Measurement of Radon Concentration Using SSNTD in Bartella Region

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Abstract
The alpha-radioactive inert gas Radon exhalation is associated with presence of Radium and its ultimate precursor uranium in the earth crust. Uranium decay deposits radon in soil, which is harmful on human and environment. The exposure of population to high concentration of alpha radioactivity mainly of Radon for a long period leads to lung cancer. The radon activity concentrations, radium contents, radon exhalation rates in twenty one soil samples collected from Bartella region, were measured using the sealed-can technique based on the CR-39 SSNTDs. In the present paper the estimated values for radon activity concentration in air space are in the range 323.2–2424 Bq/m$^3$ with mean value of 1212.7 Bq/m$^3$, the radon concentration in soil sample are 31.66–237.46 KBq/m$^3$ with mean value 118.83 KBq/m$^3$, the radium contents were found vary between 1.36-10.24 Bq/Kg with mean value 5.11 Bq/Kg, the radon mass exhalation rate vary between 10.34-77.56 mBq/Kg/hr with mean 38.81 mBq/Kg/hr, the radon surface exhalation rate are between 234.2–1756.4 mBq/m$^2$/hr with mean value of 878.6 mBq/m$^2$/hr. All values of the samples under the test are below of permissible values 370 Bq/Kg of radium content and 57600 mBq/m$^2$/hr radon exhalation, recommended by Organization for Economic Cooperation and Development (OECD). Hence the area under investigation is safe as for as health hazards of radium and safe in radiological risks due to radon exposure from the soil.

Keywords: Radon measurement, Radium content, Bartella region, SSNTDs, CR-39.

Introduction
The exposure of population to high concentration of alpha radioactivity mainly of Radon for a long period leads to pathological effects like there respiratory functional changes and the occurrence of lung cancer[1]. The radioactivity is a spontaneous decay and transformation of unstable nuclei accompanied with the emission of nuclear particles or photons, therefore the analysis of this processes may be found in wide range of complexities because nuclear radiation can occur in various types, abundances and energies[2]. Radiation plays an important role in our everyday life as the world is naturally radioactive therefor each
of us is exposed to naturally occurring quantities of radiation, in fact, radioactivity can be in the air we breathe, the soil on which we walk the dwellings in which we live and even within in our bodies[3].

Radon is found in air, rock, soil, water, and it is indicate the presence of radium and its ultimate precursor uranium in the ground. The vast variation in radon exposure depends on location considered and is mainly governed by the exhalation rate (i.e., the amount of activity released per unit area of the surface per unit time) from the ground[4],[5]. Measurement of radon exhalation rates from soil and rocks is useful in studying the health risks[6][7]. The soil–gas radon concentration and its exhalation rate depend on the local geology of the area associated mineralization geophysical and climatological parameters[8]. As a gas, radon has three main natural isotopes; namely, radon-222 (222Rn), a decay product of 238U, radon-220 (220Rn, known as thoron), produced in the decay series of thorium-232 (232Th), and radon-219 (219Rn), a decay product from the chain originating with 235U[9]. Both 238U and 232Th occur naturally in soil and rocks at variable concentrations of about 1PCi/g and also 226Ra, the parent of 222Rn[10]. The 222Rn isotope has a half-life of 3.82 days, while 220Rn isotope has half-life about 55 seconds and 219Rn isotope has a half-life of about 3.96 seconds[11]. Since radon 222Rn has long half-life time related to other isotopes, its considered to be the most significant isotope in decay series of 238U, this is show the radon problem in the environmental studies because tracing of 238U are found in most natural rocks, soil, and water. It can be measured using SSNTD (Solid State Nuclear Track Detectors) technique[12].

The plastic SSNTD detectors are most widely used because they are more sensitively than crystal and glass. This type like CR-39 Polymer can record all charged radiations, the shape and type of damage positions (tracks) on the film plastic detector depend on the mass, energy, the charge of the incident particle and on the type of solid state detector[13], and these tracks may be observed by optical microscope after enlargement by etching process.

