Measurement of radon ($^{222}$Rn) and thoron ($^{220}$Rn) concentration of plants (Vegetables) in different locations in Sulaimania City using CR-39 detector

**ABSTRACT**

**Introduction**: Radon is a radioactive gas released from the normal decay of uranium in rocks and soil depending on local geology. Radioactive decay of uranium through radium produces radon. **Materials and Methods**: In the present work, seventeen plant (vegetables) samples collected from Sulaimania Governorate. The plants have been analyzed and examined to measure the level of radon ($^{222}$Rn) and thoron ($^{220}$Rn) using plastic track detector (CR-39) for evaluation of radon and thoron concentration in this region. **Results and Discussion**: The results indicated that the higher and lower radon concentration have been found in Halabjay-con, and in Sulaimani-center, to be (119.72 Bq.m$^{-3}$, 3.236 pCi/L), (54.36 Bq.m$^{-3}$, 1.469 pCi/L), respectively, and the higher and lower thoron concentration have been found in Qaladza and in Sulaimani-center, to be (733.66 Bq.m$^{-3}$, 19.828 pCi/L), (227.33 Bq.m$^{-3}$, 9.117 pCi/L), respectively. Radiation level compared with the standard level known by the EPA (4 pCi/L) and190 Bqm$^{-3}$. The concentration of radon in all sample plants is less than international standard level 4(pCi/L) and190 (Bqm$^{-3}$), therefore the human in safety. The average effective dose equivalent (EDE) of radon from plants determined was (7.2) μSv.y$^{-1}$ for all the samples. This is lower than the normal value of (1.3) mSvy$^{-1}$ given by EPA. **Conclusions**: This study showed that the contamination in the plant (vegetables) is normal and is not considered a great radial dose for plants and consequently for humans.

**Keywords:**
Radon; Thoron; Plants; CR-39 Detector.
INTRODUCTION

Radon is a radioactive gas released from the normal decay of uranium in rocks and soil. It is an invisible, odorless, tasteless gas that seeps up through the ground and diffuses into the air, depending on local geology. Radioactive decay of uranium through radium produces radon. It decays into a series of progeny. Radon is a noble gas capable of permeating microscopic imperfections such as crevices, pores and structural failures in materials. The number and the amount of the isotopes depend on the geochemical and soil formation processes but also on atmospheric fallout, dust and ash that come from coal combustion\(^1\). There are several radionuclide in the \(^{238}\)U decay series that via alpha radiation can be easily detected using an \(\alpha\)-detector. There are many general types of alpha particle detectors that are used to measure radon, one of this detectors is Solid state alpha detectors.

The (CR-39) plastic track detector is colorless, rigid plastic, with a density of 1.30 g/ cm\(^3\), and chemical formula C\(_{12}\)H\(_{18}\)O\(_7\)\(^2\) made out of the polyallyl diglycol carbonate (PADC) resin \(^3\). It has been widely used since the 1980s as a solid state nuclear track detector \(^4\). CR-39 is the detector that used in the present study; it is sensitive to alpha particles, therefore, used as integrating detector of \(\alpha\)-particles from \(^{222}\)Rn and \(^{220}\)Rn daughter nuclei. When \(\alpha\)-particle penetrates the detector, the particle causes damage along its path, this damage is then made visible by chemical etching. The etching produces a hole in the detector along the path of the particle and this hole can be easily observed by optical microscope \(^5\) to track visualization, after using etching technique that was consists of four steps that is etching, washing, drying, and observation under optical microscope \(^6\). The measurements of radon and thoron concentrations were carried out by using a Long-tube technique (Long-tube is a plastic cylinder, made from PVC, in the form of cylinder of (2mm) thickness, a diameter of (7cm) and (30 cm)long \(^6\), used to separate (discriminate) radon (Rn-222) gas from thoron (Rn-220), with CR-39 to register the track of \(\alpha\)-particle from both radon and thoron during the time of exposure in the long-tube, with (2cm \(\times\) 1cm) dimension \(^7\). The 50 gm from each plant samples for the seventeen locations were placed in one end of the long-tube, and two CR-39 detectors were placed, one with distance 10 cm and the other at 30 cm at the bottom of the tube. The samples were left at room temperature for 35 days exposure time. After exposure the detectors were etched chemically in 6.25N solution of NaOH at (70 ± 1) °C with water bath for 5.25 hours. The normality of the etchant was calculated using the relation \(^8\).

