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ALPHA PARTICLES CONCENTRATIONS FROM SOME SOIL SAMPLES OF AL-NAJAF (IRAQ)

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Abstract. Soil samples were collected from Al-Najaf governorate, Iraq; these samples were investigated for radon concentrations using CN-85 detector, and for uranium concentrations assessment CN-85 and CR-39 detectors were used. Also, some radiation parameters due to radon concentrations were calculated. Radon concentrations were varied from 506.84 Bq·m^{-3} to1194.69 Bq·m^{-3} with an average of 894.21±77.80 Bq·m^{-3}, whereas the radium content were varied from 77.19 Bq·kg^{-1} to 181.95 Bq·kg^{-1} with an average of 136.18±11.84 Bq·kg^{-1}. The average values of the rate of radon exhalation in terms of mass, in terms of area and the soil radon concentration contributing to indoor radon activity were 1.01±0.08 Bq·kg^{-1}·h, 4.56±0.39 Bq·m^{-2}·h and 18.24±1.58 Bq·m^{-3}, respectively. It is also found that the average value of effective dose equivalent, annual effective dose and absorbed dose in soft tissues and in lungs were 0.084±0.007 WLM·y^{-1} 0.574±0.050 mSv·y^{-1}, 0.090±0.007 nGy·h^{-1} and 0.729±0.063 nGy·h^{-1}, respectively. Among others, uranium concentration, using CN-85 and CR-39 detectors, were varied from 0.85 mg·kg^{-1} to 2.0 mg·kg^{-1} with an average of 1.5±0.13 mg·kg^{-1} and from 1.16 mg·kg^{-1} to 2.17 mg·kg^{-1} with an average of 1.5±0.13 mg·kg^{-1}, respectively. The correlation between the contribution of radon to indoor with radium content and uranium concentrations of the two detectors (CN-85 and CR-39) was clear. Finally, the values of radon concentrations, radium content, radon exhalation rate in terms of area, annual effective dose and uranium concentrations in samples in this work were below the limits of the world average, so, according to the results of the area under study, this would not pose a significant risk to human beings.

Keywords: Radon-222 concentration, radon exhalation rates, radium content, uranium concentration, SSNT detector and Al-Najaf governorate

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INTRODUCTION

Uranium is naturally present in soil, rock and water. The dominant isotope, uranium-238, forms a long chain of decay products that include the key radionuclides such as radium-226 and radon-222. Radon can transfer freely through the soil, this depends on a number of factors, namely rate of diffusion, effective permeability of the soil and radon half-life. Radon detection can be made by an alpha sensitive detector from a natural alpha emitter. It has been established that the radon is a causative agent of lung cancer when existing in high concentrations (Archer *et al.* 1976). In this context, radium is a solid radioactive element at standard conditions of pressure and temperature (Anderson *et al.* 1983). The radium atoms which govern the number of radon atoms are formed (Tanner 1980). Radon is an inert gas, and having enough half-life it can diffuse through the soil and enter the atmosphere. The mechanism of emanation radon in the soil may be migrated through diffusion and conversion through the cracks in rocks, the pore spaces in solid and the weak zones such as shear, faults thrust, etc. (Shashikumar *et al.* 2009, Archer *et al.* 1973). The amount of radon that escapes from the earth depends mainly up on the amount of ^{226}Ra and ^{232}Th, in the ground along with other factors such as the type of soil cover (Sevc *et al*. 1976, UNSCEAR 1994). Many studies have been published to determine radon concentrations and uranium concentrations in soil in different countries (Jönsson *et al.* 1999, Baruah *et al.* 2013, Mehra *et al*. 2006, Kakati *et al*. 2013, Abojassim *et al.* 2017). To estimate the radon concentrations risk, it is necessary to test the correlation between radium content and the radon exhalation rate. This work aims to identify alpha particles emitters (^{222}Rn, ^{226}Ra and ^{238}U) in the selected soil samples in Al-Najaf area (Iraq), using CN-85 and CR-39 detectors. The radiological parameters, such as the radon exhalation rate in terms of area, the radon exhalation rate in terms of mass, the soil radon concentration contributing to indoor radon activity, effective dose equivalent, annual effective dose and absorbed dose in soft tissues and in lungs will be calculated. Also, to determine the correlation between the radon concentration contributing to indoor radon activity in the soil with radium content and uranium concentrations, two detectors (CN-85 and CR-39) were used.

