Determination of radon exhalation rates in soil samples using sealed can technique and CR-39 detectors

Khalil M. Thabayneh

Received: 30 August 2015 / Accepted: 19 December 2017 / Published online: 18 October 2018
© Springer International Publishing AG 2018

Abstract

Background In this study, the so-called sealed can technique dosimeters have been used to determine the radon exhalation rates in soil samples collected from different sites in Bethlehem region- Palestine.

Methods For the measurement of radon concentration emanated from these samples, alpha-sensitive, Solid State Nuclear Track Detectors (SSNTD’s) have been used. A total of 82 soil samples were collected simultaneously.

Results It was found that the radon concentrations in these soil samples varied from 19.1 Bqm\(^{-3}\) to 572.9 Bqm\(^{-3}\) with an average value of 145.0 Bqm\(^{-3}\). The radon exhalation rate in these collected samples also varied from 6.9 mBqm\(^{-2}\) h\(^{-1}\) (0.26 mBqkg\(^{-1}\) h\(^{-1}\)) to 207.2 mBqm\(^{-2}\) h\(^{-1}\) (7.84 mBqkg\(^{-1}\) h\(^{-1}\)) with an a total average value of 52.2 mBqm\(^{-2}\) h\(^{-1}\) (1.97 mBqkg\(^{-1}\) h\(^{-1}\)).

Conclusions All the values of radium content in all samples under test were found to be quite lower than the corresponding the global value 30 Bqkg\(^{-1}\). The present results show that the radon concentration and the resulting doses in all soil samples are below the allowed limit from ICRP. The radiological health implication to the population that may result from these doses is found to be low. The measurements have been taken as representing a baseline database of values of these radionuclides in the soils in the area. The results were compared with national and worldwide results.

Keywords Radon exhalation rate · Can technique · Radium content · CR-39 detectors

Background

About 55% of the natural radiation dose which people accept-
ed is contributed from radon and its short-life progenies. More attentions are paid to the issue of the health risks from them [1]; therefore, the exposure of population to high concentrations of radon and its daughters for a long period leads to pathological effects like the respiratory functional changes and the occurrence of lung cancer [2].

Radon is one of the naturally occurring radioactive elements in the environment produced from the radioactive decay of radium isotopes, which are the decay products of \(^{238}\)U, \(^{232}\)Th and \(^{235}\)U. Hence the concentrations of uranium and thorium in the soil types determine the amount of radon produced in the soil [3]. The infiltration of radon gas (\(^{222}\)Rn) from the soil has been identified as one of the main mechanisms influencing indoor radon levels in many buildings. It was reported that a worldwide average of 60% of indoor radon comes from the ground and the surrounding soil of buildings [4]. Therefore; it is of significance for radon control to delineate the potential high radon zone combining the local geological background. Especially in Palestine, the environmental radon survey started relatively late [5–7]. A large-scale indoor radon measurement has not been conducted yet. However, the database based on regional geological survey has been built in many localities. A great number of radiological data, such as the uranium, thorium contents and the distribution of soil texture are available [8–12]. The processes effective in transporting \(^{222}\)Rn from the soil to the surface are related directly to the size and configuration of the space occupied by the soil gas. Radon concentrations in soil pores at depth are dependent directly upon the radium content of the soil, emanating power for radium and soil moisture content.

Exhalation designates the escape of radon from a material to the atmosphere. In the soil, radon molecules can escape from grains of soil by diffusion or recoil into the soil pores, this process is called emanation [13]. The number of radon atoms released per unit surface area per unit time from a
material is termed as exhalation rate [11]. Normally the dominant contributor to indoor radon is the emanation from soil and fractured bedrock close to the surface. If uranium rich material lies close to the surface of the earth, there can be high radon emanation rate, resulting in high radon exposure hazards [12].

On the basis of epidemiological studies, it has been established that the enhanced levels of indoor radon in dwellings can cause health hazards and may cause serious deceases like lung cancer in human beings [13]. The epidemiological researches show the relative risk of lung cancer by 1.33 above 200 Bqm$^{-3}$ and the relative risk increases by 0.15–0.2 per 100 Bqm$^{-3}$ [14]. Estimating the radon risk, it is necessary to check the correlation between radium concentration and radon emanation potential in soil samples. In Palestine, a number of studies of radon concentrations and exhalation rates of radon from the soil and building materials are available [8, 15–18].

