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Assessment of Health Risks due to Occupational Exposure to Natural Radioactivity of Some Building Materials in Egypt

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Abstract:

This study was carried to assess the radiological health risks associated with occupational exposure to natural radioactivity in some of ceramic raw materials and building materials. The concentrations of Ra-226, Th-232, and K-40 were measured using a gamma ray spectrometer equipped with a hyper pure germanium (HPGe) detector. In the present work, the mean values of Ra-226 for fly ash, bauxite, ceramic colors and marble are higher than the world average value of 35 (Bq/kg). The mean values of Th-232 for clay, fly ash, bauxite, ceramic colors, marble and granite are higher than the world average value of 30 (Bq/kg). For K-40, field spar, ceramic colors, marble and granite have mean values that higher than the world average value of 400 (Bq/kg). The radiological health hazard parameters such as radium equivalent activity, absorbed dose rate, annual effective dose rate, excess life time cancer risk, external hazard index and internal hazard index were calculated based on the mean values of these radionuclides. The maximum values of radium equivalent activity, absorbed dose rate, annual effective dose rate, excess life time cancer risk, external hazard index and internal hazard index were 3299.98 (Bq/kg), 4429.658 (nGy/h), 3.703 (mSv/y), 12.962, 8.92 and 15.97; respectively. Also, the equivalent and effective doses due to occupational exposure were calculated with Dose Conversion Factors for External Exposure (DFEXT code).

Keywords: Natural Radioactivity, DFEXT, Gamma Spectroscopy, Radiological Risks

1. Introduction

In the past several decades, industry has rapidly progressed. As a result, the demand for exploitation of natural resources of Earth has increased at a reckless rate. The Earth's crust contains the primordial natural radionuclides Ra-226, Th-232, and K-40. As a result, ores of building materials derived from the earth's crust are sources of both external and internal gamma radiation exposure. Besides the materials used in the building's construction, decorative materials are also considered a source of radioactivity for workers in this field

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(occupational exposure) and in dwellings. Ceramic tiles used for walls and floors are among these decorative materials due to the inclusion of zircon sand in the tile glaze. Gamma radiation emitted by these radionuclides is an external source of radiation exposure, whereas radon gas exhaled from building materials is an internal source of radiation exposure **[1-4]**. The levels of exposure to these radionuclides are not significantly higher than normal background levels for most human activities involving minerals and raw materials. Certain work activities, on the other hand, can result in significantly increased exposures that may need to be restricted by regulation. The material that is causing these increased exposures is known as naturally occurring radioactive material (NORM) **[5]**. The concentration of natural radionuclides in the raw materials of some building materials is critical for assessing potential radiological hazards to human health and developing guidelines for the use and organization of those materials **[6]**. The primary goal of this study is to assess the health risks due to occupational exposure to natural radioactivity in some ceramic raw materials and building materials from identifying and quantifying natural radionuclides. To accomplish this, high purity germanium (HPGe) gamma spectrometry was used to determine the activity concentration of natural radionuclides from which radiological hazard parameters, equivalent and effective doses were calculated.

2. Materials and Methods

2.1 Sample Preparation

Some of ceramic raw materials (clay, fly ash, field spar, bauxite, ceramic colors, zirconium) and building materials (marble, granite and cement) were obtained from various Egyptian factories. The samples were ground to fine powder. To remove water and moisture, all samples were dehydrated in an oven at 105° C for one day. About 100 cc from each sample was prepared and put in plastic jars. The plastic containers were closed strongly and kept for more than four weeks to attain secular equilibrium between Ra-226 and its progenies before gamma spectroscopy. At the same time, radionuclides' background was measured.

