Measurement of indoor radon levels and assessment of radiological hazards at Al-Tuwaitha nuclear site and the surrounding areas

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Abstract

　　In the present study the radon concentration was measured in indoor places by the RAD7 (radon detector) was in some locations at Al-Tuwaitha nuclear site and some surrounding areas for the duration from 13/10/2016 to 2/1/2017 and the measurement of the indoor radon concentration ranged from (4.96±4.4 to 102±25) Bq/m^3. The high value of radon has been found at decommissioning directorate /emergency room, which is lower than the action value recommended by the Environmental Protection Agency (EPA) which is (148 Bq/m^3) while the lowest value has been founded in central laboratories directorate \ models room. These values were used to calculate the annual effective dose and the health risks for cells bronchial which caused by the inhalation of radon. The values of the annual effective doses were calculated and ranged from (0.1249 to 2.5704) mSv/y these results are lower than the value of (10 mSv/y) recommended by the International Commission Radiological on Protection (ICRP). The results from this study shows that the region has background radioactivity levels within the natural limits.

قياس مستويات غاز الرادون في الداخل وتقدير المخاطر الاشعاعية في موقع التويثه والمناطق المحيطة

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الخلاصة

في الدراسه الحالية تم قياس تركيز الرادون في الاماكن المغلقه باستخدام جهاز ال Rad7 في بعض الاماكن داخل موقع التويثه النووي وبعض المناطق المحيطه للمدة من 13/10/2016 الى 2017/1/2 و تراوحت مستويات غاز الرادون االمقاسه في الاماكن المغلقه بين (4.96 و 102) Bq/m^3. القيمة الاعلى لتركيز الرادون تم الحصول عليها في مديريه التصفية /غرفه الطوارئ و هي اقل من المستويات المسموحه بها من قبل وكاله الحمايه البيئيه الامريكية التي هي (148 Bq/m^3) والقيمه الاقل تم الحصول عليها في مديريه المختبرات المركزيه /غرفه النماذج. هذه التراكيز استخدمت لحساب الجرع الاشعاعيه السنوية والمخاطر الصحيه لخلايا الشعب الهوائية الناجمة من استنشاق الرادون. قيم الجرع الفعاله السنويه لتراكيز الرادون تراوحت بين mSv/y (0.124992 و 2.5704) التي هي اقل من القيمه المحدودة من قبل اللجنة الدولية للوقاية الإشعاعية التي هي (mSv/y 10). النتائج التي تم الحصول عليها تبين لنا ان المنطقه لديها خلفيه اشعاعيه ضمن الحدود الطبيعية.

Introduction

The sources of environmental radioactivity in the atmosphere (natural sources) are radioactive materials in the earth crust and spallation products of atmospheric gases produced by cosmic radiation. The third source of atmospheric radioactivity is the bomb produced isotopes. The earth crust contains the radioactive nuclides ^{238}U, ^{235}U and thorium-232, which, by decay, produce isotopes of the same noble gas, radon. The radon is a naturally radioactive noble gas, it's a component of ground and air and it has been present in increased concentrations from the moment humans first sought after shelter inside dwellings [1]. In some geographical locations such as building including work places occurs high radon levels. This applies mainly in work places such as underground coalfields, natural caves, subways, medical treatment areas, and water supply facilities where ground water with a high radon concentration is stored [2].

The inert radon gas has the ability to form compound in laboratory circumstances. There are three natural isotopes for the radioactive noble gas radon: ^{219}Rn is known as Actinon in the ^{235}U decay series, ^{220}Rn is known as Thoron in the ^{232}Th decay series, ^{222}Rn the most abundant isotope [3]. The ^{222}Rn (radon) has a half-life about 3.82 days and results from the natural radioactive decay chain headed by ^{238}U. The dose from exposure due to ^{219}Rn is ignored and it's not of radiological fear because of the short half-life and the usually low concentrations of ^{235}U in soils [4].

