Estimation of radiologic hazards of radon resulting from ceramic tiles used in Najran city

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\section*{ABSTRACT}
The efficiency coefficient (\(\xi\)) of CR-39 detector for radon measurements was determined in this study by using radioactive source (\(^{241}\)Am). Sealed can-technique was applied in this study to assess the activity levels of radon, radium content, radon exhalation rate, and annual effective dose for a total of 34 imported ceramic tiles samples which are used in homes and offices in Najran city. It is found that the activity concentration of \(^{222}\)Rn for most ceramic tiles samples are lower than the recommended value (300 Bqm\(^{-2}\)) except for Chinese wall ceramic and Spanish floor ceramic. All values of effective radium content in all ceramic tiles samples are lower than the action limit (370 Bqkg\(^{-1}\)). The linear relationship between the values of radon concentrations and the effective content of radium is equal to one. The exhalation rate of radon varied from 37.49 to 148.93 mBqm\(^{-2}\)h\(^{-1}\) for wall ceramic tiles samples, and is varied from 43.56 to 138.80 mBqm\(^{-2}\)h\(^{-1}\)for floor ceramic tiles samples. All values of annual effective dose are lower than the permission level except for the Chinese and Spanish ceramic tiles samples. In general, the studied ceramic tiles samples are safe to use as construction material.

\section{1. Introduction}
Soil, water, constructing materials, and decorative substances are the essential reason in presence of indoor radon. The impact of these environmental substances to indoor radon depends on radium content and exhalation rates of radon (Abo-Elmagd and Ahmed, 2018). Ceramic tiles are made from a mix of clay, sand, and other naturally materials, which are placed into sheets and burned at high temperatures (Gbenu et al., 2016). Ceramic tiles can display high levels of radioactive isotopes due to glaze of the ceramic face containing zircon. All zircon sand have isotopes of natural source, firstly those in the decay series of U-238, and Th-232 (IAEA, 2007). Ceramic tile, sandstone, marble, concrete, brick, and granite are the prevalent building materials used in construction. There is general interest of radon exhalation from building materials especially ceramic tile used in interior decoration (Abo-Elmagd, 2014), also this is due to the fact that ceramic tiles offer two radiation exposure pathway are related with inner exposure during inhalation of radon gas and its progenies, and exterior exposure due to gamma-decay of naturally-occurring radionuclide (Abo-Elmagd, Soliman, Salman, & El-Masry, 2010). Inhalation of radon daughters, where the radon emanates from the soil below the building and from construction materials with a specific, amount of Radium-226, such as concrete and ceramic brick (Ronald & Jasper, 2019). Ceramic tiles have been widely used in Najran city as decoration in many homes and offices. So determination of the level of concentrations of radioactive isotopes emanated from ceramic tiles as a building material is essential to evaluate the related radiologic hazards to human health and to build up a reference information of radiologic parameters in ceramic tiles used in Najran city.

\section{2. Materials and methods}
\subsection{2.1. Sample collection}
A total of 34 samples of imported ceramic tiles used in Najran region were collected according to Table 1. Table 1 contains all data about ceramic samples collection such as country of origin, commercial name, type of ceramic and its size (mm). The ceramic samples of two types (wall and floor), which are imported to Najran region were collected from different manufacturing companies are presented in different countries are United Arab Emirates, Spain, India, Egypt, China, and (Jeddah, Mecca and Riyadh) regions in Saudi Arabia.

\subsection{2.2. Setup of CR-39 efficiency coefficient}
In order to determine the efficiency coefficient of CR-39 track detector for radon measurements, experimentally, a sheet of CR-39 was cut into six pieces with laser beam (dimensions of 0.5 × 0.5 cm\(^2\)), and
these pieces were exposed to Alpha source 241Am with activity 0.5 μCi for different times (0, 2, 4, 6, 8, and 10 s). Assuming that the source of 241Am is a physical point in the center of a ball of radius equal to the range of alpha particles. As if radon gas was frozen in the center of this ball. After irradiation, these CR-39 detectors were etched in 6.25 M of NaOH solution for 6 h at 65°C, after that, they were washed by distilled water, and dried well in air. The etched samples were counted by an optical microscope with power 100 X to obtain manually the number of tracks for 100 fields to each sample of CR-39.

