Measurements of radon, thoron and their progeny concentrations using twin cup dosimeter for indoor Al-Madaan city – Baghdad – Iraq

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Abstract

In this study, the activity concentrations of indoor radon, thoron and their progeny have been measured in air for 61 different locations of Al-Maddan city using twin cup dosimeter. Furthermore, some useful parameters concerning the health hazards have been estimated; working level month (WLM), annual effective dose (*Eff*), and excess lung cancer per million person per year (ELC).The results show that the values of radon gas levels in the investigated districts varied from 56.28 to 194.43Bq/m^{3}with an overall average value 132.96Bq/m^3, while 0.313 to 1.085 for WLM with an overall average 0.740, respectively. The value of *Eff* and ELC have been found to vary from 1.420 to 4.918 mSv/y with an overall average value 3.354mSv/y, and 852 to 2951 with an overall average value 2013, respectively. For thoron gas only, the results showed that the thoron activity concentration varied from 15.05 to 172.40 Bq/m^3 with an overall average 76.48 Bq/m^3, and 0.021to 0.240for WLM with an overall average 0.106, respectively. The values of *Eff* and ELC have been found to vary from 0.256 to 2.94 mSv/y with an overall average1.30 mSv/y and from 57 to 652 with an overall average of 298, respectively. The concentration of radon progeny varied from 59.44 to 301.39 Bq/m^3 with an overall average 157.62 Bq/m^3. The results illustrated that there is a large variation in the values of the measured concentrations. This is due to the wide variation in the construction of the houses in Al-Madaan city. However, all investigated locations have radon concentration below the action level (200-300Bq/m^3) that recommended byICRP. Therefore, there is no health hazard of radon in the region of Al-Madaan city where measurements have been performed.

Key words

Al-madaan city, Radon and thoron concentrations, LR-115 detector.

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قياس تركيز الرادون و الثورون و وليداتها بأستخدام مجراع تؤام الكأس في مدينة المدائن– بغداد – العراق

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الخلاصة

في هذه الدراسة، تم قياس تركيز نشاط غاز الرادون والثورون ووليداتها في الهواء ل 61 موقع مختلف من مدينة المدائن باستخدام مجراع تؤام الكأس. وبالاضافة الى ذلك حُسبت بعض المعلمات المفيدة بشأن المخاطر الصحية والتي هي مستوى العمل الشهري (WLM) والجرعة السنوية الفعالة (*Eff*) واحتمالية الأصابة بسرطان الرئة لكل مليون شخص سنويا(ELC). اظهرت النتائج ان قيم مستويات غاز الرادون في المناطق

المقاسة تتغير من 56.28 الى 194.43Bq/m^3 وبمعدل 132.96Bq/m^3، في حين كان مدى قيم WLM من 0.313 الى 1.085 وبمعدل 0.740. وقد وجد ان قيم Eff وELC تتراوح من 1.420 الى 4.918mSv/y وبمعدل 3.354mSv/y ومن 852 الى 2951 وبمعدل 2013 على التوالي. اظهرت نتائج غاز الثورون ان تركيز النشاط يختلف من 15.05 الى 172.40Bq/m^3 وبمعدل 76.48Bq/m^3 ومن 0.021 الى 0.240 لقيم WLM وبمعدل 0.106 على التوالي. وقد وجد ان قيم Eff و ELC تتراوح من 0.256 الى 2.94mSv/y وبمعدل 1.30mSv/y ومن 57 الى 652 وبمعدل 298 على التوالي. ان تركيز وليدات غاز الرادون تتغير من 59.44 الى 301.39Bq/m^3 وبمعدل هو 157.62Bq/m^3. النتائج اظهرت ان هناك تفاوت كبير في قيم التراكيز المقاسة ويرجع ذلك الى تباين واسع في بناء المنازل في مدينة المدائن. ومع ذلك فقد وجد ان جميع المواقع المقاسة فيها تركيز غاز الرادون اقل من (200-300Bq/m^3) وهو مستوى العمل الذي اوصت به اللجنة الدولية. لذلك ليس هناك خطر على الصحة بسبب غاز الرادون في مدينة المدائن حيث تم اجراء القياسات.

