 50, 50 and 500 (Bq kg^{-1}), respectively (UNNSCEAR., 2000; NEA-OECD., 1979). When these materials used for building construction, they do not produce a serious radiological risk.

Table 1: Aerage (range) activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in (Bq kg^{-1}) for all raw materials used in the Qassim cement factory

Material	^{226}Ra	^{232}Th	^{40}K
Slag	21.8 (32.8-6.7)	18.4 (27.2-7.5)	170.8 (255.1-74.5)
Clay	15.8 (18.9-8.7)	13.8 (19.3-10.3)	70.7 (91.5-44)
Gypsum	9.0 (12.6-3.3)	6.5 (9.1-3.4)	184.8 (258.1-105.4)
Iron oxide	21.6 (22.8-18.8)	18.6 (19.3-17.9)	53.6 (59.1-44)
Limestone	6.2 (7.0-3.3)	3.0 (3.4-2.5)	155.5 (228.1-32.9)

Table 2: Aerage (range) activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in final products

Type of cement	^{226}Ra	^{232}Th	^{40}K
Qassim prtland	11.2 (16.6-8.6)	10.0 (14.1-7.4)	117.1 (195.6-87.1)
Riyadh prtland	13.9 (17.7-13.2)	15.1 (18.6-13.5)	186.7 (236.1-85.8)
White qssim	13.9 (15.3-11.3)	16.1 (17.5-15.2)	125.6 (149.1-95.4)
Yamamah prtland	8.0 (14.8-5.5)	9.3 (16.4-6.8)	67.7 (113.1-52)
Hail prtland	8.4 (8.7-8.2)	8.8 (8.9-8.5)	34.2 (36.9-30.8)
North region prtland	7.1 (7.3-6.8)	9.1 (9.9-9.2)	33.6 (36.8-32.3)

For portland cement:

- The highest value of ^{226}Ra activity concentration is found in the case of portland cements from the Riyadh factory 17.7±0.9 Bq kg^{-1}, which is below the limit and the lowest value in portland cements from Yamamah factory 5.5±0.3 Bq kg^{-1}
- The highest values of ^{232}Th activity concentrations is found in portland cement samples from Riyadh factory 18.6±1.0 Bq kg^{-1} and the lowest value in portland cement samples from the Yamamah factory 6.8±0.4 Bq kg^{-1}
- The highest values of ^{40}K activity concentrations is found in portland cement samples from the Riyadh factory 236.1±11.8 Bq kg^{-1} and the lowest value in portland cement samples from Hail factory 30.8±1.6 Bq kg^{-1}

For white cement from Qassim factory:

- The highest value of ^{226}Ra activity concentration was 15.3±0.8 Bq kg^{-1} and the lowest values were 11.3±0.6 Bq kg^{-1}
- The highest value of ^{232}Th activity concentration was 17.5±0.9 Bq kg^{-1} and the lowest values were 15.2±0.8 Bq kg^{-1}
- The highest value of ^{40}K activity concentration was 149.1±7.5 Bq kg^{-1} and the lowest values were 95.4±4.8 Bq kg^{-1}

The radionuclide concentrations in the portland and white cement are below the world averages for building

Table 3: Comparison between the activity concentrations in various raw materials used in Qassim cement factory with other countries

	Activity (Bq kg^{-1})			
Country/type	^{226}Ra	^{232}Th	^{40}K	References
Limestone				
Saudi Arabia	6.2	3.0	155.5	Present work
Saudi Arabia	42.8	9.0	-	Al-Dadi *et al.* (2014)
Saudi Arabia	28.6	49.2	66.0	Al-Dadi *et al.* (2014)
Australia	-	11.1	-	Beretka and Mathew (1985)
Australia	9.0	2.8	34	Sorantin and Steger (1984)
Italy	11.0	2.0	22	Rizzo *et al.* (2001)
Brazil	24.3	7.0	205	Malanca *et al.* (1993)
India	73.9	-	64.6	Kumar *et al.* (2003)
Clay				
Saudi Arabia (Qassim)	15.8	13.8	70.7	Present study
Egypt (Assiut)	33.6	68.9	130.7	El-Taher (2012)
Australia	40.7	88.8	681	Beretka and Mathew (1985)
Austria	38.3	44.7	635	Sorantin and Steger (1984)
Brazil	51.7	65.3	747	Malanca *et al.* (1993)
China	41.0	52.0	717	Ziqiang *et al.* (1988)
Norwey	63.0	47.0	1140	NEA-OECD (1979)
Pakistan	43.2	53.7	631	Tufail *et al.* (1992)
	52.0	44.0	703	NEA-OECD (1979)
Gypsum				
Saudi Arabia (Qassim)	9.0	6.5	184.8	Present work
Saudi Arabia	7.7	3.3	173	Al-Dadi *et al.* (2014)
Saudi Arabia	33.3	47.2	88.0	Al-Dadi *et al.* (2014)
India	8.3	-	26.7	Kumar *et al.* (2003)
Cyprus	3.8	2.8	20.9	Tzortzis *et al.* (2003)
Italy	6.0	2.0	32	Rizzo *et al.* (2001)