STUDY AREA

Al-Najaf lies between longitude of 19°44′, latitude of 31°59′, represents the edge of western desert of Iraq, 160 km southwest of Baghdad. It is bordered from north and northwest by Karbala, and from the south and west by Bahr Al-Najaf on a depression. It elevates 70 m above sea level (Cooperation… 2008). The geotechnical structure of soil in Al-Najaf governorate is generally as follows:

sand represents around 50% to 85% of the soil composition, with few layers of clay and silty clayey soil at different depths. It is characterized by high SPT values, which exceeds 50 blows which is dominated at this region. Its sand varies from dense to very dense, and the cemented sand is the most prevailing condition of the soil. Internal friction Angle (Ø) exceeds (35°) across the most of the regions (Al-Shakerchy 2007).

MATERIALS AND METHODS

Soil sampling strategy and laboratory methods

Ten soil samples were collected from different locations in Al-Najaf governorate. The sample sites were determined by GPS which is shown in Fig. 1 and Table 1.

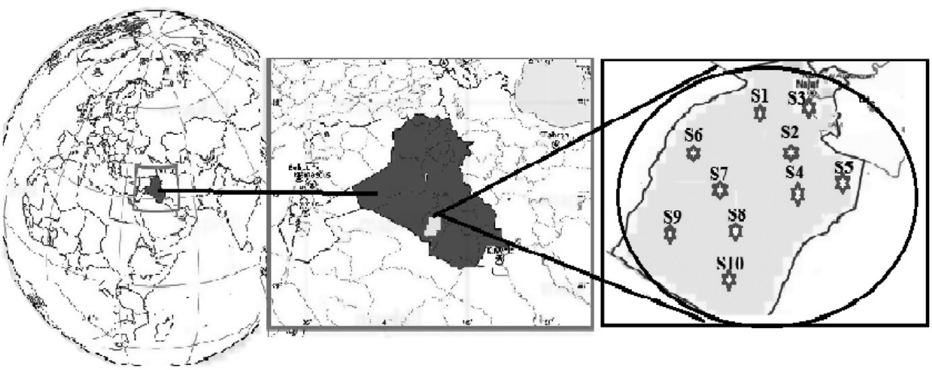

Fig. 1. Sites of study in Al-Najaf governorate

TABLE 1. THE SITES OF LOCATIONS FOR TAKING SAMPLES

No.	Location name	Sample	Coordinates
1	Al Motanaby	S1	44°22′53.662″E, 32°1′48.533″N
2	Al Askary	S2	44°22′52.701″E, 32°2′7.472″N
3	Al Jamhoriaa	S3	44°23′57.168″E, 32°1′59.881″N
4	Al Shoarah	S4	44°23′21.377″E, 32°1′40.2″N
5	Messan	S5	44°21′32.478″E, 32°3′16.807″N
6	Al Wafaa	S6	44°20′51.423″E, 32°2′52.177″N
7	Al Jazera	S7	44°19′59.966″E, 32°2′52.596″N
8	Al Ameer	S8	44°21′52.161″E, 32°0′32.683″N
9	Al Adala	S9	44°21′30.821″E, 32°1′18.069″N
10	Al Moalmen	S10	44°20′23.281″E, 31°59′30.868″N

The sealed cup technique was utilized to measure the radon concentrations and uranium concentrations in study samples. Ten soil samples were taken at depth of 15 cm from the ground surface of each site. The samples of soil were dried in an oven at 100°C and then milled in the grinder. After that, all samples were sieved through a 2-mm sieve (which is the soil testing standard in the laboratories). In the present study, radon concentrations were measured in the $Bq \cdot m^{-3}$ unit and uranium concentrations in the $mg \cdot kg^{-1}$ unit using CN-85 detector and CR-39 detector, respectively. About 0.04 kg of powder sample was put on the bottom of cylindrical plastic cup whose dimensions are 7.5 cm in height and 3.8 cm in diameter, whereas the sample-detector distance is still 5.5 cm, as shown in Fig. 2a. Radon concentrations measurement in the samples under study were performed using SSNTD (CN-85) detector whose thickness is 250 μm and its dimensions are 1×1 cm^2.The cups were sealed for 90 days. After the exposure to radiation, the (CN-85) detectors were etched by (NaOH) solution in 6.25 N, at temperature of 70°C and 5 hours. Regarding uranium concentrations, about 0.120 kg of each sample was placed in a plastic bottle of 6.5 cm in radius and 6 cm in length (see Fig. 2b). One mm^2 thick pieces (1×1) cm^2 of (CR-39) were placed indirect contact on the top of the soil sample and kept for 90 days. The exposed detectors were collected and etched with 6.25 N NaOH at 60°C for 6 hours. Finally, the tracks density (track/cm^2) were counted using a microscope with a magnification power of 400× and 100× for radon and uranium concentrations, respectively.