Radon in recent times emerged as a potentially important cause of lung cancer in the general population after smoking [5]. The Radon decay products (daughters) are the reason of 50% of the total dose creating by natural sources [6]. The main part of the radon dose is not because of the radon itself, but from short-lived alpha-emitting radon products, most particularly from ^{218}Po and ^{214}Po along with beta particles from ^{214}Bi so, most important mechanism of exposure to radon is the inhalation of its short-lived decay products. It has been found that exposure to radon is much less than exposure to its decay products [7]. In recent times there are also some studies, proposing other cancers also to be associated to indoor radon, precisely leukemia, kidney cancer, and malignant melanoma, and some other cancers as well [8].

Materials and methods

1. Areas of the study

Al Tuwaitha nuclear site is situated on the Tigris and Euphrates floodplain that is a couple of kilometers from the edges of Baghdad. The facility is encased by a sand berm four miles (6.4 km) around and 160 feet (50 m) high. Al Tuwaitha nuclear site is situated around 1 km east of the Tigris waterway 18 km south of Baghdad which covers a range roughly 1.3 km^2 [9]. Twenty locations have been chosen at Al-Tuwaitha nuclear site and some surrounding locations also selected to be the areas of the current study to make sure that all the selected locations are safe and doesn't cause any hazards on the employees these locations varied between administrative buildings, radiological laboratories, radiological storages and houses as shown in Fig.1.

Fig.1: Aerial photo for Al-Tuwaitha nuclear site and the surrounding areas for studied locations.

2. Airborne radon measurement

Indoor Radon concentration was measured in twenty locations at Al-Tuwaitha nuclear site and some surrounding locations. Each location had been locked for 24 hours means that every crack, doors and windows must be tightly close, and the nonexistence of air-conditioning system or vent. After 24 hours the measurement was done by putting the device at 1 meter high from the ground.

RAD7 is continual radon measuring device from Durridge Company (USA) as shown in Fig. 2. The RAD7 is a Sniffer that uses the 3-minute alpha decay of a radon descendant, without intrusion from other radiations, and the instantaneous alpha decay of a thoron daughter. The RAD-7 uses silicon as a semiconductor material which converts the energy of α-particles directly into electrical signals. The measuring range is between 4 to 750000 Bq m^{-3}. The sampled air enters an interaction chamber and the relative humidity, temperature and battery voltage are all parameters that are worth observing [10].

Three hours counts had been used for measuring the radon activity in which the RAD-7 pumps the air for 5 minutes into the cell of the detector, and only then counts for 5 minutes and so on. Until the three hours finished, during the three hours each radon daughters had been detected were placed on the surface of the detector and then decay, then emit alpha particles into the solid state detector as shown in Fig. 3, after that it's converted into an electric signal, these signals were accumulated in a spectrum. The RAD7 divides this spectrum into a series of 200 individual counters "channels" then RAD7 groups this spectrum of 200 channels into 8 separate windows or energy ranges. During the 5 minutes or ten the counts rate increases until it reaches it equilibrium were the activity of the daughter stabilized, at this point all the counts land in window A, then the total count rate keeps increasing more slowly and we begin to see the counts appear in window C more and more and after 3 hours or so, we reach approximately full equilibrium as we see in Fig. 4.
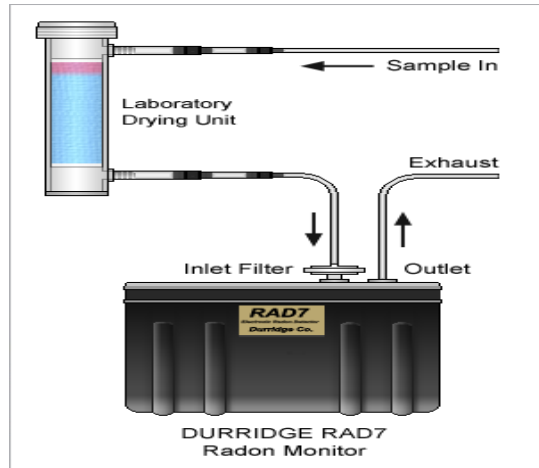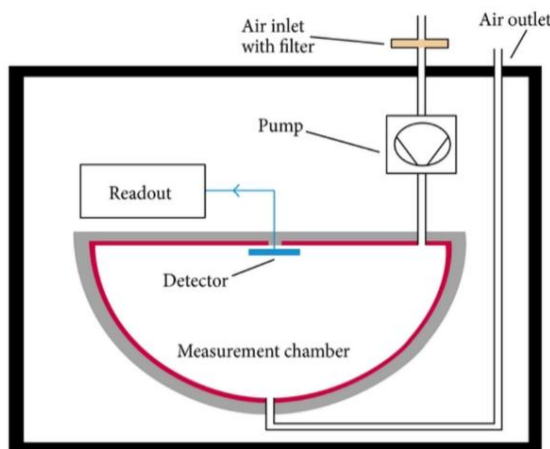
Fig. 2: RAD7 electronic radon detector.

