Iraqi Journal of Physics, 2015 *Vol.13, No.26, PP. 160-170*

Estimating excess of lung risk factor of radon gas for some houses in Al-Fallujah city

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Abstract

Instruments for the measurements of radon, thoron and its decay products in air are based mostly on the detection of alpha particles. The health hazards of radon on general public are well known. In order to understand the level and distribution of ^{222}Rn concentrations indoor in Al-Fallujah City; new technique was used, this technique was three radon–thoron mixed field dosimeters is made up of a twin chamber cylindrical system and three LR-115 type II detectors were employed. The aim of this work was to measurement radon gas using SSNTD technique door in in Al-Fallujah City, and estimation of excess in cancer due to increment in radon gas. Results for samples which are collected from January to April 2013 show that the ^{222}Rn concentration varies from 52.33 to 108.70 Bq.m^{-3} with an average of 84.64 Bq.m^{-3}, according to EPA and ICRP, the average indoor radon level should be 148 Bq/m^3 and 300 Bq/m^3, respectively, whereas approximately 15 Bq/m^3 (ranging from 1 Bq/m^3 to 100 Bq/m^3 of radon concentration is normally found in outside air. Also the values of annual effective dose and excess lung cancer per million people per year (ELC) have also been calculated and found to vary from 0.941 to 2.350 mSv.y^{-1} with an overall average of 1.581 mSv.y^{-1} and, 565 to 1410 with an overall average 948, respectively.

Key words
Radon,
Radiation Hazard,
Al-Fallujah City.

Article info.
Received: Nov. 2014
Accepted: Dec. 2014
Published: Apr. 2015

تخمين عامل زيادة خطر سرطان الرئة بسبب غاز الرادون في بعض مساكن مدينة الفلوجة

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الخلاصة

تعتمد أجهزة قياس غازي الرادون والثورون ونواتج اضمحلالها في الهواء على الكشف عن جسيمات ألفا المنبعثة منهما. من أجل دراسة مستوى تركيز وتوزيع Rn-222 في بيوت مغلقة في مدينة الفلوجة، تم استخدام تقنية جديدة، وهذه التقنية تكشف عن الرادون-الثورون في مقياس جرع خاص صنع على شكل اسطوانة مقسومة الى جزئين ونستخدم ثلاث كواشف اثر نوع LR-115، ان الهدف من هذا العمل هو قياس غاز الرادون باستخدام تقنية SSNTD في مدينة الفلوجة، وتقدير الزيادة في الاصابة بالسرطان بزيادة تركيز غاز الرادون. وتبين نتائج النماذج التي جمعت في الفترة من شهر كانون الثاني الى شهر نيسان 2013 أن تركيز Rn-222 يتباين بين 52.33-Bq.m^{-3} 108.70 وبمعدل 84.64Bq.m^{-3}، وفقا لوكالة حماية البيئة واللجنة الدولية، يجب أن يكون متوسط مستوى الرادون في الأماكن المغلقة 148 بيكريل / m^3 و 300 بيكريل / m^3 ، على التوالي، في حين أن تركيزه في الهواء الخارجي حوالي 15 بيكريل / m^3 (تتراوح من 1بيكريل / m^3 إلى 100 بيكريل/ m^3)، كما أن قيم الجرعة الفعالة السنوية والزيادة بالاصابة بسرطان الرئة لكل مليون شخص سنويا (ELC) وجدت تتباين بين 0.941- 2.350mSv.y^{-1} وبمعدل 1.581 mSv.y^{-1} و 565-1410 وبمعدل 948 على التوالي.

Introduction

Radon is a form of ionizing radiation; therefore exposure to it is the second leading cause of lung cancer after smoking. Radon is an odorless, tasteless and invisible gas produced by the decay of naturally occurring uranium in soil and water. Lung cancer is the only known effect on human health from exposure to radon in air. Radon is produced by the decay of naturally occurring uranium in soil and water, and is found in outdoor air and in the indoor air of buildings of all kinds[1].

Uranium is found in most soils and in granite as its nucleus decays to form stable lead, a process taking many, many years; it changes from one radioactive element to another in a sequence known as the uranium decay cycle. Partway through this cycle, the element radium becomes radon which as a gas moves up through the soil to atmosphere[2].

Radon, Rn-222 ($T_{1/2}$= 3.82 days), is a daughter product of ^{226}Ra, which in turn is derived from the longer-lived antecedent, ^{238}U. Thoron, Rn-220 ($T_{1/2}$= 56 seconds) is a daughter of ^{232}Th, which is present in larger amount in the earth's crust than radon. Because of thoron's short half-life, it is essentially all gone before it leaves the ground, and is of no significant radiobiologic consequence. These radionuclide series are present in slowly decreasing amounts in the environment (geologic time scale), due to radioactive decay of their parents, which has been known and understood since the end of the 20th century.