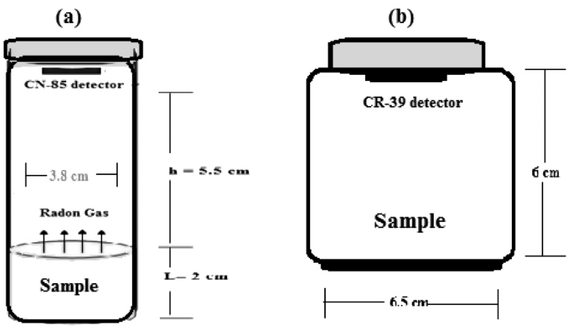

Fig. 2. Test tube technique used in the study, (a) radon concentration, (b) uranium concentration

Methods of calculations

The tracks density (ρ) of the samples were computed as follows (Morelli *et al*. 2015):

$$\rho\left(\frac{Track}{cm^2}\right) = \frac{No.Track}{Area\ of\ view} \qquad (1)$$

Radon concentration in surrounding air is measured in terms of $Bq \cdot m^{-3}$, since the most regulatory reference levels are specified in this unit.

Determination of radon concentration using CN-85 and the standard deviation (S.D.) calculation in soil samples at some sites of AL-Najaf governorate are carried out using the following equations (Al-Kofahi *et al*. 1992, Khader 1990, Wiegand, 2001):

$$C_{Rn}\left(\frac{Bq}{m^3}\right) = \frac{\rho}{K.T} \qquad (2)$$

$$S.D. = \frac{\sqrt{\sum_i^n (X_i - \bar{X})^2}}{n-1} \qquad (3)$$

Where: C_{Rn} is the radon concentration within the test tube air, above the sample in (Bq·m^{-3}), K is the calibration factor, that was taken as 0.0092 in (track/cm^2·h) /(Bq·m^{-3}) (Al-Saadi *et al*. 2015), ρ: Track density (number of track/cm^2) of the detectors exposed to the samples under study, T: Exposure time (h), σ_n *(S.D.)*: standard deviation and $X_i, \bar{X}$: count and average of count of samples.

The radium content was found using this formula (Sonkawade *et al.* 2008):

$$C_{Ra}\left(\frac{Bq}{kg}\right) = \frac{\rho\, h\, A}{M\, K\, T_e} \qquad (4)$$

Where: C_{Ra} is the radium content of a given sample, M is the mass of the sample (0.040 kg), h is the distance between the detector and the sample, and T_e is the effective exposure time (in hour) which is calculated by Sonkawade *et al*. (2008) as follows:

$$T_e(hour) = T - \frac{1}{\lambda(e^{-\lambda T} - 1)} \qquad (5)$$

The radon exhalation rate in terms of area was obtained using the following expression (Sonkawade *et al.* 2008, Thabayneh 2016):

$$E_A\left(\frac{Bq}{m^2 hour}\right) = \frac{C_{Rn} V \lambda}{A[T + \lambda^{-1}(e^{-\lambda T} - 1)]} \qquad (6)$$

Where: E_A is the radon exhalation rate in terms of mass, V refers to the volume of the cup (m^3), T refers to the time of exposure (hour), and A is the area of cross-section of the cup (12.65×10^{-4} m^2).

The radon exhalation rate in terms of mass is given by Sonkawade *et al.* (2008) and Thabayneh (2016):

$$E_M\left(\frac{Bq}{kghour}\right) = \frac{C_{Rn} V \lambda}{M[T + \lambda^{-1}(e^{-\lambda T} - 1)]} \qquad (7)$$

Where: E_M is the radon exhalation rate in terms of mass and M is the mass of the sample (kg).

