Contribution of soil in the annual effective dose due to radon in the air of some dwellings in the city of Karbala, Iraq

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Abstract

Introduction: The radon isotopes are not as significant as (^{222}Rn) due to the decay of the natural radionuclides (^{235}U), (^{232}Th) and (^{238}U) due to their short half-life, at most. (^{222}Rn) can be classified as among the most harmful radioactive elements in the world.

Material and method: In this analysis, the closed-can technique was used with solid-state nuclear track detectors (CR-39). After forty days of closed dosimeter buried in the soil of the garden, and ninety days from the closed position in the air of some dwellings were collected dosimeter and stripped of nuclear detectors impact of closed groups. For 8 hours, CR-39 detectors were chemically etched by (6.25 N) NaOH solution at 70°C and then registered within an optical microscope.

Result: The levels of soil radon concentrations ranged from 28.44 ± 0.58 to 479.76 ± 2.43 Bq/m³ with a mean value of 220.33 ± 1.64 Bq/m³, while the concentration of radon in the air of certain dwellings varied from (1.95 ± 0.27 to 46.82 ± 0.75) Bq/m³ with an average value of 21.51 ± 0.54 Bq/m³. In comparison, the annual effective dose attributed to radon in soil ranged from 0.71 ± 0.09 mSv/y to 12.10 ± 0.38 mSv/y with an average value of 5.55 ± 0.261 mSv/y, while the annual effective dose in air differed from (0.04 ± 0.02 mSv/y) to (1.18 ± 0.12 mSv/y) with an average value of (0.60 ± 0.09 mSv/y).

Conclusion: Neglecting the effects of other radon sources, the percentage share of the annual effective dose due to radon in soil measured in the air home, ranged from 0.005 ± 0.001 to 0.453 ± 0.074 with an average value of 0.130 ± 0.040 . Weak correlation between concentrations of radon in households and soil air. But roughly speaking, one can say that in soil air every 1000 Bq/m³ and 1000 mSv/y contributes around 130 Bq/m³ and 130 mSv/y in indoor air.

Key words: radon concentration; (AED); SSNTD (CR-39); soil; air; dwelling.

Introduction

The radon isotopes are not as significant as (^{222}Rn) due to the decay of the natural radionuclides (^{235}U), (^{232}Th) and (^{238}U) due to their short half-life, at most. (^{222}Rn) can be classified as among the most harmful radioactive elements in the world. Its character as a noble gas lets it spread through the atmosphere.¹ The half-lives of ^{219}Rn (actinon, 3.96 s) and ^{220}Rn (Thoron, 55.6 s) are short, and they have a low abundance relative to ^{222}Rn (Radon, 3.82 d). Because of these properties and dosimetric considerations; the alpha dose delivered to the trachea bronchial tree from ^{220}Rn is one-third that from ^{222}Rn per unit exposure of radon ^{222}Rn , which is generally of major interest. Special situations, either occupational or environmental, could pose unusual circumstances where measurement of Actinon (^{219}Rn) or Thoron (^{220}Rn) would be the primary concern but so far these situations have been rare.² Normal radioactivity is the population's main reservoir of ionizing radiation. It is found in varying concentrations both in humans and in the surrounding ecosystem, the earth is the main source of constant exposure to

human radiation regardless of its normal nature. This acts as a way of movement for the introduction of radionuclides into the environment; hence, the soil is the main source of radiological pollution.³ When present in ambient air, radon and its daughter progeny attached to aerosols constitute a significant radioactive threat to human lungs. Radon progeny accumulates in the lungs during respiration and irradiates the tissue thereby destroying the cells and can cause lung cancer.⁴ This study aims to determine how much soil contributes to the annual effective dose due to radon in the air of some of Karbala's dwellings after neglecting all other sources. We can determine the amount of contribution after the measurement of the concentration of radon in the soil and air dwellings of the study area and find a ratio of contribution between the two.