2.2 Experimental Technique

Gamma Spectroscopy was used to identify activity concentrations of the test samples. In this study a hyper pure germanium (HPGe) detector (Ortec) was used. The diameter of the hyper pure germanium crystal is 49.3 mm, the length is 47.1 mm, the end cap to crystal distance is 3 mm, and the absorbing beryllium layer is 0.5 mm. The peak to Compton ratio is 51.7 and the resolution is 2 keV at the 1332.5 keV gamma transition of Co-60. The detector is linked to an ORTEC 572A spectroscopy amplifier and an IBM compatible PC with an MCA card

(Maestro-32). A shield made of a lead cylinder and a concentric copper cylinder with a movable cover shielded the detector to reduce background noise. Energy and efficiency calibration were accomplished for the system. The gamma spectra for the investigated samples and background were accumulated in a period of 80000 seconds. The primary natural radionuclides that investigated in the present work were Radium-226, Thorium-232 and Potassium-40. The spectra were analyzed with the computer software program Maestro (EG&G ORTEC). The gamma energies that used for calculating the activity concentrations of these radionuclides ranged from 186 keV to 2614 KeV as shown in Table (1) **[7, 8].** The activity concentration (Bq/kg) of the investigated radionuclides was calculated using the following formula **[9-11]:**

$$\mathbf{A} = \frac{\mathbf{C/S}}{\varepsilon * \mathbf{I} * \mathbf{m}} \qquad \textbf{(Bq/kg)} \qquad \textbf{(1)}$$

Where C/s is the net counts per second of a peak at specific energy, ε is absolute photo peak efficiency of the detector at specific energy, I is branching ratio for the specific energy and m is the mass of the sample in kg.

Table (1): Energies and branching ratio of U-238, U-235, Th-232, and K-40.

U-238 series		
Nuclide	Energy (keV)	Photons per disintegration (%)
Pa-234m	1001	0.7
Ra-226	186.1	3.3
Pb-214	295.1	19.2
	352.1	37.1
Bi-214	609.3	46.1
	934.1	3.2
	1120.3	15.1
	1765	15.9
Uranium-235		
Nuclide	Energy (keV)	Photons per disintegration (%)
U-235	143.7	10.9
	163.3	5.1
	185.7	57.2
	205.3	5.0
Thorium-232 series		
Nuclide	Energy (keV)	Photons per disintegration (%)
Ac-228	911.2	29.1
Tl-208	583.1	30.9
	2614	35.8
Nuclide	Energy (keV)	Photons per disintegration (%)
K-40	1460	10.74

2.3 The Interference Correction of 186.1 keV& 185.72 keV

Two or more radionuclides may emit gamma rays that are located very close to one another due to the proximity in their energy values such that their emissions would form a single peak that is a combination of the counts from the two energies. One of the major interferences in the gamma spectrometry of NORM is the mutual interference between U-235 (185.72 keV, I_γ = 57.2%) and Ra-226 (186.21 keV, I_γ = 3.3%). The energy resolution of the detectors can't separate these energies **[12-16]**. Estimation the count rate of the peak 185.72 keV can be calculated in terms of the activity concentration of (205.31 keV), thus the count rate of Ra-226 of energy (186.2 keV) can be calculated. To confirm the corrected activity value for Ra-226, the next equation of the activity can be applied **[15]**.

$$\textbf{Corrected Ra} - \mathbf{226} = \mathbf{0.5709} \times \textbf{Apparent Ra} - \mathbf{226} \qquad \textbf{(2)}$$

And the equation of count rate **[16]** can be applied.

$$\mathbf{CR_{Ra} = 0.583 \times CRT} \qquad (3)$$

Where CRT: is the total count rate (counts/sec) in the 186 keV energy peak.

3. Radiological Hazard Parameters

3.1 Calculation of Radium Equivalent Activity (R_{eq})

It is commonly used to assess the gamma radiation dose resulted from Radium-226, Thorium-232, and Potassium-40. It was calculated from the equation in the references of **[17, 18, 19].**

3.2 Calculation of Absorbed Dose Rate

Outdoor absorbed dose rate (D_{out}), indoor absorbed dose rate (D_{in}) and total absorbed dose rate (D_{tot})can be calculated as following **[20-23]**:

$$\mathbf{D_{out}(nGy/h) = 0.462\, C_{Ra} + 0.604\, C_{Th} + 0.0417\, C_K} \qquad (4)$$

$$\mathbf{D_{in}\,(nGy/h) = 0.92\, C_{Ra} + 1.1\, C_{Th} + 0.081\, C_K} \qquad (5)$$

$$\mathbf{D_{tot}\,(nGy/h) = D_{out} + D_{in}} \qquad (6)$$

Where C_{Ra}, C_{Th}, and C_K are concentrations (Bq/kg) of Radium-226, Thorium-232, and Potassium-40, respectively.