The efficiency coefficient $\xi$ is calculated by the following relation (El-Sersy, 2010):

$$\xi = \varepsilon \times \eta$$  \hspace{1cm} (1)

Where $\varepsilon$ is the registration efficiency of alpha particles, which can be calculated by using the following formula (El-Samman et al., 2014; Nidal et al., 2010):

$$\varepsilon = \frac{\rho}{D}$$  \hspace{1cm} (2)

Where, $\rho$ is the tracks density (Track/cm$^2$), and D is the total number of the incident particles per cm$^2$, which can be defined as (El-Samman et al., 2014):

$$D = I \times t$$  \hspace{1cm} (3)

Where $t$ is the irradiation time (Sec), and $I$ is the number of fallen particles per unit area per unit time at point 0, and can be defined as (El-Samman et al., 2014):

$$I = \frac{Q}{2\pi Z^2} \left(1 - \sqrt{\frac{H^2}{Z^2 + H^2}} \right)$$  \hspace{1cm} (4)

Where,

$Q$: is the activity of the 241Am source (Bq).

$Z$: is the radius of the active disk of the source.

$H$: is the distance from the source to the CR-39 detector.

Etching efficiency ($\eta$) is given by the formula (Nidal et al., 2010; Rammah, Ayman, Ashraf, & Ashry, 2016):

$$\eta = 1 - \sin \theta_c$$  \hspace{1cm} (5)

Where $\theta_c = 55^\circ$ is the etching critical angel.

### 2.3. Sealed-can technique of CR-39 for radon concentrations

In this study, imported ceramic tiles samples from different countries were collected and analyzed by using closed can technique; as shown in Figure 1. The collected ceramic samples were crushed well and homogenized by passing through sieve. After that, ceramic sample of 500 g were placed in plastic containers of 24 cm in height, and 48 cm in width. The thickness of the ceramic tiles in the container is 2 cm. CR-39 sheet were severed into parts (0.5 cm × 0.5 cm) then were fitted at the bottom of paper cup, which covered by a piece of sponge with thick about 0.5 cm. This shape was essential to validate that thoron ($^{222}$Rn, $t_\frac{1}{2} = 55.6$ s) cannot arrive the detector. After an exposure time of 6 months, the paper cups will be separated from the plastic container. The detectors were removed and chemically etched. An optical microscope with power100x has been used to count the number of tracks for each detector. The activity concentration of Rn-222 (Bq/m$^3$) for ceramic tiles samples was calculated using the following equation (Ayman & Ali, 2015; Almayahi, Tajuddin, & Jaafar, 2014):

$$C = \frac{\rho}{Kt}$$  \hspace{1cm} (6)

Where K is the calibration constant (Bq/m$^3$ d)/(track/cm$^2$), $\rho$ is track density (number of tracks/cm$^2$) and $t$ is exposure time (in days). The effective radium content $C_{Ra}$ (Bqkg$^{-1}$) was intended from the relation (Saad, Abdallah, & Hussein, 2013):