The present study aimed to measure the radon concentrations in some surface soil samples collected from many sites of Bethlehem Governorate, Palestine and to calculate the radon exhalation rate, radium contents and the effective dose equivalent, in order to detect any harmful radiation effects on the human and establish a data base for surface soil samples which, is used in agriculture and a local market.

**Experimental work stages**

**Study area**

Bethlehem is a Palestinian city located in the south central West bank, approximately 10 km south of Jerusalem with a coordinates: 31° 42′'11″ N, 35° 11′'44″ E (Fig. 1) (Bethlehem governorate map.com). It is the capital of the Bethlehem Governorate of Palestinian Authority, with an area of 608 Km$^2$. The economy is primarily a tourist-driven. The total population of Bethlehem Governorate is estimated at 180,000 individuals. Out of the total Palestinian population, 44.8% live in the rural areas and 39% in urban communities, 7.5% in refugee camps. Bethlehem city having 60,000 inhabitants and it stands at an elevation of about 770 m above sea level, 30 m higher than nearby Jerusalem [19]. The region has a Mediterranean climate, with hot and dry summers and cold winters. It receives an average of 700 mm of rainfall annually, 70% between November and January. The average annual temperature is 16.5 °C, and the average annual humidity is about 60.4% [20]. Bethlehem has a Muslim majority, but is also home to one of the largest Palestinian Christian communities. Bethlehem’s chief economic is tourism, which peaks during the Christmas season when Christian pilgrims throng to the Church of the Nativity (http://www.bethlehem-city.org).

**Samples collection and preparation**

Eighty two surface samples of dry soil were collected from different locations in the Bethlehem region in the southern part of the West bank, Palestine as shown in Fig. 1. A 30 cm by 30 cm area was marked at four to six points in each sampling site by grading, depending on the size of the sites. The top layers of the soil which contained wastes that are yet to decompose were removed. Soil samples were collected to a depth of 5 cm using a coring tool that was thoroughly cleaned and dried before each sample was collected. Ultimate care was taken in the extraction of soil sections to avoid mixing or cross contamination of soil samples. About 1 kg of each sample was collected in a plastic bag at the sampling points and the sampling continued for about one week. Soil samples were well mixed after removing exotic materials such as pieces of stones and gravel [12]. The samples first sieved in a mesh sieve, and then dried in a hot air oven at temperature of 110 °C for 12 h to evaporate all moisture content and their bulk densities were determined. The respective net weights of the samples ready for measurement were recorded.

**Dosimeters preparation**

The can technique was employed for the measurement radon concentration and radon exhalation rates in soil samples from the area under investigations. Radon and its daughters reach an equilibrium concentration after a week or more and thus the equilibrium activity of emergent radon could be obtained from the time of exposure and the geometry of the container. This step was necessary to ensure that the radon gas and its daughters are confined within the sample. The samples were carefully sealed for 60 days in cylindrical containers made from a good kind of plastic with dimensions of 12.5 cm in diameter and 24 cm in depth. In each container, one CR-39 plastic detector was attached below the cork head at a certain distance (about 22.5 cm) from the surface of the material (soil sample). The sensitive part of the detector was faced to the emanating radon of the soil sample so that it could record the alpha particles resulting from the decay of radon in the whole volume of the can. Each sample container was capped tightly to an inverted cylindrical plastic cover as shown in (Fig. 2) [18]. The soil samples were put at the bottom of these containers and size of each sample were about 185 cm$^3$. The ratio of volumes of the containers and samples was more than 10, which reduces the probability of back diffusion [21].

During the exposure time of α-particles from the decay of radon and their daughters bombard the CR-39 detector in the air volume of the cylindrical containers. After a fixed time, the detectors were taken out, etched (6.25 M NaOH at 70 °C for 4 h) and the detector was washed in distilled water and allowed to air dry. The tracks were counted manually for ten randomly chosen fields of view, using an optical microscope.
with a magnification of 160, to obtain an average and representative value of track density for each dosimeter [8]. The area of the field of view was calculated by the digital microscope and found to be equal about \((5.3 \times 10^{-7} \text{ cm}^2)\); the average number of tracks per field of view was used to count the track density per m\(^2\).

