World Academy of Science, Engineering and Technology
International Journal of Environmental and Ecological Engineering
Vol:16, No:1, 2022

Environmental Impact Assessment of Ceramic Tile Materials Used in Jordan on Indoor Radon Level

Mefleh S. Hamideen

***Abstract*—**In this investigation, activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K, of some ceramic tile materials used in the local market of Jordan for interior decoration were determined by making use of High Purity Germanium (HPGe) detector. Twenty samples of different country of origin and sizes used in Jordan were analyzed. The concentration values of the last-mentioned radionuclides ranged from 30 Bq.kg^{-1} (Sample from Jordan) to 98 Bq.kg^{-1} (Sample from China) for 226Ra, 31 Bq.kg^{-1} (Sample from Italy) to 98 Bq.kg^{-1} (Sample from China) for 232Th, and 129 Bq.kg^{-1} (Sample from Spain) to 679 Bq.kg^{-1} (Sample from Italy) for 40K. Based on the calculated activity concentrations, some radiological parameters have been calculated to test the radiation hazards in the ceramic tiles. In this work, the following parameters: Total absorbed dose rate (D_R), Annual effective dose rate (H_R), Radium equivalent activity (Ra_{eq}), Radon emanation coefficient F (%) and Radon mass exhalation rate (E_m) were calculated for all ceramic tiles and listed in the body of the work. Fortunately, the average calculated values of all parameters are less than the recommended values for each parameter. Consequently, almost all the examined ceramic materials appear to have low radon emanation coefficients. As a result of that investigation, no problems on people can appear by using those ceramic tiles in Jordan.

***Keywords*—**Radon emanation coefficient, radon mass exhalation rate, total annual effective dose, radon level.

I. Introduction

NATURALLY Occurring Radionuclides Materials (NORMs), ceramic tiles as an example, are causes of internal and external exposures in houses and work buildings. Gamma-emitting radionuclides cause external exposure radiations, radon decay products that are inhaled from construction materials are short-lived generally and ceramic tile materials specifically, cause the internal exposure radiation. As a result of that, radiation exposure of people increased strongly by using buildings that contain ceramic materials which have high doses of natural radionuclides [1]-[3]. Measuring external exposure is determined by direct gamma -ray spectrometry but the most complicated to measure is the internal exposure radiation because radon emanation from materials depends on many factors, including radium content of the material, grain size, permeability, ventilation rate inside rooms and material density. Many methods to measure radon emanation coefficients and exhalation rate were mentioned in reports [4], [5].

Nowadays, there has been a great increase in the use of ceramic tiles instead of mosaic tiles as a covering and decorative material for home interiors because of its appearance, attractive colors, and its high scratch resistance [6]-[9]. Concentrations of primordial radionuclides like 226Ra, 232Th, and 40K differ from one country to the next, and even within the same country [10]. Despite the fact that many studies on activity concentrations and radon emanation coefficients of ceramics have been published throughout the world, the current results cannot tell us which type of tile has a higher activity than the others, so we need use [11]-[13].

Therefore, the aim of this study is to find the activity concentration presents in these tiles, their radon emanation coefficients, their mass exhalation rate and their contribution to indoor radon concentration and any other radiological hazards that may affect the occupants of those building contains ceramics.

Mefleh S. Hamideen is with the, Al-Balqa Applied University, Jordan (corresponding author, e-mail: mhamideen@bau.edu.jo).

II. Materials and Methods

Samples of ceramic tile were collected from local companies. The materials were crushed, sieved, kept in suitable containers, then they marked to distinguish between them. They left for four weeks to get secular equilibrium. Measurements were undertaken by (HPGe)-detector supplied by EG&G Ortec. The necessary calibration of the measuring system is performed using the standard methods and subtraction of background radiation is performed to assure precise results.

