Investigating the Level of Radon $^{222}$Rn and Radium $^{226}$Ra in Soil Samples Taken From Al-Amarah in the South of Iraq

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Abstract. Radon ($^{222}$Rn) is created in the soil by radioactive decay of Radium ($^{226}$Ra) and then emitted from the ground into the atmosphere (exhalation), environmental assessments of radon gas ($^{222}$Rn) are keys to the assessment of air pollution. The major objective of the current study was to examine the ($^{222}$Rn) exhalation rates and the ($^{226}$Ra) concentrations in the soil samples. Thirty soil samples have been collected from ten streets in the region. The ($^{222}$Rn) exhalation rate and concentrations of ($^{226}$Ra) in soil samples were calculated using “Can Technique”. The measurements have shown that the surface and mass exhalation rate were varied from 3.9$\pm$0.3 to 18.3$\pm$0.3 $/g2020 Bq.kg^{-1}.s^{-1}$, with a mean value of 7.8$\pm$0.3 $/g2020 Bq.kg^{-1}.s^{-1}$, and 12.9$\pm$0.5 to 60.7$\pm$1 $/g2020 Bq.m^{-2}.s^{-1}$, with a mean value of 25.5$\pm$0.9 $/g2020 Bq.m^{-2}.s^{-1}$, respectively. In addition, the results showed that the values for $^{226}$Ra concentrations ranged from 1.8$\pm$0.04 to 8.7$\pm$0.1 Bq.kg$^{-1}$, with a mean value of 3.7$\pm$0.1 Bq.kg$^{-1}$. Overall, the indications showed that the levels of ($^{226}$Ra) in soil samples are less than the hazardous levels of human health 370 Bq.kg$^{-1}$. 

Keywords: CR-39 detectors, Soil, Radium, Radon exhalation rates

1. Introduction

The terrestrial element of the natural environment depends on the composition of soil and rock, which contain natural radionuclides [1,2]. Generally, the soil contains a small concentration of $^{238}$U, whereas the granitic rocks have tens of ppm of $^{238}$U. Decay of $^{238}$U into a sequence of shorter-lived radionuclides inevitably creates $^{226}$Ra, which has a half-life of 1,620 years. $^{226}$Ra decays directly into $^{222}$Rn through alpha-particle emission [3]. Being a noble gas, $^{222}$Rn is chemically unreactive and it moves freely in the air spaces between rocks and in soils. It becomes a risk factor for cancer and lung cancer because of indoor accumulation [4–8]. In addition, $^{226}$Ra exposure can cause serious adverse effects, including sores, anaemia and bone cancer as $^{226}$Ra can displace calcium from the bones and it can substitute for calcium inside the body [9]. 

Therefore, exposure doses for the public should remain within the lower limits, and assessments of $^{222}$Rn and $^{226}$Ra sources are of particular importance [10].
Up to now, several studies have measured $^{222}\text{Rn}$, $^{226}\text{Ra}$ and their progenies in different samples, including spring water [11], surface and drinking water [12‒14], houses [15], building materials [16,17], phosphorus fertilizer [18], indoor air [19], soil [20‒22] and phosphate rocks [23].

Many techniques have been employed that use Solid-state nuclear track detector made from Poly-Allyl-Diglycol-Carbonate (PADC) for recording alpha-particle emission from $^{222}\text{Rn}$, $^{226}\text{Ra}$ and their progeny [24,25]. During recent years, CR 39 detectors have become increasingly interested in detecting high-energy particles generated in Pd / D co-deposition [26]. CR-39 also has the benefit of being susceptible to various energy alpha particles (6.0, 7.7, 11.0, 12.8, 16.7 and 20.0 MeV) and photon irradiation insensitivity [27]. For these reasons, CR-39 has become the important tool for scientific research, especially for $^{222}\text{Rn}$ and $^{226}\text{Ra}$ measurements.

There are two major pathways that $^{228}\text{Ra}$ can become airborne and contaminate the surrounding air: 1.) first pathway is the resuspension of residual radionuclides that were in soil contaminated by wind and sandstorms and 2.) second pathway is outdoor $^{222}\text{Rn}$ concentrations, which originate from contaminated soil [28, 29]. Therefore, wind, dust and sandstorms loaded with contaminated soil can cause health risks [30].

