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RESEARCH ARTICLE

INDOOR RADON-222 CONCENTRATION MEASUREMENTS AT FACULTY OF EDUCATION, YAFEA, ADEN UNIVERSITY, YEMEN, USING CR-39 NUCLEAR TRACK DETECTOR

Anwar Khadher Mohammed[1,*], Mokhtar Salim Saleh Al_Salimi[2], M. I. Ahmed[3]

[1] *Department of Physics, Faculty of Education, Yafea, Aden University, Yemen*
[2] *Department of Chemistry, Faculty of Education, Yafea, Aden University, Yemen*
[3] *Department of Physics, Faculty of Education, Zinjiebar, Abyan University, Yemen*

***Corresponding author: Anwar Khadher Mohammed; E-mail: anwarhdr@gmail.com**

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Abstract

In this study, the activity concentration of indoor radon-222, annual effective dose, exhalation rate of radon, and relative risk of lung cancer are reported for different indoor buildings (students' dorms, teachers' dorms, offices, laboratories, library, lecture halls, and materials store) in Faculty of Education, Yafea, Aden University, Yemen. Sealed-can technique based on CR-39 nuclear tracks detector was distributed to radon gas survey. Twenty six radon detectors were mounted in seven buildings. The Radon measurements were performed for 90 days between December 2020 and March 2021. The results showed that the radon concentration ranges from 23,18 Bq m^{-3} to 66.49 Bq m^{-3} with an average value 35.86 Bq m^{-3}, the annual effective dose ranges from 0.6 mSv y^{-1} to 1.639 mSv y^{-1} with an average value 0.979 mSv y^{-1}, the exhalation rate ranges from 10.03 m Bq m^{-2} h^{-1} to 28.50 mBq m^{-2} h^{-1} with an average value 15.68 mBq m^{-2} h^{-1} and relative risk of lung cancer ranges from 1.02 to 1.06 with an average value 1.03. A strong correlation coefficient has been observed between radon concentration and radon exhalation rate. All of the values revealed in the study were of nominal state (that is less than allowed global values) and thus have no risk for the population living in these buildings.

Keywords: Annual effective dos, Exhalation Rate, Indoor radon, Sealed can technique, Yafea.

1. Introduction

Earnest Dorn discovered the radon ($_{86}Rn^{222}$) as a radioactive gas in 1900 and named it Radium Emanation gas, which was later renamed neutron. The name, radon, was first used in the early 1920s [1]. Radon the radioactive gas, is a part of the radioactive series originating from Uranium (^{238}U). It is colorless, odourless, tasteless, and is a noble gas, which made it so difficult to detect.

Radon-222 is believed that it leads to lung cancer after smoking, when people are exposed to high concentrations of radon and its progeny for a long period [2]. Radon-222 can be found in soil, rocks and water. The main source of indoor radon is radon in soil [3]. The isotopes of radon found in nature (^{222}Rn, ^{220}Rn, and ^{219}Rn) are the product of a natural decay series of Uranium (^{238}U), Thorium (^{232}Th) and Actinium (^{235}U), respectively. Soil and rocks under houses plus building materials are ordinarily the principal contributors to indoor radon which is typically four or five times more concentrated than the radon outdoors, where greater air dilution occurs. Additional contributions to indoor radon come from external air, soil, water and natural gas [4]. Among three natural isotopes of radon, the isotope ^{222}Rn is responsible for approximately half of the effective dose received by the population from natural radiation sources because it has a half-life (3.82 days) which is much greater than that of ^{220}Rn (55.6 s) and ^{219}Rn (3.92 s) [5, 6].

When inhaled, radon gas densely ionizing alpha particles emitted by deposited short-lived decay products of radon (^{218}Po and ^{214}Po) can interact with biological tissue in the lungs leading to DNA damage. Cancer is generally thought to require the occurrence of at least one mutation, and proliferation of intermediate cells that have sustained some degree of DNA damage can greatly increase the pool of cells available for the development of cancer. Since even a single alpha particle can cause major genetic damage to a cell, it is possible that radon-related DNA damage can occur at any level of exposure. Therefore, it is unlikely there is a threshold concentration below which radon does not have the potential to cause lung cancer. Most of our time is spent indoors; therefore, the measurement and evaluation of radon concentrations and effective dose in buildings are important [7, 8].