Environmental framework

Karbala is called the capital of the governorate of Karbala, and as part of the alluvial plain it is the districts of the Middle Euphrates and the Husayniyah River flows through its lands. As

in **Figure 1**. From a strategic point of view, it is bordered to the north by the city of Baghdad, at a distance of 105 km, and to the northwest by the city of Anbar, at a distance of 112 km; and the governorate of Najaf borders it to the south-west, at a distance of 45 km, along with the governorate of Babylon, bordering it to the south-east, and the free zone bordering it to the north. Though sand increases to the south of the town of Karbala and its sand increases to the west, where Lake Al-Razzaza is situated, Karbala covers a region of up to 2793 km², with latitude position (32.34°-32.37°N) and longitude (58.43°-60.44°E).⁵ The soil was of sandy type: it contains small particles of rocks and minerals, and usually, the composition and structure of that soil are composed of sand consisting of rocks broken down by erosion factors, as it contains either a high or low percentage of organic matter and includes sand formation to more than 35% and less than 15% of clay and silt as it has a high rough texture and it should be noted that the percentage of sand, clay and silt is determined after disposal of organic matter in the soil.

Materials and Methods

In the current analysis, 55 houses were chosen in the district of Karbala, where one detector was randomly positioned in the house air and the other was buried in the garden of the house, which is 5-10 meters from the house. The houses that were selected for the study were built from bricks, cement, plaster, and parts of the houses were covered with ceramics and kashi, with a building area ranging from 50 m² to 150 m², and were built in different times, including the old and the modern. The integrated passive radon dosimeters of super grade standard SSNTDs CR-39 have been used, the methodology is based on the closed can (**Figure 2**). Such dosimeters are made of plastic containers with a diameter of 6.8 cm and a depth of 4.6 cm. A triangular opening with a diameter of 0.75 cm was placed at the center of the cover. The gap was filled with a 1.3 cm × 5 cm sponge piece and 0.5 cm long, pushed against the inner wall of the seal. Within the cup was placed a small piece of CR-39 with a region of roughly 2 cm² and tied to its base. This configuration was sufficient to ensure thoron (²²⁰Rn; T_{1/2} = 55.6 s) did not penetrate the detector. On average, about 55 dosimeters were typically spread within the dwellings of the chosen locations in

each survey, as in **Table 1**. In each home, one dosimeter was placed in the room at a height of around 2 m above the floor, and radon was collected in the subsoil by putting the dosimeters upside-down at a depth of 50 cm in the earth at the bottom of the trap. Usually, the dosimeters were exposed inside the houses for three months to test radon in the dirt. Though the dosimeters were left to measure the radon gas in the soil for up to 40 days. In a beaker in a water bath equipped with an electrical heater and temperature (70±0.1), the collected dosimeters were then chemically grinded using a NaOH solution and an 8-hour concentration of (6.25)M topic. An optical microscope was used to count the number of tracks per cm² recorded for each detector a magnification of 100× up to 400×.

Figure 1. Map of location samples in Karbala city.

Figure 2. Passive-cumulative dosimeter radon

Table 1. Samples code and locations that have been selected in Karbala city

Sample code	Location	Sample code	Location	Sample code	Location	Sample code	Location	Sample code	Location
K1	Tahady	K12		K24		K35	Frehaa	K46	
K2	Amel	K13	Al muhandisin	K25		K36	Al atibba	K47	Askaree
K3	Saif Saad	K14		K26		K37	Al moadafeen	K48	
K4	Hosainia	K16	Askaree	K27	Al hur	K38		K49	Al jawad
K5	Alamin	K17		K28		K39	Askaree	K50	
K6	Salam	K18	Yarmouk	K29		K40		K51	Yarmouk
K7	Eawn	K19		K30		K41		K52	
K8	Ramadan	K20	Mamalachy	K31		K42	Al hussein	K53	Frehaa
K9	Benaa al jahez	K21		K32	Al abbas	K43		K54	
K10		K22	Al hur	K33		K44	Askaree	K55	Al hur
K11	Yarmouk	K23		K34	Hosainia	K45			