Widely varying radon levels exist in different regions related to geological circumstances. New concern regarding radon exposures is traceable to the discovery that there are more houses with high radon levels than previously realized and to the use of a new method of expressing and summing doses from partial body exposures, such as the lung dose from radon daughters. This method of expressing dose was promulgated by the ICRP and the NCRP based on defined weighting factors which make it possible to sum partial body doses and thereby estimate a total body dose which would have a quantifiable risk. This quantity is defined as the Effective Dose (ED). Thus, the previously estimated partial body environmental radon dose to the tracheobronchial epithelium (TBE) (2500 mrem/year) was not included in whole body dose calculations because that exposure was limited to a small fraction of the body[3].

There are many articles studied the concentration of radon in several countries such as:

- In 2010, Abdullah and Hussein measured indoor radon concentration levels in the right area of Shirkatt district (Iraq) using SSNTDs. The radon concentrations ranged between 50.38 and 212.35 Bq.m^{-3} with an average value of 103.98 Bq.m^{-3} [4].
- In 2010, Karim estimated radon concentrations in Baghdad Governorate, Iraq (air dust, water and soil) utilizing CR-39 detector. He was found that the concentrations of radon were 3.135 ppm, 0.0859 ppm and 3.38 ppm in air dust, water and soil, respectively [5].
- In 2010, Atia et al. measured radon concentrations in Missan Governorate using CR-39 as SSNTD. They were found that the radon concentrations ranged from 131.5 to 281.139 Bq.m^{-3} [6].
- In 2011, Hassan measured radon concentrations in dwellings in Al – Hamdaniya city – Nineveh Governorate / Iraq. The measurements were performed in 25 dwellings utilizing CR-39 as SSNTD. Radon concentrations ranged from 18 to 60 Bq.m^{-3} with an average value of 37.4 Bq.m^{-3} [7].

In 2003, a new war against Iraq brought an even greater load of depleted uranium to Iraq. In November 2004, the city of Fallujah

was targeted by heavy attacks, by the latest occasion of which the city was completely destroyed. Exceptional increases in birth defects and cancer among the survivors led to the expectation that depleted uranium had been used in the heavy fighting between the Americans and the locals.
The aim of this work is to measure radon gas using SSNTD technique and estimation of excess in cancer due to increment in radon gas.

The study area
Al-Fallujah is a city in the Iraqi province of Al-Anbar, located at 69 kilometers west of Baghdad on the Euphrates. Al-Fallujah city grew from a small town in 1947 to a population of 326,471 within Iraq, it is known as the "city of mosques" for the more than 200 mosques found in the city and surrounding villages. Fallujah lies in a strategic position at a junction between the Iraqi Capital; Baghdad, and Al–Anbar Governorate. This city stands at an elevation of around 40 meters above sea level.
The Twin cup technique was applied in order to prepare the radon dosimeters. These dosimeters were settled in 16 different locations in Al-Fallujah city. In order to measure the outdoor radon concentrations, the locations of the dosimeters were chosen to cover approximately the hall area of Al-Fallujah. However, Table 1 shows the locations of the radon dosimeters.

Table 1 : The locations of the radon dosimeters

Dosimeter Location	*Details*
A1	Neighborhood Republic
A2	District teachers
A3	Near the new distribution
A4	Near the mosque JlbnAbiTalib
A5	Military district (near the Mosque Hassan)
A6	Mosque near the senders
A7	Neighborhood police
A8	Mosque near Al-Fayad
A9	The second district Aljughaifi
A10	Near the mosque Alsdeq
A11	Near 60th Street
A12	Nazzal neighborhood
A13	Control of the Golan Heights, near the church
A14	Military Ocean neighborhood
A15	District engineers
A16	Green neighborhood

The Theory Part

1.Units of measurement for radon levels

Almost all measurements of radon levels in the home or outdoors are expressed as the concentration of radon in units of picocuries per liter of air (pCi/liter), or in SI units as Becquerel per cubic meter (Bq/m^3), but radon daughters are expressed in working levels (WL). A working level month (WLM) is defined as 170 hours (2l.25 working days/month x 8 hrs/day) in a work place at one WL. Thus, a 12 hour a day exposure in the home at one WL, corresponds to approximately 26 working level months per year i.e. 2.1 X the occupational exposure, assuming equal radon levels at home and in the work place. Exposure rate is typically given in working level months per year (WLM/year) [8].The WL unit was developed for use in radon occupational exposure assessment since often there was incomplete information on the degree of equilibrium with daughter products. It is the dose delivered in one liter of air that results in the emission of 1.3 x 10^5 MeV of potential alpha energy. The amount of time spent in the mine or in the home determines the number of WLM associated with a particular exposure level, but because most people spend more time at home than at work, the WLM could be higher than from a comparable mine radon daughter concentration. Typical outdoor levels in the U.S.A. are given by NCRP report No. 78 [9] as 0.2 pCi/Liter.