3.3 Annual Effective Dose Rate

Outdoor annual effective dose rate (E_{out}), indoor annual effective dose rate (E_{in}) and total annual effective dose rate (E_{tot}) can be calculated using the following equations, with an outdoor occupancy of 20% and an indoor occupancy of 80% **[24, 25]:**

$$\mathbf{E_{out}(mSv/y) = D_{out}(nGy/h) * 2000\,(h/y) * 0.7\,(Sv/Gy) * 0.2 * 10^{-6}} \qquad (7)$$

$$\mathbf{E_{in}(mSv/y) = D_{in}(nGy/h) * 2000(h/y) * 0.7(Sv/Gy) * 0.8 * 10^{-6}} \qquad (8)$$

$$\mathbf{E_{tot}(mSv/y) = E_{out} + E_{in}} \qquad (9)$$

Where 0.7 (Sv/Gy) is a factor for converting absorbed dose in air to effective dose, 0.2 is the outdoor occupancy factor, 0.8 is the indoor occupancy factor and 2000 (h/y) is the exposure time.

3.4 Calculation of Cancer Risk

It indicates that a person might have cancer if overexposed to materials that cause cancer. Outdoor cancer risk ($ELCR_{out}$), indoor cancer risk ($ELCR_{in}$) and total cancer risk ($ELCR_{tot}$) can be determined from the following equations **[26-28]**:

$$ELCRout = Eout * LE * RF \quad (10)$$

$$\mathbf{ELCR_{in} = E_{in} * LE * RF} \quad (11)$$

$$\mathbf{ELCR_{tot} = ELCR_{out} + ELCR_{in}} \quad (12)$$

Where LE is the life expectancy (standard; 70 years), RF (Sv^{-1}) is the fatal risk factor per Sv and it equals (0.05) for stochastic effects.

3.5 Calculation of External Hazard Index (H_{ex})

It evaluates external exposure that caused by gamma rays released by radionuclides in many construction materials used in houses and it can be determined as following:

$$\mathbf{H_{ex} = (C_{Ra}/370 + C_{Th}/259 + C_K/4810) \leq 1} \quad (13)$$

For the radiation hazard to be negligible, it must be lower than the unity.

3.6 Calculation of Internal Hazard Index (H_{in})

Internal hazard index (H_{in}) calculates the internal exposure to carcinogenic radon and its short-lived progenies and it is given by the following formula **[29-31]**:

$$\mathbf{H_{in} = (C_{Ra}/185 + C_{Th}/259 + C_K/4810) \leq 1} \quad (14)$$

For the radiation hazard to be negligible, it must be lower than the unity.

3.7 Evaluation of External Occupational Exposure

Organ doses due to external occupational exposure were determined. Where the summation includes the tissues with tissue weighting factor (W_T), while W_{rem} is the weighting factor for the remainder (0.2) and h_{rem} is the committed dose equivalent per unit integrated exposure for the remainder tissues, it is given as $\mathbf{h_{rem} = 1/5\ \Sigma h_t}$. The equivalent dose ($H_T$) to any organ from raw materials and the effective dose (E) can be calculated using these coefficients as following **[32, 33]**:

$$\mathbf{H_T = A * T * 3600\,(sec/hr) * h_t} \quad \mathbf{(Sv)} \quad (15)$$

Where, A: activity concentration (Bq/m^3), T: exposure time (8 hr/d * 5 d/week *50 week/year), h_t: equivalent dose in tissue "t" per unit integrated exposure (Sv m^3/sec Bq).

$$E = A * T * 3600\ (sec/hr) * e \qquad (Sv) \qquad (16)$$

Where, **e (**Svm^3/secBq) is the effective dose per unit integrated exposure computed as $\Sigma W_T h_t$.