In order to measure the radon(C) concentrations in the soil and air of the buildings, the trace surface density on the detectors used was measured in (line/cm²) and using the equation below:^{6,7}

$$C = \frac{\rho}{kt} \quad \text{Eq. 1}$$

Where t is the exposure period (day) and k is the CR-39 nuclear track detector adjustment factor equivalent to 0.223 [(track/cm²) per (Bq day/m³)].⁸ The calibration factor (k value was determined by the calibration process which used standard radon source (Radium ²²⁶Ra) and used the equation

$$k = \frac{\rho_0}{C_0 t_0} \quad \text{Eq. 2}$$

where, C₀ is the standard radon concentration (Bq/m³), ρ₀ is the number of track density (track/cm²), and t₀ is the exposure time day for the calibration process. The calibration experiment was performed at the nuclear laboratory, department of physics, college of sciences, Kerbala University. Five detectors were exposed to the standard radon concentration; the average value of calibration factor and its standard deviation was 0.223 track/cm² per (day Bq/m³).⁸

In terms of (mSv/y) units, the annual effective dosage (AED) was obtained using the relationship:^{9,10}

$$AED (mSv/y) = C \times F \times H \times T \times D \quad \text{Eq. 3}$$

where F is the equilibrium parameter equivalent to (0.4), (H) the occupancy parameter equivalent to (0.8), (T) the hour in a year, (T = 8760 h/y), and (D) the transition dosage factor equivalent to [9 × 10⁻⁶ (mSv)/(Bq·h·m⁻³)].

Results

To achieve the aims of this research, we examined the concentration of radon gas in the air of some sample region dwellings by administering passive closed dosimeters. As we analyzed the concentration of radon in the soil at a depth (50 cm) in the research region to find a connection between the radon concentration in the soil and the dwellings in the environment. Furthermore, assessing the amount of soil adds to the successful annual exposure attributable to radon in the environment of some of Karbala's dwellings by neglecting all other outlets.

Table 2 indicates closed dosimeter radon concentrations in soil and radon concentrations in (55) homes in Karbala District, it can be noted that the maximum average soil (Cs) radon concentration was found in K45 and K46 (479.76±2.43 Bq/m³), Whereas the lowest average concentration of radon in soil (28.44±0.58 Bq/m³) was identified in K1 and K15 with a mean value of 220.33±1.64 Bq/m³. It can also be observed from **Table 2** that the radon concentrations in air dwellings (Ca) vary from (1.95±0.27 Bq/m³) (K16) to (46.82±0.75 Bq/m³) (K32 and K53), with an average value of (21.51±0.54 Bq/m³). Furthermore, the annual effective soil radon dose (AEDs) ranged from 0.71±0.09 mSv/y in K1 and K15 to 12.10±0.38 mSv/y in K45 and K46 with an average value of 5.55±0.261 mSv/y, although the annual effective dose ranges between (0.04±0.02 mSv/y) (K16) and (1.18±0.12 mSv/y) (K32 and K53) with an overall value of (0.60±0.09 mSv/y) in air dwellings (AED a). **Figure 3** shows the weak correlation (R²=0.0569) between radon concentrations in household air and soil.

Figure 3. Correlation between radon concentration in air and soil

Table 2. The track density in air (ρ_a) and soil (ρ_s), the radon concentration in air (C_a) and soil (C_s), annual effective dose in air (AED_a) and soil (AED_s) for (55) houses in Karbala city.