#### Table 1. Characteristics of collected ceramic tiles samples used in Najran city.

| Country of origin | Commercial name                      | Type of ceramic tiles | Size (mm)  |
|-------------------|--------------------------------------|-----------------------|------------|
| The United Arab Emirates (U.A.E) | Ras Al-Khaimah glazed ceramic (R. A. K) | wall                  | 300 × 900  |
|                   | floor                                | floor                 | 250 × 400  |
| Spain             | GARO Revestimiento glazed ceramic    | wall                  | 300 × 600  |
|                   | floor                                | floor                 | 250 × 400  |
| Spain             | Cerypsa                              | floor                 | 250 × 370  |
| India             | IT ceramic (Bili)                    | Wall                  | 300 × 600  |
|                   | floor                                | floor                 | 250 × 400  |
| Egypt             | Oscar ceramic                        | Floor                 | 250 × 350  |
|                   | Pharaohs ceramic                     | Floor                 | 250 × 350  |
| China             | Alinco polish ceramic tiles          | Wall                  | 600 × 600  |
|                   | floor                                | floor                 | 250 × 400  |
| Kingdom of Saudi Arabia (Jeddah) | Dar glazed ceramic tiles             | Floor                 | 492 × 398.5|
| Kingdom of Saudi Arabia (Mecca)  | Forsan ceramic                       | Wall                  | 200 × 500  |
|                   | floor                                | floor                 | 250 × 400  |
| Kingdom of Saudi Arabia (Riyadh) | Porcelain                           | Floor                 | 600 × 600  |
|                   |                                     | Floor                 | 300 × 300  |
where $\rho$ is the counted track density, $h$ is the area between the CR-39 detector and the upper of the sample (m), the calibration factor of the CR-39 detector is $K$, $M$ is the mass of the sample (Kg) and $(T_e)$ is the exposure time which can be determined using the equation:

$$T_e = \frac{T}{C_0} \left( \frac{1 - e^{-\lambda_{rn}T}}{\lambda_{rn}} \right)$$

Where $T$ is the exposure time, and $\lambda_{rn}$ decay constant for radon (h$^{-1}$). The radon exhalation rate ($E_x$) was obtained from the following relation (Saad et al., 2013):

$$E_x = \frac{C_{rn}AV}{AT_e}$$

Where, $C_{rn}$ is radon exposure (Bqm$^{-3}$h), $\lambda_{rn}$ radon decay constant (h$^{-1}$), $A$ is surface area of ceramic samples (m$^2$), $V$ is volume of the can (m$^3$), $T$ is the time of exposure (h).

### 2.4. Radiologic hazard parameters

#### 2.4.1. Annual effective dose

The annual effective dose $D_{eff}$ (mSvy$^{-1}$) results from Rn-222 can be calculated from the following equation (UNSCEAR, 2000b):

$$D_{eff} = ((0.17 + 9F) C_{rn}) \times 0.8 \times 10^{-6} \times 8760$$

Where $F$ equal 0.4 is the equilibrium factor between radon and its progeny, $C_{rn}$ is the concentration of radon, number of hours per year $= 8760$ h and 0.8 is the indoor occupancy factor.

#### 2.4.2. Alpha index

The alpha index has been used as an indicator of the extra alpha radiation exposure resulting from the inhalation producing from construction materials like (cement, concrete, granite, ceramic, etc), and can be calculated from the following relation (EC, 1999; Moharram, Suliman, Zahran, Shennawy, and El Sayed (2012); Omeje et al., 2018):

$$I_{\alpha} = \frac{C_{Ra}}{200Bq \ kg^{-1}}$$

where $C_{Ra}$ is the activity concentration of Ra-226 (Bq kg$^{-1}$) in the building material. When the activity concentration of Ra-226 of a building material overrides the value of 200 Bqkg$^{-1}$, it is possible that the radon exhalation from this material could cause indoor radon concentrations exceeding 200 Bqm$^{-3}$ (EC, 1999; Omeje et al., 2018), and the high limit of radon concentration ($I_{\alpha}$) is equal to 1 (Omeje et al., 2018; Tufail, Nasim, Sabiha, & Tehsin, 2007).

#### 2.4.3. Excess Lifetime Cancer Risk

The excess lifetime cancer risk (ELCR) is one of the radiologic parameters, which can be determined using the following equation (Shoeib, and Thabayneh., 2014;
Taskin, Karavus, Ay, Topuzoglu, Hidiroglu, & Karahan, 2009):

\[ ELCR = D_{eff} \times DL \times RF \] (12)

where \( D_{eff} \), DL and RF are the total annual effective dose equivalent (mSv y\(^{-1}\)), the duration of life (70 years) and risk factor (0.05 Sv\(^{-1}\)) for stochastic effects, which is recommended by ICRP 60 for general public (Taskin et al., 2009; Thabayneh & Jazzar, 2013).