\[
C = \left( \frac{W}{Weq} \right) \times 1000 / V
\]

\(C\) : is the normality or concentration of solution.\(W\) : is the weight (gm) of NaOH solution. \(Weq\) : is the equiv-
alent weight equal (40) for NaOH solution. V: is the volume of distilled water (100ml). When the three processes (etching – washing – drying) were finished, the tracks were counted for both detectors using an optical microscope and the track density is calculated by the relation;

**Track density (\( \rho \)) = Average of total pits/Area of field view** \( (2) \)

The concentration of radon and thoron were measured using radium (\(^{226}\)Ra) and thorium (\(^{232}\)Th) with activity (2\( \mu \)Ci and 8\( \mu \)Ci) respectively. The emanation rate of radon and thoron from the samples can be calculated by the relation that described in \( (8) \). The concentration of radon and thoron were measured by the following equation \( (9) \) and the results are shown in Tables 1, 2.

\[
C \text{ (Bq.m}^{-3}\text{)} = ( \rho_{\text{Rn}} - \text{BG} ) / ( KF_{\text{Rn}} \times T_{\text{exposure}} )
\]

(3)

Where \( C \text{ (Bq.m}^{-3}\text{)} \) is concentration of (radon, thoron), \( \rho_{\text{Rn}} \) is the track density of (radon, thoron), BG is background, and \( KF_{\text{Rn}} \) is calibration factor of radon and thoron.

Transfer factor (TF) is a useful parameter for the radiological assessment. It is defined as the steady-state concentration ratio between one physical situation and another \( (10) \). The equation (3) was used to determine the transfer factor between soil and plant, as following below \( (11) \).

\[
\text{TF} = C_{\text{Plant}} / C_{\text{Soil}}
\]

(4)

Where \( C_{\text{Soil}} \) is the concentration of soil and \( C_{\text{Plant}} \) is the concentration of plant. The activity (A) and the specific activity (S.A) of radon and thoron were determined by the following \( (12) \) and the results are shown in Table 4.

\[
A (\text{Bq}) = C_{w} (\text{Bq/m}^{3}) \times V(\text{m}^{3})
\]

(5)

\[
\text{S.A (Bq/Kg)} = A(\text{Bq}) / M(\text{Kg})
\]

(6)

\( V(\text{m}^{3}) \) is the volume of the tube, and \( M(\text{Kg}) \) is the mass of the samples. Also the effective dose equivalent (EDE) of radium (\(^{226}\)Ra) was determined by the following and the results are shown in Table 4.

\[
\text{EDE} = \text{S.A} \times \text{Ip} \times \text{DCF}
\]

(7)

DCF = Dose Conversion Factor, (DCF) of Radium in plant is 1.25 * \( 10^{-7} \) Sv Bq\(^{-1}\), and Ip is the rate of individual food consumption (90) Kg y\(^{-1}\) for plant (vegetables) and Ip (kg y\(^{-1}\)) is mass of food consumed annually \( (13) \).

The working level (WL) is a single value used to describe the radon daughter concentration in a way that also reflects their biological hazard. The working level (WL) and working level month (WLM) were determined using the relation found in \( (14) \). The measured \(^{222}\)Rn concentration values can be converted into WL units by
using the equilibrium factor (F) from this relation:

\[ F = WL \times 3700 / C_{Rn} \]  \hspace{1cm} (8)

**RESULTS**

In this study the tracks registered by two detectors, one at 10 cm from the sample and the other is at 30 cm away from the samples. The detector at 30 cm (upper) was record the radon gas only, and at 10 cm (lower) detector was record (radon+thoron). Then the signals will be separated by \( \rho_{\text{Thoron}} = \rho_{\text{lower}} - \rho_{\text{upper}} \). However, it has been mentioned before in (7). The calibration for radon \( K_{\text{Radon}} = 0.025 \) (track/cm\(^2\))/(Bq.m\(^{-3}\).h) and for thoron \( K_{\text{Thoron}} = 0.0030 \) (track/cm\(^2\))/(Bq.m\(^{-3}\).h). The track density of radon and thoron and emanation rate values have been measured for the plant samples of different locations under study, as shown in the Tables 1, 2. The emanation rate values for radon gas have been found to be greater than the emanation rate for thoron. This can be attributed to the difference in the production rate for both gases in the same period of time, and since the production rates depends on \( \lambda^{-1} \)