4. Results and Discussion

Table (2) and **figure (1)** show the average activity concentrations of Ra-226, Th-232 and K-40 for the investigated samples. For Ra-226 activity concentrations, fly ash, bauxite, ceramic colors, and marble have values that are higher than the world average value of 35 (Bq/kg) **[34]**. But the samples of clay, field spar, zirconium, granite and cement have values that are lower than the world average. For Th-232, the mean values for clay, fly ash, bauxite, ceramic colors, marble and granite are higher than the world average 30 (Bq/kg) **[34]**. But the samples of field spar, zirconium and cement have mean values that are lower than the world average value. The average values of K-40 for the samples of field spar, ceramic colors, marble and granite are higher than the world average value of 400 (Bq/kg) **[34]**. But the samples of clay, fly ash, bauxite, zirconium and cement have average values which lower than the world value. The error for the measured activity was estimated as 10 %, the sources of this error are the detector efficiency, the peak area, the gamma intensity and sample weight.

Table (2): The average activity concentrations (Bq/kg) of Ra-226, Th-232 and K-40 in the investigated samples.

Sample	Ra-226	Th-232	K-40
Clay	26.55±1.23	33.52±1.31	279.68±6.91
Fly ash	453.06±10.07	391.98±7.50	111.82±8.36
Field spar[b]	34.07±1.59	25.56±1.17	1332.76±19.50
Bauxite	590.99±17.08	569.70±14.42	134.77±17.31
Ceramic colors	662.23± 8.03	88.71±3.47	537.14±19.03
Zirconium[a]	2677.69±14.71	481.32±5.60	8.20±0.71
Marble	43.19±1.78	80.97±2.08	1155.26±15.86
Granite[b]	31.77±2.03	39.32±1.94	757.73±17.83
Cement	31.37 ±1.46	6.84±0.51	53.35±2.16
Worldwide Average	35	30	400

a: worldwide average values of activity concentration of Ra-226 and Th-232 for zirconium are 3000 (Bq/kg) and 600 (Bq/kg), respectively **[34]**.

b: U-235 can't be detected and thus the activity of Ra-226 don't need correction because the activity of daughters of Ra-226 is nearly equal to that of Ra-226.

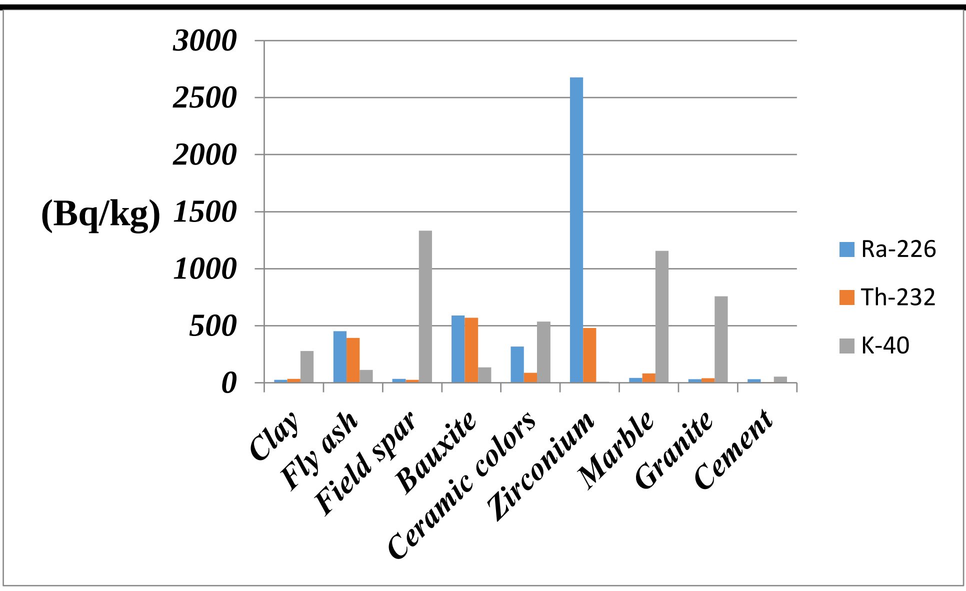

Figure (1): Average activity concentrations (Bq/kg) due to natural radionuclides in the investigated samples.