3. Results and discussion

Initially, the efficiency coefficient was practically set in a new way as follows; the detector was exposed to alpha particles from a known source of radiation intensity and energy for specific periods of time. The films were then developed and the number of tracks was determined after subtraction of the radiation background. Figure 2 shows a typical visual image of tracks of alpha particle in detector of CR-39. The average number of alpha particle tracks as a function of irradiation time was illustrated in Figure 3, which produced a strong linear correlation \( (R^2 = 0.989) \). The mean value of efficiency coefficient in this study is in agreement with many other studies such as (Ayman & Ali, 2015; Hafez & Hussein, 2001; Khan, Varshney, Rajendra, Tyagi, & Ramachandran, 1990; Nabil & AbdelFattah, 2013; Nidal et al., 2010) as shown in Table 2.

Most of houses in Najran city have internal decoration made of ceramics tiles. The experimental data are summarized in Tables 3 and 4. These tables show activity concentration of radon, effective radium content, exhalation rate, and annual effective dose. The radon activity concentration in wall, and floor ceramic tiles samples are ranged from 119.55 ± 37.00 Bqm\(^{-3}\) (Spain Garo) to 474.95 ± 75.50 Bqm\(^{-3}\) (China) and from 138.93 ± 38.73 Bqm\(^{-3}\) (Spain Garo) to 442.64 ± 57.31 Bqm\(^{-3}\) (Spain Creyps), respectively, as shown in Table 5. Wall and floor ceramic tiles samples from China

![Figure 2. Optical image of alpha particle tracks in the CR-39 detectors.](image)

![Figure 3. Average No of alpha particles tracks as a function of irradiation Time.](image)

| Efficiency coefficient (Track cm\(^{-2}\). day\(^{-1}\) per Bqm\(^{-3}\)) | References |
|-----------------------------|------------|
| 0.18                        | Khan et al. (1990) |
| 0.18                        | Hafez and Hussein (2001) |
| 0.18                        | Nidal et al. (2010) |
| 0.17                        | Nabil and Abdel Fattah (2013) |
| 0.20                        | Ayman and Ali (2015) |
| 0.20                        | Present study |
The activity concentrations of Rn-222 (Bq/kg) for ceramic tiles samples.

Table 3. Activity concentrations of Rn-222 (Bq/kg-1) for ceramic tiles samples.

| Country of origin | Wall | Floor | Wall | Floor | Wall | Floor | Wall | Floor |
|-------------------|------|-------|------|-------|------|-------|------|-------|
| Emirates (R. A. K) | 193.86 ± 12.15 | 180.93 ± 25.35 | 226.17 ± 7.30 | 232.63 ± 12.80 | 96.77 ± 9.84 | 90.32 ± 9.50 | 116.13 ± 3.50 | 112.90 ± 6.63 |
| Spain (Garo)       | 168.01 ± 21.92 | 71.08 ± 8.50 | 142.16 ± 33.80 | 135.70 ± 43.42 | 83.87 ± 9.20 | 35.48 ± 6.00 | 67.74 ± 18.80 | 70.97 ± 19.90 |
| Spain (Creypsa)    | NF | NF | 426.49 ± 56.13 | 458.80 ± 58.80 | NF | NF | 212.90 ± 27.13 | 229.03 ± 30.10 |
| India (BIII)       | 245.55 ± 7.340 | 239.09 ± 15.55 | 213.24 ± 11.31 | 200.32 ± 23.00 | 122.58 ± 11.10 | 119.35 ± 11.10 | 100.00 ± 8.60 | 106.45 ± 8.70 |
| Egypt (Oscar)      | NF | NF | 277.86 ± 9.13 | 310.17 ± 11.80 | NF | NF | 154.83 ± 8.80 | 138.71 ± 1.53 |
| Egypt (Pharaohs)   | NF | NF | 290.79 ± 13.22 | 284.33 ± 3.60 | NF | NF | 141.93 ± 4.70 | 145.16 ± 3.60 |
| China (Alinco polish) | 387.72 ± 61.12 | 562.19 ± 24.00 | 219.71 ± 9.26 | 348.95 ± 24.10 | 193.54 ± 14.00 | 280.64 ± 16.75 | 109.67 ± 5.51 | 174.19 ± 12.80 |
| Saudi Arabia (Forsan) | NF | NF | 290.79 ± 24.50 | 374.79 ± 48.00 | NF | NF | 154.83 ± 14.00 | 138.71 ± 1.53 |
| Saudi Arabia (Al-Dar) | 129.24 ± 36.60 | 161.55 ± 33.00 | 271.40 ± 7.10 | 297.25 ± 7.70 | 64.51 ± 8.03 | 80.64 ± 9.00 | 164.51 ± 11.83 | 135.48 ± 0.51 |
| Saudi Arabia (Porcelain) | 161.55 ± 24.36 | 142.16 ± 40.00 | 271.40 ± 7.10 | 297.25 ± 7.70 | 80.64 ± 9.00 | 70.97 ± 8.42 | 135.48 ± 2.70 | 148.38 ± 4.60 |