The higher and lower radon concentration found in Halabjay-con, and in Sulaimani-center, are \((119.72\text{ Bq.m}^{-3}, 3.236 \text{ pCi }/\text{L})\), \((54.36 \text{ Bq.m}^{-3}, 1.469 \text{ pCi}/\text{L})\), respectively, and the higher and lower thoron concentration found in Qaladza and in Sulaimani-center, are \((733.66 \text{ Bq.m}^{-3}, 19.828 \text{ pCi}/\text{L})\), \((227.33 \text{ Bq.m}^{-3}, 9.117 \text{ pCi}/\text{L})\); respectively. The concentration of radon and thoron in the same region are varying and different because attributed to the geological composition of the soil for uranium and thorium, that the plants are growing on them. The concentration of thoron is more than the concentration of radon in all locations, because the half-life of thorium \(1.39\times10^{10}\text{y} \) is longer than the half-life of uranium \(4.47\times10^{9}\text{y} \). The results obtained were generally lower than the normal level at the European regional reference laboratory for radon measurements organized by the IAEA. The radon level (standard level) varied between 65kBq.m\(^{-3}\).h and 397kBq.m\(^{-3}\).h \(^{16}\). The major environmental concerns associated with the radon and thoron concentrations are ranged from \((7160 - 8765) \text{ Bqm}^{-3}\) and from \((740 - 1975) \text{ Bq.m}^{-3}\), respectively \(^{17}\).

The comparison between the seventeen regions was obtained, the results showed low radiation level when compared with the standard level known by the IAEA \(^{18}\). The EPA suggested that the standard level of radon is \(4 \text{ (pCi/L)}\). Also, the U.S. Environmental Protection Agency (EPA) recommends taking action to reduce radon that have a radon level at or above \(4 \text{ (pCi/L)} \) \(^{19}\). The EPA has suggested that immediate intervention is required only if the concentration of Radon (\(^{222}\text{Rn}\)) level is above 190 Bqm\(^{-3}\) for radon, and that below 40 Bqm\(^{-3}\) no intervention. And the human in the safety \(^{20}\) the concentration of radon in all plant samples is less than \(4 \text{ (pCi/L)}\) and 190 Bqm\(^{-3}\).

The comparison of the concentration of radon and thoron in the soils \(^{20}\) with that of radon and thoron in the plants, of present work are presented in the Tables 1, 2. The concentration in plants is less than the concentration in soil because the transfers of uranium and thorium from the soil to the plant is very small. The transfer of radionuclides from the soil to the plant depends on the many factors; the meteorological and geological factors as well as on the physical characteristics (Porosity of Soil, grain-size distribution and moisture content) and chemistry of the soil and absorption the isotopes by the plant from the soil.
### Table 1. Concentration of radon estimation in plant from different locations in Sulaimania governorate