Introduction

Radon is ubiquitous gas present in the natural environment supposed to be the most important factor of health hazards caused by natural radioactivity. Inhalation of radon and its progeny can cause a significant health hazard, if it is present at enhanced levels beyond maximum permissible limit [1,2]. There are various factors, which affect radon levels such as the difference in soil texture or porosity. The exact source of radon in soil air may be at a deep distant from the surface of the ground. The lower radon concentration in the top layer of the soil is attributable to the proximity of the soil to the atmosphere [3].The radiation dose received by a dweller from all natural sources, about 52% is only due to breathing of radon and its short-lived daughter products [4]. It is well documented fact that the pathological effects like respiratory functional changes and the occurrence of lung cancer may be caused by the long exposure of a person to the high radon levels [5–8].The measurements of radon can be continuous or discrete by carrying out grab sampling. It can be passive or active.

Several techniques are used for the measurements of radon, thoron and their progeny. Some techniques measure the short-term values are called active techniques and other measuring the integrated values is called passive techniques. For the direct measurements of radon, thoron and their progeny, LR-115 type-II plastic track detectors are placed in a container or double dosimeter cup. This simple cup was made of cardboard in different versions [3, 9]. The α-particles from radon and its progeny have a range of about 5 cm in air. The measurement of radon concentration is a simple event. Both radon isotopes (^{222}Rn and ^{220}Rn) would be theoretically detected unless some sort of discriminating mechanism applied [10]. There are generally two ways to solve the problem; the first is that preventing the thoron entering the detecting device, and another is to discrimination between radon and thoron isotopes.

The Twin cup technique using LR-115 detectors [11] have been employed to measure the concentration of radon and its progeny in the indoor environment for the assessment of detrimental effects among the human population living in the study areas of districts of Al-Madaan city, which is a large city in Baghdad (the capital of Iraq).

There are many studies using this technique. In 2013, Mohd Shakir Khan et al. have measured of indoor radon, thoron and their progeny using twin cup dosimeters in rural areas of northern India. In 2014, Mona Ahmed has measured radon, thoron and their progeny concentrations in Al-Fallujah city in Iraq.

Area of study (Al-Madaan)

Al-Madaan an Iraqi city located a few kilometers southeast of Baghdad and characterized by abundant farmland. In the present investigations, measurements of indoor radon, thoron and their progeny have been carried out for health risk assessment using twin cup dosimeters fitted with LR-115 detectors in the 61 location of Al-Madaan city, these districts, also were shown in Fig. 1.