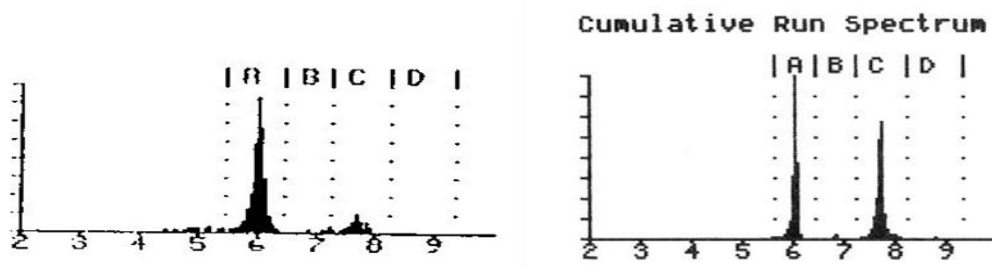*Fig. 3: Measurement-chamber-of- the-RAD-7-detect.*

Fig. 4: Alpha energy spectrum for detecting new radon (window A) and old radon (C).

3. Estimation of annual effective dose from radon

Radon poses an easily reducible health risk to populations all over the world [11]. However, since the radon is the main reason of lung cancer among people who have never smoked it's important to calculate the annual effective dose [12].

AED (mSv/y) = $C_{Rn} \times F \times O \times$ (DCF) (1)

where

AED: is the annual effective dose.

C_{Rn}: the specific activity of indoor radon in Bq/m^3.

F: The global average of equilibrium factor for indoor radon and its descendant which is equal to (0.4).

O: the global average indoor occupancy factor (7000 h y^{-1}).

DCF: the dose conversion factor (9 nSv/h per Bq/m^3).

4. Indoor radon exposure and radiation hazards

Alpha particles represent the major form of radiation radiated as a product of the radon decay. Beta and gamma-particles are also released from the decay of radon descendants. Alpha particles are more biologically significant than either beta or gamma radiations because in comparison with beta particles (electrons) and gamma radiation (photons) they are considered as having a high Linear Energy Transfer (LET). Because of this high relative biological efficiency alpha particles reacts much more readily with the DNA and creating oxidative stress through radiolysis despite their restricted penetrating capability. Tissue regions and cell kinds can be particularly subject to biological destruction because they are within depths crossable by alpha particle exposure. The most important alpha emitters from radon decay are ^{218}Po (6.0 MeV) and ^{214}Po (7.69 MeV) and have penetration depths of 47 μm and 70 μm respectively, proposing high levels of radiation, mostly of the bronchial epithelium and at bifurcation locations, when breathe in into the lungs [13].