| No. | Location          | \(q^{(222\text{Rn}+220\text{Rn})}\) track/cm² | \(q^{222\text{Rn}}\) track/cm² | Ema. of 222Rn  | Con. of 222Rn Bq/m³ | Con. of 222Rn pCi/L | Con. of 222Rn (Bq/m³) In soil (6) |
|-----|------------------|---------------------------------|-------------------------------|----------------|---------------------|---------------------|---------------------------------|
| 1   | Penjween         | 2023 ± 45                       | 1145±39                       | 1.363          | 54.42               | 1.471               | 131.55                         |
| 2   | Rania            | 3297 ± 57                       | 2031±45                       | 2.417          | 96.68               | 2.613               | 112.88                         |
| 3   | Halabjay-con     | 4035 ± 64                       | 2514±50                       | 2.993          | 119.72              | 3.236               | 154.37                         |
| 4   | Halabjay-taza    | 3113 ± 56                       | 1550±39                       | 1.845          | 73.80               | 1.994               | 125.50                         |
| 5   | Mawat            | 2859 ± 53                       | 1870±43                       | 2.226          | 89.04               | 2.406               | 112.55                         |
| 6   | Dukan            | 2233 ± 47                       | 1288±36                       | 1.539          | 61.32               | 1.657               | 200.43                         |
| 7   | Arbat            | 3417 ± 58                       | 2114±46                       | 2.517          | 100.76              | 2.723               | 77.79                          |
| 8   | Said-Sadq        | 2881 ± 54                       | 1615±40                       | 1.922          | 76.88               | 2.078               | 99.93                          |
| 9   | Chwarta          | 3501 ± 59                       | 2020±45                       | 2.405          | 96.20               | 2.600               | 110.68                         |
| 10  | Qaladza          | 3782 ± 61                       | 1933±44                       | 2.301          | 92.04               | 2.487               | 127.24                         |
| 11  | Sulaimani-Center | 1992 ± 45                      | 1142±34                       | 1.359          | 54.36               | 1.469               | 163.79                         |
| 12  | Takeea           | 3917 ± 63                       | 2256±47                       | 2.686          | 107.44              | 2.904               | 123.34                         |
| 13  | Baniejan         | 3277 ± 57                       | 1856±43                       | 2.205          | 88.20               | 2.384               | 95.89                          |
| 14  | Chamchamal       | 3476 ± 59                       | 1799±42                       | 2.142          | 85.68               | 2.316               | 178.43                         |
| 15  | Bazeean          | 3881 ± 62                       | 2471±50                       | 2.942          | 117.68              | 3.180               | 159.11                         |
| 16  | Khurmal          | 3614 ± 60                       | 2111±46                       | 2.513          | 100.52              | 2.717               | 174.65                         |
| 17  | Alahiy           | 2661 ± 52                       | 1422±38                       | 1.693          | 67.68               | 1.829               | 138.72                         |

### Table 2. Concentration of thoron estimation in plant from different locations in Sulaimania governorate

| No. | Location          | \(q^{(222\text{Rn}+220\text{Rn})}\) track/cm² | \(q^{220\text{Rn}}\) track/cm² | Ema. of 220Rn  | Con. of 220Rn Bq/m³ | Con. Of 220Rn pCi/L | Con. of 220Rn (Bq/m³) in soil(6) |
|-----|------------------|---------------------------------|-------------------------------|----------------|---------------------|---------------------|---------------------------------|
| 1   | Penjween         | 2023 ± 45                       | 878 ± 30                       | 1.045          | 348.33              | 9.414               | 496.97                         |
| 2   | Rania            | 3297 ± 57                       | 1266 ± 35                     | 1.507          | 502.33              | 13.576              | 402.52                         |
| 3   | Halabjay-con     | 4035 ± 64                       | 1521 ± 39                     | 1.811          | 603.66              | 16.315              | 543.71                         |
| 4   | Halabjay-taza    | 3113 ± 56                       | 1563 ± 40                     | 1.861          | 620.33              | 16.765              | 520.89                         |
| 5   | Mawat            | 2859 ± 53                       | 989 ± 31                      | 1.177          | 392.33              | 10.604              | 502.16                         |
| 6   | Dukan            | 2233 ± 47                       | 945 ± 31                      | 1.125          | 375.00              | 10.135              | 750.04                         |
| 7   | Arbat            | 3417 ± 58                       | 1303 ± 36                     | 1.551          | 517.00              | 13.973              | 293.32                         |
| 8   | Said-Sadq        | 2881 ± 54                       | 1266 ± 35                     | 1.507          | 502.33              | 13.576              | 417.67                         |
| 9   | Chwarta          | 3501 ± 59                       | 1481 ± 38                     | 1.763          | 587.66              | 15.883              | 456.72                         |
| 10  | Qaladza          | 3782 ± 61                       | 1849 ± 43                     | 2.201          | 733.66              | 19.828              | 512.19                         |
| 11  | Sulaimani-Center | 1992 ± 45                      | 859 ± 29                      | 1.012          | 337.33              | 9.117               | 665.55                         |
| 12  | Takeea           | 3917 ± 63                       | 1661 ± 41                     | 1.977          | 658.00              | 17.811              | 462.97                         |
| 13  | Baniejan         | 3277 ± 57                       | 1425 ± 38                     | 1.676          | 565.33              | 15.279              | 299.48                         |
| 14  | Chamchamal       | 3476 ± 59                       | 1677 ± 41                     | 1.996          | 665.33              | 17.982              | 479.73                         |
| 15  | Bazeean          | 3881 ± 62                       | 1410 ± 37                     | 1.678          | 559.33              | 15.117              | 319.81                         |
| 16  | Khurmal          | 3614 ± 60                       | 1503 ± 39                     | 1.789          | 59.633              | 16.117              | 363.43                         |
| 17  | Alahiy           | 2661 ± 52                       | 1239 ± 35                     | 1.475          | 491.66              | 13.288              | 338.72                         |
DISCUSSION