Table (3) shows a confirmation for the activity concentrations (Bq/kg) and count rates of Ra-226 after correction for some of the investigated samples in this study with those using equations in references **[15, 16]**. It is clear that the corrected activity values of Ra-226 in this study for the samples of zirconium, ceramic colors, fly ash and clay are higher than those obtained using equation of reference **[15]**, but the corrected activity values for the samples of bauxite, marble and cement are lower than those obtained using the same equation. For the count rate, it is observed that the corrected values of count rate of Ra-226 in this study for the samples of zirconium, ceramic colors, fly ash and clay are little higher than those obtained using equation of reference **[16]**, but the corrected values of count rate of Ra-226 for the samples of bauxite, marble and cement are little lower than those obtained using the same equation.

Table (3): Confirmation for the activity concentrations and count rates of Ra-226 after correction.

Sample	Activity of Ra-226 before correction in the present work	Activity of Ra-226 after correction in the present work	Activity of Ra-226 using **[15]**	Count rate of Ra-226 after correction in the present work	Count rate of Ra-226 using **[16]**
Zirconium	4560.17	2677.69	2603.40	0.632	0.610
Bauxite	1315.69	590.99	751.13	0.084	0.104
Ceramic colors	1071.56	662.23	611.75	0.042	0.040
Fly ash	649.66	453.06	370.89	0.096	0.081
Marble	105.64	43.19	60.31	0.005	0.007
Clay	42.73	26.55	24.39	0.004	0.003
Cement	62.10	31.37	35.45	0.003	0.004

Table (4) indicates a comparison of mean activity concentrations of natural radionuclides for some of the investigated samples between the present study and published results from other countries. For cement, the mean activity concentration of Ra-226 of the present study is higher than that of Sri Lanka and China, but lower than that of India. For Th-232 and K-40 the present study has the lowest values and the lowest value of radium equivalent activity. For granite, the present study has the lowest values for Ra-226, Th-232 and K-40. For marble, the present study has a mean value of activity concentration of Ra-226 that higher than Pakistan and Malysia, but less than that of Iraq. For Th-232 and K-40 the present study has the highest values and the highest value of radium equivalent activity. For clay, the present study has the lowest values of Ra-226, Th-232 and K-40, thus the lowest value for radium equivalent activity. For Bauxite, the present study has the highest mean values of activity concentration compared to other countries. For fly ash, the present study has mean values of Ra-226, Th-232 activity concentration and a value of radium equivalent activity that much higher than those of Croatia. For zirconium, the present study has a mean value of Ra-226 activity concentration that higher than that of Egypt and Australia, but lower than that of China. The mean values of Th-232 and K-40 activity concentration of this study are higher than that of Egypt, but lower than that of Australia and China. For field spar, the mean values of Ra-226 and Th-232 activity concentration of this study are higher than that of Egypt, but lower than that of Turkey. The mean value of K-40 activity concentration of this study is much higher than those of Egypt and Turkey. The variation of concentration of radionuclides in raw materials and processed building products can vary significantly, according to their origin and geological locations **[35]**.

Table (4): A comparison of mean activity concentrations of natural radionuclides (Bq/kg) for some of the investigated samples between the present study and published results from other countries.