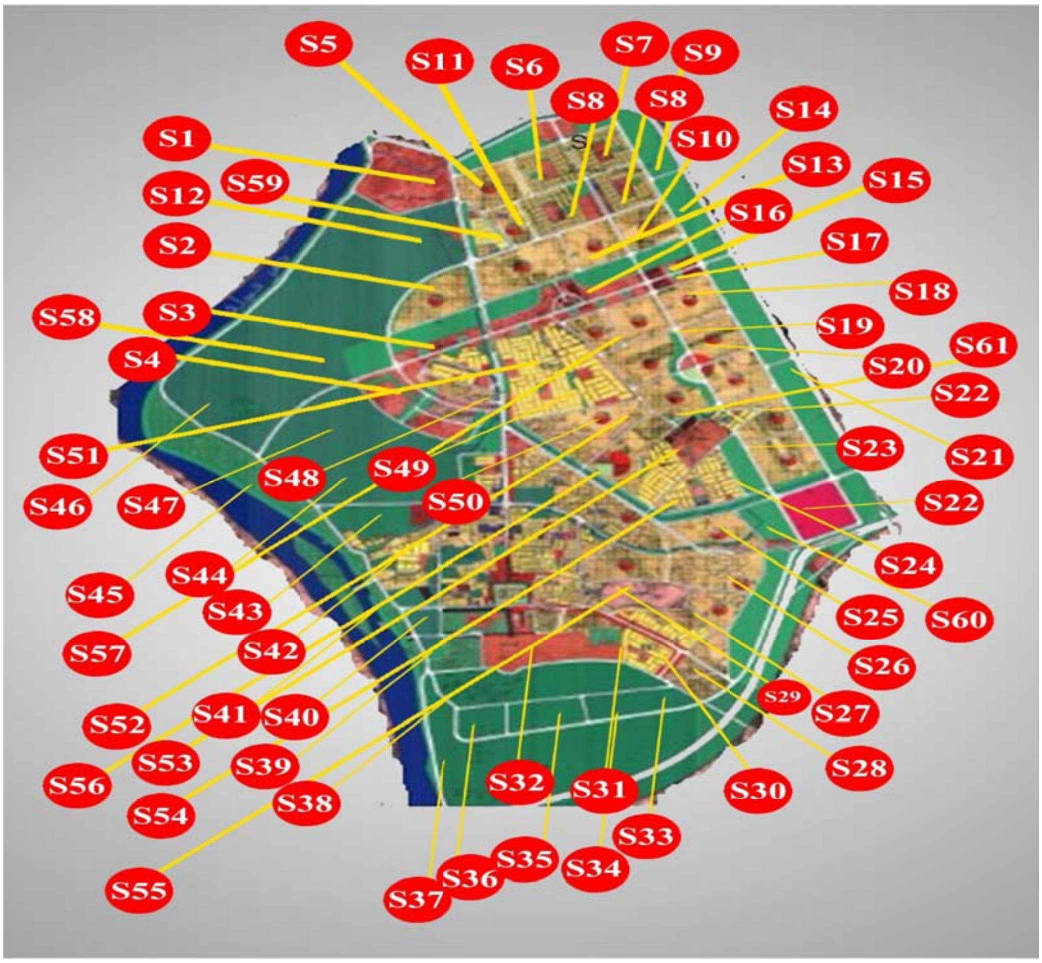
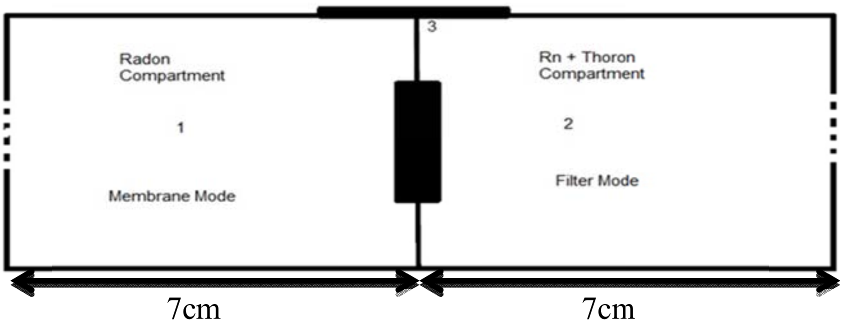


Fig.1: The investigated districts of Al-Madaan city.

Material and methods

The twin cup dosimeters Fig.2 employed for mixed radon, thoron and their progeny measurements have been developed and standardized by reference [12] and reported elsewhere [13–15]. Fig.3 depicts the schematic representation of twin cup dosimeter. It consists of two chambers; each chamber has a length of 7 cm and a radius of 4.5cm. LR-115 type-II plastic track detectors were placed one in each chamber inside the dosimeter cup for the discrimination of radon and thoron, and one detector placed externally for the 'bare mode' exposure. The detector1 placed in chamber 1 (or the membrane compartment) measures radon only which diffuses into it from the ambient air through a semi permeable membrane having permeability constant in the range of 10^{-8}–10^{-7} $cm^2.s^{-1}$ [16, 17]. This membrane allows more than 95% of radon gas to diffuse and suppresses thoron gas to less than 1%. The detector 2 placed in chamber 2 (or the filter compartment) allows both radon and thoron gases to diffuse into it. The detector 3 placed externally for 'bare mode' exposure registers α-tracks attributable to airborne radon, and thoron gases and their α-emitting progeny, mainly ^{218}Po, ^{214}Po, ^{216}Po, and ^{212}Po [14]. The α- particles originating from radon, thoron and their progeny were registered as tracks in the LR-115 plastic track detectors, if they have their energies in the range of about 1.7–4.1 MeV [18]. Thus, the radon short-lived decay products, which plate out on the surface of the detectors will not be detected because their α-particles are too energetic [19]. The twin cup dosimeters were suspended in the dwellings and dry tube-wells for exposure of about 45 days. After exposure, the dosimeters were retrieved and the detectors etched in 2.5 N NaOH solution at (60±1) ^{0}C for a period of about 60 min in the etching bath to reveal the α-particle tracks. Subsequently, these α-tracks were counted using CCD (charge coupled devise) camera connected with an optical microscope at a magnification of 400X and the track density of through etched holes was evaluated in order to determine the concentrations of radon, thoron and their progeny. Fig.3 shows the counting system and an example image for the counted tracks.