Codes	Air			Soil		
	ρ_a Track/cm ²	C_a Bq/m ³	AED_a mSv/y	ρ_s Track/cm ²	C_s Bq/m ³	AED_s mSv/y
K1	55.00±0.82	2.74±0.18	0.06±0.02	133.18±1.28	28.44±0.58	0.71±0.09
K2	86.21±0.92	4.29±0.23	0.10±0.03	203.63±1.58	43.48±0.72	1.09±0.11
K3	117.42±1.08	5.85±0.26	0.14±0.04	344.53±2.06	73.57±0.94	1.85±0.15
K4	48.63±0.69	2.34±0.30	0.05±0.04	908.15±3.34	193.92±1.54	4.89±0.24
K5	560.56±2.36	27.93±0.57	0.70±0.09	798.89±3.13	170.59±1.44	4.30±0.23
K6	602.69±2.45	30.02±0.60	0.75±0.09	989.09±3.49	211.21±1.61	5.32±0.25
K7	644.82±2.53	32.12±0.62	0.81±0.10	1940.11±4.89	414.28±2.26	10.45±0.35
K8	560.56±2.36	27.93±0.57	0.70±0.09	1654.80±4.51	353.36±2.08	8.91±0.33
K9	179.84±1.33	8.96±0.31	0.22±0.05	1049.05±3.59	224.01±1.66	5.65±0.26
K10	211.05±1.45	10.51±0.35	0.26±0.05	1824.01±4.74	389.49±2.19	9.82±0.34
K11	242.26±1.72	12.07±0.38	0.30±0.06	1189.95±3.83	254.10±1.77	6.41±0.27
K12	273.47±1.83	13.62±0.40	0.34±0.06	1260.40±3.94	269.14±1.82	6.79±0.28
K13	60.09±0.68	2.99±0.76	0.07±0.02	696.79±2.93	148.79±1.35	3.75±0.21
K14	91.30±1.05	4.54±0.77	0.11±0.03	555.89±2.61	118.70±1.20	2.99±0.19
K15	97.13±1.09	4.84±0.24	0.12±0.03	133.18±1.28	28.44±0.58	0.71±0.09
K16	39.26±0.69	1.95±0.27	0.04±0.02	1749.91±4.70	373.67±2.14	9.42±0.34
K17	81.39±1.00	4.05±0.33	0.10±0.03	608.69±2.73	129.97±1.26	3.27±0.20
K18	518.43±2.52	25.83±0.55	0.65±0.08	2130.31±5.12	454.90±2.36	11.47±0.37
K19	65.65±0.89	3.27±0.40	0.08±0.03	418.48±2.27	89.36±1.04	2.25±0.16
K20	686.95±2.91	34.22±0.64	0.86±0.10	1940.11±4.89	414.28±2.26	10.45±0.35
K21	349.91±2.07	17.43±0.45	0.44±0.07	703.79±2.94	150.28±1.36	3.79±0.21
K22	476.30±2.42	23.73±0.53	0.59±0.08	1084.19±3.65	231.51±1.68	5.84±0.26
K23	686.95±2.91	34.22±0.64	0.86±0.10	1084.19±3.65	231.51±1.68	5.84±0.26
K24	855.47±3.24	42.62±0.72	1.07±0.11	1274.40±3.96	272.13±1.83	6.86±0.29
K25	771.21±3.08	38.42±0.68	0.96±0.10	2130.31±5.12	454.90±2.36	11.47±0.37
K26	813.34±3.16	40.52±0.70	1.02±0.11	418.48±2.27	89.36±1.04	2.25±0.16
K27	855.47±3.24	42.62±0.72	1.07±0.11	989.09±3.49	211.21±1.61	5.32±0.25
K28	897.60±3.32	44.72±0.73	1.12±0.11	1274.40±3.96	272.13±1.83	6.86±0.29
K29	304.68±1.93	15.18±0.43	0.38±0.06	1049.05±3.59	224.01±1.66	5.65±0.26
K30	335.89±2.03	16.73±0.44	0.42±0.07	1683.11±4.55	359.41±2.10	9.06±0.33
K31	367.10±2.12	18.29±0.47	0.46±0.07	908.15±3.34	193.92±1.54	4.89±0.24
K32	939.73±3.40	46.82±0.75	1.18±0.12	1084.19±3.65	231.51±1.68	5.84±0.26
K33	602.69±2.72	30.02±0.60	0.75±0.09	893.99±3.32	190.90±1.53	4.81±0.24
K34	518.43±2.52	25.83±0.55	0.65±0.08	1749.91±4.64	373.67±2.14	9.42±0.34
K35	139.26±1.30	6.93±0.27	0.17±0.04	1749.91±4.64	373.67±2.14	9.42±0.34
K36	181.39±1.49	9.03±0.33	0.22±0.05	608.69±2.73	129.97±1.26	3.27±0.20
K37	223.52±1.65	11.13±0.36	0.28±0.05	228.28±1.67	48.74±0.76	1.23±0.12
K38	265.65±1.80	13.23±0.40	0.33±0.06	418.48±2.27	89.36±1.04	2.25±0.16
K39	307.78±1.94	15.33±0.43	0.38±0.06	798.89±3.13	170.59±1.44	4.30±0.23
K40	349.91±2.07	17.43±0.45	0.44±0.07	703.79±2.94	150.28±1.36	3.79±0.21
K41	349.91±2.07	17.43±0.45	0.44±0.07	1084.19±3.65	231.51±1.68	5.84±0.26
K42	429.52±2.30	21.40±0.50	0.54±0.08	1260.40±3.94	269.14±1.82	6.79±0.28
K43	460.73±2.38	22.95±0.52	0.57±0.08	555.89±2.61	118.70±1.20	2.99±0.19
K44	491.94±2.46	24.51±0.54	0.61±0.09	767.24±3.07	163.83±1.41	4.13±0.22
K45	772.83±3.08	38.50±0.68	0.97±0.10	2246.72±5.26	479.76±2.43	12.10±0.38
K46	804.04±3.15	40.06±0.70	1.01±0.11	2246.72±5.26	479.76±2.43	12.10±0.38
K47	434.17±2.31	21.63±0.50	0.54±0.08	1179.30±3.81	251.82±1.76	6.35±0.27
K48	476.30±2.42	23.73±0.53	0.59±0.08	989.09±3.49	211.21±1.61	5.32±0.25
K49	518.43±2.52	25.83±0.56	0.65±0.08	608.69±2.73	129.97±1.26	3.27±0.20
K50	265.65±1.80	13.23±0.40	0.33±0.05	703.79±2.94	150.28±1.36	3.79±0.21
K51	476.30±2.42	23.73±0.54	0.59±0.08	989.09±3.49	211.21±1.61	5.32±0.25
K52	518.43±2.52	25.83±0.56	0.65±0.08	608.69±2.73	129.97±1.26	3.27±0.20
K53	939.73±3.40	46.82±0.75	1.18±0.12	960.09±3.44	148.79±1.35	3.75±0.21
K54	555.89±2.61	27.69±0.77	0.69±0.09	991.30±3.49	118.70±1.20	2.99±0.19
K55	771.21±3.08	38.42±0.68	0.96±0.10	893.99±3.32	190.90±1.53	4.81±0.22
Mean	427.04±2.29	21.51±0.54	0.60±0.09	1044.54±3.59	220.33±1.64	5.55±0.261
Max.	939.73±3.40	46.82±0.75	1.18±0.12	2246.72±5.26	479.76±2.43	12.10±0.38
Min.	39.26±0.69	1.95±0.27	0.04±0.02	133.18±1.28	28.44±0.58	0.71±0.09