The correspondence between WLs and radon concentration in air in pCi/liter depends on the extent to which radon daughters (which impart dose to the tracheobronchial epithelium dose, "TBE") are in equilibrium with the parent radon. At complete equilibrium, one pCi/liter results in an exposure equal to 0.01 working levels. The assumption is generally made that inside buildings the radon decay product/radon equilibrium is 50%. Thus, inside buildings, 1 pCi/liter = 0.005 WL, or 1 WL= 200 pCi/Liter [8].

2. Radiation hazard

Radiation effects comprise of (1) deterministic effects that occur with certainty after doses high enough to cause major cell killing and (2) stochastic effects that are considered to occur more or less in proportion to the dose at all dose levels. Table 2 shows average dose received due to different radiation sources[10].

Table 2: Average annual effective dose per caput.

1	*Source Dose*	$mSv.y^{-1}$
2	Natural background	**2.4**
3	Diagnostic Medicine	**0.4**
4	Atmospheric weapon testing	**0.005**
5	Chernobyl accident	**0.001**
6	Nuclear fuel cycle	**0.0001**
7	Occupational Exposure	**0.001**

Out of 98% of the average radiation dose received by human beings is from natural sources, about 52% is due to the inhalation of radon, thoron and their progenies resent in the dwellings as mentioned by UNSCEAR. The International agency for Research on Cancer (IARC) has recognized radon as a class A carcinogen and as such it is considered to have no minimum acceptable dosage threshold.

3. Equilibrium factor

The short-lived decay products of radon gas are assumed to achieve a state of radioactive equilibrium with their parent in open air, with an effective half-life of about 30 min. If one considers only radioactive disintegration, the state of equilibrium generally varies as a function of the mean age of the radon atoms. Atmospheric processes such as turbulent mixing or wet and dry deposition however results in a state of disequilibrium between the activity concentration of radon gas in air and its decay products associated with the aerosols. The state of equilibrium can then be described by the equilibrium factor, F, i.e. the ratio of the equilibrium equivalent concentration (EEC) to the radon activity concentration:

$F= EEC / C_{Rn}$ (1)

$EEC = F\times C_{Rn}$ (2)

Knowledge of the amount of the short-lived radon progenies in air is necessary to obtain: (1) equilibrium factor (F) and (2) the unattached fraction (fp) of radon progeny. The fraction of indoor radon progeny attached to airborne particles is highly dependent on particle concentration [11]. The particle concentration varies between 10^3 particles/cm^3 and 10^6 particles/cm^3 depending upon the aerosols sources and human activities indoors and outdoors.

The lungs dose due to the unattached radon decay products is much greater than the dose due to the radon progeny attached to the aerosol particles [12].

Unattached fraction can be measured directly or can be calculated from the concentration measurement aerosols. The fp values vary from 0.005 and 0.2 and depend on the concentration number of the aerosols. Freshly generated ^{218}Po ions are mostly positively charged (88%) and react rapidly with trace gases and vapors in air and become small particles called clusters or "unattached" decay products with a size spectrum between 0.5 and 3 nm diameters. Neutralization of the unattached ^{218}Po ions can be described by three processes: Recombination with small air ions, electron scavenging by OH radicals formed by radiolysis of water vapor and charge transfer by molecules of lower ionization potential [13].

EPA relates radon levels to the radon decay product levels by assuming that 40% of the radon decay products produced remain in the air for inhalation. However, equilibrium factor can vary between 0.1-0.9.

4. Lung cancer risk

Lung cancer risk is defined as the excess deaths per million persons per year (MPY) due to lung cancer per unit exposure to radon and its short lived daughters. A risk coefficient, defined as the number of lung cancer cases per MPY per working level month (WLM), is determined from the epidemiological data of the occupationally exposed mine workers.