Sandstorms are characteristic of the cities in southern Iraq, specifically Al-Amarah city (Centre of Misan province). The soil can be transferred by sandstorms to the city streets. But vehicle movement over the streets represents a source of fugitive soil, especially during the summer. Fugitive soil is a concern because heavy vehicle movement creates dust that can migrate to nearby residential areas.

Soil movement may cause an increase in background radiation levels; soils transferred by the wind and the sandstorms cause many problems regarding health, especially to the respiratory system.

This is, to our knowledge, the first research to make a survey of $^{222}\text{Rn}$ and making a map showing the distribution of radium within Al-Amarah city (Centre of Misan province). The main motivation for this work has to measure $^{222}\text{Rn}$ exhalation rates of Radon, also to estimate $^{226}\text{Ra}$ concentrations of soil samples from the streets of Al-Amarah.

2. Materials and methodologies

2.1. Region of study

Thirty samples of the soil were collected from different locations of streets of Al-Amarah, Al-Amarah is the busy administrative capital city of Misan and a big economic centre for the surrounding agricultural area. The city locates at latitude (31.873222°N), and longitude (47.136194°E), with a total area roughly (16,072 km$^2$) and an estimated population of 511,542 as of 2012[31]. The main streets of this city always crowded with people and soils of different heights are distributed on both sides of these streets as illustrated in Figure1.
Figure 1. Sketch map of the locations of Region of study a) Iraq b) street of Al-Amirah city.

2.2. Samples collection

In this project ten streets were monitored, and thirty soil samples were taken, at surface level (0–10) cm in depth, from various sites of the streets (three samples for each street). The serial numbers, symbols and locations of the samples are presented in Table 1.

| SN. | Symbol | Location name                  | Latitude/Longitude     |
|-----|--------|--------------------------------|------------------------|
| 1   | La     | Al-Mualemin district.St.       | 31°52'07.54 "N 47°08'53.91 "E |
| 2   | Lb     | Al-Mator St.                  | 31°49'47.62 "N 47°08'04.40 "E |
| 3   | Lc     | Al-Btera St.                  | 31°49'55.72 "N 47°08'06.03 "E |
| 4   | Ld     | Al-Hussain district.St.       | 31°50'29.57 "N 47°09'30.92 "E |
| 5   | Le     | Al-Motor St.                  | 31°49'55.72 "N 47°08'06.03 "E |
| 6   | Lf     | Baghdad St.                   | 31°51'10.49 "N 47°09'03.24 "E |
| 7   | Lg     | Al- Basrah St.                | 31°49'29.60 "N 47°08'29.58 "E |
| 8   | Lh     | AlMalaab St.                  | 31°49'17.75 "N 47°07'42.58 "E |
| 9   | Li     | Al-Matar St.                  | 31°50'06.79 "N 47°07'02.67 "E |
| 10  | Lj     | AL-Musharah St.               | 31°51'31.73 "N 47°09'55.72 "E |
2.3. Samples preparation

In the laboratory, all samples were grinded and dried in the oven (110°C) for 4 hours to be free from moisture; a mesh was used to sieve the soil. About 100 ± 0.05% g of the sample has been enclosed in a plastic can. Then, samples were stored for three-weeks to maintain a radioactive balance between the 226Ra and its daughters such as 222Rn, 218Po, 214Pb, 214Bi and 214Po [32]. The closed can technique consists of can with diameter of 4.8 cm and height 10 cm coated with a 0.5 cm thick compressed sponge to flush out dust and thoron. [33-35]. The CR-39 dimensional detector (1cm×1 cm) has been retained in a tight, closed plastic can over the sample in direct contact with the soil surface as shown in Figure 2. The CR-39 detectors were left for 30 days with the soil sample. Thus, the detector captured alpha-particle tracks emitted by 222Rn(T1/2= 3.82 days) of gas produced by decay of 226Ra. Unexposed control (1cm× 1cm) CR-39 detectors were used for calculation of the backgrounds in the same environment of the experiments.