In the USA, , they reported radon alone to be a reason for almost 15,000 – 20,000 lung cancer deaths per year [9]. The risk is reported to be proportional to the radon level down to EPA‟s action level of 0.14 8 Bq L^{-1} and probably even below this level [9, 10]. The International Commission on Radiological Protection (ICRP) recommended radon concentration of (200-600) Bq m^{-3} for dwellings [11]. The emphasized the importance of controlling radon exposure in dwellings and work places arising from existing exposure situations was also emphasized [12].

Solid state nuclear track detectors (SSNTDs) are the most reliable detectors that are widely used in measuring radon and its progeny in the air especially from type CR-39 detectors. It is made from allyl diglycol carbonate monomer and it is chemical formula $C_{12}H_{18}O_7$, it is occupy a special place among the various solid state nuclear track detectors, because of their isotropy, transparency, low cost, high detection efficiency for light and heavy charged particles, and high sensitivity for track registration. Also, these detectors allow the long-term measurement of the alpha activity of indoor radon [13, 14].

The aim of this study was to the measure concentration levels of indoor radon-222 at different buildings in Faculty of Education, Yafea, Aden University, Yemen by using CR-39 nuclear track detector with sealed can technique (passive technique). The annual effective dose, exhalation rate and relative risk of lung cancer (RRLC) were calculated.

2. Measurement Technique

2.1. The Study Area

The study area is located southeast of the Capital of the Republic of Yemen, Sana'a, and it is 113 kilometers far from the capital city. It is located in about 165 kilometers to the northeast of the governorate of Aden. The area is considered one of the districts of Lahj governorate, which has a hill-like terrain interrupted by some mountains, and it belongs to the great hill of Yafea. The area is about 2000-2200 meters above sea level. It lies at 13^0 51' 37" N 45^0 14' 22" E. Its climate is moderate in summer and is cold in winter. It receives moderate rain in summer and autumn. Some high-populated communities surround the study area (see Figure (1)).

In this work, the study location are the buildings of Faculty of Education, Yafea, Aden University, Yemen including (students' dorms, teachers" dorms, offices, laboratories, library, lecture halls and materials store).

Fig. 1: *Map of Yemen showing the study area enclosed by a black circle.*

2.2. Indoor Radon Measurements

The technique used in the present study is based on (CR-39) nuclear track detectors (NTDs). GM Scientific Limited, Bristol, UK, manufactures the detectors. The passive radon dosimeter geometry is a closed can from plastic material. The schematic diagram of the can is shown in Figure (2), 6 cm in diameter and 7 cm in depth. A circular hole of radius 0.75 cm is made at the center of the lid. The hole is covered by a piece of sponge of 3 cm×3 cm and of thickness of 0.5 cm, glued into the interior surface of the lid. A small piece of CR-39 with an area of about 1.5 cm × 1.5 cm and a thickness of 0.65 mm is put inside the can and fixed to its bottom using double sided adhesive tape. The design of the can ensures that all aerosols and radon decay products are deposited on the soft sponge from the outside and that only radon gas, among other constituents, diffuses through it to the sensitive volume of the can. Each piece of CR-39 is given an identification mark, by scratching each piece in the top left corner with something sharp. These pieces are marked from number 1-26.

We distributed 26 dosimeters at the buildings of Faculty of Education, Yafea. The dosimeters are hung from the ceiling at a height of about 2 m from the ground. The buildings under study were built using cement, sand, bricks, iron structure and concrete as the construction materials. More details are listed in Table (1). After 90 days, the dosimeters were collected and chemically etched for seven hours using a 30% solution of KOH at a temperature of 70.0 ± 0.1 ^{O}C. The alpha tracks density were counted manually for each detector using the optical microscope of 400 x magnification to count the number of tracks per cm^2 recorded on each detector used.