Determination of radiation contents in each container is performed by putting the container at the top of the detector cap for 12 hours. The specific activity (A_i) of the radionuclide was calculated using the (1) [5], [7]:

$$A_i = \frac{C_i}{\varepsilon(E_i).I.t.M} \tag{1}$$

where C_i is the net peak area of gamma- ray at energy E_i, ε (E_i) is the absolute efficiency of gamma ray, I is the absolute probability of gamma decay, t is the counting time, and M is the sample mass.

One of the indices that used to determine the radiation hazards from a radionuclide mixture in the material is the Radium equivalent activity (Ra_{eq}) which can be calculated using the (2) [14], [15]:

$$Ra_{eq} = A_{Ra} + 1..43A_{Th} + 0.077A_K \tag{2}$$

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

The ceramic materials can be regarded safe for human usage if the external gamma-dose is maintained below a minimum value of 1.5 $mSv.y^{-1}$ and the radium equivalent activity (Raeq) is maintained below 370$Bq.kg^{-1}$.

The indoor-absorbed dose rate D in ($nGy.h^{-1}$) can be determined for ceramic materials and other building materials by (3) [16]:

$$D = 0.12A_{Ra} + 0.14A_{Th} + 0.0096A_K \quad (3)$$

One can define an expression for the indoor annual effective dose $E_{eff.}$ in ($mSv.y^{-1}$), by using suitable factors of 0.7 $Gy.Sv^{-1}$ and annual exposure time for people that spend 80% of their time inside houses of 7000h/y, the indoor annual effective dose E_{eff} by the following relation [10], [16]:

$$E_{eff.} = 0.7(Sv.Gy^{-1})x7000(h.y^{-1})xD(Gy.h^{-1}). \quad (4)$$

For ceramic materials like that tested in this work, the indoor annual effective dose, should not exceed the limit of 0.3 $mSv.y^{-1}$ to be considered safe for human use.

The ratio between radon escape to radon production from the material sample is defined as Radon Emanation Coefficient F (%) which can be calculated by first measuring radon after closing the samples directly and measuring after attaining secular equilibrium between radon and its progenies (i.e., ^{214}Pb and ^{214}Bi). The net count rate of gamma ray of progenies C (t) at time t can be written as [4], [17], [18]:

$$C(t) = C_{eq}\left(1 - e^{\lambda t}\right) + C_o e^{\lambda t} \quad (5)$$

where λ is the decay constant of radon, C_{eq} is the net count rate at t greater than 30 days, C_o is the net count rate at t equals zero [4]. The radon emanation coefficient F (%) can be defined as [19]:

$$F = \frac{C_{eq} - C_o}{C_{eq}} x100 \quad (6)$$

Similarly, the radon mass exhalation rate E_m in ($Bq.kg^{-1}.h^{-1}$) can be calculated using the following relation [5], [15], [20]:

$$E_m = FA_{Ra}\lambda \quad (7)$$

where also, A_{Ra} is the concentration of ^{226}Ra in ($Bq.kg^{-1}$).

III. Results and Discussion

Table I presents the values of the measured activity concentrations for different Ceramic samples commonly used by people in houses of Jordan. It can be clearly seen from the table that the values of the concentrations ranged from 30 $Bq.kg^{-1}$ (sample from Jordan) to 98 Bq.kg-1 (sample from China) for ^{226}Ra, 31 $Bq.kg^{-1}$(sample from Italy) to 98 $Bq.kg^{-1}$ (sample from China) for ^{232}Th, and 129 $Bq.kg^{-1}$(sample from Spain) to 679 $Bq.kg^{-1}$ (sample from Italy) for ^{40}K. One can notice a variation in the values of these concentrations so that a new parameter (radium equivalent activity) can be used to test the gamma ray risks. The largest value of that parameter is 306 $Bq.kg^{-1}$ (sample from China) whereas the smallest value is 111 $Bq.kg^{-1}$ (sample from Italy). Simply, we notice that all values of radium equivalent activity, Ra_{eq} fall below the allowed value for building materials which is 370 $Bq.kg^{-1}$. The variations in the values of Ra_{eq} in all ceramic tile material belongs to the row materials that these tiles constructed from. Fig. 1 below shows the distribution of activity concentrations of all radionuclides and radium equivalent activity values in all samples and the correlation between them.