![Figure 2. Arrangement of the can technique.](image)

2.4. Method of etching and scanning

CR-39 was etched at a constant temperature of 70°C water bath with a control accuracy of 0.1 over 6 hours to detect tracks with solution of NaOH (6.25 N) after completion of the exposure time. Then all detectors has been washed in distilled water for at least15 min [36-38]. The tracks of alpha have been observed and counted using an optical microscope type BEL-Photonics Odel Bio 3T, Italy, at a magnification of 100X.

2.5. Measurements of 222Rn exhalation rate in soil gas

\[ C_{Rn} = \frac{\rho}{\delta \, T} \quad (1) \]

\( \rho \) is a net track density (track/cm²), \( \rho = \rho_1 - \rho_2 \). Whereas, \( \rho_1 \) and \( \rho_2 \), are track densities recorded from the exposed and unexposed CR-39, respectively. \( \delta \) is the factor of sensitivity (track/cm².day for one Bq/m³), which depends on the critical angle \( \theta_c \) and \( T \) is the time of exposure. The sensitivity factor is computed using the following equation [40, 41]:

\[ \delta = \frac{r}{4} \left[ 2 \cos \theta_c - \frac{r}{R_{\alpha}} \right] \quad (2) \]

As \( r \) (cm) is the radius of the can, \( R_{\alpha} \) (cm) is the alpha particle range in the air. The parameter values are shown in Table 2.
### Table 2. The parameters and its values of sensitivity factor.

| SN. | Symbol | Symbol value |
|-----|--------|--------------|
| 1   | T      | 30 days      |
| 2   | θc     | 35°          |
| 3   | r      | 2.4 cm       |
| 4   | Rα     | 4.15 cm      |
| 5   | δ      | 0.636 cm=0.0569 (track cm⁻² day⁻¹ Bq⁻¹ m⁻³) |
| 6   | h      | 5.6-6.9 cm   |
| 7   | l      | 3.1-4.4 cm   |

The surface exhalation rate of ²²²Rn is determined using the following expression [42, 43].

\[
\Phi_{222Rn}^S = \left( \frac{\rho V}{\delta A T_e} \right) \lambda_{222Rn} \tag{3}
\]

\[
T_e = \left[ T - \frac{\lambda_{222Rn} T}{1 - e^{-\lambda_{222Rn} T}} \right] \tag{4}
\]

\[
\Phi_{222Rn}^m = \Phi_{222Rn}^S \left( \frac{A}{m} \right) \tag{5}
\]

\[
\Phi_{222Rn}^m = \Phi_{222Rn}^S \left( \frac{hA}{m} \right) \tag{6}
\]

2.6. Measurements of the ²²⁶Ra concentration

After the radioactive balance has been formed in the closed can, the ²²²Rn gas is used to calculate the concentration of ²³⁶Ra (Bq kg⁻¹) in soil samples. According to “closed can technique” introduced by Somogyi 1986 [44], the ²²⁶Ra concentration is calculated by the following formula:

\[
C_{Ra} = \left( \frac{\rho / \delta T_e}{hA/m} \right) \tag{6}
\]

where \( h \) (cm) is diameter of space between the soil surface and the detector in the Can.

3. Results and Discussion

\( \Phi_{222Rn}^S \) and \( \Phi_{222Rn}^m \) are estimated for the samples by Eqs. 3 and 5, respectively, and the results of the ²²²Rn exhalation rate for soil samples in form of surface area and mass are set out in Table 3. The mass exhalation rate was found to range from 3.9±0.3 to 18.3±0.3 μBq.kg⁻¹.s⁻¹ with a mean value of 7.8±0.3 μBq.kg⁻¹.s⁻¹. The minimum value for the ²²²Rn exhalation rate was found in sample Le with value 3.9±0.3 μBq.kg⁻¹.s⁻¹, while a maximum of ²²²Rn exhalation rate was found in Lh with value 18.3±0.3 μBq.kg⁻¹.s⁻¹ as shown in Figure 3.