The transfer factors of radionuclides from the soil to the plant of radon ranged from minimum value (0.3059) recorded in the location (Dukan) to maximum value (1.2952) recorded in the location (Arbat). While the transfer factors of radionuclides from the soil to the plant of thoron ranged from minimum value (0.4999) recorded in the location (Dukan) to maximum value (1.8877) recorded in the location (Baniejan), respectively. The concentration in both samples is very low, therefore, the plant is normal for eating as a food for the human and human in safe, as shown in Table 3.

Table 3. Transfer factors from soil to plant in radon and thoron

| No. S | Location           | TF of Rn-222 | TF of Rn-220 |
|-------|--------------------|--------------|--------------|
| 1     | Penjween           | 0.41370      | 0.700907     |
| 2     | Rania              | 0.856485     | 1.247963     |
| 3     | Halabjay-con      | 0.775539     | 1.110261     |
| 4     | Halabjay-taza     | 0.588048     | 1.190904     |
| 5     | Mawat              | 0.791115     | 0.781285     |
| 6     | Dukan              | 0.305942     | 0.499973     |
| 7     | Arbat              | 1.295282     | 1.76258      |
| 8     | Said-Sadq         | 0.769339     | 1.202696     |
| 9     | Chwarta            | 0.869172     | 1.286696     |
| 10    | Qaladza            | 0.723357     | 1.432398     |
| 11    | Sulaimani-Center  | 0.331888     | 0.506844     |
| 12    | Takeea             | 0.871088     | 1.421258     |
| 13    | Baniejan           | 0.919804     | 1.887705     |
| 14    | Cham-chamal        | 0.480188     | 1.386884     |
| 15    | Bazeean            | 0.739614     | 1.748945     |
| 16    | Khurmal            | 0.575551     | 1.640839     |
| 17    | Alahiy             | 0.487889     | 1.451523     |
| Average|                   | 0.693764     | 1.250568     |

The annual effective dose equivalent of radium obtained for each sample is shown in Table 4. The average effective dose equivalent of (7.2) μSv.y⁻¹ for all the samples is lower than the normal background value of 1.3 mSv.y⁻¹ given by EPA.

The higher and lower specific activity (S.A) of radon have been found to be 0.909 Bq.Kg⁻¹ in Halabjay-con, and 0.413 Bq.Kg⁻¹ in Sulaimani-center, and the higher and lower specific activity (S.A) of thoron have been found to be 5.576 Bq.Kg⁻¹ in Qaladza, and 2.564 Bq.Kg⁻¹ in Sulaimani-center, respectively, as shown in Tables 4, 5 and 6. The values of radon and thoron WL, mWL and equilibrium factor (F) from plant (vegetables) samples under the study are given in Tables 5, 6. For radon, the higher and lower values of WL, recorded in the locations (Sulaimani-Center) and (Halabjay-Con) are (0.0324) WL and (0.0147) WL respectively, and the higher and lower values of mWL, found in the same two locations are (0.1601) mWL, (0.0726) mWL.