**Results**

**The radon concentrations**

The calculated track density was converted into radon concentrations in Bq m\(^{-3}\) using the calibration factor (k) obtained from the manufacturer, where every track per cm\(^2\) per hour on the CR-39 detectors corresponds to an exposure of 12.3 Bq m\(^{-3}\) for the activity of radon gas and its daughters. From the measured average track densities (after background subtraction), the radon concentrations were calculated using the measured average track densities according to the following relation [22, 23]:

\[
C_{Rn} (\text{Bq} \text{m}^{-3}) = K \frac{\rho}{T_{\text{eff}}}
\]

And

\[
T_{\text{eff}} = t + \tau (e^{-\lambda \tau} - 1)
\]

Where: \(C_{Rn}\) is the radon concentration (Bq m\(^{-3}\)); \(k\) is the calibration factor (Bq m\(^{-3}\)/tracks m\(^{-2}\) h\(^{-1}\)); \(\rho\) is the track density (tracks / m\(^2\)); \(T_{\text{eff}}\) is the effective exposure time in hour, \(\tau\) is the mean life of radon (5.5 days = 132 h), \(t\) is the total exposure time and \(\lambda\) is \(^{222}\text{Rn}\) decay constant (= \(7.56 \times 10^{-3}\) h\(^{-1}\)). This type of correction is needed only for a closed system.
The calculated track density was converted into radon concentrations in Bq m\(^{-3}\) using the calibration factor (k) obtained by the manufacturer, where every track per cm\(^2\) per day on the CR-39 detectors corresponds to an exposure of 12.3 Bq m\(^{-3}\) for the activity of radon gas and its daughters [18].

Table 1 shows the values of radon concentration in soil samples collected from different sites in Bethlehem region-Palestine. It is seen that the values of radon concentration in the collected samples vary from 19.1 Bq m\(^{-3}\) to 572.9 Bq m\(^{-3}\) with an average of 145.0 Bq m\(^{-3}\). It is noteworthy from Table 1 that the radon concentration of soil samples is the least in Bethlehem City (191 Bq m\(^{-3}\)) but the highest in Al- Shawawra site (572.9 Bq m\(^{-3}\)). The soil in this region is laterite that is a fine-grained soil created from weathering of rocks. Such soils contain high concentrations of iron oxides, iron hydroxides and high uranium content [24]. Its high uranium content is reflected by the high radium content; high radon concentration and the soil porosity play an important role in radon exhalation.

### Table 1  Radon concentrations in different soil samples collected from Bethlehem region- Palestine

| Zone                | No. of samples | \(C_{Rn}\) (Bq m\(^{-3}\)) | Zone                | No. of samples | \(C_{Rn}\) (Bq m\(^{-3}\)) |
|---------------------|----------------|-----------------------------|---------------------|----------------|-----------------------------|
|                     | Min. | Max. | Av. | Min. | Max. | Av. |
| Bethlehem City      | 6    | 19.1 | 302.1 | 126.7 | Dar Salah     | 4    | 107.7 | 190.9 | 149.2 |
| Beit Jala           | 4    | 74.2 | 144.6 | 109.5 | Al Obeidiya   | 6    | 40.1  | 91.4  | 63.3  |
| Beit Sahour         | 6    | 24.1 | 224.1 | 106.0 | Jurat Alsham'a | 4   | 167.5 | 243.2 | 205.2 |
| Doha                | 4    | 159.9 | 478.9 | 319.2 | Beit Fajjar   | 6    | 35.4  | 67.0  | 47.8  |
| Al- khader          | 4    | 522.7 | 538.4 | 530.0 | Al Jab'a      | 4    | 96.1  | 322.4 | 209.1 |
| Artas               | 4    | 21.3 | 39.8  | 30.6  | Nahalin       | 4    | 37.3  | 223.2 | 130.2 |
| Tuku'               | 4    | 35.1 | 45.1  | 40.3  | Wadi Fukin    | 4    | 61.0  | 68.2  | 64.5  |
| Za'tara             | 4    | 61.0 | 71.4  | 66.0  | Hussan        | 4    | 42.6  | 99.5  | 71.1  |
| Al- Shawawra        | 6    | 56.7 | 572.9 | 231.1 | Battir        | 4    | 52.9  | 166.8 | 109.6 |
| Total Samples       | 82   |      |      |      |               |      |      |      |