As seen in Table 3, the mass exhalation rate in the samples Lc, Ld, and Lg lies between 8.4±0.5 μBq.kg⁻¹.s⁻¹ and 8.7±0.3 μBq.kg⁻¹.s⁻¹. In addition, the three locations Lb, Le, and Li approximately have the same values; this may be because the composition of ²³⁸U is identical in the Earth's crust. The values found in the analyzed samples of the mass exhalation rate are less or identical to those reported in the Singh et al. 9.03 μBq.kg⁻¹.s⁻¹, Somogyi et al. 20.3 μBq.kg⁻¹.s⁻¹, Chauhan 6.88 μBq.kg⁻¹.s⁻¹, Zubair et al. 5.52 μBq.kg⁻¹.s⁻¹ and Mir A. Feroz 92 μBq.kg⁻¹.s⁻¹[43-48].
As seen in Table 3, surface exhalation values were calculated to vary from 12.9±0.5 Li, to 60.7±1 Lh μBq.m⁻².s⁻¹ with a mean value of 25.5 ± 0.9 μBq.m⁻².s⁻¹. The value of the surface exhalation rate in the sample Lf is approximately equal to that of Lg as shown in Figure 4.

A possible reason for these results may be due to the nature of the soil and its properties. The mean value of surface exhalation rate in this study is low compared to Somogyi et al. 50 μBq.m⁻².s⁻¹ [45] and greater than Chauhan 14.6 μBq.m⁻².s⁻¹[46], Zubair et al. 14.3μBq.m⁻².s⁻¹ [47]. The surface and mass exhalation rate in the sample Lh is high compared to other streets, this difference can be referred to the change in the nature of the soil and crowding of this street.

Table 3. Mass and surface exhalation rates for 30 street soil samples.

| SN. | Symbol | Track density SEM, Tr.cm⁻² | $\phi_{ms}^m$ (μBq.kg⁻¹.s⁻¹) SEM | Average$\pm$SEM | Value$\pm$SEM | Average$\pm$SEM |
|-----|--------|-----------------------------|-----------------------------------|-----------------|------------|----------------|
| 1   | La1    | 2328±30                     | 8.2±0.10                          | 24.2±0.3        |            |                |
| 2   | La2    | 1640±37                     | 5.8±0.10                          | 17.0±0.4        | 19.4±0.4   |                |
| 3   | La3    | 1646±37                     | 5.8±0.10                          | 17.1±0.4        |            |                |
| 4   | Lb1    | 1271±65                     | 3.7±0.20                          | 12.4±0.6        |            |                |
| 5   | Lb2    | 1762±16                     | 5.1±0.05                          | 17.2±0.2        | 13.8±0.3   |                |
| 6   | Lb3    | 1200±7.0                    | 3.5±0.02                          | 11.7±0.07       |            |                |
| 7   | Lc1    | 2347±28                     | 7.5±0.09                          | 23.6±0.3        |            |                |
| 8   | Lc2    | 3004±387                    | 9.6±1.00                          | 30.3±4.0        | 26.5±1.5   |                |
| 9   | Lc3    | 2549±35                     | 8.1±0.10                          | 25.7±0.4        |            |                |
| 10  | Ld1    | 2306±66                     | 8.3±0.20                          | 22.9±0.7        |            |                |
| 11  | Ld2    | 2345±4.0                    | 8.4±0.02                          | 23.3±0.04       | 23.8±0.4   |                |
| 12  | Ld3    | 2535±48                     | 9.1±0.20                          | 25.2±0.5        |            |                |
| 13  | Le1    | 1996±24                     | 3.6±0.04                          | 16.8±0.2        |            |                |
| 14  | Le2    | 2400±31                     | 4.3±0.05                          | 20.2±0.3        | 18.2±1.4   |                |
| 15  | Le3    | 2077±463                    | 3.7±0.80                          | 17.5±3.9        |            |                |
| 16  | Lf1    | 3541±570                    | 11.9±2.0                          | 35.7±5.7        |            |                |
| 17  | Lf2    | 3364±30                     | 11.3±0.1                          | 33.9±0.3        | 31.7±2.2   |                |
| 18  | Lf3    | 2536±77                     | 8.6±0.30                          | 25.5±0.8        |            |                |
| 19  | Lg1    | 2192±82                     | 6.1±0.20                          | 21.8±0.8        |            |                |
| 20  | Lg2    | 2275±140                    | 6.3±0.40                          | 22.6±1.0        | 31.3±0.9   |                |
| 21  | Lg3    | 4996±52                     | 13.8±0.1                          | 49.6±0.5        |            |                |
| 22  | Lh1    | 6376±90                     | 18.8±0.3                          | 62.3±0.9        |            |                |
| 23  | Lh2    | 4858±35                     | 14.3±0.1                          | 47.5±0.3        | 60.7±1     |                |
| 24  | Lh3    | 7400±184                    | 21.8±0.5                          | 72.3±2.0        |            |                |
| 25  | Li1    | 1271±28                     | 3.8±0.08                          | 12.4±0.3        |            |                |
| 26  | Li2    | 1501±74                     | 4.5±0.20                          | 14.7±0.7        | 12.9±0.5   |                |
| 27  | Li3    | 1200±44                     | 3.6±0.10                          | 11.7±0.4        |            |                |
| 28  | Lj1    | 1753±20                     | 4.2±0.05                          | 15.8±0.2        |            |                |
| 29  | Lj2    | 1737±38                     | 4.2±0.09                          | 15.7±0.3        | 17.0±0.5   |                |
| 30  | Lj3    | 2160±115                    | 5.2±0.30                          | 19.5±1.0        |            |                |