For thoron, the higher and lower values of WL, recorded in the locations (Qaladza) and (Sulaimani-Center) are (0.1963) WL and (0.0912) WL, and the higher and lower values of mWL, recorded in the locations (Qaladza) and (Sulaimani-Center) are (0.9798) mWL, (0.4506) mWL respectively, the standard level of mWL of Radon concentration as suggested by EPA are 50 mWL and 10 mWL respectively. However, it does not call for any intervention since EPA (20) the results obtained in this work is less than this standard level.
### Table 4. Effective dose equivalent of radon estimation in plant from different location in Sulaimania governorate

| No. | Location       | Activity of $^{222}$Rn $\times 10^{-3}$ (Bq) | Specific Activity of $^{222}$Rn (Bq/Kg) | EDE of $^{226}$Ra ($\mu$Sv$^{-1}$) |
|-----|----------------|---------------------------------------------|----------------------------------------|-----------------------------------|
| 1   | Penjween       | 20.68                                       | 0.413                                  | 4.65                              |
| 2   | Rania          | 36.74                                       | 0.729                                  | 8.20                              |
| 3   | Halabjay-con   | 45.49                                       | 0.909                                  | 10.23                             |
| 4   | Halabjay-taza  | 28.04                                       | 0.560                                  | 6.30                              |
| 5   | Mawat          | 33.83                                       | 0.677                                  | 7.62                              |
| 6   | Dukan          | 23.30                                       | 0.466                                  | 5.24                              |
| 7   | Arbat          | 38.29                                       | 0.766                                  | 8.62                              |
| 8   | Said-Sadq      | 29.21                                       | 0.580                                  | 6.52                              |
| 9   | Chwarta        | 36.56                                       | 0.731                                  | 8.22                              |
| 10  | Qaladza        | 34.97                                       | 0.699                                  | 7.86                              |
| 11  | Sulaimani-Center | 20.66                                    | 0.413                                  | 4.65                              |
| 12  | Takeea         | 40.83                                       | 0.817                                  | 9.19                              |
| 13  | Baniejan       | 33.57                                       | 0.670                                  | 7.53                              |
| 14  | Chamchamal     | 32.56                                       | 0.851                                  | 7.32                              |
| 15  | Bazeean        | 44.72                                       | 0.894                                  | 10.10                             |
| 16  | Khurmal        | 38.20                                       | 0.764                                  | 8.59                              |
| 17  | Alahiy         | 25.72                                       | 0.514                                  | 5.78                              |

EDE: Effective Dose Equivalent.

### Table 5. Equilibrium factor of radon estimation in plant from different locations in Sulaimania governorate

| N   | Location         | WL of $^{222}$Rn | mWL of $^{222}$Rn | F(equilibrium factor) of $^{226}$Rn |
|-----|------------------|------------------|-------------------|-------------------------------------|
| 1   | Penjween         | 0.0149           | 0.0728            | 0.9994                              |
| 2   | Rania            | 0.0261           | 0.1287            | 0.9989                              |
| 3   | Halabjay-con     | 0.0324           | 0.1601            | 1.0013                              |
| 4   | Halabjay-taza    | 0.0199           | 0.0983            | 0.9977                              |
| 5   | Mawat            | 0.0241           | 0.1191            | 1.0014                              |
| 6   | Dukan            | 0.0166           | 0.0820            | 1.0016                              |
| 7   | Arbat            | 0.0272           | 0.1344            | 0.9988                              |
| 8   | Said-Sadq        | 0.0208           | 0.1028            | 1.0010                              |
| 9   | Chwarta          | 0.0260           | 0.1285            | 1.0000                              |
| 10  | Qaladza          | 0.0249           | 0.1230            | 1.0009                              |
| 11  | Sulaimani-Center | 0.0147           | 0.0726            | 1.0006                              |
| 12  | Takeea           | 0.0290           | 0.1433            | 0.9987                              |
| 13  | Baniejan         | 0.0278           | 0.1372            | 0.9942                              |
| 14  | Chamchamal       | 0.0232           | 0.1146            | 1.0018                              |
| 15  | Bazeean          | 0.0318           | 0.0318            | 0.9998                              |
| 16  | Khurmal          | 0.0272           | 0.1344            | 1.0012                              |
| 17  | Alahiy           | 0.0183           | 0.0904            | 1.0004                              |