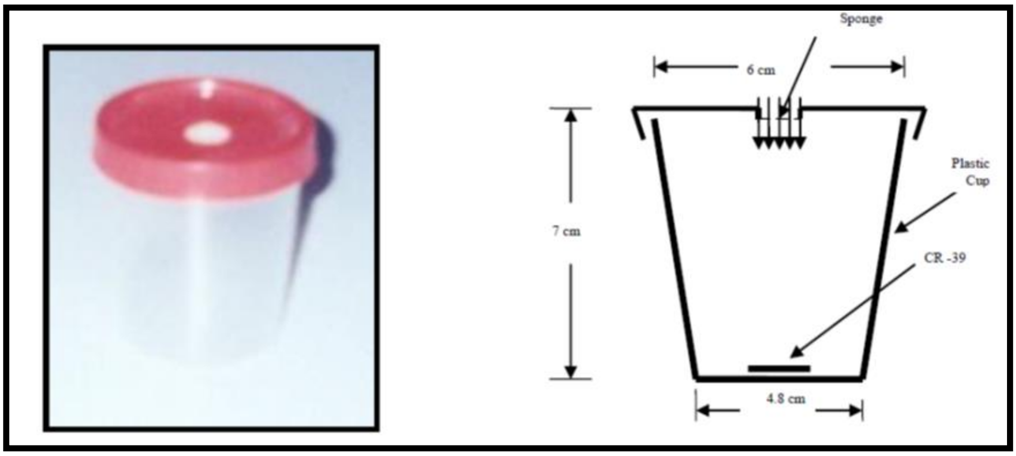

Fig. 2: *schematic diagram showing the geometry of the CR-39 base radon dosimeter.*

The track density was determined and converted into activity concentration C_{Rn} (Bq m^{-3}) using the following equation [15].

$$C_{Rn} = \frac{\rho_{Rn}}{K_{Rn} t} \tag{1}$$

Where ρ_{Rn} is the track density (tracks per cm^2), K_{Rn} is the calibration constant which was previously determined to be 8 ± 0.8 tracks cm^{-2} h^{-1} (kBq m^{-3})$^{-1}$ [15], and t is the exposure time.

2.3. Dose Estimation and Lung Cancer Risk

To estimate the radon effective dose rate (ED) expected to be received by the workers of these health centers at any town due to indoor radon, the conversion coefficient from the absorbed dose and the indoor occupancy factor has to be taken into account. In the UNSCEAR, 2000a report [16], the committee recommended to use 9.0 nSv h^{-1} per Bq m^{-3} for the conversion factor (D_f) (effective dose received by adults per unit ^{222}Rn activity per unit of air volume), 0.4 for the equilibrium factor of radon indoors (E_f) and 0.8 for the indoor occupancy factor (O_f).

We used the following formula to calculate the effective dose rate (ED) [8, 17]:

$$\text{ED (mSv y}^{-1}) = C_{Rn}\ D_f\ O_f\ E_f .\ 24\times365.\ 10^{-6} \tag{2}$$

The relative risk of lung cancer (RRLC) due to indoor exposure to radon was calculated using the following equation [8, 17]:

$$\text{RRLC} = \exp(0.00087352\ C_{Rn}) \tag{3}$$

2.4. The Exhalation Rate

The increase in radon concentration levels in air of the room is because of radon exhalation from all the inner space of the room. The exhalation rate, E_x (in mBq m^{-2} h^{-1}), was calculated using the following empirical equation [18]:

$$E_x = \frac{C V \lambda}{A\left[t + \frac{1}{\lambda\left(e^{\lambda t} - 1\right)}\right]} \tag{4}$$

Where, C is the integrated radon exposure in (Bq m^{-3} h), V is the effective volume of the cup in m^3; λ (λ=7.55×10^{-3} h^{-1}) is the decay constant for radon; t is the exposure time in hrs., and A is the area of the cup in m^2.

3. Results and discussion

Table (2) presents the activity concentrations of indoor radon-222, exhalation rate (mBq m^{-2} h^{-1}), annual effective dose (mSv y^{-1}) and relative risk of lung cancer (RRLC) were measured at different buildings (students' dorms, teachers' dorms, offices, laboratories, library, lecture halls and materials store) at Faculty of Education, Yafea, Aden University, Yemen. The table also shows that the average of activity concentrations of indoor radon-222 are 41,65, 23.81, 36.54, 26.40, 31.32, 26.40 and 64.49 Bq m^{-3} at students' dorms, teachers' dorms, offices, laboratories, library, lecture halls and materials store, respectively. We notice that in the teacher's dorms, which contain three floors, the radon concentration rate in the ground floor was 28.18 Bq m^{-3}, in the first floor was 20.11 Bq m^{-3}, and in the second floor was 22.8 Bq m^{-3}. The main reason of increasing the radon concentration rate in the ground floor was emitting the radon from soil in the ground floors, radon gas enters buildings through the cracks in concrete floors and walls, through gaps between floors and slab, around drains and pipes, and small pores of hollow-block walls, while the reason of variation of the radon concentration in first and second floors was the bad ventilation [19]. The comparison between the concentrations of indoor radon-222 for all buildings were plotted in Figure (3). The highest concentration values were recorded in materials store, 64.49 Bq m^{-3}, while the lowest concentration value of 23.81Bq m^{-3} was recorded in teachers' dorms. The overall average of radon concentration for all buildings was 35.86 Bq m^{-3}. We can note that the concentrations of indoor radon-222 in material store is higher than the other buildings. The main reason of increasing the radon concentration in the materials store was the bad ventilation since there are not windows and it is always closed. In general, primary factors affected the radon concentrations in indoor air are ventilation, season, height, building age and building material [20] (see Table (1)).