Max value 18.3±0.3  Max value 60.7±1
Min value 3.9±0.30  Min value 12.9±0.5
|               | Average value |                | Average value |                |
|---------------|---------------|---------------|---------------|---------------|
| SEM: Standard Error of the mean | 7.8 ± 0.3     | 25.5 ± 0.9    |

**Figure 3.** Histogram demonstrating the change in the rate of mass exhalation in soil samples for all regions studied in Al-Amarah.
Figure 4. Histogram demonstrating the change in the rate of surface exhalation in soil samples for all regions studied in Al-Amarah.

The amount of $^{226}$Ra concentration was determined in all samples by using Eq.6. in 10 samples for different streets are presented in Table 4. The $^{226}$Ra concentrations were varied from $1.8\pm0.04$ to $8.7\pm0.10$ Bq.kg$^{-1}$ with a mean value of $3.7\pm0.1$ Bq.kg$^{-1}$ Figure 5.

Table 4. $^{226}$Ra concentrations in the 30 samples collected from streets in Al- Amarah district of Misan Province, Iraq.

| SN. | Symbol | $C_{Ra}\pm SEM$ (Bq.kg$^{-1}$) | Average $C_{Ra}\pm SEM$ (Bq.kg$^{-1}$) |
|-----|--------|-------------------------------|---------------------------------|
| 1   | La1    | $3.9\pm0.05$                 |                                 |
| 2   | La2    | $2.8\pm0.06$                 | $3.2\pm0.06$                    |
| 3   | La3    | $2.8\pm0.06$                 |                                 |
| 4   | Lb1    | $1.8\pm0.09$                 |                                 |
| 5   | Lb2    | $2.4\pm0.02$                 | $2.0\pm0.04$                    |
| 6   | Lb3    | $1.7\pm0.01$                 |                                 |
| 7   | Lc1    | $3.6\pm0.04$                 |                                 |
| 8   | Lc2    | $4.6\pm0.60$                 | $4.0\pm0.20$                    |
| 9   | Lc3    | $3.9\pm0.05$                 |                                 |
| 10  | Ld1    | $3.9\pm0.10$                 |                                 |
| 11  | Ld2    | $4.0\pm0.01$                 | $4.1\pm0.07$                    |
| 12  | Ld3    | $4.3\pm0.08$                 |                                 |
Table 1