1) Radon Cup Mode Detector
2) Rn + Thoron Cup Mode Detector
3) Bare Mode Detector

Fig.2: Schematic diagram of twin cup dosimeter.

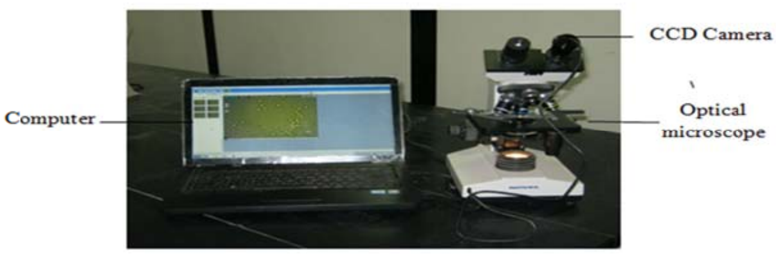


Fig.3: The track counting system.

The estimations of radon, thoron, and their progeny concentrations

The concentrations of radon and thoron gases were calculated using the following modified equations [13, 20, 21]:

$$C_{Rn}\left(\frac{Bq}{m^3}\right) = \frac{\rho_m}{K_{rm}\,.\,T} \tag{1}$$

$$C_T\left(\frac{Bq}{m^3}\right) = \frac{\rho_f - T\,.\,C_{Rn}\,.\,K_{rf}}{K_{tf}\,.\,T} \tag{2}$$

$$C_T\left(\frac{Bq}{m^3}\right) = \frac{\rho_f}{K_{tf}\,.\,T} - \left(\frac{K_{rf}}{K_{tf}}\right).C_{Rn} \tag{3}$$

where K_{rf} (=0.020± 0.004 tracks .cm^{-2} . d $^{-1}$ / Bq.m^{-3}) and K_{tf} (= 0.016 ± 0.005 tracks .cm^{-2} .d $^{-1}$ / Bq.m^{-3}) are the calibration factors for radon and thoron gases in filter mode, and K_{rm} (= 0.019± 0.003tracks.cm^{-2} .d $^{-1}$ / Bq.m^{-3}) is the calibration factor for radon in membrane mode [13, 20, 21]. T is the time of exposure (30 days). ρ_m and ρ_f are the track densities (in tracks.cm^{-2}) in membrane mode and in filter mode, respectively. C_{Rn} and C_T are the radon and thoron concentrations (in Bq.m^{-3}).

The detector 3 exposed externally (i.e., 'bare mode' exposure) registers the tracks of radon, thoron and their α-emitting progenies present in the ambient air. The cup detector sensitivity for radon is close to that of the bare detector. The track density for 'bare mode' exposure is ρ_b, and calibration factor K_b (in tracks.cm^{-2}.d^{-1}/Bq.m^{-3})should be same for all α-emitters [13].

However, another parameters concern radon and thoron concentrations can be estimated. These parameters are; the working level month, the excess lung cancer per million persons per year (ELC), and the annual effective dose (E*ff*), which can be explained as follow:

The working level (WL) is based on the assumption that 100 pCi (=3.7 Bq) worth of ^{222}Rn is present in a liter of air and that each of its four short-lived daughters is also decaying is secular equilibrium with it (i.e. they all display an activity of 3.7 Bq each). The relation between the units, WL, Bq/L and Bq/m^3 is [7]: 1 WL = 3.7 Bq/L = 3.7 * 10^{3}Bq/m^3. Therefore, WLM defined as WL for 170 hours (per month) [7]. 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 WLM, is determined from the epidemiological data of the occupationally exposed mine workers. The excess lung cancer risk (ECL) per MPY was estimated by the following equation [7]:

Excess Cancer Risk = F * Risk factor * O * WLM (4)

The UNSCEAR committee suggests the equilibrium factor (F) 0.4 for radon and 0.1 for thoron and occupancy factor (O) 0.8 for the indoor environment [6]. From the measured indoor radon (or/and thoron) concentrations, the annual effective dose due to inhalation of radon gas (Eff) have been calculated using the UNSCEAR model [23]:

E*ff* (mSv/y) = CRn * F * O * T * D (5)

where T is time in hours per year (8760 h/y) and D is the dose conversion factor (9.0 × 10^{-6}mSv / Bq m^{-3} h).