Materials and Methods

1. Radon gas concentration in soil samples

The radon activities, were detected by passive technique of solid state nuclear track detectors using “Sealed Can technique”[14][17]. Twenty one soil samples were collected from various locations of Bartella region (the location of study area Bartella is in Iraq, 21 kilometers East of Mosul city, between Latitude: 36° 21' 13.3" (36.3537°) north and Longitude: 43° 22' 52.6" (43.3813°) east, elevation:307 meters, 1,007 feet), these samples milled, crushed, sieved by 2-mm mesh, 75 gm of each sample was placed inside a plastic cylindrical container facing a CR-39 track detector into a diffusion chamber Figure 1.

Which was then closed for a period of 90 days (from 5 March 2017 to 3 June 2017) after getting equilibrium between radium and radon. CR-39 detector of area (1×1 cm²) were placed at the closed top end of a plastic cup (6.5 cm in diameter, 10.5 cm length) while the distance between the sample surface to the detector is 9 cm and the sample thickness is 1.5 cm. After 90 days, the detectors are removed and etched by NaOH at normality 6.25 N and heat 70 °C in water bath to reveal the tracks. The detectors were washed and dried, tracks were counted using a microscope at a magnification of 400x.

The track densities were measured using the following equation[18]:

\[
\text{Track density } p = \frac{\text{Total number of tracks}}{\text{Area of the field of view}}
\]
The track density \( \rho \) (in track/cm\(^2\)) is related to the radon activity concentration (in air space) \( C_{Rn} \) (Bq/m\(^3\)) and the exposure time \( T \) (in day) by the formula[19]:

\[
\rho = KC_{Rn}T
\]  
(2)

Where \( K \) is the sensitivity or calibration factor of CR-39 its value (2.758\times10^{-2} \) Traks.cm\(^2\).day\(^{-1}\)/Bq.m\(^3\)) given by[20].

Radon concentration in the soil samples calculated using the relation[21][22]:

\[
C_s = \lambda_{Rn}C_{Rn}HT/L
\]  
(3)

Where \( C_s \) Radon concentration in the soil samples (Bq/m\(^3\)), \( C_{Rn} \) Radon concentration in air space (Bq/m\(^3\)), \( \lambda_{Rn} \) decay constant for radon (0.1814 day\(^{-1}\)), \( H \) height of air space in the can (9cm), \( T \) exposure time (90 day), \( L \) thickness of the sample in the can (1.5cm).

2. Radium content in soil samples

Since the half-life of \(^{226}\)Ra is 1600 years and that of \(^{222}\)Rn is 3.82 days, it is reasonable to assume that an effective equilibrium (about 98%) for radium- radon members of the decay series is reached in about four weeks. Once the radioactive equilibrium is established, one may use the radon alpha analysis for the determination of steady state activity concentration of radium. The activity concentration of radon increase with time \( T \), after the closing of the can, according to the relation[23]:

\[
C_{Rn} = C_{Ra}(1 - e^{-\lambda_{Rn}T})
\]  
(4)

Where \( C_{Ra} \) is the effective radium content of the sample, \( \lambda_{Rn} \) is the decay constant of \(^{222}\)Rn. Since a plastic track detector measures the time-integrated value of the above expression, i.e. the total number of alpha disintegrations in unit volume of the can with a sensitivity \( K \) during the exposure time \( T \), hence the track density observed is given by the relation[24]:

\[
\rho = KC_{Ra}T_e
\]  
(5)

Where \( T_e \) denotes, the effective exposure time given by[25]:

\[
T_e = [T - \lambda_{Rn}^{-1}(1 - e^{-\lambda_{Rn}T})]
\]  
(6)

The effective radium content of the soil sample can be calculated by formula[24]:

\[
C_{Ra}(Bq.Kg^{-1}) = \left( \frac{\rho}{KT_e} \right) \left( \frac{HA}{M} \right)
\]  
(7)

Where \( M \) is the mass of the soil sample in Kg, \( A \) is the area of cross-section of the can in m\(^2\), \( H \) is the distance between the detector and top surface of the soil sample in meter, \( T_e \) effective exposure time in day.