Material	Country	Activity (Bq/kg)			Ra_{eq}	Reference
		Ra-226	Th-232	K-40		
Cement	Sri Lanka	23.0	29.0	832.0	71.0	**[36]**
	India	47.4	57.7	312.4	154.0	**[37]**
	China	29.1	15.8	333.2	77.0	**[38]**
	Egypt	**31.37**	**6.84**	**53.35**	**45.36**	**Present Study**
Granite	Greece	67	95	1200	---	**[39]**
	India	82	112	1908	---	**[40,41]**
	Jordan	41.5	58.4	897	---	**[41, 42]**
	Egypt	**31.77**	**39.32**	**757.73**	**146.34**	**Present Study**
Marble	Iraq	49.32	15.3	1046	151.7	**[43]**
	Pakistan	27.8	24.4	59.3	67.97	**[44]**
	Malysia	19	16.5	243.3	61.3	**[45]**
	Egypt	**43.19**	**80.97**	**1155.26**	**246.07**	**Present Study**
Clay	Australia	41	89	681	220	**[46, 47]**
	Germany	78	62	962	241	
	Finland	59	67	673	207	
	Egypt	**26.55**	**33.52**	**279.68**	**95.22**	**Present Study**
Bauxite	Hungary	419	256	47	--	**[48]**
	China	370	400	63	--	
	Greece	150	205	28.3	--	
	Egypt	**590.99**	**569.70**	**134.77**	**1410.03**	**Present Study**
Fly Ash	Croatia	53.3	54.4	361.7	158.9	**[49]**
	Egypt	**453.06**	**391.98**	**111.82**	**1017.23**	**Present Study**
Zirconium	Egypt	428.4	61.1	N/D	---	**[50]**
	Australia	2249.6	503.2	325.6	---	**[51]**
	China	14386.7	7952	2226.3		**[52]**
	Egypt	**2611.06**	**481.32**	**8.20**	**3299.98**	**Present Study**
Field Spar	Egypt	6.9	6.48	283.2	--	**[50]**
	Turkey	1973.4	354.2	131.9	--	**[53]**
	Egypt	**34.07**	**25.56**	**1332.76**	**173.23**	**Present Study**

Table (5) shows the radiological hazard indices that determined from the measured activity concentrations of Ra-226, Th-232 and K-40 for all investigated samples. The radium equivalent activity was determined to know if the investigated samples are suitable to be used as building materials. The obtained Ra_{eq} values ranged from 45.36 to 3299.98 (Bq/kg). It is observed that fly ash, bauxite, ceramic colors and zirconium have values that are higher than 370 (Bq/kg) that set as the upper limit for building material **[34]**, whereas clay, field spar, marble, granite and cement have values that are less than upper limit. The results of (D_{out}) varied from 20.897 to 1497.368 (nGy/h), all samples have values that exceed the world average value of 59 (nGy/h) **[34]** except for clay and cement. The results of (D_{in}) varied between 40.802 and 2932.290 (nGy/h), all samples have values that exceed the permissible level of 84 (nGy/h) **[34]** except for clay that has a value nearly equal to the world average value and cement that has a value under permissible level. Thus all investigated samples have results of (D_{tot}) exceed the permissible level of 143 (nGy/h) **[34]** except for clay and cement. The calculated values of outdoor annual effective dose rate ranged from 0.006 to 0.419 (mSv/y).The samples of fly ash, bauxite and zirconium have values that higher than the world mean value 0.07 (mSv/y) **[34]**, but the samples of clay, field spar, ceramic colors, marble, granite and cement have values that lower than the world mean value.The calculated values of indoor annual effective dose rate ranged from 0.046 to 3.284(mSv/y). The samples of fly ash, bauxite, ceramic colors and zirconium have values that higher than the world mean value 0.41 (mSv/y) **[34]**, but the samples of clay, field spar, marble, granite and cement have values that lower than the world mean value. Thus the samples of fly ash, bauxite, ceramic colors, and zirconium have values of total annual effective dose rate that higher than the world mean value 0.48 (mSv/y) **[34]**, whereas the samples of clay, field spar, marble, granite and cement have values that lower than the world mean value. The calculated values of outdoor excess life time cancer risk ranged from 0.02 to 1.467 and all investigated samples have values that higher than the world mean value $0.29*10^{-3}$ **[34]**. The calculated values of indoor excess life time cancer risk ranged from 0.160 to 11.495. The values of total excess life time cancer risk for all investigated samples are higher than the world mean value $1.45*10^{-3}$ **[34]**. The calculated values of both external and internal hazard index are higher than the permissible level **[34]** for the samples of fly ash, bauxite, ceramic colors, and zirconium, but the samples of clay, field spar, marble, granite and cement have values that lower than unity.