It is well known that there is a correlational statistics regarding radon concentrations between soil and indoor. The soil radon concentration contributing to indoor radon activity ($C_{Rn}^{ind.}$) can be calculated according to the radon exhalation rate of soil samples according to equation (8) (Mahur *et al*. 2008, Saad *et al*. 2013, Nazaroff and Nero Jr. 1988).

$$C_{Rn}^{ind.}\left(\frac{Bq}{m^3}\right) = \frac{E_A S_r}{V_r \emptyset} \qquad (8)$$

Where: φ is the air exchange rate that is equal 0.5 (hour)$^{-1}$, *Sr* is the internal surface area and *Vr* is the volume of the room. In present study, the ratio (S_r) to (V_r) is equal 2 m^{-1} (Saad *et al.* 2013).

Using the soil radon concentration contributing to an indoor radon activity factor, many radiation hazards indices due to radon such as effective dose equivalent (E_P) in the MLM·y^{-1} unit, annual effective dose (H_E) in the mSv·y^{-1} unit, the dissolved in soft tissues ($D_{Soft\ tissue}$) in the nGy·h^{-1} unit and dose rate due to alpha-radiation in the lung (D_{Lung}) in the nGy·h^{-1} unit, can be estimated as follows:

The annual *WLM* (effective dose equivalent) can be calculated using equation (8), which was proposed by Nazaroff and Nero Jr. (1988) and ICRP (1993).

$$E_p\left(\frac{WLM}{y}\right) = \frac{t \cdot n \cdot F \cdot C_{Rn}^{ind.}}{(170)\cdot(3700)} \qquad (9)$$

Where: *t* is the number of hours per year that equal to (8,760 hours), *n* is the occupancy factor of time spending indoors (0.8) (UNSCEAR 2000), *F* is the equilibrium factor between radon and its decay products (0.4) (UNSCEAR 2000), 1/3700 is a conversation factor (in WL·Bqm^3), and 170 is the number of hours per month. The conversion factor of 6.3 mSv·WLM^{-1} that was prescribed by ICRP (1987) was used to estimate effective dose from radon (ICRP 1987).

The annual effective dose (H_E) was calculated (UNSCEAR 2000, Al-Bataina *et al*. 1997):

$$H_E\left(\frac{mSv}{y}\right) = C_{Rn}^{ind.} \times F \times T_{Oc} \times D \qquad (10)$$

F is the ^{222}Rn indoor equilibrium factor (0.4), T_{Oc} is time (8,760 h·y^{-1}) and *D* for dose conversion factor (9) nSv·y^{-1} per Bq·m^{-3}.

The dissolved radon in soft tissues due to the concentration in air ($C_{Rn}^{ind.}$) was calculated using the following relationship for soft tissues other than the lungs was derived by ICRP (1993):

$$D_{Soft\ tissue}\left(\frac{nGy}{h}\right) = 0.005\ C_{Rn}^{ind.}\left(\frac{Bq}{m^3}\right) \qquad (11)$$

While, dose rate due to alpha-radiation in the lung was determined as follows (ICRP 1993, Alharbi and Abbady 2013):

$$D_{Lung}\left(\frac{nGy}{h}\right) = 0.04\, C_{Rn}^{ind.}\left(\frac{Bq}{m^3}\right) \qquad (12)$$

In the present study, uranium concentrations (C_U) were measured in the same ten soil samples using two different methods, the first method – by radon concentrations using CN-85 detector, whereas the second method was achieved theoretically using CR-39, as follows:

The activity of ^{222}Rn in the samples will be calculated in the unit of Bq from the following relation (Alharbi and Abbady 2013):

$$A_{Rn} = C_{Rn} V \qquad (13)$$

The activity of radon (A_{Rn}) can also be calculated in sample using the following equation (Tykva and Sabol 1995):

$$A_{Rn} = \lambda_{Rn} N_{Rn} \qquad (14)$$

Using the law of secular equilibrium is an ideal way to find the numbers of uranium atoms (N_U) in the sample using the following equation:

$$\lambda_U N_U = \lambda_{Rn} N_{Rn} \qquad (15)$$

Where: λ_U is uranium decay constant (4.98×10^{-18} sec^{-1}); then W_U is uranium weight in the sample which can be calculated according to the following equation (Tykva and Sabol 1995):

$$W_U\,(gm) = \frac{N_U\ W_{mol.}}{N_{AV.}} \qquad (16)$$

Where: $W_{mol.}$ is the weight of molecular uranium, $N_{AV.}$ – the number of Avogadro (6.023×10^{23} atom×mol^{-1})