Min value: 19.1 Bq m\(^{-3}\), Max value: 572.9 Bq m\(^{-3}\), Total average value: 145.0 Bq m\(^{-3}\)

Fig. 3 The geographical distribution of \(^{222}\)Rn concentrations in soil for Bethlehem governorate.
The results show that it is possible to map the radon concentrations from soil in Bethlehem region based on the present databases. The distribution based on averaged $^{222}\text{Rn}$ concentrations of each site is plotted in Fig. 3.

**The radon exhalation rate**

The radon exhalation study is important for understanding the relative contribution of the material to the total radon concentration found in the dwellings. The equation used for surface exhalation rate is written as [25, 26]:

$$E_A (Bq m^{-2} h^{-1}) = \frac{CV\lambda}{AT_{eff}}$$

And for mass exhalation rate is written as:

$$E_M (Bq kg^{-1} h^{-1}) = \frac{CV\lambda}{MT_{eff}}$$

Where; $E_A$: is the surface radon exhalation rate, $E_M$: is the mass radon exhalation rate, $C$: is the mass radon exhalation rate, $V$: is the void volume of the container (m$^3$), $A$: is the area of the sample (m$^2$), $M$: is the mass of the sample (kg).

Table 2, shows the values of the surface and mass exhalation rates of radon for soil samples collected from different sites in Bethlehem region. The surface exhalation rate in these collected samples varies from 6.9 mBqm$^{-2}$ h$^{-1}$ (Bethlehem city) to 207.2 mBqm$^{-2}$ h$^{-1}$ (Al-Shawawra site) with a total average value of 52.2 mBqm$^{-2}$ h$^{-1}$. The mass exhalation rate has been found to vary from 0.26 mBqkg$^{-1}$ h$^{-1}$ to 7.84 mBqkg$^{-1}$ h$^{-1}$ with an average value of 1.97 mBqkg$^{-1}$ h$^{-1}$.

**The effective radium content**

The effective radium content, $C_{Ra}$ was found from the following relation [18, 23]:

$$C_{Ra} (Bq kg^{-1}) = \frac{ChA}{MT_{eff}}$$

Where: $C_{Ra}$ is the effective radium content of soil sample (Bqkg$^{-1}$) and $h$ is the distance between the detector and the top of the soil sample.

The effective radium content, $C_{Ra}$, of soil samples collected from different sites in Bethlehem region are listed in Table 3. It is clear from the table that the values of effective radium content vary from 1.46 to 44.1 Bqkg$^{-1}$ with an average value of 11.1 Bqkg$^{-1}$. The average effective radium content in soil estimated by using a conversion factor of 6.3 mSv (WLM)$^{-1}$ by ICRP [30].

Table 3, shows the values of the annual effective dose, $E_{eff}$, of soil samples collected from different sites in the area under investigations. The effective dose equivalent, $E_{eff}$, in these soil samples vary from 0.09 to 2.55 mSvy$^{-1}$ with an average value of 0.65 mSvy$^{-1}$.

**Table 2** Surface exhalation rate, $E_A$ and mass exhalation rate, $E_M$, in soil samples collected from Bethlehem region- Palestine