Table (6) shows the annual equivalent (H_T) and effective doses (E) due to external exposure of workers to natural radionuclides in the investigated samples. For ceramic raw materials, it is obvious that skin receives the highest external exposure 7.23E-03 (mSv/y), but esophagus and pancreas receive the lowest external exposure 2.92E-03 (mSv/y). For marble, it is clear that skin receives the highest external exposure 3.04E-03 (mSv/y), but esophagus and pancreas receive the lowest external exposure 1.18E-03 (mSv/y). For granite, it is obvious that skin receives the highest external exposure 1.91E-03 (mSv/y), but pancreas receives the lowest external exposure 7.40E-04 (mSv/y). For cement, it is clear that skin receives the highest external exposure 1.28E-04 (mSv/y), but pancreas receives the lowest external exposure 5.01E-05 (mSv/y). The annual effective doses due to occupational exposure to ceramic raw materials, marble, granite and cement are 3.37E-03, 1.35E-03, 8.47E-04 and 5.74E-05 (mSv/y), respectively which much less than the permissible level of 20 (mSv/y) **[54]**.

Table (5): Radiological hazard parameters for the investigated samples.

Sample	Ra_{eq} (Bq/kg)	D_{out} (nGy/h)	D_{in} (nGy/h)	D_{total} (nGy/h)	E_{out} (mSv/y)	E_{in} (mSv/y)	E_{total} (mSv/y)	$ELCR_{out}$	$ELCR_{in}$	$ELCR_{total}$	H_{ex}	H_{in}
Clay	95.22	43.804	83.213	127.018	0.012	0.093	0.105	0.043	0.326	0.369	0.26	0.33
Fly Ash	1017.23	448.434	852.473	1300.907	0.126	0.955	1.080	0.439	3.342	3.781	2.75	3.96
Field Spar	173.23	86.751	167.406	254.157	0.024	0.187	0.212	0.085	0.656	0.741	0.47	0.56
Bauxite	1410.03	619.980	1175.769	1795.750	0.174	1.317	1.490	0.608	4.609	5.217	3.81	5.39
Ceramic Colors	493.42	226.227	440.283	666.509	0.063	0.493	0.556	0.222	1.726	1.948	1.33	2.21
Zirconium	3299.98	1497.368	2932.290	4429.658	0.419	3.284	3.703	1.467	11.495	12.962	8.92	15.97
Marble	246.07	116.174	220.666	336.841	0.033	0.247	0.280	0.114	0.865	0.979	0.66	0.78
Granite	146.34	70.025	133.857	203.882	0.020	0.150	0.170	0.069	0.525	0.593	0.40	0.48
Cement	45.36	20.897	40.802	61.700	0.006	0.046	0.052	0.020	0.160	0.180	0.12	0.21
Worldwide Average	**370**	**59**	**84**	**143**	**0.07**	**0.41**	**0.48**	**$0.29*10^{-3}$**		**$1.45*10^{-3}$**	**≤ 1**	**≤ 1**

Table (6): Annual equivalent doses and effective doses due to external exposure to the investigated samples (mSv/y).

Organ	Annual equivalent doses (mSv/y)			
	Ceramic raw materials	Marble	Granite	Cement
R Marrow	3.41E-03	1.37E-03	8.62E-04	5.84E-05
Adrenals	3.10E-03	1.25E-03	7.87E-04	5.32E-05
B Surface	4.95E-03	1.82E-03	1.14E-03	7.88E-05
Brain	3.40E-03	1.37E-03	8.59E-04	5.82E-05
Breast	3.66E-03	1.45E-03	9.13E-04	6.19E-05
G Bladder	2.95E-03	1.19E-03	7.46E-04	5.05E-05
Esophagus	2.92E-03	1.18E-03	7.43E-04	5.03E-05
ST Wall	3.14E-03	1.26E-03	7.90E-04	5.35E-05
SI Wall	3.00E-03	1.21E-03	7.62E-04	5.15E-05
ULI Wall	3.04E-03	1.22E-03	7.68E-04	5.20E-05
LLI Wall	3.06E-03	1.23E-03	7.75E-04	5.24E-05
Heart	3.12E-03	1.25E-03	7.87E-04	5.33E-05
Kidneys	3.19E-03	1.28E-03	8.03E-04	5.44E-05
Liver	3.16E-03	1.27E-03	7.97E-04	5.40E-05
Lungs	3.41E-03	1.36E-03	8.56E-04	5.80E-05
Ovaries	3.07E-03	1.24E-03	7.81E-04	5.28E-05
Pancreas	2.92E-03	1.18E-03	7.40E-04	5.01E-05
Skin	7.23E-03	3.04E-03	1.91E-03	1.28E-04
Spleen	3.19E-03	1.28E-03	8.03E-04	5.44E-05
Testes	3.56E-03	1.42E-03	8.91E-04	6.04E-05
Thymus	3.26E-03	1.31E-03	8.22E-04	5.57E-05
Thyroid	3.23E-03	1.29E-03	8.12E-04	5.50E-05
U Bladder	3.12E-03	1.25E-03	7.87E-04	5.33E-05
Uterus	2.94E-03	1.19E-03	7.46E-04	5.05E-05
Muscle	3.42E-03	1.37E-03	8.59E-04	5.82E-05
H_{rem}	3.41E-03	1.36E-03	8.56E-04	5.80E-05
E	3.37E-03	1.35E-03	8.47E-04	5.74E-05