materials 50, 50 and 500 (Bq kg^{-1}) for ^{226}Ra, ^{232}Th and ^{40}K, respectively (UNNSCEAR., 2000; NEA-OECD., 1979).

From Table 3 the following observations can be recorded. For Limestone, the activity concentration of ^{226}Ra in the present study was lower than other studies obtained from Saudi Arabia, Australia, Brazil and India. While the activity concentration of ^{232}Th was higher than Italy and it was comparable with Australia. It was lower than other studies performed in Saudi Arabia and Brazil. Furthermore, the activity concentration of ^{40}K was higher than other study in Saudi Arabia, Australia, Italy and India. However, it was lower than Brazil. For Clay, the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K were lower than all recording values in other countries. For gypsum, the activity concentration of ^{226}Ra was higher than other study in Saudi Arabia, India, Cyprus and Italy. The activity concentration of ^{232}Th was higher than Cyprus, Italy, other study in Saudi Arabia, India. However, it was lower than the other study in Saudi Arabia. However, the activity concentration of ^{40}K was higher than the recording values of other countries.

The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K for all measured samples of Qassim portland cement and the other countries were shown in Table 4. The activity concentration of ^{226}Ra in Qassim portland cement was lowest when it compares with other portland cement from other countries. However, the activity concentration of ^{232}Th was higher than Lebanon and Egypt but it was lower than Egypt (Assuit), Chain, Malaysia, Sweden and Ghana. Regarding to the activity concentration of ^{40}K, it was higher than India, Lebanon, Egypt (Assuit). However, it was lower than Germany, Italy and Pakistan. The activity concentration of portland cement changes from country to other country considering that various materials used in cement production. The contents of ^{226}Ra, ^{232}Th and ^{40}K in cements materials depend on their chemical composition that related to geological source and geochemical characteristics. The activity concentration of ^{226}Ra in Croatia portland cements was measured to be 129 Bq kg^{-1} and in Malaysian cements was 81.4 Bq kg^{-1}, the lower concentrations was 20.4 Bq kg^{-1} (Table 4). More accurate measurements for activity concentration of the building materials, it gives the calculation of the corresponding radiological parameters with accurate results.

Radiation hazard parameters

Estimation of dose rate: Monte Carlo method can be applied to calculate a conversion factor. This factor can be used to transform the specific activities of ^{40}K, ^{226}Ra and ^{232}Th

Table 4: Comparison between the activity concentrations of portland cement samples from Qassim factory with that of other countries

	Activity (Bq kg^{-1})			
Country	^{226}Ra	^{232}Th	^{40}K	Reference
Saudi Arabia	11.2	10	117.1	Present study
Saudi Arabia	20.4	8.7	158.0	Al-Dadi *et al.* (2014)
Saudi Arabia	21.7	16.1	262.2	Alharbi and AlZahrani (2012)
Saudi Arabia	38.4	45.3	86.0	El-Taher (2012)
Saudi Arabia	33	34	170	AlZahrani (2012)
Egypt (Assuit)	35.6	43.17	82.08	El-Taher *et al.* (2010)
Egypt	3.84	1.63	4.35	Kamal *et al.* (2011)
Albania	55	17	179	Xhixha *et al.* (2013)
China	52	103	310	Zhao *et al.* (2012)
Coroatia	129	23.1	252.4	Sofilic *et al.* (2011)
Ghana	35.9	25.4	233	Kpeglo *et al.* (2011)
India	59.2	14.8	107.4	Byju *et al.* (2012)
Iran	31.1	12.4	121	Fathivand and Amidi (2007)
Germany	40.2	19.9	251.0	UNNSCEAR (2000)
Italy	38	22	218	El-Taher (2012)
Japan	35.8	20.7	139.4	Kpeglo *et al.* (2011)
Lebanon	73.2	9	79.7	Kobeissi *et al.* (2008)
Malaysia	81.4	59.2	203.5	Khan and Khan (2001)
Pakistan	26.1	28.7	272.9	Khan and Khan (2001)
Sweden	55	47	241	NEA-OECD (1979)
U.K	22	18	155	NEA-OECD (1979)