The excess lung cancer risk per MPY was estimated by using the following equation[14]:

Excess Cancer Risk = Equilibrium factor × Risk factor × O × WLM (3)

The UNSCEAR committee suggests the equilibrium factor 0.4 and occupancy factor (O) 0.8 for the indoor environment. Where WLM can be calculated using the following equation:

$WLM = WL \times (8760/ 170)$

Experimental work

The radon–thoron mixed field dosimeter employed for this work measurements is made up of a twin chamber cylindrical system (as mentioned in the previous subsection) using 12 µm thick, LR-115 type II, cellulose nitrate based SSNTDs manufactured by Kodak Pathe, France.

The dosimeter is schematically shown in Fig.1. Each chamber has a length of 4.1 cm and a radius of 3.1 cm. The SSNTD1 (LR-115 type II) placed in compartment M measures radon alone which diffuses into it from the ambient air through a semi-permeable membrane (e.g. cellulose nitrate, which is used here) of 25µm thickness having diffusion coefficient in the range of 10^{-8}–10^{-7}cm^2 s^{-1}. It allows the buildup of about 90% of the radon gas in the compartment and suppresses thoron gas concentration by more than 99%. The mean time for radon to reach the steady-state concentration inside the cup is about 4.5h. On the other hand, the glass fiber filters paper of thickness 0.56 mm in the compartment F allows both radon and thoron gases to diffuse in and hence the tracks on SSNTD2 placed in this chamber are related to the concentrations of both the gases. The SSNTD exposed in the bare mode (placed on the outer surface of the dosimeter) registers alpha tracks attributable to both the gases and their alpha-emitting progeny, namely ^{218}Po, ^{216}Po, ^{214}Po and ^{212}Po. The prepared dosimeters are placed in different locations at Al–Fallujah city.

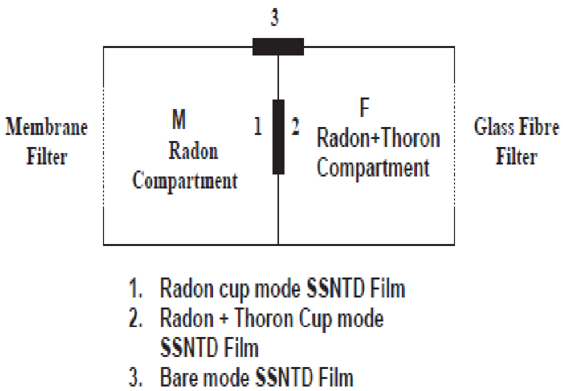

Fig 1: Twin cup radon–thoron dosimeter.

During the exposure time, α-particles emitted by the radon and thoron radionuclides and their progeny have bombarded the SSNTD films. After the irradiation, the exposed films were etched in a NaOH solution with optimum conditions (2.5N at 70°C for 60 minutes for LR-115 II films). After these chemical treatments the track densities on the LR-115II SSNTD were determined by an optical microscope.

To estimate the radon, thoron and their progeny concentrations, the standard calibration method was used. The details of standard calibration methods, which used for Twin cup dosimeter, are described and the concentration of radon and thoron gases were calculated in terms of ($Bq.m^{-3}$) using the following expression [15].

$$C_{Rn} = \frac{tracks}{T\ast k} \tag{4}$$

where C_{Rn} is the radon or thoron or their progeny concentration, $tracks$ is the tracks registered on SSNTD films, T is the exposure time (in this work, 45 days were used), and k is the calibration factor, which have the following values for the three films;[16]

- **k** for radon measurements only (compartment M) is = 0.023 ± 0.004 $tracks.cm^{-2}d^{-1}/Bq.m^{-3}$.
- **k** for radon and thoron measurements (compartment F) is = 0.018 ± 0.002 $tracks.cm^{-2}d^{-1}/Bq.m^{-3}$.
- **k** for radon and thoron and their progeny measurements (for bare mode) is = 0.020 ± 0.002 $tracks.cm^{-2}d^{-1} / Bq.m^{-3}$[16].

Results and discussion

The overall results, which contain the radon concentration, the equilibrium equivalent radon concentration, working level month, annual effective dose, and excess lung cancer per million person per year (ELC), of radon, thoron, and radon's progeny illustrated in Tables 3-5.