The inhaled noble radon gas, is constantly exist in the air volume of the lungs at the concentration in air (X_{RnAir}) and is relatively dissolved in soft tissues. Taking the solubility factor for soft tissues to be 0.4 and suggesting that the short-lived decay products decay in the same tissue as radon gas, the following equation for soft tissues other than the lungs was derived by the [14].

$$D_{Soft\ tissue}(nGy/h)=0.005\ X_{RnAir}\ (Bq/m^3)\ (2)$$

where X_{RnAir} is the concentration of radon. In the case of the lungs, in addition to the dissolved radon, the radon that contains air in the lungs must be taken into account. Taking the air volume in the lungs of ($3.2 \times 10^{-3}\ m^3$) for the "reference man"

and taking further that the short-lived decay products will remain in the lungs [14].

$$D_{lung}(nGyh^{-1})=0.04\ X_{RnAir}(Bqm^{-3}) \quad (3)$$

The effective dose equivalent rate had been calculated by placing a quality factor of 20 for alpha-radiation and placing a weighting factor of 0.12 for the lungs and of 0.88 for the other tissues as: [14].

$$H_{eff}(nSv\ h^{-1}) = 0.18\ X_{RnAir}\ (Bq\ m^{-3})\ (4)$$

Results and discussion

In this study, the indoor radon concentration had been measured for 3 hours in twenty locations at Al-Tuwaitha nuclear site and some surrounding locations in autumn and winter season. The chosen location were different in sizes, the covering material for the wall and the ventilation system. Table 1 shows the date for each measurement, the different locations for the measurement which determined by using GPS technique and the concentrations of radon in these locations. Fig. 5 shows indoor radon concentrations as a function for location. It was found that the higher activity of radon was in decommissioning directorate /emergency room which was a small room compared with the other locations, the walls were covered with ceramic material, there wasn't any kind of cracks or windows and the door were tightly closed. The low activity was in central laboratories directorate \ models room, this low value because of the walls and the ground were covered with a plastic material which minimize the emission of the radon. This variation in the activity of the radon returns to many reasons includes :the air temperature, moisture, the dimensions of the room, the differences in the ventilation system in fact some location doesn't have any ventilation system except the

door which we left it close the whole time of measurement, the nature of the building material, the existence of a carpet on the floor of the rooms, the walls covered with a painting material or not all these conditions effects the emission of the radon.

It is oblivions that the detected concentration values of indoor ^{222}Rn in some locations is higher than the average values of 46Bq/m^3 in dwelling. But the average value is well below the action level suggested by the US Environmental Protection Agency (EPA) (148 Bq/m^3) inside houses [15]. On the other hand, the World Health Organization (WHO) suggested that countries adopt reference levels for the indoor radon of (100 Bq/m^3), and recommends for the public health that the reference level should not go beyond 300 Bq/m^3 if that level cannot be fulfilled [16]. The International Commission on Radiological Protection (ICRP) has therefore reviewed the higher value for the reference level for radon gas in

dwellings from the level in the 2007 recommendations of 600 Bq/ m^3 to 300 Bq/ m^3. Table 2 shows variation of dose relationship from radon measurements from indoor air at Al-Tuwaitha nuclear site and some surrounding locations and illustrated at Fig.6. The values of the annual effective doses for radon inhalation by the people were calculated and ranged from (0.1249 to 2.5704) mSv/y these result are lower than the value of (10 mSv/y) recommended by the ICRP.

Since there is no recognized hazardous level of radon, and there is always be some risk that can be reduced by lowering the radon level in the chosen location this can be done using a vent pipe system and fan, which pulls radon from beneath the location and vent it to the outside. This system known as a soil suction radon reduction system. Sealing foundation cracks and other opening makes this kind of system more operative [4].

Table 1: Indoor radon concentrations in deferent locations.

Sample Point no.	Date	Location	GPS Coordinates		Indoor radon concentrations (Bq/m^3)
			E	N	
P1	13/10/2016	Radiological and Nuclear Safety Directorate \ Equipment storage	44.51349	33.20700	87.8±19
P2	16/10/2016	Central Laboratories Directorate\ sample preparation room	44.512924	33.207395	4.96±4.4
P3	17/10/2016	Radiological and Nuclear Safety Directorate \ sample preparation room	44.51339	33.20694	7.78 ± 5.6
P4	18/10/2016	Treatment of Radioactive Waste Management Directorate \ control cameras room	44.517862	33.20185	31.8±18
P5	20/10/2016	Scientific Information Center (Central Library)\ Basement	44.512924	33.20739	35.9 ±15.1
P6	23/10/2016	Nuclear applications Directorate	44.509423	33.20605	18.5±9