To find uranium concentrations (C_U) in units of mg×kg^{-1} or part per million (ppm), the following equation was used:

$$C_U\,(ppm) = \frac{W_U}{W_s} \qquad (17)$$

Where: W_s is the weight of sample. Uranium concentrations (C_U) were measured theoretically according to Islam and Abdullah (1998) using SSNTDs (CR-39), as follows (Islam and Abdullah 1998, Baykara *et al.* 2007):

$$C_U(ppm) = \frac{952.\rho_t}{R_\alpha \rho N_A \left(8\lambda_{238} + \frac{7\lambda_{235}}{140}\right).10^{-6}} \qquad (18)$$

Where: C_U is uranium concentrations (mg×kg^{-1}), N_A is the Avogadro′s number, ρ is the soil sample density, ρ_t is the track density on the detector surface, R_α the mean alpha particle range which equal to 48 µm in soil for 4–8 MeV energy range (Biersack and Ziegler 1998), 7 and 8 are alpha particle numbers for ^{235}U and ^{238}U decay chains respectively, and 1/40 is the ratio of the isotopic abundances of ^{238}U and ^{235}U in natural uranium.

RESULTS AND DISCUSSION

The results of radon concentrations and radium content in soil samples of some sites of Al-Najaf governorate are presented in Table 2. It can be seen that the highest radon gas concentration was 1194.69 Bq·m^{-3} in S6 site, whereas the lowest radon gas concentration was 506.84 Bq·m^{-3} in S2 site with an average value of 894.21±77.80 Bq·m^{-3}, the latter results can also be shown in Fig. 3 for ease of comparison. The radium content in soil samples ranges from 77.19 Bq·kg^{-1} in Al Askary site (S2 sample code) to 181.95 Bq·kg^{-1} in Al Wafaa site (S6 sample code) with an average value of 136.18±11.84 Bq·kg^{-1}, as demonstrated in Table 2 and Fig. 4. From the measurement results in the studied area, the soil radon concentration in the area was lower than the world average soil radon concentration (7,400) Bq·m^{-3} (Kaur *et al.* 2015). Also, the observed values of radium content in samples were less than the level of 370 Bq·kg^{-1} which was recommended by OECD (1979).The difference in the radon concentrations and radium content at the present study is due to difference in the underlying bedrocks and the geology of the studied areas (Abojassim *et al.* 2017, Thabayneh 2016).

TABLE 2. C_{RN} AND C_{RA} IN THE SOIL SAMPLES UNDER STUDY

No.	Sample code	C_{Rn} (Bq·m^{-3})	C_{Ra} (Bq·kg^{-1})
1	S1	615.44	93.73
2	S2	506.84	77.19
3	S3	977.47	148.87
4	S4	760.26	115.78
5	S5	687.85	104.76
6	S6	1194.69	181.95
7	S7	1013.68	154.38
8	S8	1049.88	159.89
9	S9	1122.29	170.92
10	S10	1013.68	154.39
	Average± S.D	894.21±77.80	136.18±11.84