It is clear from Table 3 that the values of radon gas levels in the districts of Al-Fallujah city varied from 52.33 to 108.70 $Bq.m^{-3}$ with an overall average of 84.64 $Bq.m^{-3}$, and 0.291 to 0.605 for WLM with an overall average of 0.471, respectively. The values of annual effective dose and ELC have been found to vary from 1.320 to 2.742 $mSv.y^{-1}$ with an overall average of 2.135 $mSv.y^{-1}$, and 792.22 to 1645.38 with an overall average of 1281.26, respectively. Fig.2 shows the histogram of the radon concentration at the measured location, while Fig.3illustrates the WLM as a function of radon gas. The annual effective dose and ECL was plotted against radon concentration

and nice fitting equations were suggested, as shown in Fig. 4.
It is evident from Table3 that there is a large variation in the values of concentration of radon. This is due to the reason that there was a wide variation in the construction of the houses in Al-Fallujah city. There are houses made of clay bricks and plastered without any white-wash having higher radon levels. The lower values of radon and its progeny have been observed in the houses which were plastered and painted with good quality distemper and adequately ventilated. It is also seen from Table 3 that all investigated locations have radon concentration below the action level 200 Bq.m^{-3}recommended by ICRP [17].

Table 3: The overall results of radon gas only.

Sample's Code	***Radon Concentration (Bq/m^3)***	***The equilibrium equivalent ^{222}Rn concentration (C_{EEC})***	***Working Level Month (WLM)***	***Annual Effective Dose E_{ff} (mSv/y)***	***Excess Lung Cancer per Million Persons per Year*** (ELC)
A1B	67.10	26.84	0.373	1.693	1015.66
A2B	77.83	31.13	0.433	1.964	1178.17
A3B	77.83	31.13	0.433	1.964	1178.17
A4B	92.59	37.04	0.515	2.336	1401.62
A5B	81.86	32.74	0.456	2.065	1239.11
A6B	52.33	20.93	0.291	1.320	792.22
A7B	85.88	34.35	0.478	2.167	1300.05
A8B	85.88	34.35	0.478	2.167	1300.05
A9B	108.70	43.48	0.605	2.742	1645.38
A10B	73.81	29.52	0.411	1.862	1117.23
A11B	104.67	41.87	0.583	2.641	1584.44
A12B	95.28	38.11	0.530	2.404	1442.24
A13B	89.91	35.96	0.500	2.268	1360.99
A14B	81.86	32.74	0.456	2.065	1239.11
A15B	92.19	36.88	0.513	2.326	1395.52
A16B	86.55	34.62	0.482	2.184	1310.21

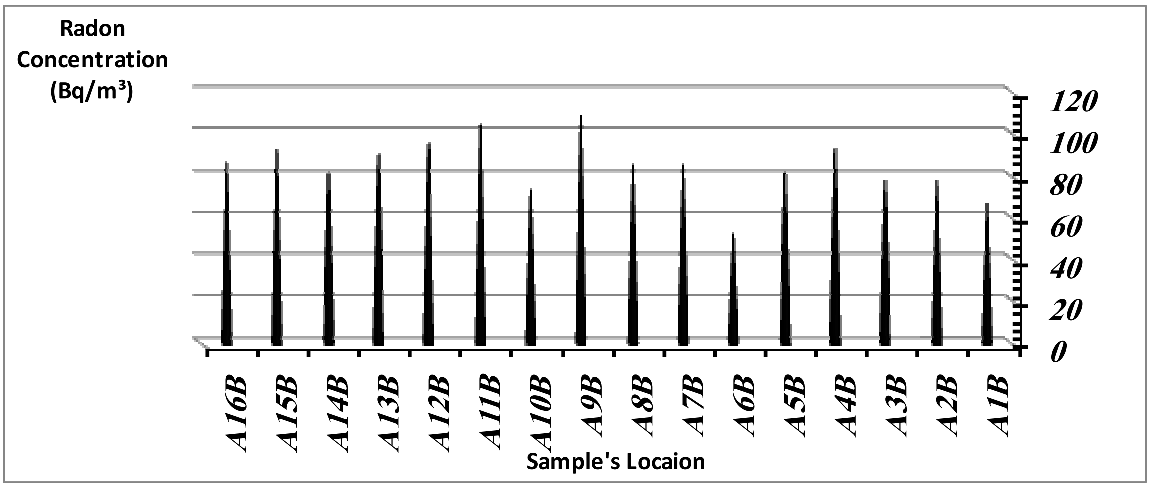

Fig. 2: Radon concentration at measured location.