Discussion

The explanation for the variability of these recipes is attributed to the natural complexity of the land on which these houses were constructed, as well as the varying materials used in the design.

Table 3 and **Figure 4** show that the amount of soil contribution to radon concentrations in the air of the homes of the study area.

Contribution to the soil at an annual effective dose due to radon in air dwellings [C_a/C_s] or [AED_a/AED_s] ranges from 0.005 ± 0.001 (K16) to 0.453 ± 0.074 (K26) with an average value of (0.130 ± 0.040) , this means that every 1000 Bq/m^3 or 1000 mSv/y in soil air contributes approximately 130 Bq/m^3 or 130 mSv/y indoor air for both concentrations of radon and the annual effective radon gas dose, respectively. This means that the ratio between the rate of radon concentrations in residential air and the rate of radon concentrations in the soil as well as between the rate of the radon dose in the air and the rate of the radon dose in the soil is the same amount and this amount is called the contribution of soil to the concentrations and doses of radon produced in the air while neglecting all factors that affect radon concentration and dose.

The average concentration of soil gas radon in the city of Karbala is lower than that of 6.71 kBq/m^3 in Saudi Arabia¹¹ and 5.74 kBq/m^3 in Iraq¹², 4.35 kBq/m^3 in Egypt¹³, 2.63 kBq/m^3 in Kassala-Sudan¹⁴ and 2.71 kBq/m^3 in France¹⁵. In comparison, the radon concentration levels in this sample are lower than those reported in 8.20 kBq/m^3 of Rabak city Sudan¹⁶, 40.1 kBq/m^3 of Slovenia¹⁷ and 2.87 kBq/m^3 of Iraq⁸.