(A_K, A_{Ra} and A_{Th}) to absorbed dose rate at 1 m above the ground (in nGy h^{-1} by Bq kg^{-1}) as Eq. 2 (UNNSCEAR., 2000):

$$D\ (\text{nGy h}^{-1}) = 0.0417A_K+0.462A_{Ra}+0.604A_{th} \qquad (2)$$

In natural environmental radioactivity situations, the effective dose is calculated from the absorbed dose by applying the factor 0.7 Sv Gy^{-1} (UNNSCEAR., 2000):

$$\text{Indoor: Dose (nGy h}^{-1})\times 8.760\times 0.8\times 0.7\ \text{Sv Gy}^{-1}$$

$$\text{Outdoor: Dose (nGy h}^{-1})\times 8.760\times 0.2\times 0.7\ \text{Sv Gy}^{-1}$$

The annual effective dose rate outdoors in units of μSv $year^{-1}$ is calculated by the following formula (Saito *et al.*, 1998):

$$\text{Annual effective dose rate} = D\times T\times F$$

where, D is the calculated dose rate (in nGy h^{-1}), T is the outdoor occupancy time (0.2×24 h $\times 365.25$ d ≈ 1753 h $year^{-1}$) and F is the conversion factor (0.7×10^{-6} Sv Gy^{-1}).

γ-ray radiation hazard indexes: The natural radioactivity of building materials is usually determined from ^{226}Ra, ^{232}Th and ^{40}K contents. ^{226}Ra and its daughter produce from the U series and they give around 98.5% of the radiological effects. The γ-ray radiation hazards due to the specified radionuclides were determined by three various indices (NEA-OECD, 1979). The radium equivalent (Raeq) was defined as a radiological index used to estimate the gamma radiation hazard resulting from environmental samples which contain ^{226}Ra, ^{232}Th and ^{40}K and it can be calculated using Beretka and Mathew formula (Beretka and Mathew, 1985):

$$Ra_{eq} = A_{Ra}+1.43A_{Th}+0.077A_K$$

where, A_{Ra}, A_{Th} and A_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1}, respectively. The Raeq is associated to the external γ-dose and internal dose resulting from radon and its daughters. The limit value of Raeq need to be less than 370 Bq kg^{-1}. Beretka and Mathew (1985) explained two additional indices that show the external and internal radiation hazards. The external hazard indicator is obtained from Raeq expression through the assumption that its maximum value allowed (equal to unity) agrees to the upper limit of Raeq (370 Bq kg^{-1}). This indicator value need to be less than unity to be the radiation hazard insignificant; i.e., the radiation exposure due to the radioactivity from construction materials is limited to 1.0 mSv $year^{-1}$. Then, the external hazard indicator can be explained as Eq. 3:

$$H_{ex} = \frac{A_{Ra}}{370}+\frac{A_{Th}}{259}+\frac{A_K}{4810}\leq 1 \qquad (3)$$

where, A_{Ra}, A_{Th} and A_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1}, respectively.