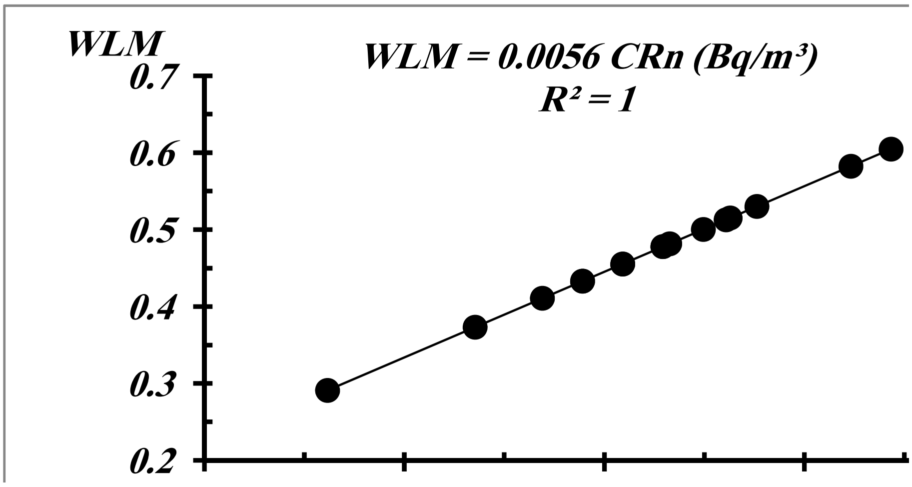

Fig. 3: Monthly working level as a function radon concentration

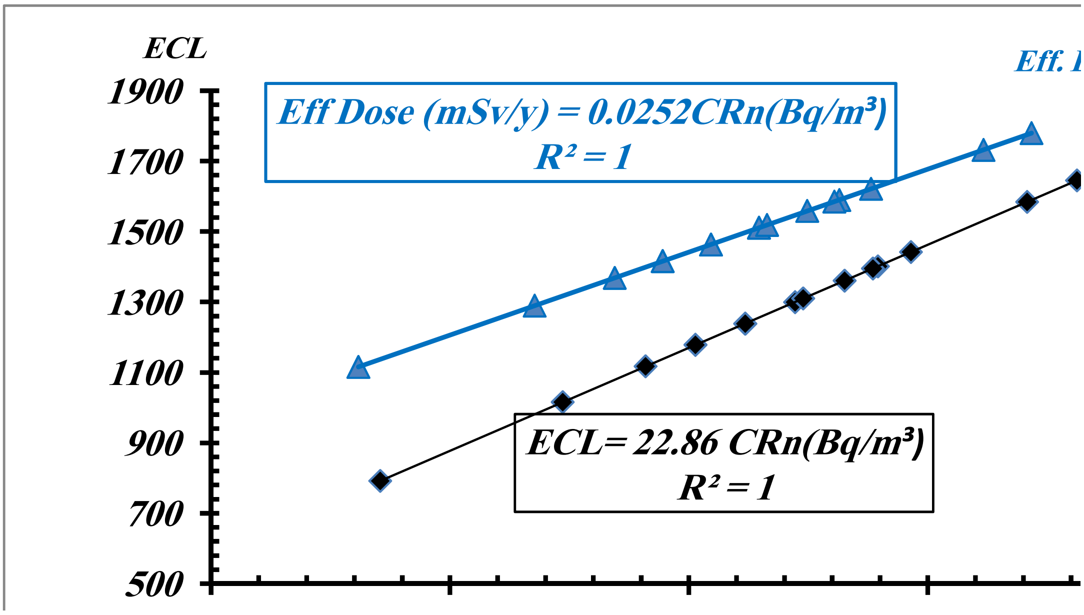

Fig. 4: The black line represents Excess Lung Cancer per Million Persons per Year (ELC) as a function of radon concentration while the blue line represents the annual effective dose as a function of radon concentration.

For thoron gas only, the results illustrated in Table 4, which showed that the thoron concentration varied from 29.76 to 60.46 Bq.m^{-3} with an overall average of 40.04 Bq.m^{-3}, and 0.166 to 0.336 for WLM with an overall average of 0.223. The values of annual effective dose and ECL have been found to vary from 0.751 to 1.525 mSv.y^{-1} with an overall average of 1.01 mSv.y^{-1} and from 451 to 915 with an overall average of 606, respectively.

The concentration of radon progeny, which was found for 16 important districts in Al-Fallujah, was illustrated in Table 5. It was varied from 37.31 to 93.13 Bq.m^{-3} with an overall average of 62.65 Bq.m^{-3}, whereas WLM varied from 0.208 to 0.518 with an overall average of 0.349. The values of annual effective dose and ECL have also

been calculated and found to vary from 0.941 to 2.350 mSv.y^{-1} with an overall average of 1.581 mSv.y^{-1} and, 565 to 1410 with an overall average 948, respectively.
However, Fig. 6 shows the radon, thoron, and radon progeny concentrations for the measured locations. It is clear from this figure that radon concentration larger than radon progeny which in turn larger than thoron concentration. These values reflect the increase of radium contain in the Al-Fallujah environment (espial in soil) comparing with thorium contain.