Results and discussion

Table 1 shows the investigated locations of the study area, radon, thoron, and their progeny concentrations. The radon concentration varied from 56.28 to 194.43 Bq /m^3 with an overall average value of 132.96 Bq/m^3, the thoron concentration varied from 15.05 to 172.40 Bq/m^3 with an overall average of 76.48 Bq/m^3, and their progeny concentration varied from 59.44 to 301.39 Bq.m^{-3} with an overall average of 157.62 Bq/m^3. Furthermore, the lowest value of radon concentration was observed in Al-Rasheed district, which can be classified as residential area that does not include any agricultural soils lands and this district, in general, have a new buildings, i.e. the buildings of this district don't have cracks. The highest was observed in Aalioi Al-Shlal Village1, which includes many agricultural lands. It is known that the agricultural lands contain soils with high amounts of fertilizer that compose with a significant concentration of ^{238}U. However, it is clear that there is a large variation in the values of the measured concentrations. This can be attributed to the wide variation in the construction of the houses in Al-Madaan 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. However, all the values of the radon concentration below the allowed permissible limit, 200-300Bq/m^3, recommended by ICRP [22].

Furthermore, Fig.4 illustrates the ratios between the radon to the thoron concentrations. This figure suggested that the average ratio between radon concentration and the concentration of thoron gas is 2.99 which is below the normal ratio which is four indicating that the study area has soils contain higher concentrations of thorium-232 (which results the thoron gas). Furthermore, one can easily note the variation of the ratio with the investigated districts and increasing it in some districts (i.e. increasing U-238 against Th-232). These increasing ratios could be attributed to the nature of soils, which are agricultural origin that include fertilizer contains significant concentrations of uranium-238.

Table 1: Radon, thoron, and their progeny concentrations for the investigated locations.

Districts	Sample	C_{Rn} (Bq/m³)	C_T (Bq/m³)	C_p (Bq/m³)
AL-Gameaa District1	S1	138.65	82.34	257.50
Zarqa AL-ymama School	S2	122.22	89.82	155.56
AL-Basheer School	S3	149.76	99.01	193.89
AL-Zubeer School	S4	108.45	102.66	108.06
AL- Qadisiyah District1	S5	153.38	103.72	232.78
Al-Lag Area 1	S6	162.80	50.16	180.28
AL-Sahroon District1	S7	107.49	76.77	185.00
Mohammed Wasmi Village1	S8	128.99	108.36	195.00
Al-Wahda area1	S9	92.03	70.32	168.06
The First Dir'iya	S10	157.00	17.69	174.72
AL- Sheikh Ali area	S11	161.35	55.63	186.94
Al-Lag area 2	S12	75.60	85.20	134.72
The Second Dir'iya	S13	127.29	117.46	152.50
AL-Wahda area 2	S14	174.88	36.54	85.28
AL-Mashroaa area	S15	127.78	48.15	118.06
AL-Lag area 3	S16	115.70	82.14	116.39
AL-Tigara area	S17	78.74	50.58	142.50
AL-Sahroon District2	S18	132.85	67.77	143.06
Abdul Baqi Village	S19	90.58	52.94	120.00
Panorama Region1	S20	113.04	82.33	80.00
Aldjaarh area	S21	71.50	87.45	210.83
AL-Rasheed District	S22	56.28	136.31	164.44
AL-Buaba area	S23	122.95	115.32	261.39
AL-Khalsa area1	S24	123.43	78.42	107.78
AL-Khalsa area2	S25	122.71	96.73	167.78
AL- Qadisiyah District2	S26	164.01	44.32	149.72
Panorama Region2	S27	117.87	55.90	148.61
AL-Hurria area	S28	128.50	69.34	140.83
AL-Wahda area3	S29	149.76	15.05	238.33
AL-Hdarrien District1	S30	135.99	15.55	143.61