3. Radon exhalation in soil samples

The surface exhalation rate \( E_A \) (Bq.m\(^{-2}\).hr\(^{-1}\)) of the sample for release of radon can be calculated by using the expression[26]:

\[
E_A = \frac{CV\lambda}{AT_e}
\]  
(8)

The mass exhalation rate \( E_M \) (Bq.Kg\(^{-1}\).hr\(^{-1}\)) of sample can be calculated by expression[26]:

\[
E_M = \frac{CV\lambda}{MT_e}
\]  
(9)

Where in the above tow expressions \( \lambda \) is the decay constant for radon in (hr\(^{-1}\)), \( V \) is effective volume of the can in (m\(^3\)), \( C \) in (Bq/m\(^3\).hr) is the integrated radon exposure, \( A \) is area cross-section of can in (m\(^2\)), \( M \) is the sample mass in (Kg), \( T_e \) is effective exposure time in (hr), the integrated radon exposure was computed using the relation[6]:

\[
C = C_{Rn}T
\]  
(10)

Where \( C_{Rn} \) (Bq/m\(^3\)) radon activity concentration, \( T \) the total exposure time in (hr).

Results and Discussion

The results of mass and surface exhalation rates of radon, the radon activity concentration in air space, radon concentration content in
soil, and radium content for twenty one soil samples are presented in Table 1.

Table 1: Results of radon and radium concentrations, radon exhalation rates in soil samples.

| No. | Sample number | $p$ Track/cm² | $C_{Ra}$ Bq/m³ | $C_{Ra} \times 10^3$ Bq/m³ | $C_{Ra}$ Bq/Kg | $E_A$ Bq.m², hr⁻¹ | $E_M$ Bq.Kg², hr⁻¹ |
|-----|---------------|---------------|----------------|-----------------|--------------|----------------|-------------------|
| 1   | BART01        | 4520          | 1826           | 178.86          | 7.68         | 1323           | 58.43             |
| 2   | BART02        | 6000          | 2424           | 237.46          | 10.24        | 1756           | 77.56             |
| 3   | BART03        | 4133          | 1670           | 163.58          | 7.05         | 1210           | 53.44             |
| 4   | BART04        | 4573          | 1847           | 181.00          | 7.81         | 1338           | 59.10             |
| 5   | BART05        | 3906          | 1578           | 154.61          | 6.67         | 1143           | 50.49             |
| 6   | BART06        | 2933          | 1185           | 116.09          | 5.00         | 858.6          | 37.92             |
| 7   | BART07        | 2400          | 969.7          | 94.98           | 4.10         | 702.6          | 31.03             |
| 8   | BART08        | 4266          | 1723           | 168.88          | 7.28         | 1249           | 55.16             |
| 9   | BART09        | 5066          | 2047           | 200.52          | 8.65         | 1483           | 65.50             |
| 10  | BART10        | 2266          | 915.8          | 89.71           | 3.87         | 663.5          | 29.30             |
| 11  | BART11        | 1733          | 700.3          | 68.60           | 2.96         | 507.4          | 22.41             |
| 12  | BART12        | 1040          | 420.2          | 41.16           | 1.77         | 304.4          | 13.44             |
| 13  | BART13        | 3240          | 1309           | 128.23          | 5.53         | 948.5          | 41.89             |
| 14  | BART14        | 1200          | 484.8          | 47.49           | 2.04         | 351.3          | 15.51             |
| 15  | BART15        | 3600          | 1454           | 142.48          | 6.14         | 1053           | 46.54             |
| 16  | BART16        | 1600          | 646.4          | 63.32           | 2.73         | 468.4          | 20.68             |
| 17  | BART17        | 933           | 377.1          | 36.93           | 1.59         | 273.2          | 12.06             |
| 18  | BART18        | 1280          | 517.1          | 50.65           | 2.18         | 374.7          | 16.54             |
| 19  | BART19        | 2093          | 845.7          | 82.85           | 3.57         | 612.8          | 27.06             |
| 20  | BART20        | 5466          | 2208           | 216.36          | 9.33         | 1600           | 70.67             |
| 21  | BART21        | 800           | 323.2          | 31.66           | 1.36         | 234.2          | 10.34             |
|     | Min           | 800           | 323.2          | 31.66           | 1.36         | 234.2          | 10.34             |
|     | Max           | 6000          | 2424           | 237.46          | 10.24        | 1756           | 77.56             |
|     | Mean          | 3002          | 1212.7         | 118.83          | 5.11         | 878.6          | 38.81             |