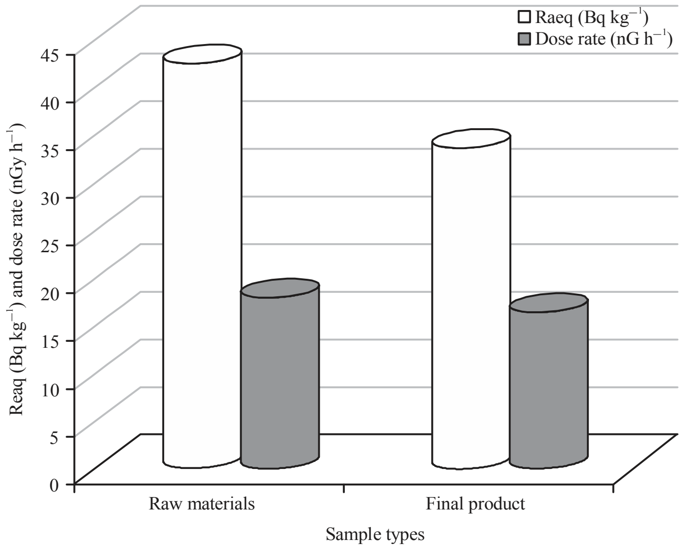

Fig. 1: Comparison between the average values of radium equivalent Raeq (Bq kg^{-1}) and absorbed dose rate (nGy h^{-1}) for raw materials and cement products from the Qassim cements factory

Table 5: Average values of radiation hazard parameters for raw materials used in Qassim cement

Type of materials	Raeq (Bq kg^{-1})	Dose rate (nGy h^{-1})	H_{ex}	H_{in}	Iγr
Slag	25.2	12.2	0.01	0.01	0.02
Clay	89.6	43.0	0.03	0.04	0.08
Gypsum	33.0	15.9	0.01	0.01	0.03
Iron oxide	52.1	23.9	0.02	0.03	0.06
Limestone	12.9	6.1	0.00	0.01	0.01

Table 6: Average values of radiation hazard parameters for products of Qassim, Riyadh, Yamamah, Hail and North region cement factories in Saudi Arabia

Kind of cements	Raeq (Bq kg^{-1})	Dose rate (nGy h^{-1})	H_{ex}	H_{in}	Iγr
Qassim	33.70	16.44	0.01	0.01	0.03
Riyadh	48.55	23.95	0.02	0.02	0.04
White	45.74	22.00	0.02	0.02	0.05
Yamama	26.01	12.47	0.01	0.01	0.03
Hail	23.32	10.86	0.01	0.01	0.03
North region	22.41	10.48	0.01	0.01	0.03

The obtained results presented in this study showed that the averages of radiation hazard parameters for all raw materials (slag, iron oxide and clay samples) were lower than the acceptable level. This level was 370 Bq kg^{-1} for Raeq, 1 for Iγr, hex $\leq$1 and 59 (nGy h^{-1}) for absorbed dose rate as shown in Table 5. Comparing the results, it is evident that there are variations in the Raeq of different cement types. This fact is important for selecting suitable cements used for buildings or constructions. The variation in radium equivalent may be resulting from the raw materials of cement before they are used for building material. According to the final products presented in this investigation showed that the averages of radiation hazard parameters for all products were lower than the acceptable level 370 Bq kg^{-1} for radium equivalent Raeq, 1 for level index Iγr, the external hazard index hex $\leq$1 and 59 (nGy h^{-1}) for absorbed dose as shown in Table 6.

The highest values of radiation hazard parameters (135.0 Bq kg^{-1}, 64.1 nGy h^{-1}, 0.05, 0.06, 0.13 of radium equivalent Raeq, absorbed dose rate, the external hazard index hex , internal hazard and level index Iγr, respectively) are associated with Riyadh cement factory. The lowest values of radiation hazard parameters (17.0 Bq kg^{-1}, 7.9 nGy h^{-1}, 0.00, 0.01, 0.02 of radium equivalent Raeq, absorbed dose rate, the external hazard index hex , internal hazard and level index Iγr, respectively) are found in white cement factory samples.

Comparison between the radiation hazards for raw materials and final products: Figure 1 shows a comparison between the radiation hazards for raw materials and final products used and product in Qassim cement factory.

From Fig. 1 the following observations can be noted:

- The average values of radiation hazard parameters (33.7 Bq kg^{-1} and 16.4 nGy h^{-1}of radium equivalent Raeq and absorbed dose rate, respectively) are associated with final product samples
- The average values of radiation hazard parameters (42.7 Bq kg^{-1} and 18.0 nGy h^{-1} for radium equivalent Raeq and absorbed dose rate, respectively) are found in raw material samples
- The manufacturing operation reduces the radiation hazard parameters. However final products do not pose a significant radiological hazard when used for building construction