NF: Wall type of ceramic is not found in the study region

The values of effective radium content for floor ceramic tiles samples are ranged from 43.56 ±12.14 Bq/m² (Spain (Garo)) to 138.80 ±18.00 Bq/m² (China). The values for wall ceramic tiles are ranged from 59.68 ±18.43 Bq/kg (Spain (Garo)) to 237.09 ±37.70 Bq/kg (China). Figure 4 shows a comparison of average radium concentrations in different countries in which the higher value of radium content for ceramic tiles in China, and the lower value in Spain (Garo). All values of effective radium content for ceramic tiles samples in all countries are lesser than the recommended limit of 370 Bq/kg (OECD, 1979), the average values of exhalation rate of radon and annual effective dose are produced in Table 5.

The Exhalation rate of radon for floor ceramic tiles samples are ranged from 43.56 ±12.14 Bq/m² (Spain (Garo)) to 138.80 ±18.00 Bq/m² (China), and for wall ceramic tiles samples its values are ranged from 37.49 ±7.62 Bq/m² (Spain (Creypsa)), and its values for wall ceramic tiles are ranged from 43.56 ±12.14 mBq/m² (Spain Garo) to 12.55 ±2.00 mBq/m² (China) for wall ceramic tiles samples are ranged from 3.16 ±1.01 mSv/y (Spain Garo) to 11.69 ±1.51 mSv/y(Spain (Creypsa)). All values of annual effective dose due to emitted radon from ceramic samples are ranged from 3.16 ±1.01 (Spain Garo) to 12.55 ±2.00 mSv/y (China). The values of annual effective dose are lower than the permission level (10mSv/y) (UNSCEAR, 2000b, Annex B) except its values of wall ceramic from China, and floor ceramic from Spain (Creypsa) are relatively higher than the action level. The values of Alpha index (Iα) and ELCR...
for wall, and floor ceramic tiles samples produce in Table 6. The values of alpha index $I_\alpha$ are ranged from 0.3–1.19, and 0.35–1.10 with an average of 0.59, and 0.65 for wall, and floor ceramic tiles samples, respectively. Nearly, all average values of alpha index for ceramic tiles samples are lower than unity which is the recommended value of $I_\alpha$. This recommended value resulting from the recommended limit concentration of $^{226}\text{Ra}$ is 200 Bq kg$^{-1}$ (Rafique et al., 2011). The values of ELCR are ranged from 0.011–0.044, and 0.013–0.041 with an average of 0.022, and 0.024 for wall, and floor ceramic tiles samples respectively as in Table 6.