Considering the great importance of radon as a result of the health effects on human life, many researchers in various countries around the world conduct research and studies to measure the concentrations effective dose of it in the air of houses of those countries in order to reduce the risks resulting from it and develop the necessary solutions to it through special programs. By comparing the findings of the current research with the findings of local and international studies, we noticed that the concentrations of radon in the air of dwellings of the city

of Karbala were lower than the concentration of radon in the air of both Iraq's houses¹⁸, Egypt¹⁹, France²⁰, Iraq²¹⁻²³, Jordan^{24,25}, Kosovo²⁶, Iran²⁷, Ghana²⁸, Palestine²⁹, India³⁰, Mali³¹, Romania³², Spain³³, Turkey³⁴, Sudan³⁵, Iraq³⁶, Libya³⁷, USA³⁸, Greece³⁹, Saudi Arabia⁴⁰ and Yemen⁴¹.

Table 3. Contribution of soil to radon concentrations C_a/C_s or annual effective dose AED_a/AED_s in the air for (55) houses in Karbala city.

Codes	C_a/C_s or AED_a/AED_s	Codes	C_a/C_s or AED_a/AED_s
K1	0.096 ± 0.034	K30	0.047 ± 0.024
K2	0.099 ± 0.034	K31	0.094 ± 0.034
K3	0.075 ± 0.030	K32	0.202 ± 0.049
K4	0.012 ± 0.001	K33	0.157 ± 0.044
K5	0.164 ± 0.044	K34	0.069 ± 0.029
K6	0.142 ± 0.041	K35	0.019 ± 0.015
K7	0.078 ± 0.031	K36	0.070 ± 0.029
K8	0.079 ± 0.031	K37	0.228 ± 0.053
K9	0.040 ± 0.022	K38	0.148 ± 0.042
K10	0.027 ± 0.018	K39	0.090 ± 0.033
K11	0.048 ± 0.024	K40	0.116 ± 0.037
K12	0.051 ± 0.025	K41	0.075 ± 0.091
K13	0.020 ± 0.011	K42	0.080 ± 0.031
K14	0.038 ± 0.021	K43	0.193 ± 0.048
K15	0.170 ± 0.045	K44	0.150 ± 0.043
K16	0.005 ± 0.001	K45	0.080 ± 0.031
K17	0.031 ± 0.009	K46	0.084 ± 0.032
K18	0.057 ± 0.026	K47	0.086 ± 0.032
K19	0.036 ± 0.012	K48	0.112 ± 0.037
K20	0.083 ± 0.032	K49	0.199 ± 0.049
K21	0.116 ± 0.037	K50	0.088 ± 0.032
K22	0.103 ± 0.035	K51	0.112 ± 0.037
K23	0.148 ± 0.042	K52	0.199 ± 0.049
K24	0.157 ± 0.044	K53	0.322 ± 0.063
K25	0.084 ± 0.032	K54	0.416 ± 0.071
K26	0.453 ± 0.074	K55	0.201 ± 0.049
K27	0.202 ± 0.049	Mean	0.130 ± 0.040
K28	0.164 ± 0.044	Max.	0.453 ± 0.074
K29	0.068 ± 0.028	Min.	0.005 ± 0.001

Figure 4. The percent of soil contribute to the annual effective dose due to radon in the air of fifty-five dwellings in the city of Karbala.

Conclusions

Because of the results obtained in Karbala City's soil and air dwellings and comparing the results with other local and foreign research, we may conclude that such results may not present a major challenge to the lives of citizens residing in the field of analysis. This analysis found that soil radon concentrations range from $(28.44 \pm 0.58 - 479.76 \pm 2.43)$ Bq/m³ to the mean of (220.33 ± 1.64) Bq/m³. The values of radon concentrations in dwellings using dosimeters vary from (1.95 ± 0.27) Bq/m³ to (46.82 ± 0.75) Bq/m³ with an average value of (21.51 ± 0.54) Bq/m³, showing results within the permitted limits. In addition, we observed that the amounts of radon in Karbala dwellings and

soil are below the standards recognized globally. Each 1000 Bq/m³ of soil air contributes about 130 Bq/m³ in dwellings' air. This means that the ratio between the rate of radon concentrations or annual effective dose in residential air and the rate of radon concentrations or annual effective dose in the soil, respectively.

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