| Sample Code | Value 1  | Value 2  | Value 3  |
|-------------|---------|---------|---------|
| Le1         | 1.7±0.02 |         |         |
| Le2         | 2.0±0.03 | 1.8±0.04|         |
| Le3         | 1.8±0.40 |         |         |
| Lf1         | 5.7±0.90 |         |         |
| Lf2         | 5.4±0.05 | 5.1±0.40|         |
| Lf3         | 4.0±0.10 |         |         |
| Lg1         | 2.9±0.10 |         |         |
| Lg2         | 3.0±0.20 | 4.1±0.10|         |
| Lg3         | 6.7±0.07 |         |         |
| Lh1         | 8.9±0.10 |         |         |
| Lh2         | 6.8±0.05 | 8.7±0.10|         |
| Lh3         | 10.4±0.2 |         |         |
| Li1         | 1.8±0.04 |         |         |
| Li2         | 2.1±0.10 | 1.9±0.07|         |
| Li3         | 1.7±0.06 |         |         |
| Lj1         | 2.0±0.02 |         |         |
| Lj2         | 2.0±0.04 | 2.2±0.07|         |
| Lj3         | 2.5±0.10 |         |         |

Max value: 8.7±0.10
Min value: 1.8±0.04
Average value: 3.7±0.1

Figure 5. Histogram demonstrating the change in 226Ra concentration in soil samples for all regions studied in Al-Amarah.
The $^{226}$Ra concentrations in all samples were slightly less than recorded by both Singh et al.[43] and Zubair et al.[47], but the value of the $^{226}$Ra in the sample Lh3 is approaching to those reported by Zubair et al.[47]. The results of our study are compared to the results of other studies [43-48] in Table 5.

Table 5. Literature curated by country the mass, surface exhalation rate and $^{226}$Ra concentrations in soil samples.

| Authors          | Sample code | $\varphi_{Rn}^m$ $\mu$Bq.kg$^{-1}$.s$^{-1}$ | $\varphi_{Rn}^S$ $\mu$Bq.m$^{-2}$.s$^{-1}$ | $C_{Ra}$ Bq.kg$^{-1}$ |
|------------------|-------------|------------------------------------------|------------------------------------------|------------------------|
| Somogyi et al[45]| A-7         | 20.30                                    | 50.0                                     | -                      |
|                  | A-11(1)     | 47.00                                    | 40.0                                     | -                      |
| Singh et al[43]  | Raja ka Talab | 9.03                                     | 29.9                                     | 24.72                  |
|                  | Dehri       | 8.05                                     | 26.6                                     | 22.06                  |
| Chauhan[46]      | S-1         | 6.88                                     | 14.6                                     | -                      |
|                  | S-2         | 7.94                                     | 16.6                                     | -                      |
| Zubair et al[47] | Soil-1      | 5.52                                     | 14.3                                     | 12.10                  |
|                  | Soil-2      | 6.75                                     | 17.5                                     | 14.80                  |
| Mir, F. A.[48]   | Cherawan    | 92.00                                    | -                                        | 06.68                  |
| Present study    | Al-Amarah   | 7.8 $\mp$ 0.3                            | 25.5 $\mp$ 0.9                           | 3.7$\mp$ 0.1           |

The heterogeneous distribution of the $^{226}$Ra concentrations and exhalation rate of radon will become more apparent if we arrange our data on a map, as shown in the Figure 6.
Figure 6. Map showing the average $^{226}$Ra concentration and exhalation rate of radon for each street in study.
4. Conclusions
The average value of the mass exhalation rate and the surface exhalation rate in all soil samples are in safety level according to UNSCEAR (2000) and ICRP (1993) [49, 50].

The $^{226}$Ra concentration in all soil samples of (Al-Amarah) streets was lower than the average value of activity in soil samples as considered by UNSCEAR(2000) [49]. Finally, a lower level of the radon exhalation rate and the $^{226}$Ra concentration under the studied areas does not mean that all areas of (Al-Amarah) city are safe from the radiation. We need more researches to get a clear radiation map for more different regions of this city.