### Table 4. Exhalation rate (mBqm$^{-2}$h$^{-1}$), and annual effective dose (mSv/y) for ceramic tiles samples.

| Country of origin | Wall | Floor | Wall | Floor | Wall | Floor | Wall | Floor |
|-------------------|------|-------|------|-------|------|-------|------|-------|
| Emirates (R. A. K) | 60.79 ± 7.80 | 56.74 ± 11.30 | 72.95 ± 8.54 | 70.92 ± 3.52 | 5.12 ± 0.70 | 4.78 ± 0.30 | 5.98 ± 0.40 | 6.15 ± 0.14 |
| Spain (Garo)      | 42.55 ± 6.52 | 44.58 ± 15.90 | 22.29 ± 15.83 | 52.68 ± 9.30 | 4.44 ± 0.94 | 1.88 ± 1.40 | 3.59 ± 1.15 | 3.76 ± 0.90 |
| Spain (Cryepsa)   | NF | NF | 133.73 ± 19.41 | 143.87 ± 19.60 | NF | NF | 12.12 ± 1.55 | 11.27 ± 1.50 |
| India (Bhil)      | 77.00 ± 8.80 | 74.97 ± 4.40 | 66.87 ± 1.73 | 62.81 ± 6.10 | 6.49 ± 0.20 | 6.32 ± 0.30 | 5.29 ± 0.61 | 5.63 ± 0.30 |
| Egypt (Oscar)     | NF | NF | 97.26 ± 8.00 | 87.13 ± 1.60 | NF | NF | 8.19 ± 0.31 | 7.34 ± 0.24 |
| Egypt (Pharaohs)  | NF | NF | 89.16 ± 5.32 | 91.18 ± 3.00 | NF | NF | 7.68 ± 0.15 | 7.51 ± 0.30 |
| China (Alinco polish) | 121.58 ± 11.03 | 176.29 ± 34.00 | 68.89 ± 1.10 | 109.42 ± 18.70 | 14.85 ± 3.00 | 10.24 ± 1.80 | 9.22 ± 0.63 | 5.80 ± 0.30 |
| Saudi Arabia (Forsan) | 91.18 ± 16.20 | 117.52 ± 11.71 | 42.55 ± 9.42 | 48.63 ± 10.60 | 9.90 ± 1.12 | 7.68 ± 0.80 | 8.71 ± 0.50 | 7.17 ± 0.18 |
| Saudi Arabia (Porcelain) | 93.21 ± 15.30 | 85.10 ± 9.22 | 44.58 ± 8.80 | 50.66 ± 9.93 | 4.27 ± 1.01 | 3.76 ± 0.70 | 7.85 ± 0.20 | 7.17 ± 0.18 |

### Table 5. Average values of $^{222}\text{Rn}$ (Bq m$^{-3}$), $^{226}\text{Ra}$ (Bq kg$^{-1}$), exhalation rate (mBqm$^{-2}$h$^{-1}$), and annual Effective Dose (mSv/y) for ceramic tiles samples.

| Country of origin | Wall | Floor | Wall | Floor | Wall | Floor | Wall | Floor |
|-------------------|------|-------|------|-------|------|-------|------|-------|
| Emirates (R. A. K) | 187.40 ± 15.50 | 229.40 ± 10.12 | 93.55 ± 9.30 | 114.51 ± 5.10 | 58.76 ± 0.42 | 71.93 ± 3.20 | 4.95 ± 0.41 | 6.06 ± 0.30 |
| Spain (Garo)      | 119.55 ± 37.00 | 138.93 ± 38.73 | 59.68 ± 18.43 | 69.35 ± 19.34 | 37.49 ± 7.62 | 43.56 ± 12.14 | 3.16 ± 1.01 | 3.67 ± 1.10 |
| Spain (Cryepsa)   | NF | 442.64 ± 57.31 | NF | 220.96 ± 28.61 | NF | 138.80 ± 18.00 | NF | 11.69 ± 1.51 |
| India (Bhil)      | 242.33 ± 1.90 | 206.78 ± 17.30 | 120.96 ± 9.46 | 103.22 ± 8.63 | 75.99 ± 6.93 | 64.84 ± 5.42 | 4.60 ± 0.05 | 5.46 ± 0.46 |
| Egypt (Oscar)     | NF | 294.20 ± 10.40 | NF | 146.77 ± 5.15 | NF | 92.20 ± 3.24 | NF | 7.77 ± 0.27 |
| Egypt (Pharaohs)  | NF | 287.56 ± 8.30 | NF | 143.54 ± 4.12 | NF | 90.17 ± 2.60 | NF | 7.60 ± 0.22 |
| China (Alinco polish) | 474.95 ± 75.50 | 284.33 ± 7.25 | 237.09 ± 37.70 | 141.93 ± 3.61 | 148.93 ± 34.50 | 89.16 ± 2.30 | 12.55 ± 2.00 | 7.51 ± 0.20 |
| Saudi Arabia (Forsan) | 332.80 ± 30.51 | 145.40 ± 36.70 | 166.12 ± 15.23 | 72.58 ± 18.32 | 104.35 ± 17.65 | 45.59 ± 11.50 | 8.79 ± 0.81 | 3.84 ± 1.00 |
| Saudi Arabia (Porcelain) | 145.40 ± 28.80 | 300.48 ± 12.40 | 72.58 ± 14.34 | 150.00 ± 6.20 | 45.59 ± 4.60 | 94.22 ± 4.00 | 3.84 ± 0.80 | 7.94 ± 0.33 |
| Saudi Arabia (Al-Dar) | 151.86 ± 26.71 | 284.33 ± 7.50 | 75.80 ± 13.33 | 141.93 ± 3.61 | 47.62 ± 3.80 | 89.16 ± 2.30 | 4.01 ± 0.71 | 7.51 ± 0.20 |