Conclusions

1.The^{222}Rn concentration varies from 52.33 to 108.70 Bq.m^{-3} with an average of 84.64 Bq.m^{-3}, according to EPA and ICRP, the average indoor radonlevel should be 148 Bq/m^3 and 300 Bq/m^3, respectively, whereas approximately 15 Bq/m^3 (ranging from1Bq/m^3 to 100 Bq/m^3 of radon concentration is normally found in outside air [18].

2.The values of annual effective dose and ECL have also been calculated and found to vary from 0.941 to 2.350 mSv.y^{-1} with an overall average of 1.581 mSv.y^{-1} and, 565 to 1410 with an overall average 948, respectively, where ECL variation is from 16-114 and 26-62 per million per year if UNSCEAR and ICRP limits are applied respectively[14].

Table 4: The overall results of thoron gas.

Sample's Code	*Thoron Concentration (Bq/m^3)*	*The equilibrium equivalent ^{222}Rn concentration (C_{EEC})*	*Monthly Working Level (WLM)*	*Annual Effective Dose E_{ff} (mSv/y)*	*Excess Lung Cancer per Million Persons per Year*
A1A	58.76	23.50	0.327	1.482	889
A2A	33.62	13.45	0.187	0.848	509
A3A	41.17	16.47	0.229	1.039	623
A4A	41.15	16.46	0.229	1.038	623
A5A	60.46	24.18	0.336	1.525	915
A6A	30.31	12.13	0.169	0.765	459
A7A	51.63	20.65	0.287	1.303	782
A8A	44.43	17.77	0.247	1.121	673
A9A	38.77	15.51	0.216	0.978	587
A10A	29.76	11.90	0.166	0.751	451
A11A	37.65	15.06	0.210	0.950	570
A12A	31.61	12.64	0.176	0.797	478
A13A	33.55	13.42	0.187	0.846	508
A14A	31.31	12.52	0.174	0.790	474
A15A	39.15	15.66	0.218	0.988	593
A16A	37.25	14.90	0.207	0.940	564

Table 5: The overall results of radon's progeny only.

Sample's Code	Radon's Progeny Concentration (Bq/m^3)	The equilibrium equivalent ^{222}Rn concentration (C_{EEC})	Monthly Working Level (WLM)	Annual Effective Dose E_{ff} (mSv/y)	Excess Lung Cancer per Million Persons per Year
A1C	68.71	27.48	0.382	1.733	1040
A2C	61.06	24.42	0.340	1.540	924
A3C	76.49	30.60	0.426	1.930	1158
A4C	77.78	31.11	0.433	1.962	1177
A5C	83.27	33.31	0.463	2.101	1260
A6C	64.95	25.98	0.361	1.639	983
A7C	93.13	37.25	0.518	2.350	1410
A8C	66.89	26.76	0.372	1.688	1013
A9C	51.03	20.41	0.284	1.287	772
A10C	37.31	14.92	0.208	0.941	565
A11C	40.39	16.16	0.225	1.019	611
A12C	54.41	21.77	0.303	1.373	824
A13C	44.97	17.99	0.250	1.134	681
A14C	58.57	23.43	0.326	1.478	887
A15C	63.98	25.59	0.356	1.614	969
A16C	59.43	23.77	0.331	1.499	900