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References
[1] Cember H and Johnson T E 2009 Introduction to Health Physics 4th Edition McGraw-Hill New York
[2] Sannappaa J, Chandrashekarar M S, Sathish R L A, Parameshb L and Venkataramaiabc P 2003 Study of background radiation dose in Mysore city Karnataka State India Radiation Measurements 37 55-65
[3] Cecil L DeW and Jaromy R G 2000 Radon-222. Environmental tracers in subsurface hydrology Springer Boston MA 175-194
[4] Younis Mohamed Atiah Al-zahy et al., 2012 Measurement of Radon-222 exhalation rate in different kinds tablet medicine samples by Detectors CR-39 Journal of kerbala university 10 221-227
[5] Singh S, Malhotra R, Kumar J and Singh L 2001 Indoor radon measurements in dwellings of Kulu area, Himachal Pradesh using solid state nuclear track detectors Radiation Measurement 34 505-508
[6] Khan M S, Zubair M, Verma D, Naqvi A H, Azam A and Bhardwaj M K 2011 The study of indoor radon in the urban dwellings using plastic track detectors, Environmental earth sciences 63 279-282
[7] Darby S, Hill D and Doll R 2005 Radon: a likely carcinogen at all exposures. Annals of Oncology 12 1341–1351
[8] Olivier C and Agnès R, Dominique L., Solenne B, Denis H, Pierre V and Margot T 2006 Lung cancer attributable to indoor radon exposure in France: impact of the risk models and uncertainty analysis Environ. Health Perspect 114 1361-1366
[9] Schlenker R A 1985 The distribution of radium and plutonium in human bone Metals in Bone. Springer Dordrecht 127-147
[10] Sharma N, Singh J, Esakki S C and Tripathi R M A 2016 study of the natural radioactivity and radon exhalation rate in some cement used in India and its radiological significance Journal of Radiation Research and Applied Sciences 9 47-56
[11] Horvath A, Bohus L O, Urbani F, Marx G, Piroth A, and Greaves E D 2000 Radon concentrations in hot spring waters in northern Venezuela Journal of environmental radioactivity 47 127-133
[12] Li T, Wang N and Li S 2015 Preliminary investigation of radon concentration in surface water and drinking water in Shenzhen City South China Radiation protection dosimetry 167 59-64
[13] Abojassim A A & Mohammed H A U 2017 Comparing of the uranium concentration in tap water samples at Al-Manathera and Al-Herra Regions of Al-Najaf Iraq Karbala International Journal of Modern Science 3 111-118
[14] Pisapak P, and Bhongsuwan T 2017 Radon concentration in well water from Namom district (Southern Thailand): a factor influencing cancer risk, *Journal of Radioanalytical and Nuclear Chemistry* 1-8

[15] Bauchinger M, Schmid E, Braselmann H, and Kulka U 1994 Chromosome aberrations in peripheral lymphocytes from occupants of houses with elevated indoor radon concentrations, *Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis* 310 135-142

[16] Rafique M and Rathore M H 2013 Determination of radon exhalation from granite dolerite and marbles decorative stones of the Azad Kashmir area Pakistan *International Journal of Environmental Science and Technology* 10 1083-1090

[17] Iwaoka K, Hosoda M, Suwankot N, Omori Y, Ishikawa T, Yonehara H, and Tokonami S 2015 Natural radioactivity and radon exhalation rates in man-made tiles used as building materials in Japan *Radiation protection dosimetry* 167 135-138

[18] Sasaki T, Gunji Y and Okuda T 2007 Suppression methods of radon emanation from phosphorus fertiliser and diatomaceous earth *Radiation protection dosimetry* 124 75-84

[19] Bahtijari M, Stegnar P, Shemsidini Z, Kobal I and Vaupotič J 2006 Indoor air radon concentration in schools in Prizren, Kosovo *Radiation protection dosimetry* 121 469-473

[20] Roussetski A S, Lipson A G, Saunin E I, Tanzella F and McKubre M 2017 Detection of high energy particles using CR-39 detectors Part 2: Results of in-depth destructive etching analysis *International Journal of Hydrogen Energy* 42 429-436

[21] Fish B R 2016 ed. *Surface Contamination: Proceedings of a Symposium Held at Gatlinburg, Tennessee* June 1964 Elsevier

[22] Mosier-Boss P A, Gordon F E, Forsley L P and Zhou D 2017 Detection of high energy particles using CR-39 detectors part 1: Results of microscopic examination, scanning and LET analysis *International Journal of Hydrogen Energy* 42 416-428.