![Figure 4](image-url)
shown in Table 6. All values of ELCR for two types of wall and floor ceramic tiles samples are higher than the global value (0.29 × 10\(^{-3}\)) (UNSCEAR, 2000a, Scientific Annexes). Through these results, the risk of cancer increases as the exposure time increases or remains for a long time in the places contain these materials.

4. Conclusion

The achieved results in this study indicate that:

(1) The efficiency coefficient (ξ) of CR-39 detector was determined in this study by using radioactive source Am-241, and its value is in agreement with many other studies.

(2) The average values of radon concentrations (Bqm\(^{-3}\)) of the most ceramic tiles samples in all countries are below the permission limit recommended by ICRP.

(3) The average values of effective radium content (Bqkg\(^{-1}\)) in ceramic tiles samples in all countries are lesser than the recommended limit of 370 Bqkg\(^{-1}\).
Table 6. Average values of alpha index and excess lifetime cancer risk (ELCR) for ceramic tiles samples.

| Country of  | \(a\) | ELCR\(\times 10^{-3}\) |
|------------|------|----------------------|
|            | Wall | Floor | Wall | Floor |  |
| Emirates (R. A. K) | 0.47 | 0.57 | 17.33 | 21.21 |  |
| Spain (Garo) | 0.30 | 0.35 | 11.06 | 12.85 |  |
| Spain (Crypsa) | NF | 1.10 | NF | 40.92 |  |
| India (BII) | 0.60 | 0.52 | 22.40 | 19.11 |  |
| Egypt (Oscar) | NF | 0.73 | NF | 27.20 |  |
| Egypt (Pharaohs) | NF | 0.72 | NF | 26.60 |  |
| China (Alincopolish) | 1.19 | 0.71 | 43.93 | 26.29 |  |
| Saudi Arabia (Forsan) | 0.83 | 0.36 | 30.77 | 13.44 |  |
| Saudi Arabia (Al-Dar) | 0.36 | 0.75 | 13.44 | 27.79 |  |
| Saudi Arabia (Porcelain) | 0.38 | 0.71 | 14.04 | 26.29 |  |
| Average | 0.59 | 0.65 | 21.85 | 24.17 |  |
| Range | 0.3–1.19 | 0.35–1.10 | 11.06–43.93 | 12.85–40.92 |  |

(4) The average values of exhalation rate of radon for the most ceramic tiles samples in some countries are relatively higher than the safe limit of UNSCEAR.

(5) All values of annual effective dose are lower than the permission level except for the Chinese and Spanish ceramic tiles samples.

(6) Nearly alpha index values for all samples of ceramic tiles are lower than unity.

(7) The ELCR values for ceramic tiles samples are nearly higher than the world value.

In general the studied ceramic tiles samples are safe to use as construction material, and there is a good covenant between all measurements of radon concentration, effective radium content, and exhalation rate in the studied ceramic tiles samples.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

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