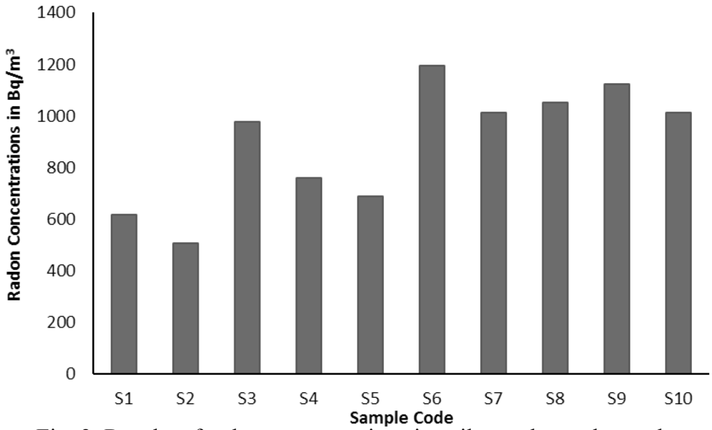

Fig. 3. Results of radon concentrations in soil samples under study

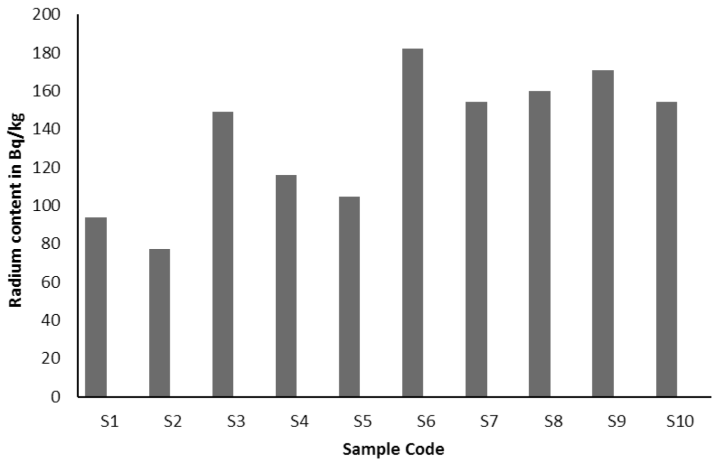

Fig. 4. Results of radium content in the soil samples under study

The results for radon exhalation rate per unit mass, radon exhalation rate per unit area and the radon concentration contribute to indoor air in soil samples belonging to some areas of Al-Najaf governorate are reported in Table 3. The distribution of the radon exhalation rates in terms of mass, radon exhalation rates in terms of area and radon concentration contribute to indoor air of the soil samples collected from Al-Najaf governorate are illustrated in Fig. 5. The values of radon exhalation rate at mass and radon exhalation rate at area varied from 0.57 Bq·kg^{-1}·h to 1.36 Bq·kg^{-1}·h with an average of 1.01±0.08 Bq·kg^{-1}·h and varied from 2.58 Bq·m^{-2}·h to 6.09 Bq·m^{-2}·h with an average of 4.56±0.39 Bq·m^{-2}·h in soil samples belonging to the study area, respectively. From Table 3 it is also found that the values of $C_{Rn}^{ind.}$ are ranged from 10.32 Bq·m^{-3} to 24.36 Bq·m^{-3} with an average value of 18.24±1.58 Bq·m^{-3}. The average value of radon exhalation rate in terms of area for the study was much less than the world average of 57.6 Bq·m^{-2}·h (Zubair *et al.* 2012) and 118.8 Bq·m^{-2}·h given by UNSCEAR (2000). The variation in values of radon exhalation rate may be due to the differences in radium content and porosity of the soil (Abojassim *et al.* 2017, Thabayneh 2016).

TABLE 3. E_M, E_A AND $C_{Rn}^{ind.}$ IN THE SOIL SAMPLES UNDER STUDY

No.	Sample code	Radon Exhalation Rates		$C_{Rn}^{ind.}$ (Bq·m^{-3})
		E_M (Bq·kg^{-1}·h)	E_A (Bq·m^{-2}·h)	
1	S1	0.70	3.14	12.56
2	S2	0.57	2.58	10.32
3	S3	1.11	4.98	19.92
4	S4	0.86	3.88	15.52
5	S5	0.78	3.51	14.04
6	S6	1.36	6.09	24.36
7	S7	1.15	5.17	20.68
8	S8	1.19	5.35	21.4
9	S9	1.28	5.72	22.88
10	S10	1.16	5.18	20.72
Average± S.D		1.01±0.08	4.56±0.39	18.24±1.58

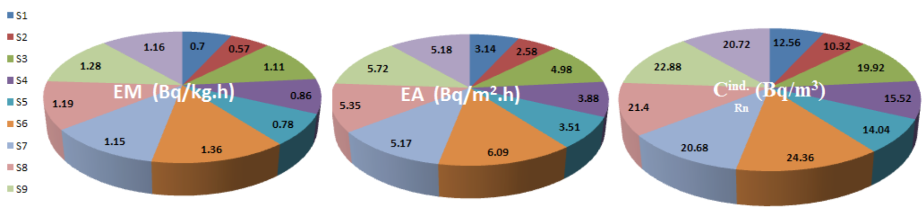

Fig. 5. The distribution of E_M, E_A and $C_{Rn}^{ind.}$ in the soil samples under study