The calculated values for radon activity concentration in air space are in the range 323.23-2424 Bq/m³ with mean value of 1212.7 Bq/m³, the radon concentration in soil sample are 31.66-237.46 KBq/m³ with mean value of 118.83 KBq/m³, the radium contents were found vary between 1.36-10.24 Bq/Kg with mean value 5.11 Bq/Kg, the radon mass exhalation rate vary between 10.34-77.56 mBq/Kg/hr with mean 38.81 mBq/Kg/hr, the radon surface exhalation rate are between 234.2-1756.4 mBq/m²/hr with mean value of 878.6 mBq/m²/hr. The min values found in the sample BART21 and max values in sample BART02, radium content comparable with 2.85-4.37 Bq/Kg of ref.[27]. In Table 2 comparison between the obtained results and the published data in different countries for soil samples.

Table 2: The comparison with the other published data in different countries.

| No. | Country | $C_{Ra}$ (Bq.m³) | References |
|-----|---------|------------------|------------|
| 1   | Iraq    | 1212.7           | present work|
| 2   | Iraq    | 1386.23          | 2014 ref.[28] |
| 3   | Iraq    | 616.6            | 2014 ref.[29] |
| 4   | Iraq    | 478              | 2012 ref.[30] |
| 5   | India   | 2200             | 2014 ref.[31] |
| 6   | India   | 1308.8-2105.6    | 2013 ref.[6] |
| 7   | India   | 448              | 2010 ref.[32] |
| 8   | India   | 457              | 2013 ref.[33] |
| 9   | India   | 1117             | 2014 ref.[34] |
| 10  | Egypt   | 717              | 2015 ref.[35] |
| 11  | Egypt   | 136.99-874.51    | 2016 ref.[36] |
| 12  | Egypt   | 36.98-576.18     | 2012 ref.[37] |
| 13  | Algeria | 285              | 2008 ref.[38] |
| 14  | Libya   | 516              | 2013 ref.[39] |
| 15  | Nepal   | 2321             | 2015 ref.[40] |
| 16  | Turkey  | 1795             | 2006 ref.[41] |

Figure 2 represent the values of radium content with the samples, its vary from one sample to another due to radium content in sample location.
Figure 2: Radium content (Bq/Kg) in samples.

Figure 3 shows a good positive correlation (1.00) has been obtained between the radium content and the radon exhalation rates for soil samples, it is evident that as the content of radium increased, the exhalation rates as well as increase.

The variation in radon exposure depends on location considered and is mainly governed by the exhalation rate, the soil–gas radon concentration and its exhalation rate depend on the local geology of the area associated mineralization geophysical and climatological parameters. The Bartella region is an open area around houses, it has large amount of wind and air causes raised radon gas from soil to diffusion to air, so the results of the measurements show very low values of radon and radium concentrations, thoron gas (half-life 56 s) is an alpha emitter which is also present in soil and environments, the average diffusion distance of thoron gas is very small compared to that of radon, which means that the present results might also contained a small amount of thoron and therefore might be considered roughly as an upper limit results which are still within the allowed limit therefor the area under study is safe for life from natural radiation.

Conclusions

The results of this investigation showed considerable presence of radon and radium in soil samples in Bartella region. Radon concentrations in the soil air are known to vary with time due to changes in soil moisture, soil permeability, wind, air temperature and air pressure. A correlation coefficient of 1.00 between the radium content and radon exhalation rate has been obtained. The obtained values of radium contents and radon exhalation were found to be less than the maximum permissible values of 370 Bq/Kg and 57600 mBq/m²/hr as the recommendation of OECD[42]. Hence the area under investigation is safe as for as health hazards of radium and safe in radiological risks due to radon exposure from the soil.

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