WL: Work Level.
mWL: month Work Level.
Table 6. Equilibrium factor of thoron estimation in plant in different locations in Sulaimania governorate

| N  | Location               | Activity of $^{220}\text{Rn}$ *10$^{-3}$ (Bq) | Specific Activity of $^{220}\text{Rn}$ (Bq/Kg) | WL of $^{220}\text{Rn}$ | mWL of $^{220}\text{Rn}$ | F (equilibrium factor) of $^{220}\text{Rn}$ |
|----|------------------------|-----------------------------------------------|-----------------------------------------------|--------------------------|---------------------------|------------------------------------------|
| 1  | Penjween               | 132.37                                        | 2.647                                          | 0.0941                   | 0.4649                    | 0.9995                                    |
| 2  | Rania                  | 190.89                                        | 3.818                                          | 0.1348                   | 0.6661                    | 0.9928                                    |
| 3  | Halabjay-con          | 229.39                                        | 4.588                                          | 0.1632                   | 0.8064                    | 1.0003                                    |
| 4  | Halabjay-taza         | 235.72                                        | 4.714                                          | 0.1677                   | 0.8286                    | 1.0025                                    |
| 5  | Mawat                  | 149.08                                        | 2.982                                          | 0.1060                   | 0.5237                    | 1.0000                                    |
| 6  | Dukan                  | 142.50                                        | 2.850                                          | 0.1014                   | 0.5010                    | 1.0005                                    |
| 7  | Arbat                  | 196.46                                        | 3.929                                          | 0.1397                   | 0.6903                    | 0.9997                                    |
| 8  | Said-Sadq             | 190.88                                        | 3.818                                          | 0.1358                   | 0.6710                    | 1.0026                                    |
| 9  | Chwarta                | 223.31                                        | 4.466                                          | 0.1588                   | 0.7847                    | 0.9998                                    |
| 10 | Qaladza                | 278.79                                        | 5.576                                          | 0.1963                   | 0.9798                    | 1.0000                                    |
| 11 | Sulaimani-Center       | 128.18                                        | 2.564                                          | 0.0912                   | 0.4506                    | 1.0003                                    |
| 12 | Takeea                 | 250.42                                        | 5.008                                          | 0.1781                   | 0.8800                    | 1.0039                                    |
| 13 | Baniejan               | 214.82                                        | 4.296                                          | 0.1528                   | 0.7550                    | 1.0000                                    |
| 14 | Cham-chamal           | 252.82                                        | 5.056                                          | 0.1798                   | 0.8884                    | 0.9992                                    |
| 15 | Bazeean                | 212.54                                        | 4.251                                          | 0.1517                   | 0.7496                    | 1.0035                                    |
| 16 | Khurmal                | 226.60                                        | 4.532                                          | 0.1612                   | 0.7965                    | 1.0002                                    |
| 17 | Alahiy                 | 186.83                                        | 3.737                                          | 0.1329                   | 0.6566                    | 1.0001                                    |

Figs 1, 2 show’s the relationship between track densities and radon concentrations. The straight line represents fit of the data. When the track density increases the concentration also increase, therefore, the relation is linearity and the track density is related strongly to the concentration.

![Figure 1](image.png)

**Figure 1.** The relation between the track density per unit time and radon concentration
Figure 2. The relation between the track density per unit time and thoron concentration

Figure 3 shows the relationship between the track density of radon and the track density of thoron with the samples. The number of the track density of radon is more than the number of the track density of thoron because the half-life of radon (3.82 days) is longer than the half-life of thoron (55.6 seconds) (thoron decay before radon). It is important to understand that EPA’s recommended action level of 4.0 pCi/l of radon is a technology driven standard that originated in the mid-1980s, -0- pCi/l.

Figure 3. The relation between the track density of radon and thoron in the all location under study

CONCLUSIONS

This study gave the the information about the levels of harmful of radon in environment and to understand the behavior of radiation. This study showed that the maximum concentration of radon in the samples were lower than the global permissible limit of exposure to radon (200 Bq.m⁻³), therefore, the vegetable samples for eating were considered to be safe for inhabitants. It was suggested that the values reported in the current study can be considered as within the “normal level” of radiation, therefore, the
human in safety. Radon concentrations are of interest because this gives very important information to monitoring the environmental contamination.

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