CONCLUSION

The natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K were measured for raw materials and final products used in the Qassim cement factory Saudi Arabia and compared with the results of Riyadh, Yamamah, Hail and North region cement factories. Also the results were compared with other cement factories in some countries. The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K for all measured samples of Qassim portland cement are comparable with the corresponding values of other countries. The obtained results show that the averages of radiation hazard parameters for Qassim, Riyadh, Yamamah, Hail and North region cement factories are lower than the acceptable level 370 Bq kg^{-1} for radium equivalent Raeq, 1 for level index Iγr, the external hazard index hex $\leq$1 and 59 (nGy h^{-1}) for absorbed dose rate. The manufacturing operation reduces the radiation hazard parameters but they are still less than the world limit. Hence, cement does not produce a significant radiological risk if it is used for building construction. The radioactivity in raw materials and final products of cement changes from one country to another using same type of material from different locations. The results may be important to the point of view of determining satisfactory materials for use in cement manufacture. It is significant to point out that these values are not the representative values in the countries mentioned but for the regions from where the samples were collected.

ACKNOWLEDGMENT

The authors thank to Deanship of Scientific Research at Qassim University for financial support under contract No. SR-D-014- 2485.

REFERENCES

Al-Dadi, M.M., H.E. Hassan, T. Sharshar, H.A. Arida and H.M. Badran, 2014. Environmental impact of some cement manufacturing plants in Saudi Arabia. J. Radioanal. Nucl. Chem., 302: 1103-1117.

AlZahrani, J.H., 2012. Assessment of radioactivity and the exposure doses from local cement types in Saudi Arabia. J. Am. Sci., 8: 215-220.

Alharbi, W.R. and J.H. AlZahrani, 2012. Assessment of natural radioactivity levels and associated radiation hazards of building materials used in Saudi Arabia. J. Am. Sci., 8: 651-656.

Amrani, D. and M. Tahtat, 2001. Natural radioactivity in Algerian building materials. Applied Radiat. Isot., 54: 687-689.

Beretka, J. and P.J. Matthew, 1985. Natural radioactivity of Australian building materials, industrial wastes and by-products. Health Phys., 48: 87-95.

Byju, S.B., S. Arunima, C.E. Pereira, A. Sunil and R.M. Jose, 2012. Natural radio nuclides in cements and clay based building materials used in South West coastal region of India. Asian J. Phys. Sci., 1: 38-46.

El-Taher, A. and H.A. Madkour, 2011. Distribution and environmental impacts of metals and natural radionuclides in marine sediments in-front of different wadies mouth along the Egyptian Red Sea Coast. Applied Radiat. Isot., 69: 550-558.

El-Taher, A. and S. Al-Ashrah, 2015. Occurrence of ^{222}Rn in irrigation water from Wadi Al-Rummah Qassim province, Saudi Arabia. Proceedings of the International Conference on Applied Sciences and Industrial Technology, February 24-26, 2015, Shah Alam, Selangor, Malaysia.

El-Taher, A., 2010. Gamma spectroscopic analysis and associated radiation hazards of building materials used in Egypt. Radiat. Prot. Dosimetry, 138: 166-173.

El-Taher, A., 2011. Terrestrial gamma radioactivity levels and their corresponding extent exposure of environmental samples from Wadi El Assuity protective area, Assuit, Upper Egypt. Radiat. Prot. Dosim., 145: 405-410.

El-Taher, A., 2012. Assessment of natural radioactivity levels and radiation hazards for building materials used in Qassim Area, Saudi Arabia. Rom. J. Phys., 57: 726-735.

El-Taher, A., S. Makhluf, A. Nossair and A.S. Abdel Halim, 2010. Assessment of natural radioactivity levels and radiation hazards due to cement industry. J. Applied Radiat. Isotopes, 68: 169-174.

Fathivand, A.A. and J. Amidi, 2007. Assessment of natural radioactivity and the associated hazards in Iranian cement. Radiat. Protect. Dosimetry, 124: 145-147.

Kadum, A., A.H. Bensaoula and B. Dahmani, 2013. Measurement of natural radioactivity in cement of Tlemcen-Algeria by using well-Shape NaI(Tl) detector. J. Nat. Sci. Res., 3: 182-191.

Kamal, M.K., A.A. Nasser, N.A. Hassan and A.R. El-Sersy, 2011. Environmental safety of natural and manufactured building materials. Concrete Res. Lett., 2: 201-212.

Khan, K. and H.M. Khan, 2001. Natural gamma-emiting radionuclides in Pakistani Portland cement. Applied Radiation Isotopes, 54: 861-865.