TABLE I
Activity Concentration ($Bq.kg^{-1}$) of ^{226}Ra, ^{232}Th, ^{40}K, Radon Emanation Coefficient F (%), Radon Mass Exhalation Rate E_M (Bq/kg.h), Radium Equivalent Activity Ra_{eq} ($Bq.kg^{-1}$), Total Absorbed Dose Rate D ($nGy.h^{-1}$) and Annual Effective Dose $E_{eff.}$ (mSv) for Ceramic Tiles

Sample ID	Country of Origin	F (%)	E_m (Bq/kg.h)	Ra_{eq} ($Bq.kg^{-1}$)	D ($nGy.h^{-1}$)	E_{eff} (mSv)	Activity Concentrations ($Bq.kg^{-1}$) ^{226}Ra	^{232}Th	^{40}K
C1	Jordan	1.8	0.0005	176	18	0.09	40±3	87 ± 5	145 ± 25
C2	Jordan	2.8	0.0009	174	18	0.09	43±5	79 ± 5	234 ± 45
C3	Jordan	2.1	0.0005	185	19	0.09	30±5	90 ± 6	342 ± 65
C4	Jordan	3.6	0.001	202	21	0.10	45±4	97 ± 5	231 ± 43
C5	Jordan	4.0	0.002	189	20	0.10	64±5	78 ± 5	171 ± 33
C6	Italy	0.4	0.0001	111	12	0.06	45±7	31 ± 3	280 ± 48
C7	Italy	0.6	0.0003	171	19	0.09	65±5	55 ± 7	349 ± 65
C8	Italy	1.2	0.0003	177	19	0.09	32±8	65 ± 6	679 ± 63
C9	Italy	0.8	0.0004	173	19	0.09	67±7	59 ± 8	286 ± 51
C10	Italy	2.5	0.001	196	21	0.10	75±6	67 ± 4	324 ± 81
C11	Spain	4.0	0.001	147	16	0.08	48±7	62 ± 6	129 ± 71
C12	Spain	3.0	0.001	161	18	0.09	56±6	59 ± 8	266 ± 54
C13	Malaysia	11.0	0.006	210	23	0.11	73±7	72 ± 3	439 ± 98
C14	Saudia	1.0	0.0003	145	15	0.07	34±6	67 ± 7	201 ± 55
C15	Saudia	0.6	0.0002	179	19	0.09	52±7	76 ± 5	239 ± 97
C16	Saudia	0.2	0.00009	137	15	0.07	59±8	38 ± 3	307 ± 59
C17	Greece	3.0	0.001	167	18	0.09	45±4	67 ± 8	342 ± 99
C18	Greece	5.7	0.003	190	21	0.10	60±2	69 ± 6	400 ± 69
C19	China	3.4	0.003	288	31	0.15	98±7	106 ± 5	505 ± 94
C20	China	3.3	0.002	306	33	0.16	88±6	129 ± 3	435 ± 78

In this work, other radiation risk parameters have been used to measure the effect of gamma ray originated from the radionuclides comes from different types of ceramic tile materials. The total absorbed dose rate D ($nGy.h^{-1}$) and annual effective dose $E_{eff.}$ (mSv) for Ceramic samples are determined and their values are listed in Table I. One can notice from Table I and Fig. 2 that the values of the total absorbed dose rate D ($nGy.h^{-1}$) for all samples are within the allowed world average limit of 84 $nGy.h^{-1}$. The highest values found in samples from China.