5. Conclusion

Results show that some raw materials, as fly ash, bauxite, ceramic colors and zirconium lead to over-exposure due to high hazard indices such as H_{ex} and H_{in} (more than unity), Ra_{eq} (higher than the exemption limits (370 Bq/kg), D_{out}, D_{in}, D_{total}, E_{out}, E_{in}, E_{total}, $ELCR_{out}$, $ELCR_{in}$ and $ELCR_{total}$ exceed the upper limit of exposure. It can be concluded that although hazard indices to workers due to exposure to natural radionuclides of some raw materials is within the permissible level but the summation of hazard indices values beside inhalation and ingestion of dust and the associated high concentration of radon represent a significant risk and potential radiological hazards. It can be concluded that specific regulations are necessary applied in ceramic, granite & marble industry due to high activities of whole masses (many tons) of raw materials within the field. To reduce the risks of eye, skin and respiratory organs recommendations were to limit the exposure time to 8-hr work shift during 40-hr workweek over 50 week per year taken into consideration all radiation protection concepts.

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الملخص العربى

تقييم المخاطر الصحية الناتجة عن التعرض المهنى للنشاط الإشعاعى الطبيعى لبعض مواد البناء

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أجريت هذه الدراسة لتقييم المخاطر الصحية الإشعاعية الناتجة عن التعرض المهني للنشاط الإشعاعي الطبيعي في بعض مواد السيراميك الخام ومواد البناء ، وتم قياس تركيزات النظائر المشعة (الراديوم-226 و الثوريوم-232 و البوتاسيوم-40) باستخدام مطياف أشعة جاما مع كاشف الجرمانيوم عالي النقاء (HpGe).وكانت القيم المتوسطة للنشاط الاشعاعي للراديوم-226 لعينات (الرماد المتطاير والبوكسيت وألوان السيراميك والرخام) أعلى من متوسط القيمة العالمية والذي يكافيء 35 (بيكريل / كجم). كما ان متوسط قيم النشاط الاشعاعي للثوريوم-232 لعينات (الطفلة والرماد المتطاير والبوكسيت وألوان السيراميك والرخام والجرانيت) أعلى من المتوسط العالمي والذي يكافيء 30 (بيكريل / كغم). اما بالنسبة للبوتاسيوم-40 ، فإن القيم المتوسطة للنشاط الاشعاعي لعينات (فيلد سبار وألوان السيراميك والرخام والجرانيت) أعلى من القيمة المتوسطة العالمية البالغة 400 (بيكريل / كغم). كما تم حساب مخاطر الصحة الإشعاعية مثل النشاط المكافئ للراديوم ، ومعدل الجرعة الممتصة ، ومعدل الجرعة الفعالة السنوية ، وخطر الإصابة بالسرطان على مدى الحياة ، ومؤشر الضرر الناتج عن التعرض الخارجي للاشعاع ، ومؤشر الضرر الناتج عن التعرض الداخلي للاشعاع بناءً على القيم المتوسطة للتركيزات الاشعاعية لهذه النويدات المشعة. كما تم حساب الجرعات المكافئة والفعالة بسبب التعرض المهني باستخدام عوامل تحويل الجرعة للتعرض الخارجي (كود DFEXT).