Districts	Sample	C_{Rn} (Bq/m³)	C_T (Bq/m³)	C_p (Bq/m³)
Qusabaa area	S31	133.33	79.63	211.39
Alstih area	S32	83.33	58.65	163.61
Mohammed Wasmi Village2	S33	151.69	18.68	176.67
AL-Gameaa District2	S34	105.31	127.10	159.44
Asia BintMuzahim School	S35	193.24	75.90	301.39
AL-Bismia area	S36	126.09	106.63	226.67
AL-Gameaa District3	S37	173.19	43.17	90.56
AL- Khnasa area1	S38	155.07	144.31	67.22
Saad Ibn Abi Waqas School	S39	178.74	23.11	144.72
Kasra area	S40	140.34	120.15	172.22
Al-Door district	S41	168.60	46.83	226.11
Aalioi AL-shlal Village1	S42	194.93	16.49	162.78
AL-Diwania al garbia Elimination	S43	176.81	27.51	166.39
Youth center al-madaan	S44	138.65	97.77	212.78
Mohammed Wasmi Village3	S45	187.44	17.50	171.39
Al-sooq area	S46	163.04	48.69	77.78
AL-Bareed street1	S47	114.01	88.15	197.78
AL-Madaan Gas station	S48	127.78	113.27	102.22
Im AL-qura school	S49	194.93	43.65	69.17
AL-Mzlaqa district	S50	170.29	73.23	59.44
AL-Iraq school	S51	113.53	76.28	117.78
Aalioi AL-shlal Village2	S52	82.85	172.40	135.56
AL-Hdarrien District1	S53	90.10	150.95	140.83
AL-Bareed street2	S54	183.09	15.37	174.44
Bawi area	S55	106.76	113.30	152.50
AL-Khnasa area2	S56	106.28	91.25	164.44
Al-Kasra area	S57	119.08	123.82	198.61
Thak AL-goub area	S58	102.17	99.68	173.61
Al-Gazraa area	S59	106.28	160.39	108.89
ImQasur School	S60	136.47	79.89	108.61
Al-Rasheed District	S61	175.60	17.61	116.11
Average		**132.96**	**76.48**	**157.62**

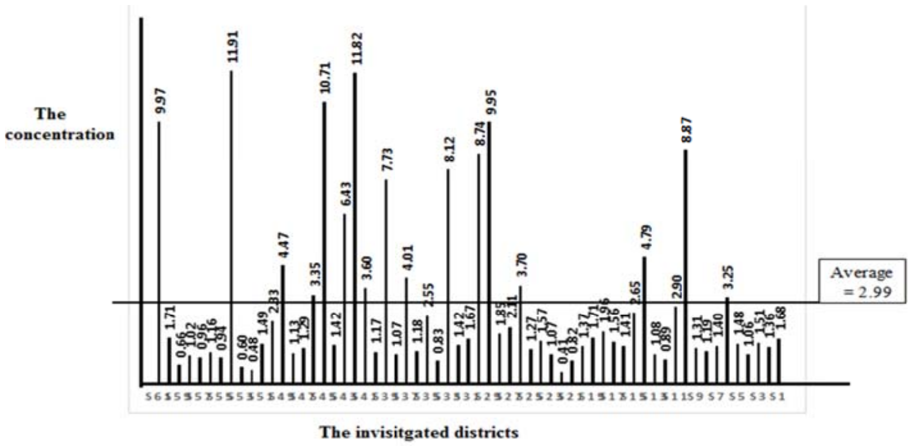


Fig.4: The ratio of radon and thoron concentrations.

For radon measurements, WLM varies from 0.313 to 1.085 with an overall average 0.740, *Eff* varies from1.420 to 4.918 mSv/y with an overall average 3.354 mSv/y, and ELC varies from 852 to 2951 with an overall average value 2013, respectively. While for thoron measurements, WLM varies from 0.021 to 0.223 with an overall average

0.106, *Eff* ranges from 0.256 to 2.94 mSv/y with an overall average 1.30 mSv/y, and ELC ranges from 57 to 652 with an overall average of 289, respectively.

However, the results of *Eff* suggested that the main contribution (about 67%) of the annual effective dose to the human, which is 5 mSv/y, come from the inhalation of radon and this, represents evidence about the health effects of radon and agreed well with international registered values [2].

Furthermore, these parameters (WLM, *Eff*, and ECL) have been plotted as functions of radon concentration, as in Fig.5, and thoron concentration, as in Fig.6. As expected, the behaviors of these parameters with respect to concentration are linear, but from these figures, one can be deduced useful fitting equations, which are listed in Figs.5 and 6. The deduced fitting equations help us for estimation of WLM, *Eff* and ECL without going to the tedious mathematical expressions and by measuring radon or thorn concentration, i.e. by measuring radon and thoron concentrations even with active devises, one can easily estimate these parameters.