Kobeissi, M.A., O. El Samad, K. Zahraman, S. Milky, F. Bahsoun and K.M. Abumurad, 2008. Natural radioactivity measurements in building materials in Southern Lebanon. J. Environ. Radioactivity, 99: 1279-1288.

Kpeglo, D.O., H. Lawluvi, A. Faanu, A.R. Awudu and P. Deatanyah *et al*., 2011. Natural radioactivity and its associated radiological hazards in Ghanaian cement. Res. J. Environ. Earth Sci., 3: 160-166.

Kumar, A., M. Kumar, B. Singh and S. Singh, 2003. Natural activities of ^{238}U, ^{232}Th and ^{40}K in some Indian building materials. Radiation Measur., 36: 465-469.

Landsberger, S., C. Brabec, B. Canion, J. Hashem, C. Lu, D. Millsap and G. George, 2013. Determination of ^{226}Ra, ^{228}Ra and ^{210}Pb in NORM products from oil and gas exploration: Problems in activity underestimation due to the presence of metals and self-absorption of photons. J. Environ. Radioact., 125: 23-26.

Malanca, A., V. Pessina and G. Dallara, 1993. Radionuclide content of building materials and gamma ray dose rates in dwellings of rio grande do norte, Brazil. Radiat. Protect. Dosimetry, 48: 199-203.

Mollah, A.S., G.U. Ahmed, S.R. Husain and M.M. Rahman, 1996. The natural radioactivity of some building materials used in Bangladesh. Health Phys., 50: 849-851.

NEA-OECD., 1979. Exposure to radiation from natural radioactivity in building materials. Report by NEA Group of Experts, OECD, Paris.

Paredes, C.H., W.V. Kessler, R.R. Landolt, P.L. Ziemer and D.J. Paustenbach, 1987. Radionuclide content of and ^{222}Rn emanation from building materials made from phosphate industry waste products. Health Phys., 53: 23-29.

Popic, J.M., B. Salbu, T. Strand and L. Skipperud, 2011. Assessment of radionuclide and metal contamination in a thorium rich area in Norway. J. Environ. Monitor., 13: 1730-1738.

Rizzo, S., M. Brai, S. Basile, S. Bellia and S. Hauser, 2001. Gamma activity and geochemical features of building materials: Estimation of gamma dose rate and indoor radon levels in Sicily. Applied Radiat. Isotopes, 55: 259-265.

Saito, K., N. Petoussi-Henss and M. Zankl, 1998. Calculation of the effective dose and its variation from environmental gamma ray sources. Health Phys., 74: 698-706.

Sofilic, T., D. Barisic, U. Sofilic and M. Durokovic, 2011. Radioactivity of some building and raw materials used in Croatia. Polish J. Chem. Technol., 13: 23-27.

Sorantin, H. and F. Steger, 1984. Natural radioactivity of building materials in Austria. Radiat. Protect. Dosimetry, 7: 59-61.

Tufail, M., N. Ahmad, S.M. Mirza, N.M. Mirza and H.A. Khan, 1992. Natural radioactivity from the building materials used in Islamabad and Rawalpindi, Pakistan. Sci. Total Environ., 121: 283-291.

Tzortzis, M., H. Tsertos, S. Christofides and G. Christodoulides, 2003. Gamma-ray measurements of naturally occurring radioactive samples from Cyprus characteristic geological rocks. Radiat. Meas., 37: 221-229.

UNNSCEAR., 2000. Sources and effects and risks of ionizing radiation. Report to the General Assembly, with Scientific Annexes, United Nations Scientific Committee on the Effects of Atomic Radiation (UNNSCEAR), New York, USA.

Xhixha, G., A. Ahmeti, G.P. Bezzon, M. Bitri and C. Broggini *et al*., 2013. First characterisation of natural radioactivity in building materials manufactured in Albania. Radiat. Protect. Dosim., 155: 217-223.

Zhao, C., X. Lu, N. Li and G. Yang, 2012. Natural radioactivity measurements of building materials in Baotou, China. Radiat. Protect. Dosimetry, 152: 434-437.

Ziqiang, P., Y. Yin and G. Mingqiang, 1988. Natural radiation and radioactivity in China. Radiat. Protect. Dosimetry, 24: 29-38.