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

Medición de la concentración de radón (^{222}Rn) y torón (^{220}Rn) en diferentes plantas (vegetales) ubicadas en la ciudad de Sulaimania empleando el detector CR-39

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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) mSv.y^{-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.

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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 -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 C12H18O7(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 α-particles from ^{222}Rn and ^{222}Rn daughter nuclei. When α-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).

MATERIALS AND METHODS

Seventeen different kinds of plants (vegetables) samples were collected from the surface of the earth from different locations of Sulaimania governorate in the Kurdistan region under study. The samples were cleaned, rocks the green parts of the plant and dried in the oven at 105 ^{o}C(1) for six days in order to get rid of humidity in them. The samples were grind and pulverized several times and mixed very well by a mixer and sieved through a fine mesh (~ 0.5mm) in order to obtain a homogenous grain size distribution powder. Each sample separated in a plastic can, labeled according to the location and sealed well and stored for about five weeks prior to reach secular equilibrium for further measurements. Most of the experimental work had been done during the summer season.

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 α-particle from both radon and thoron during the time of exposure in the long-tube, with (2cm× 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) ºC with water bath for 5.25 hours. The normality of the etchant was calculated using the relation (7).

$$\mathbf{C = (W / Weq) \times 1000 / V} \qquad (1)$$

C : is the normality or concentration of solution.W: is the weight (gm) of NaOH solution. Weq: is the equivalent 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 (ρ) = 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 (2μCi and 8μCi) respectively. The emanation rate of radon and thoron from the samples can be calculating 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.

$$C\ (Bq.m^{-3}) = (\rho_{Rn} - BG) / (KF_{Rn} * T_{exposure}) \quad (3)$$

Where C (Bq.m^{-3}) is concentration of (radon, thoron), ρ_{Rn} is the track density of (radon, thoron), BG is background, and KF_{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].

$$TF = C_{Plant} / C_{Soil} \quad (4)$$

Where C_{Soil} is the concentration of soil and C_{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.

$$A\ (Bq) = C_w\ (Bq/m^3) * V(m^3) \quad (5)$$

$$S.A\ (Bq/Kg) = A(Bq) / M(Kg) \quad (6)$$

V(m^3) is the volume of the tube, and M(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.

$$EDE = S.A * Ip * DCF \quad (7)$$

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;

$$\mathbf{F = WL \times 3700 / C_{Rn}} \quad (8)$$

RESULTS

In this study the tracks registered by two detectors, one at 10 cm from the sample and the other is at 30cm 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 ($\rho_{\mathbf{Thoron}} = \rho_{lower} - \rho_{upper}$). However, it has been mentioned before in [(7)]. The calibration for radon (K_{Radon} = 0.025 (track/cm^2)/($Bq.m^{-3}.h$) and for thoron (K_{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 λ^{-1}

The higher and lower radon concentration found in Halabjay-con, and in Sulaimani-center, are (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 found in Qaladza and in Sulaimani-center, are (733.66 $Bq.m^{-3}$, 19.828 pCi/L), (227.33 $Bq.m^{-3}$, 9.117 pCi/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 1.39×10^{10}y is longer than the half-life of uranium 4.47×10^{9}y [(15)]. 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) Bqm^{-3} and from (740 - 1975) $Bq.m^{-3}$, 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(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(pCi/L) [(19)]. The EPA has suggested that immediate intervention is required only if the concentration of Radon (^{222}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 (pCi/L) and 190 Bqm^{-3}.

The comparison of the concentration of radon and thoron in the soils [(6)] 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	ϱ(^{222}Rn+ ^{220}Rn) track/cm^2	ϱ^{222}Rn track /cm^2	Ema. of ^{222}Rn	Con. of ^{222}Rn Bq/m^3	Con. of ^{222}Rn pCi/L	Con. of ^{222}Rn (Bq/m^3) 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	ϱ(^{222}Rn+ ^{220}Rn) track/cm^2	P^{220}Rn track /cm^2	Ema. of ^{220}Rn	Con. of ^{220}Rn Bq/m^3	Con. Of ^{220}Rn pCi/L	Con. of ^{220}Rn (Bq/ m^3) 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 6.33	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 minmum 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 minmum value (0.4999) were recorded in the location (Dukan) to maximum value (1.8877) was recorded in the location (Baniejan), respectively. The concentration in both samples 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) $\mu Sv.y^{-1}$ for all the samples is lower than the normal background value of 1.3 $mSv.y^{-1}$ given by EPA[5].

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 WL, 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 differen location in Sulaimania governorate

No.	Location	Activity of ^{222}Rn $*10^{-3}$(Bq)	Specific Activity of ^{222}Rn (Bq/Kg)	EDE. of ^{226}Ra (μSvy^{-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 ^{222}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}Rn $*10^{-3}$ (Bq)	Specific Activity of ^{220}Rn (Bq/Kg)	WL of ^{220}Rn	mWL of ^{220}Rn	F (equilibrium factor) of ^{220}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

Fig.s 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.