| Sample Point no.	Date	Location	GPS Coordinates		Indoor radon concentrations (Bq/m³)
			E	N	
P7	24/10/2016	Radiation and Nuclear Safety Directorate \ second building	44.512697	33.20803	31.6±11
P8	25/10/2016	Radiological and Nuclear Safety Directorate \ Department of nuclear safety	44.512987	33.20672	18.5±9
P9	27/10/2016	Department of Agriculture \ Laboratory fertilizer	44.51632	33.20703	17.7±8
P10	31/10/2016	Ishtar \ alttakhi school	44.53204	33.19256	11.8±4
P11	2016/12/7	Decommissioning Directorate \ equipment storage	44.51770	33.20509	10.6±7
P12	2016/12/12	The Organization presidency \ room	44.51703	33.20592	19.2±11
P13	2016/12/13	Decommissioning Directorate \ emergency room	44.5174	33.2050	102±25
P14	2016/12/14	Al-alearifih \ Salam neighborhood	44.55268	33.20885	44.3±16
P15	2016/12/15	Jisr Diyala \ Riyadh	44.52725	33.2247	10.9±8
P16	2016/12/6	Management and Treatment of Radioactive Waste /meeting room	44.517862	33.20185	41.3±16
P17	2016/12/22	Jisr Diyala \ area of energy storage	44.531385	33.22133	26.6±13
P18	2016/12/19	Jisr Diyala \ Riyadh 70 Street	44.52722	33.2243	25.1±12
P19	2016/12/26	Alwardia \ Secondary of alnnabi yahyaa	44.54756	33.18242	11.8±8
P20	2017/1/2	Alwardia area /aljiearah clinic	44.55180	33.17725	25.1±12
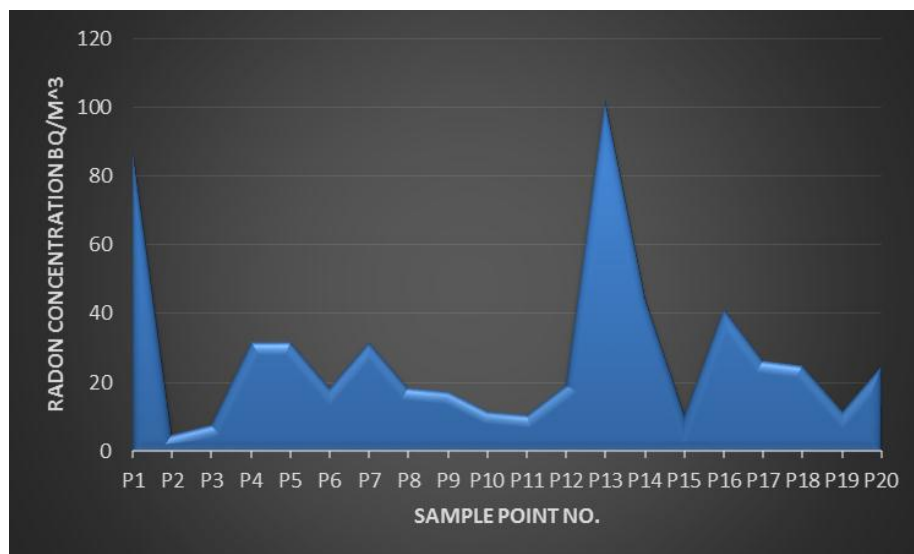
Fig.5: Indoor radon concentration as a function for location.