Table 1: *Type of building, materials of construction, ventilation type and the building age for location under study.*

Building type	floor	No. of detector	Type of constriction material	Ventilation type	Building age
Students' dorms	Ground	7	Rocks + concrete + wood	Partial ventilation	40 years
Teachers' dorms	Ground	2	Cement bricks + concrete	Partial ventilation	30 years
	First	3			
	Second	2			
Offices	Ground	3	Rocks + concrete +	Partial ventilation	40 years
Laboratories	Ground	3	Rocks + concrete +	Partial ventilation	40 years
Library	Ground	1	Rocks + concrete +	Partial ventilation	40 years
Lecture halls	Ground	3	Cement bricks + concrete	Partial ventilation	12 years
Materials store	Ground	1	Rocks + concrete +	Poor ventilation	40 years

The recorded values of radon concentrations in this study (see Table (2)) are much lower than the radon action level 200-600 Bq m^{-3} recommended by ICRP-1993 [21], lower than the new reference level of 100 Bq m^{-3} set by WHO [7] and below the action level of 148 Bq m^{-3}, recommended by the Environmental Protection Agency (EPA) [22]. The mean score of radon concentration in this study, is lower than the international average value (population weighted) since the average radon of 40 Bq m^{-3} has been reported by UNSCEAR, 2000a [16].

As presented in Table (2) the radon effective dose rate ranges from 0.50 to 1.63 mSv y^{-1}. The average radon effective dose rate calculated is 0.97 mSv y^{-1}. The average effective dose is lower than the "normal" back ground level of 1.1 mSv y^{-1}; as quoted by UNSCEAR, 2000a [16], but way below even the lower limit of the recommended action level 3-10 mSv y^{-1}, as reported by the ICRP-1993 [21].

In addition, Table (2) shows that the average values of exhalation rate range from 10.03 to 28.50 mBq m^{-2} h^{-1}. The average exhalation rate calculated is 15.68 mBq m^{-2} h^{-1}. The average values of exhalation rate is lower than the permission value (57.600 mBq m^{-2} h^{-1}) set by UNSCEAR, 2000b ANNEX B [23]. There are very strong relations between radon concentration and exhalation rate with coefficients (R^2=0.996) as shown in Figure 4. These strong relations specify that the Radon concentration is closely dependent on exhalation rate at all buildings of the study area.

The relative lung cancer risk (RRLC) ranges from 1.069 to 1.043, with an average of 1.053, which is very low and not constituting any health hazards to the students and staff members in these buildings.

Table 2: *Rates of indoor radon concentration measurements, effective dose, exhalation rate and radon relative lung cancer risk.*

Building type	floor	No. of detector	Radon concentration ($Bq\ m^{-3}$)			ED ($mSv\ y^{-1}$)	Ex ($mBq\ m^{-2}\ h^{-1}$)	RRLC %
			Min.	Max.	Mean			
Students' dorms	Ground	7	31.78	71.85	41.65	1.50	18.28	1.03
Teachers' dorms	Ground	3	22.5	41.9	28.18	0.711	12.37	1.02
	First	3	17.9	23.4	20.11	0.507	8.82	1.01
	Second	2	20.26	25.33	22.8	0.575	8.89	1.02
	Average	8	17.9	41.9	23.81	0.600	0.031	1.02
Offices	Ground	3	30.40	40.07	36.54	0.922	16.04	1.03
Laboratories	Ground	3	23.03	32.24	26.40	1.02	11.59	1.02
Library	Ground	1	31.32			0.790	13.74	1.03
Lecture halls	Ground	3	24.87	28.55	26.40	0.666	11.59	1.02
Materials store	Ground	1	64.94			1.639	28.50	1.06
Average		26	35.86			0.979	15.68	1.03