| Zone                | $E_A$ (mBq m$^{-2}$ h$^{-1}$) | $E_M$ (mBq kg$^{-1}$ h$^{-1}$) |
|---------------------|-------------------------------|-------------------------------|
|                     | Min.  | Max.  | Av.  | Min.  | Max.  | Av.  |
| Bethlehem City      | 6.9   | 108.7 | 45.6 | 0.26  | 4.11  | 1.72 |
| Beit Jala           | 26.7  | 52.0  | 39.2 | 1.01  | 1.97  | 1.50 |
| Beit Sahour         | 8.7   | 80.6  | 38.1 | 0.33  | 3.05  | 1.44 |
| Doha                | 57.5  | 172.3 | 115.0| 2.18  | 6.52  | 4.33 |
| Al-khader           | 188.0 | 193.7 | 190.5| 7.11  | 7.32  | 7.20 |
| Artas               | 7.7   | 14.3  | 11.0 | 0.29  | 0.54  | 0.42 |
| Tuku’a              | 12.6  | 16.2  | 14.4 | 0.48  | 0.61  | 0.55 |
| Za’tara             | 22.0  | 25.7  | 23.9 | 0.83  | 0.97  | 0.90 |
| Al-Shawawra         | 20.4  | 207.2 | 83.4 | 0.77  | 7.84  | 3.16 |
| Dar Salah           | 38.7  | 68.7  | 53.7 | 1.46  | 2.60  | 2.05 |
| Al Obeidya          | 14.4  | 32.9  | 22.8 | 0.55  | 1.24  | 0.86 |
| Jurat Alsham’a      | 60.2  | 87.5  | 73.9 | 2.28  | 3.31  | 3.00 |
| Beit Fajjar         | 12.7  | 24.1  | 17.2 | 0.48  | 0.91  | 0.65 |
| Al Jab’a            | 34.6  | 116.0 | 75.3 | 1.31  | 4.39  | 2.85 |
| Nahalin             | 13.4  | 80.3  | 46.9 | 0.51  | 3.04  | 1.78 |
| Wadi Fukin          | 22.0  | 24.6  | 23.3 | 0.83  | 0.93  | 0.89 |
| Hussan              | 15.3  | 35.8  | 25.6 | 0.58  | 1.35  | 0.97 |
| Battir              | 19.0  | 60.0  | 39.5 | 0.72  | 2.27  | 1.50 |
| **Total**           | **Min. value: 6.9** | **Max. value: 207.2** | **Av. value: 52.2** | **Min. value: 0.26** | **Max. value: 7.84** | **Av. value: 1.97** |
samples in the present study is found to be less than the global value $30 \text{ Bq kg}^{-1}$ [27].

Figures 3 and 4 show the correlation between radium concentration with both surface and mass exhalation rates for Bethlehem governorate, there is a linear correlation appeared throughout these figures, this findings is similar to that found in other studies [27, 28, 31] (Fig. 5).

A lot of data have been published regarding radon exhalation rates in open literature. The results of the current study have been compared with the already published data (Table 4). As can be seen from this table, the surface and mass exhalation rates in the study area are lower than those reported in different studies around the world, thus seem to be safe from the health aspects.

### Discussion

The measurements indicate higher levels of radon concentration emanated from most soil samples collected from Bethlehem region. The levels are higher in samples collected from the west and south sites compared with other samples collected from east sites. This concentration may be due to higher radium and uranium contents in these samples or comes from-NORM which is the main sources of radiation in soils and rocks [32]. Other similar measurements performed by various researchers showed that the soil gas radon concentration may vary over a wide range depending on weather conditions, climate factors and soil type. The obtained results show that the values of radon concentrations of the most samples are below the allowed limit from ICRP. The International Commission on Radiological Protection recommended that a radon concentration from 200 to 600 $\text{Bq m}^{-3}$ for dwelling [33]. Again, the radon levels presented above are more than the new reference level $(100 \text{ Bq m}^{-3})$ set by WHO [34]. Hence, the result shows that this area is safe as for as the health hazards of radon are concerned.

It is assessed that of the most important parameters, which determine the radon exhalation rate from the soil, is the quantity of radium and the porosity of the soil. It is observed that the radon exhalation rate from soil is bigger than that from building materials [11]. This difference is determined by a bigger porosity of the soil.

In all the locations surveyed, the annual effective dose was less than even the lower limit of the recommended action level $(3–10 \text{ mSv y}^{-1})$ reported by the ICRP [33] for the same period of occupancy.