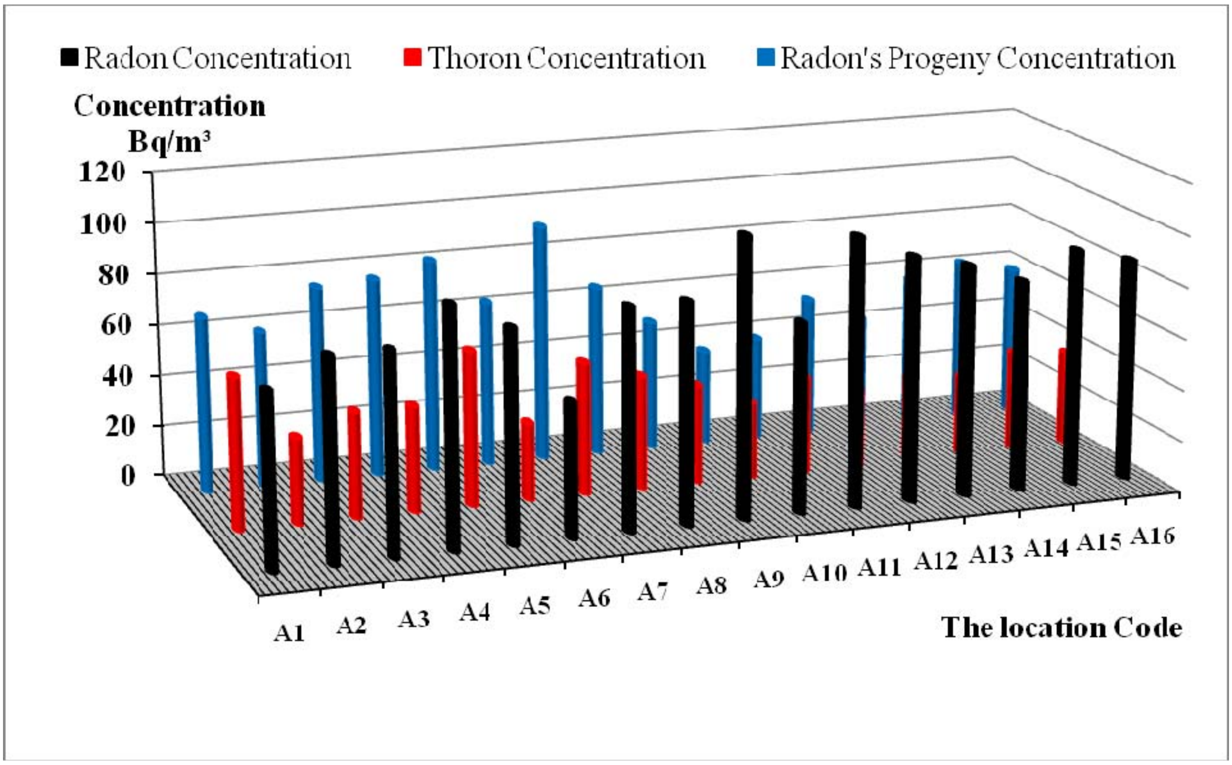

Fig. 6: The concentration of; radon(black), thoron (red), and radon's progeny (blue) at the measured location.

References

[1] Seyed Ali Rahimi, BehzadNikpour Universal Journal of Public Health 1, 2 (2013) 26-31.
[2] Doug Macdougall, "Nature's Clocks; How Scientists Measure the Age of Almost Everything", University of California Press, 2008.
[3] A. B. Brill, The Journal of Nuclear Medicine, 35, 2 (Feb 1994) 342-348.
[4] A. Abdullah, H. I. Hussein, Journal of University of Anbar for Pure Science, 4, 1 (2010) 60 - 64.
[5] M. S. Karim, Journal of College of Education, 1 (2010) 343 - 354.
[6] Y. M. Atia, K. Abd-Aladel, H. B. Mahood, M. A. Hssoni, Journal of Basra Researches, B6, 36 (2010) 35 - 42.
[7] S. Y. Hasan, Tikrit Journal of Pure Science, 16, 3 (2011) 164 - 167.
[8] UNSCEAR United Nations Scientific Committee on the Effects of Atomic Radiation Sources, Effects and Risks of Ionizing Radiations. New York, United Nations Publication, 2000.
[9] NCRP (National Council on Radiation Protection and Measurements). 'Evaluation of Occupa2wnal and Environmental Exposures to Radon and Radon Daughters in the United States', NCRP Report No. 78 1984.
[10] E.Bỉviken, G.Storvik, 'Deterministic and stochastic particle filters for state space estimation. In 'Sequential Monte Carlo methods in practice'". Freytas, N, Gordon, N. and Doucet, A. eds. Cambridge University Press, 2001.
[11] E.A. Martell, Proc. Nati. Acad. Sci. USA. 80 (1983) 1285-1289.
[12] A. Mohamed, A. A. Ahmed, A. E. Ali, M. Yuness, Journal of Nuclear and Radiation Physics, 3, 2 (2008) 101-108.
[13] K. D. Chu, P. K..Hopke Environmental Science and Techology, 22, (1988) 711-717.
[14] M. A. Ahad, S. Rehman, M. L. Mirza Radiat Prot Dosimetry 107, 4 (2003) 269-275.
[15] M. Tirmarche, J.D. Harrison, D. Laurier, F. Paquet, E. Blanchardon, J.W. Marsh, International Commission on Radiological Protection, Ann ICRP. 40,1 (2010) 1-64.
[16] K.P. Eappen, Y.S. Mayya, Radiat. Meas., 38 (2004) S5–S17.
[17] Wondie Megbar, Bhardwaj M.K, I. J. E. M. S., 5 .3 (2014) 173-176.
[18] UNSCEAR Annex E. Sources-to-Effects Assessment for Radon in Homes and Work- places. United Nations, New York, NY, 2009.