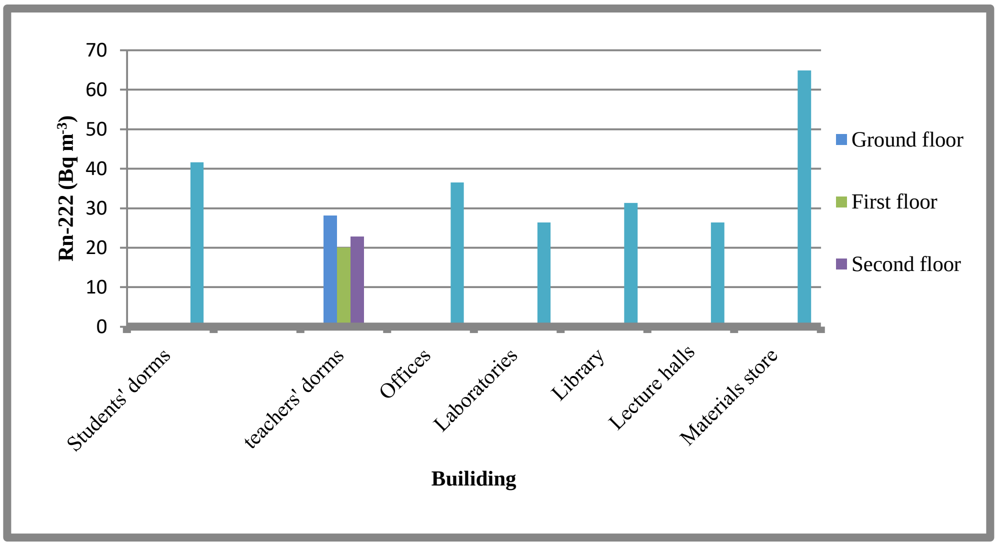

Fig. 3: *Radon concentration from buildings of the studied location*

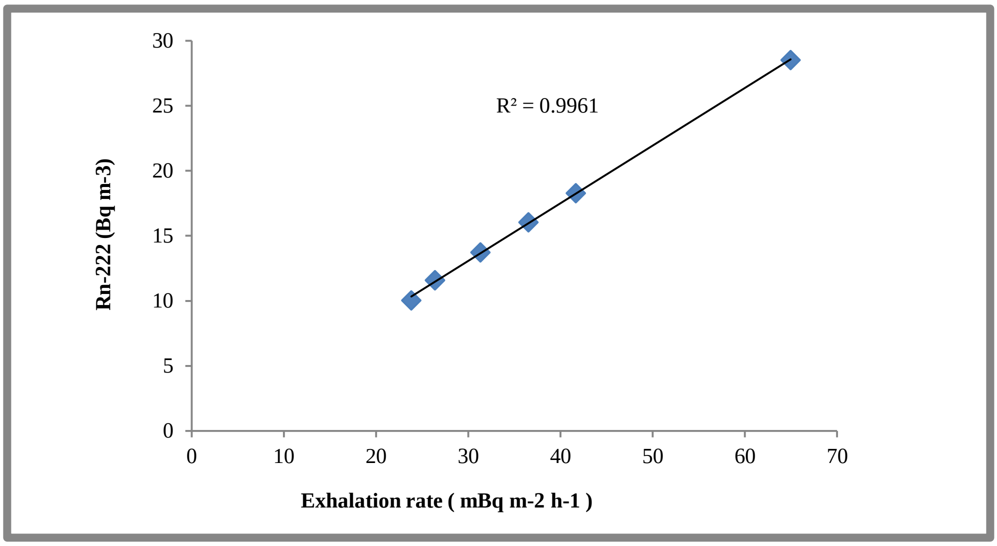

Fig. 4: *Correlation between radon concentration and Exhalation rate*

By comparing results in Table (3), between the values of radon concentration, effective dose, exhalation rate and lung cancer risk from different regions in Yemen and other countries, we find that our value of radon concentration is closer to the values obtained in Taiz (Yemen) and Aden (Yemen), but it is lower than the values obtained in Ja'ar (Yemen), Saudi Arabia , Sudan , Palestine, Turkey, Macedonia, Iraq , India, USA, and Brazil. Our value of effective dose is closer to the values obtained in Palestine and Saudi Arabia but it is lower than the value obtained in India. For exhalation rate we find that our result is higher than the value obtained in Palestine but it is lower than the value obtained in Saudi Arabia. The last values in Table (3) are lung cancer risk we find that our result is approximately equal to the value obtained in Sudan.