The results of E_p (effective dose equivalent in the unit of WLM·y^{-1}), H_E (annual effective dose), $D_{Soft\ tissue}$ (the dissolved radon in soft tissues) and D_{Lung} (dose rate due to alpha-radiation in the lung) were calculated and listed in Table4.The values of *Ep* in terms of WLM·y^{-1} were varied from 0.048 to 0.113 with an average value of 0.084±0.007, whereas the values of H_E in terms of mS·y^{-1} were varied from 0.325 to 0.768 with an average value of 0.574±0.050. The latter indices values are found to be slightly smaller than the levels of 3–10 mSv·y^{-1} recommended by ICRP (1993). The results of the dissolved radon in soft tissues and dose rate due to alpha-radiation in the lung (nGy·h^{-1}) are ranged from 0.051 to 0.121 with an average value of 0.090±0.007 and varied from 0.412 to 0.974 with an average value of 0.729±0.063, respectively. These values are found to be within the safe limits that were recommended by ICRP (1993). The results showed that these areas could be safe from the health hazard point of view as far as the radon is concerned.

TABLE 4. E_P, H_E, $D_{SOFT\ TISSUE}$ AND $D_{LUNG,\ SURFACE}$ IN THE SOIL SAMPLES UNDER STUDY

No.	Sample code	E_p (WLM·y^{-1})	H_E (mSv·y^{-1})	$D_{Soft\ tissue}$ (nGy·h^{-1})	$D_{lung\ surface}$ (nGy·h^{-1})
1	S1	0.058	0.396	0.062	0.502
2	S2	0.048	0.325	0.051	0.412
3	S3	0.093	0.628	0.099	0.796
4	S4	0.072	0.489	0.077	0.620
5	S5	0.065	0.442	0.070	0.561
6	S6	0.113	0.768	0.121	0.974
7	S7	0.096	0.652	0.103	0.827
8	S8	0.100	0.674	0.107	0.856
9	S9	0.107	0.721	0.114	0.915
10	S10	0.096	0.653	0.103	0.828
Average± S.D		0.084±0.007	0.574±0.050	0.090±0.007	0.729±0.063

Table 5 and Fig. 6 present the results of uranium concentrations for the same ten samples mentioned above using CN-85 and CR-39 detectors. The results show that the maximum value of uranium concentrations as measured by CN-85 detector was 2.0 mg·kg^{-1} and the minimum value was at 0.85 mg·kg^{-1}. However, the maximum and minimum values of uranium concentrations which were measured by CR-39 detector were 2.17 mg·kg^{-1} and 11.16 mg·kg^{-1}, respectively. The average value of uranium concentrations as measured by CN-85 and CR-39 detectors were 1.5±0.13 mg·kg^{-1} and 1.6±0.11mg·kg^{-1}, respectively. It is found that, in all of the sites, the C_U is lower than 11 mg·kg^{-1} (ppm) that was published by UNSCEAR (1994).

TABLE 5. C_U USING CN-85 AND CR-39 DETECTORS IN THE SOIL SAMPLES UNDER STUDY

No.	Sample code	C_U (mg·kg^{-1}) CN-85	C_U (mg·kg^{-1}) CR-39
1	S1	1.03	1.25
2	S2	0.85	1.16
3	S3	1.64	1.72
4	S4	1.27	1.48
5	S5	1.15	1.27
6	S6	2.0	2.17
7	S7	1.70	1.81
8	S8	1.76	1.79
9	S9	1.87	1.87
10	S10	1.69	1.54
Average± S.D		1.5±0.13	1.6±0.11

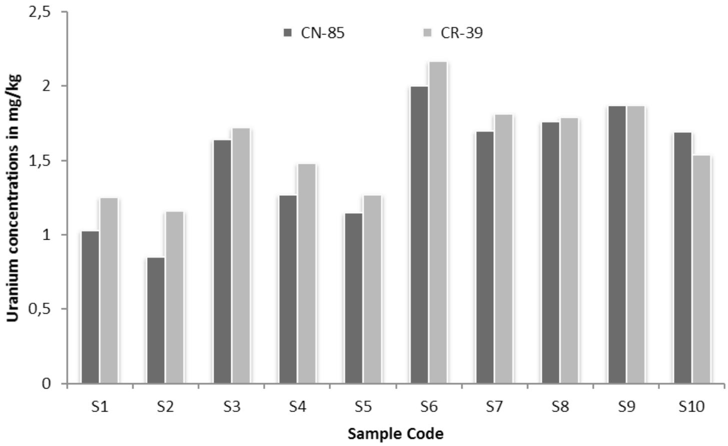

Fig. 6. C_U using CN-85 and CR-39 detectors in the soil samples collected from Al-Najaf governorate