Table 2: Variation of dose relationship from indoor radon measurements from air in the Al-Tuwaitha nuclear site and the surrounding locations.

| Sample point no.	D_{soft} tissues (nGy/h)	D_{Lung} (nGy/h)	Annual effective dose (mSv/y)	H_{eff} (nSv/h)
P1	0.439	3.512	2.21256	15.804
P2	0.0248	0.1984	0.124992	0.8928
P3	0.0389	0.3112	0.196056	1.4004
P4	0.159	1.272	0.80136	5.724
P5	0.1795	1.436	0.90468	6.462
P6	0.0925	0.74	0.4662	3.33
P7	0.158	1.264	0.79632	5.688
P8	0.0925	0.74	0.4662	3.33
P9	0.0885	0.708	0.44604	3.186
P10	0.059	0.472	0.29736	2.124
P11	0.053	0.424	0.26712	1.908
P12	0.096	0.768	0.48384	3.456
P13	0.51	4.08	2.5704	18.36
P14	0.2215	1.772	1.11636	7.974
P15	0.0545	0.436	0.27468	1.962
P16	0.2065	1.652	1.04076	7.434
P17	0.133	1.064	0.67032	4.788
P18	0.1255	1.004	0.63252	4.518
P19	0.059	0.472	0.29736	2.124
P20	0.1255	1.004	0.63252	4.518
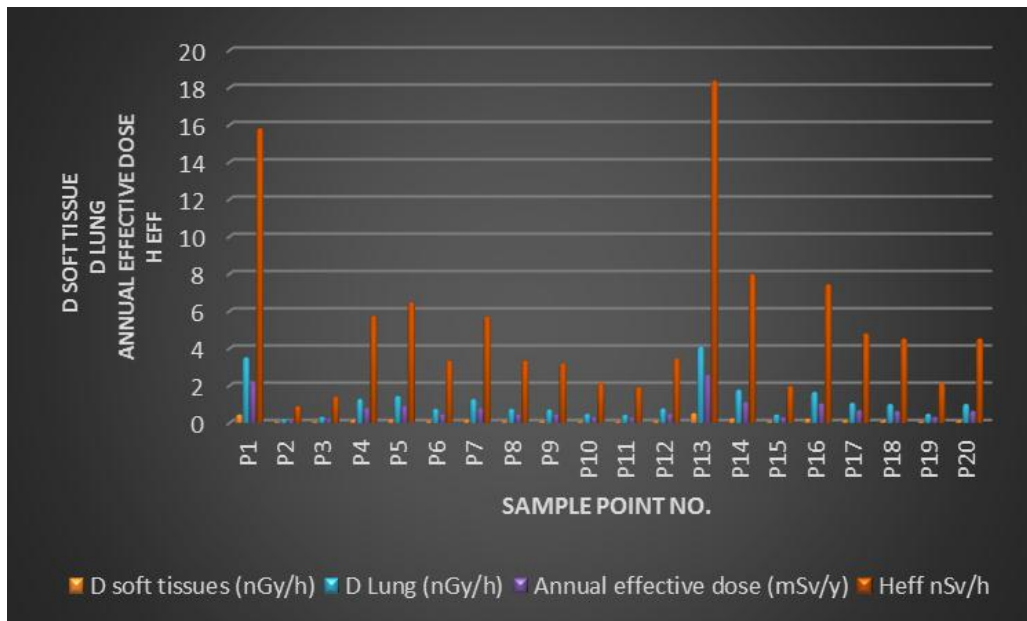
Fig. 6: Average values of $D_{soft\ tissues}$, D_{Lung}, H_{eff} and Annual effective dose by location.

Conclusions

1. Based on the moveable device RAD7, the indoor air radon concentration values in work places were found to be lower than the action level for International Atomic Energy Agency (IAEA) which is 1000 Bq/m^3 as a yearly average concentration for indoor radon in workplaces.

21

2. The indoor air radon concentration values in dwellings were found to be lower than the action level recommended by the US Environmental Protection Agency (EPA) which is 148 Bq/m^3 inside houses.

3. The variation in the activity of the indoor air radon returns to many causes this includes: the air temperature, moisture, the dimension of the room, the difference in the ventilation system, the nature of the building material.

4. The results of the radon activity concentration from this study shows that the region has background radioactivity levels within the safe limits. doi: 10.3390/ijms140714024.

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