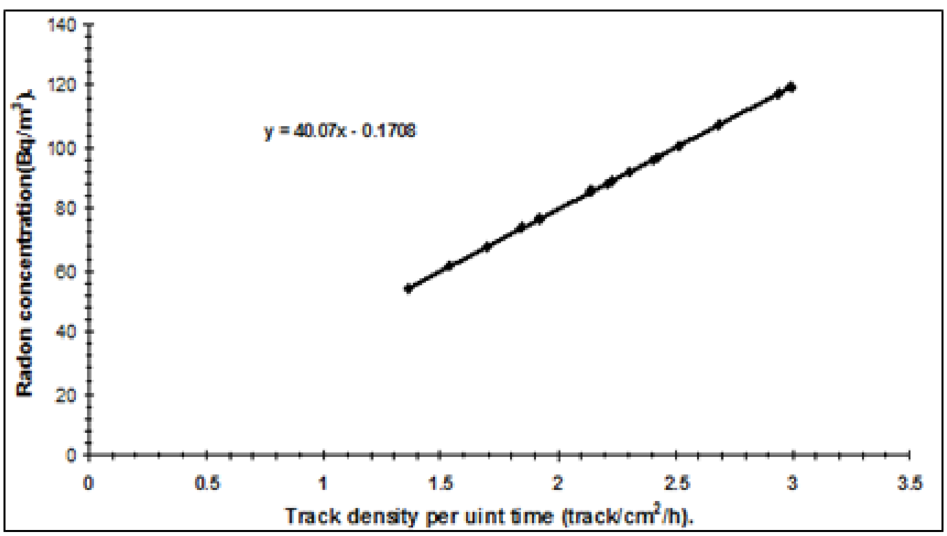

Figure 1. The relation between the track density per unit time and radon concentration

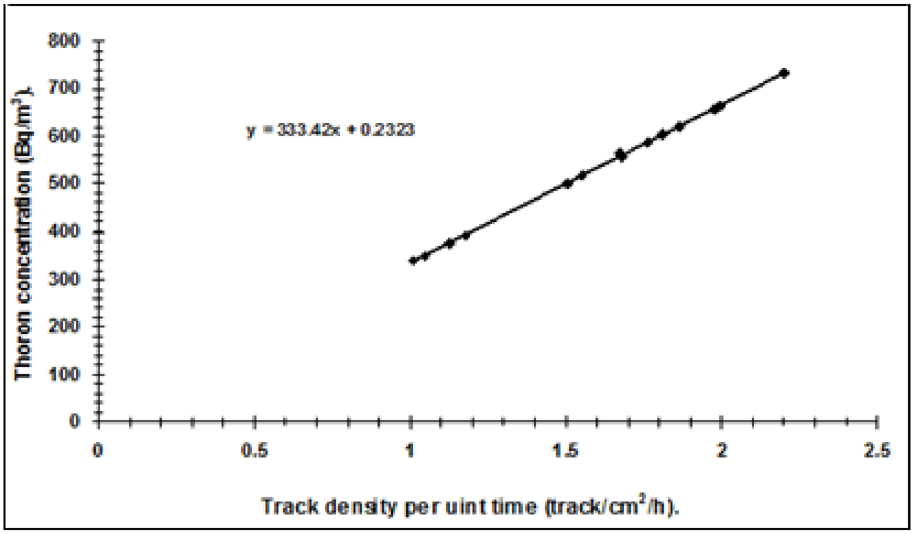

Figure 2. The relation between the track density per unit time and thoron concentration

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 (55.6seconds) (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, -(4) pCi/l.

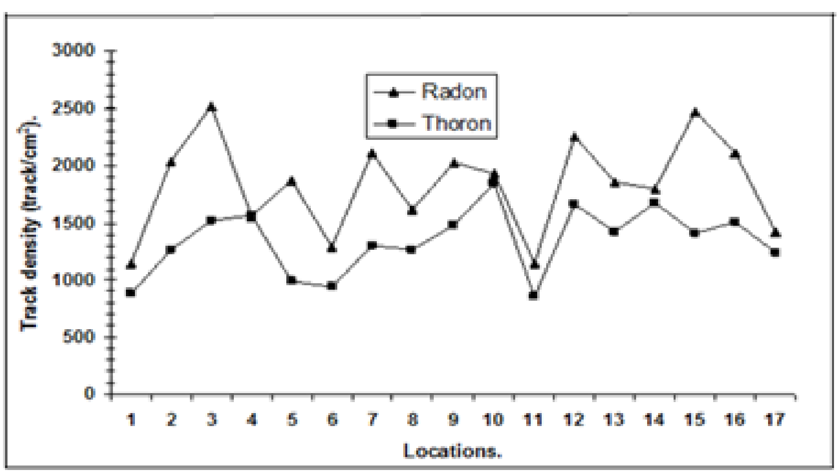

Figure 3. The relation between the track density of radon and thoron in the all location under study

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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