### Table 3  The effective dose equivalent, $E_{\text{eff}}$ and soil $^{226}\text{Ra}$ contents, $C_{\text{Ra}}$, in some zones of Bethlehem region - Palestine

| Zone             | $E_{\text{eff}}$ (mSv y$^{-1}$) | $C_{\text{Ra}}$ (Bq kg$^{-1}$) |
|------------------|-------------------------------|-------------------------------|
|                  | Min. | Max. | Av. | Min. | Max. | Av. |
| Bethlehem City   | 0.09 | 1.34 | 0.56 | 1.5  | 23.1 | 9.7 |
| Beit Jala        | 0.33 | 0.64 | 0.49 | 5.7  | 11.0 | 8.4 |
| Beit Sahour      | 0.11 | 1.00 | 0.47 | 1.8  | 17.2 | 8.1 |
| Doha             | 0.71 | 2.13 | 1.42 | 12.2 | 36.7 | 24.5|
| Al-khader        | 2.33 | 2.40 | 2.36 | 40.0 | 41.2 | 40.6|
| Artas            | 0.10 | 0.18 | 0.14 | 1.6  | 3.0  | 2.4 |
| Tuku’            | 0.16 | 0.20 | 0.18 | 2.7  | 3.5  | 3.1 |
| Za’tara          | 0.27 | 0.32 | 0.29 | 4.7  | 5.5  | 5.1 |
| Al-Shawawra      | 0.25 | 2.55 | 1.03 | 4.3  | 44.1 | 17.8|
| Dar Salah        | 0.48 | 0.85 | 0.66 | 8.2  | 14.6 | 11.4|
| Al Obeidiya      | 0.18 | 0.41 | 0.28 | 3.1  | 7.0  | 4.9 |
| Jurat Alsham’a   | 0.75 | 1.08 | 0.91 | 12.8 | 18.6 | 15.7|
| Beit Fajjar      | 0.16 | 0.30 | 0.21 | 2.7  | 5.1  | 3.7 |
| Al Jab’a         | 0.43 | 1.43 | 0.93 | 7.4  | 24.7 | 16.0|
| Nahalin          | 0.17 | 0.99 | 0.58 | 2.9  | 17.1 | 10.0|
| Wadi Fikin       | 0.27 | 0.30 | 0.29 | 4.7  | 5.2  | 4.9 |
| Hussan           | 0.19 | 0.44 | 0.32 | 3.3  | 7.6  | 5.5 |
| Battir           | 0.24 | 0.74 | 0.49 | 4.1  | 12.8 | 8.4 |
| Total            |       |      |      | 4.3  | 44.1 | 17.8|

![Fig. 4](image_url) The correlation between radium concentrations ($C_{\text{Ra}}$) with surface exhalation rate ($E_A$) for Bethlehem governorate

![Fig. 5](image_url) The correlation between radium concentrations ($C_{\text{Ra}}$) with mass exhalation rate ($E_m$) for Bethlehem governorate
The variation of the effective radium content in the present study may be attributed to the variation of uranium concentrations according to the region of the soil and the high values in some samples belonging to soil samples nearby radioactive-rich granite, phosphate, sandstone and quartzite. Thus, our results reveal that the area is safe as far as the hazardous health effects of radium are concerned. The soil of this area is advisable for use in brick manufacturing for building construction and in agricultural matters.

**Conclusion**

Radon concentration levels of the soil samples collected from different sites in Bethlehem region – Palestine, were measured using the sealed can technique. The radon exhalation rates (both the surface and mass exhalation rates); the effective radium content and effective dose equivalent, in these samples were determined to assess the radiological hazards from the Palestinian different materials. The radon concentration levels and the annual effective dose are, on average, within/below the action level recommended by the ICRP (1993) and UNSCEAR (2000).

The radon exhalation study is important for understanding the relative contribution of the material to the total radon concentration found in the dwellings. The results of this study were compared with national and worldwide results.

Except some sites, the present work shows that soil materials do not pose a significant radiation hazard, and thus the use of these materials in the agriculture and construction of these are considered to be safe for the population. Hence it can be concluded that the study area is safe from the health hazard of radon and radium points of view. From this study, there is a strong positive correlation between the indoor radon concentration and the soil radium content. There is also a strong positive correlation between the radium content in soils and the area or mass exhalation rate of radon from soil.

The obtained results can be used as reference information to assess any changes in the radioactive background level due to geological processes in the investigated area.

This study can be used as a baseline for future investigations and the data obtained in this study may be useful for natural radioactivity mapping. It seems necessary to determine the radon concentrations in the soil of other parts of Palestine. The results may also be used as a reference data for monitoring possible radioactivity pollutions in future.