Fig. 7 and Fig. 8 show the correlation between the soil radon concentration contributing to indoor radon activity with radium content and uranium concentrations using two detectors (CN-85 and CR-39) for all soil samples under study in which the correlation coefficient was calculated. A very good correlation (correlation coefficient = 1) has been observed between $C_{Rn}^{ind.}$ and C_{Ra} of soil samples. Also, a positive correlation (r=0.90) was seen between uranium concentration using the two SSNTDs (CN-85 and CR-39) in soil of the studied area.

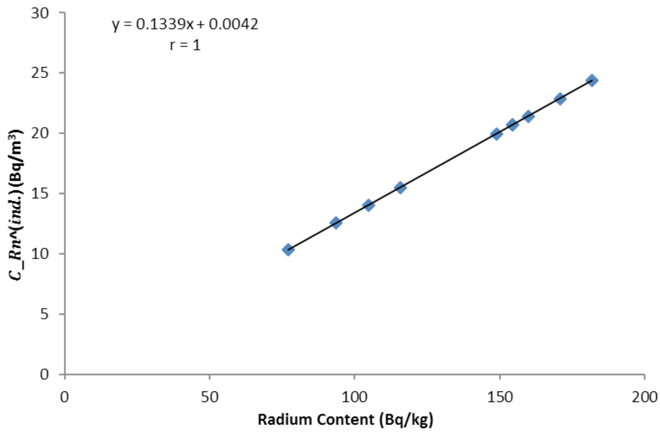

Fig. 7. Correlation between $C_{Rn}^{ind.}$ with C_{Ra} in soil

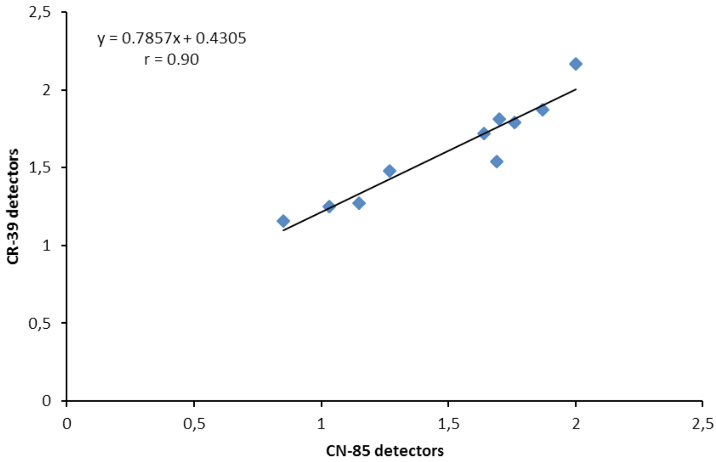

Fig. 8. Correlation of C_U between two detectors CN-85 and CR-39 detectors in soil

Hence, for construction purposes, the soil samples collected from Al-Najaf governorate can be used, as it seems that it does not imply any risks due to this level of radon concentrations, radium content, radon exhalation rate and uranium concentrations. Moreover, the results have revealed that the E_P, H_E, $D_{Soft\ tissue}$ and $D_{Lung\ surface}$ resulted from the soil radon concentration contributing to indoor radon activity of the soil samples in the studied area does not pose risk to human beings.

CONCLUSIONS

The radon concentrations, radium content and uranium concentrations in the samples were found to be less than the recommended limit. Also, the results in the present work indicated that the radon exhalation rate in terms of area, annual effective dose, $D_{Soft\ tissue}$ and D_{Lung} due to alpha-radiation in the lung were within the limit recommended by the UNSCEAR (2000) and ICRP (1993), respectively. A good correlation was observed between $C_{Rn}^{ind.}$ with radium content and uranium concentrations using two SSNTDs (CN-85 and CR-39) in soil. Therefore, it could be concluded that the area of study is free of risk of exposure to radon, radium and uranium, as they do not pose any hazard due to the low radon exhalation.

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