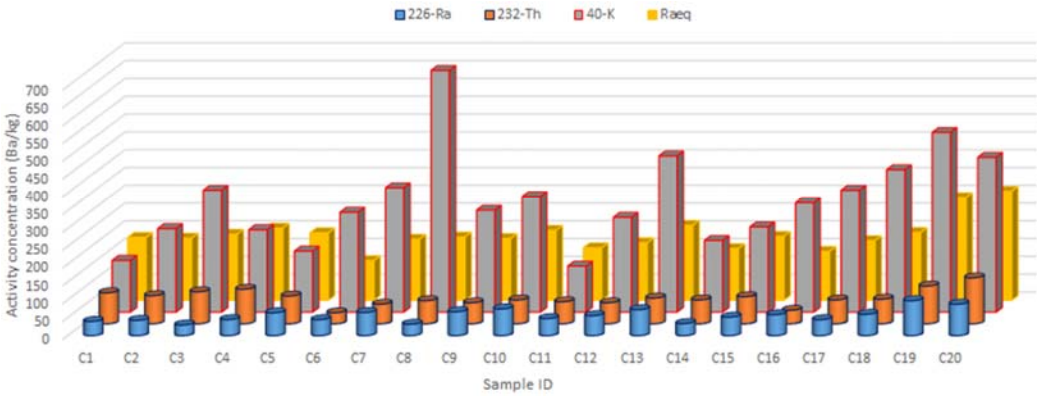

Fig. 1 Distribution of activity concentrations of ^{226}Ra, ^{232}Th, ^{40} K and radium equivalent activity in ceramic samples

The maximum estimated $E_{eff.}$ Value was found to be 0.16 mSv in Chinese samples also, while the minimum one was 0.06 mSv for one of the Italian samples. In general, all $E_{eff.}$ values are within the world average limit of 0.3 mSv for a safe dose. The variation of D values through all samples can be seen also from Fig. 2.

Fig. 2 Distribution of total absorbed dose rate in ceramic samples

The values of Radon emanation coefficient F (%) and Radon mass exhalation rate E_m (Bq/kg.h) for all samples are determined and inserted in Table I. All values of F (%) and E_m (Bq/kg.h) varied from small values in some Saudi samples to high values in some Malaysian samples. The maximum values for both radiological risks are small and below the values reported globally in some publications [7], [10]. The reduction in values of F (%) and E_m (Bq/kg.h) agrees with the scientific explanation which states that radon cannot emerge from solid materials like ceramic due to small porosity of ceramics. One can notice from the last table that no correlation between E_m (Bq/kg.h) values and the activity concentration of radium radionuclides from the same ceramic sample and values of F (%) is not uniform in samples that have the same radium concentration. The fluctuation of the radon emanation coefficient with tested samples is shown in Fig. 3. The highest value comes from Malaysia (C13).

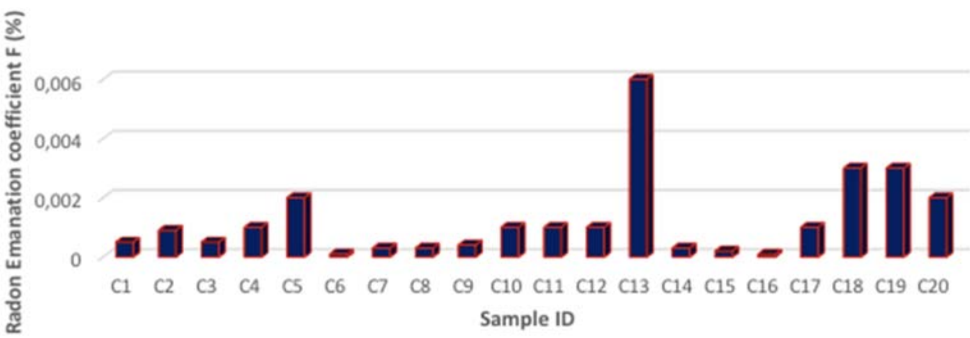

Fig. 3 Distribution of radon emanation coefficient in ceramic samples

IV. Conclusions

Noticing the calculated values of radon emanation coefficients, radon mass exhalation rates, radium equivalent activities, total absorbed dose rates and annual effective dose for all ceramic samples usually used in local market of Jordan, the tested ceramic samples are safe to use in buildings that may contain people to live in or workplaces and constructions to use them regularly.

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