**Acknowledgements** I gratefully acknowledge the working staff in chemistry lab at Hebron University who’s helped me in the etching and washed the detectors before it readings.

**Availability of data and material** Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

**Author contribution** KM Thabayneh distributed, collected and read the dosimeters, analyzed, wrote the text, reviewed and approved the final manuscript.

**Compliance with ethical standards**

**Ethics approval and consent to participate** Not applicable.

**Consent for publication** Not applicable.

**Competing interests** The author declares that they have no competing interests.

**References**

1. Haijing J, Liangquan G, Yanchang L, Yi G. Preliminary study on a regional radon concentration in surface soil prediction method. Prog Nucl Scie Technol. 2011;1:364–7.
2. Chauhan R. Radon exhalation rates from stone and soil samples of Aravali hills in India. Iran J Radiat Res. 2011;9(1):57–61.
3. Shashikumar T, Ragini N, Chandrashekara M, Paramesh L. Studies on radon in soil, its concentration in the atmosphere and gamma exposure rate around Mysore city, India. Curr Sci. 2008;94(9):1180–5.
4. Qiuju G, Kainan S, Jianping C. Methodology study on evaluation of radon flux from soil in China. Radiat Prot Dosim. 2004;112(2):291–6. https://doi.org/10.1093/rdp/nch387.

5. Dabayneh K, Awawdeh K. Measurements of $^{222}\text{Rn}$ concentration levels and calculates exhalation rates in some dwellings of Dura City – Palestine. Al-Azhar J Science. 2007;18(2):17–28.

6. Abu-Samreh M, Thabayneh K, Eliyad M. Assessment of indoor radon levels in dwellings of Beit Fajjar city, Palestine. Hebron University Res J (A). 2012;6:47–60.

7. Leghrouz AA, Abu-Samreh MM, Sheshadeh AK. Measurements of indoor radon concentration levels in dwellings in Bethlehem, Palestine. Health Phys. 2013;104(2):163–70.

8. Dabayneh K. Radioactivity measurements in different types of fabricated building materials used in Palestine. Arab J Nuclear Sci Appl. 2007;40(3):207–19.

9. Dabayneh K, Snoor A, Abdel-Haleem S. Environmental nuclear studies of natural and manmade radioactivity at Hebron region in Palestine. Al-Quds Univ J Res Stud. 2008;12:23–42.

10. Dabayneh K, Mashal L, Hasen F. Radioactivity concentration in soil samples in the southern part of the west bank-Palestine. Rad Prot Dos. 2008;131(2):265–71.

11. Dabayneh K. $^{222}\text{Rn}$concentration level measurements and exhalation rates in different types of building materials used in Palestinian buildings. Isotope Radiat Res J. 2008;40(2):277–89.

12. Thabayneh K, Jazzar M. Natural radioactivity levels and estimation of radiation exposure in environmental soil samples from Tulkarem province – Palestine. Open J Soil Sci. 2012;2:7–16.

13. Singh J, Singh H, Singh S, Bajwa B. Uranium, radium and radon exhalation studies in some soil samples using plastic track detectors. Indian J Phys. 2009;83(8):1147–53.

14. Algaim HR, Dakhil RM, Al-Khalifa IJ. Determination of radon and thoron activity in the soil by using solid state nuclear track detectors (SSNTDs), passive technique. Adv Appl Sci Res. 2012;3(2):950–61.

15. Nabil M, Hamed A. Measurement of radon concentration in soil at North Gaza. M. sc thesis: Islamic University of Gaza; 2005.

16. El-Ghossain MO, Abu Saleh RM. Radiation measurements in soil of Nusiate in the middle of Gaza-strip using nuclear track detector CR-39 and Electra plus. J Al-Aqsa Univ. 2006;10:273–80.

17. El-Ghossain MO, Abu Saleh RM. Radiation measurements in soil in the middle of Gaza-strip using different type of detectors. Islamic Univ J (Series of Natural Studies and Engineering). 2007;15(1):23–37.

18. Shqipara F, Dwaikut N, Saffarin G. Measurement of radon exhalation rate from building materials. Res Rev J Physics. 2013;2(1):10–9.