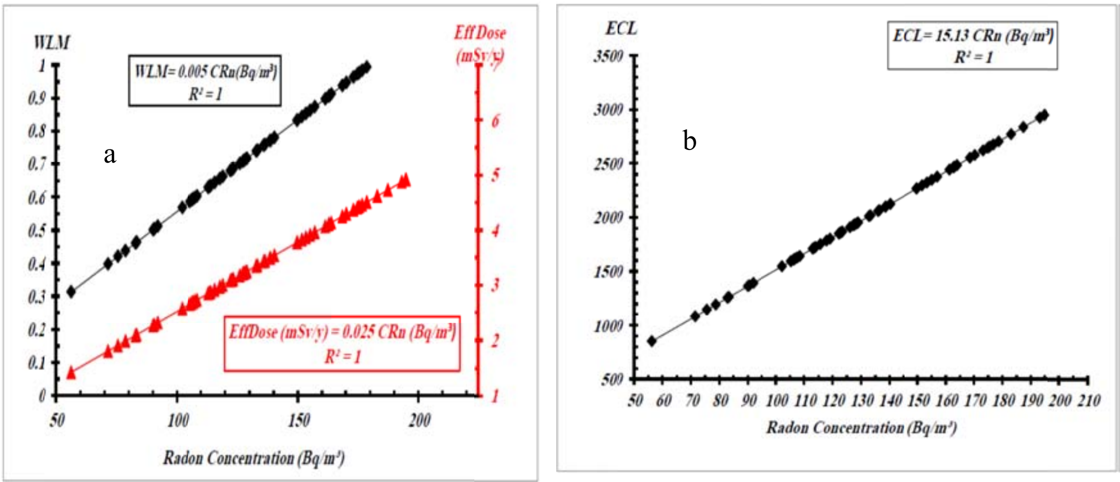


Fig.5: Radon concentration viruses with a) working level month (WLM) and annual effective dose Eff, and b) the excess lung cancer per million persons per year (ELC).

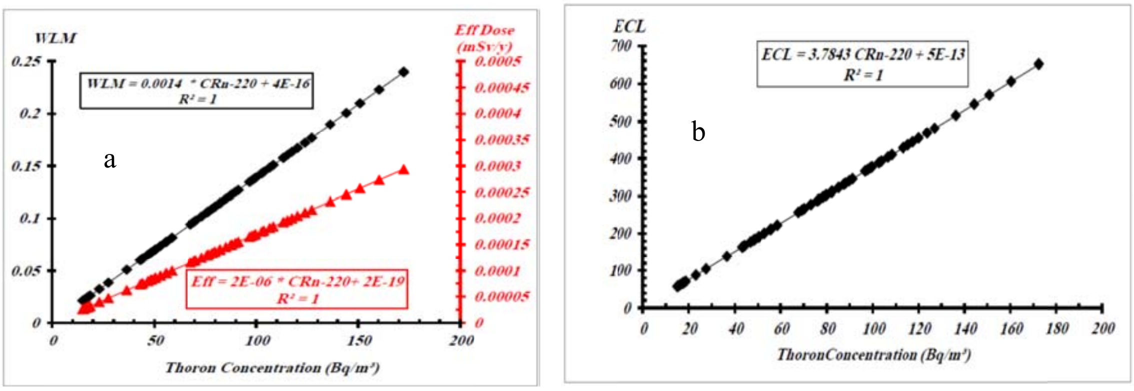


Fig.6: Thoron concentration viruses with a) working level month (WLM) and annual effective dose Eff, and b) the excess lung cancer per million persons per year (ELC).

Conclusions

The results illustrated that there is a large variation in the values of the measured concentrations. This is due to the wide variation in the construction of the houses in Al-Madaan city. It is found that the results of concentrations of radon, thoron and their progeny were higher in 'bare mode' exposure than by the twin cup dosimetric analysis. In addition, the results suggested that the soils of the study area have thorium nature because the overall average value of the ratio between radon and thoron concentrations deviated to thoron. Also, the estimated results of *Eff* showed that the main contribution of the total annual absorbed dose comes from the radon inhaled effective dose. However, all investigated locations have radon concentration below the action level (200-300 Bq.m^{-3}) recommended by ICRP [22]. Therefore, there is no health hazard of radon in the region of Al-Madaan city where measurements have been performed.

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