[27] Roussetski A S, Lipson A G, Saunin E I, Tanzella F and McKubre M 2017 Detection of high energy particles using CR-39 detectors Part 2: Results of in-depth destructive etching analysis *International Journal of Hydrogen Energy* 42 429-436

[32] Duñas C, Liger E, Cañete S, Pérez M and Bolívar J P 2007 Exhalation of 222 Rn from phosphogypsum piles located at the Southwest of Spain *Journal of environmental radioactivity* 95 63-74
[33] Misdaq M A et al 2001 A new method for evaluating radon and thoron α-activities per unit volume inside and outside various natural material samples by calculating SSNTD detection efficiencies for the emitted α-particles and measuring the resulting track densities Applied Radiation and Isotopes 55 205-213

[34] Misdaq M A, Khajmi H and Ktata A 1998 Study of the influence of porosity on the radon emanation coefficient in different building material samples by combining the SSNTD technique with Monte Carlo simulations Radiation Physics and Chemistry 53 : 385-390

[35] Ismail A H and Jaafar M S 2009 Experimental measurements on CR-39 response for radon gas and estimating the optimum dimensions of dosimeters for detection of radon In Proceedings of the 3rd Asian Physics Symposium Bandung Indonesia 22-23.

[36] Ghosh, Dipak, Deb A, Bera S, Sengupta R, and Patra K K 2008 "Assessment of alpha activity of building materials commonly used in West Bengal, India." Journal of environmental radioactivity, 99 316-321.

[37] Yousef H A, Saleh G M, El-Farrash A H and Hamza A 2016 Radon exhalation rate for phosphate rocks samples using alpha track detectors Journal of Radiation Research and Applied Sciences 9 41-46

[38] Al–Fifi Z, El-Araby E H and Elhaes H 2012 Monitoring of Radon Concentrations in Jazan beach soil Journal of Applied Sciences Research 8 : 823-827

[39] Mann N, Kumar A, Kumar S and Chauhan R P 2016 Measurement of indoor radon–thoron in air and exhalation rates in soil samples from western Haryana INDIA Radiation Protection Dosimetry 171 248-53

[40] Azam A, Naqvi A H and Srivastava D S 1995 226Ra concentration and radon exhalation measurements using LR-115 type II plastic track detectors Nuclear geophysics 9 653-657

[41] Barillon R, Klein D, Chambaudet A and Devillard C 2020 Comparison of effectiveness of three radon detectors (LR115, CR39 and silicon diode pin) placed in a cylindrical device-theory and experimental techniques Nuclear Tracks and Radiation Measurements 22 281-282

[42] Sharma N, and Virk H S 2001 Exhalation rate study of radon/thoron in some building materials Radiation Measurements 34 467-469

[43] Singh S, Sharma D K, Dhar S and Kumar A 2007 Uranium, radium and radon measurements in the environs of Nurpur area, Himachal Himalayas India Environmental Monitoring and Assessment 128 301-309

[44] Thabayneh K M 2018 Determination of radon exhalation rates in soil samples using sealed can technique and CR-39 detectors Journal of Environmental Health Science and Engineering 16.2 : 121-128

[45] Somogyi G, Abdel-Fattah H, Hunyadi I and Toth-Szilagyi M 1986 Measurement of exhalation and diusion of radon in solids by plastic track detectors Nuclear Track 12 701-704

[46] Chauhan R P 2011 Radon exhalation rates from stone and soil samples of Aravali hills in India Iranian journal of radiation research 9 57-61

[47] Zubair M, Khan M S and Verma D 2012 Measurement of radium concentration and radon exhalation of soil samples collected from some areas of Bulandshahr district Uttar Pradesh India using plastic track detectors Iranian journal of radiation research 10 83-87

[48] Mir A, Feroz and Rather A S 2015 Measurement of radioactive nuclides present in soil samples of district Ganderbal of Kashmir Province for radiation safety purposes Journal of Radiation Research and Applied Sciences 8(2) 155-159
[49] UNSCEAR 2000 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

[50] ICRP 1993 International Commission on Radiological Protection Protection Against Rn-222 at Home and at Work Annals of the ICRP 65 Pergamon Oxford