19. PCBS. The Palestinian Central Bureau of Statistics. The Population, Housing and Establishment Census - 2007, Press conference on the preliminary findings, Ramallah, Palestine, 2008. http://www.pCBS.gov.ps

20. ARJ. The Geographical Information System Unit (GIS); ARJ, 2010. www.arj.org.

21. Hafez A, Hussein A, Rasheed N. A study of radon and thoron release from Egyptian building materials using polymeric nuclear track detectors. Appl Radiat Isot. 2001;54:291–8.

22. Baykara O, Dogru M. Measurements of radon and uranium concentration in water and soil samples from east Anatolian active fault systems, Turkey. Radiat Meas. 2006;41:362–7.

23. Youssef H, Embaby A, El-Farrash A, Laken H. Radon exhalation rate in surface soil of graduate’s villages in West Nile delta, Egypt, using can technique. Int J Recent Sci Res. 2015;6(4):3440–6.

24. Lawrence C, Akber R, Bollhofer A, Martin P. Radon-222 exhalation from open ground on and around a uranium mine in the wet–dry tropics. J Environ Radioact. 2009;100:1–8.

25. Youssef HA, El-Farrash AH, Abu Ela A, Merza Q. Measurement of radon exhalation rate in some building materials using nuclear track detectors. World J Nucl Sci Technol. 2015;5:141–8. http://www.scirp.org/journal/wjnst

26. Sarma HK. Radon activity and radon exhalation rates from some soil samples by using SSNTD. Int J Adv Res Elect, Electron Instrum Eng. 2013;2:2320–3765.

27. Elzain A-EA. Estimation of soil gas radon concentration and the effective dose rate by using SSNTDs. Int J Sci Res Publ. 2015;5(2):1–5. www.ijsrp.org

28. Elzain A-EA. Determination of radium concentration and radon exhalation rate in soil samples using CR-39. Adv Appl Sci Res. 2015;6(2):96–102. Available online at www.pelagiaresearchlibrary.com

29. UNSCER, United Nations Scientific Committee on the Effects of Atomic Radiation, "Sources and effects on ionizing radiation". Report to the General Assembly, with Scientific Annexes. United Nations, New York, USA, 2000.

30. ICRP, International commission on radiological protection. “lung cancer risk from indoor exposures to radon daughters”, a report of a task group of the ICRP publication 50, Oxford: Pergamon Press, 1987.

31. ShahirKhan M, Naqvi AH, Azam AS. Radium and radon exhalation studies of soil. Iran J Radiat Res. 2011;8(4):207–10.

32. Abu Samreh M, Thabayneh K, Khrais F. Measurement of radioactivity concentration levels of natural radionuclides in soil samples from Bethlehem region – Palestine. Turkish J Eng Env Sci. 2014;38(2):113–25.

33. ICRP, International Commission on Radiological Protection, "Protection Against Rn-222 at Home and at Work", Annals of the ICRP 65. Pergamon, Oxford, 1993.

34. WHO, World Health Organization. WHO handbook on indoor radon. A public health perspective. Switzerland: WHO Press, 2009.

35. Tawfiq NF, Jaleel J. Radon concentration in soil and radon exhalation rate at Al-Dora refinery and surrounding area in Baghdad. Detection. 2015;3:37–44. Published Online in Sci Res. http://www.scirp.org/journal/detection

36. Mahur AK, Sharmab A, Sonkawade RG, Sengupta D, Sharmac A, Prasad R. Measurement of radon exhalation rate in sand samples from Gopalpur and Rushikulya beach Orissa, Eastern India. Phys Procedia. 2015;80:140–3. Available online at www.sciencedirect.com

37. Nasir T, Ahmad N. The effect of grain size on radon exhalation rate in soil samples of Dera Ismail Khan in Pakistan. J Basic Appl Sci. 2012;8:430–6.

38. Farid SM. Indoor radon in dwellings of Jeddah city, Saudi Arabia and its correlations with the radium and radon exhalation rates from soil. Indoor Built Environ. 2016;25(1):269–78. https://doi.org/10.1177/1420326X14536749. ibe.sagepub.com

39. Thabayneh KM. Determination of alpha particles concentration in some soil samples and the extent of their impact on health. Sains Malaysia. 2016;45(5):699–707.