Table 3: *Comparison of results with other results in various locations in the world*

Country	Mean conc. (Bq m^{-3})	ED (mSv y^{-1})	Exhalation rate (mBq m^{-2} h^{-1})	RRLC %	Reference
Saudi Arabia	81.67	1.41	78.85		[6]
Sudan	50	0.56		1.053	[8]
Palestine	83	1.05	3.23		[24]
Turkey	87				[25]
Macedonia	115				[26]
Iraq	41.4	0.4			[27]
India	182.7	6.2			[28]
USA	148				[29]
Brazil	82				[30]
Taiz (Yemen)	34				[31]
Aden (Yemen)	38				[32]
Jaar (Yemen)	52.9				[33]
Yefea (yemen)	35.86	0.979	30.45	1.03	Present study

4. Conclusion

Radon concentration measurements were performed in buildings in Faculty of Education, Yafea, Aden University, Yemen. The mean value of indoor radon concentration measured at buildings was below the action level recommended by ICRP. The ventilation rate in the buildings and construction materials play a very important role in controlling indoor radon concentration. In addition, the calculated effective dose rate for all buildings was lower than the average value given by UNSCEAR and below the ICRP action level. Furthermore, exhalation rate is lower than the permission value set by UNSCEAR. Consequently, the relative lung cancer risk for radon exposure is low in these buildings and they can be considered safe when the hazardous health effects of radon are concerned.

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مقالة بحثية

قياس تراكيز غاز الرادون داخل مباني كلية التربية يافع، جامعة عدن، اليمن، باستخدام كاشف المسار النووي

انور خضر محمد بدر[1,*]، مختار سالم صالح السالمي[2]، محمود عيسى احمد[3]

[1] قسم الفيزياء، كلية التربية يافع، جامعة عدن، عدن، اليمن
[2] قسم الكيمياء، كلية التربية يافع، جامعة عدن، عدن، اليمن
[3] قسم الفيزياء، كلية التربية زنجبار، جامعة ابين

الباحث الممثّل: انور خضر محمد بدر؛ البريد الالكتروني: anwarhdr@gmail.com

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المُلخّص

تضمنت هذه الدراسة اجراء قياسات لتراكيز غاز الرادون والجرعة الفعالة وكذلك معدل انبعاث الرادون ونسبة الخطر من سرطان الرئة في مباني كلية التربية يافع، جامعة عدن، اليمن. باستخدام تقنية العلب المغلقة المعتمدة على كواشف المسارات النووية CR-39. حيث وزع ست وعشرون علبة على مباني كلية التربية يافع (سكن الطلاب، سكن المدرسين، المكاتب، المختبرات، المكتبة، قاعات المحاضرات، مستودع المواد). حيث تركت العلب لمدة تسعين يوماً بين شهري ديسمبر 2020 ومارس 2021. وقد وجد أن تركيز غاز الرادون في هذه المباني يتراوح بين $23.18\ Bq\ m^{-3}$ إلى $66.49\ Bq\ m^{-3}$ بمعدل $35.86\ Bq\ m^{-3}$ وكذلك وجد أن الجرعة الفعالة للساكنين تتراوح بين $0.6\ mSv\ y^{-1}$ إلى $1.639\ mSv\ y^{-1}$ بمعدل $0.979\ mSv.y^{-1}$ وأيضاً وجد ان نسبة انبعاث الرادون من المباني يتراوح بين $10.03\ mBq\ m^{-2}\ h^{-1}$ إلى $28.50\ mBq\ m^{-2}\ h^{-1}$ بمعدل $15.68\ mBq\ m^{-2}\ h^{-1}$ ووجد أن معدل خطر سرطان الرئة تتراوح 1.02 الى 1.06 بمعدل 1.03. وقد لوحظ من خلال هذه الدراسة ان كل القياسات التي حصلنا عليها اقل من المعدل المسموح به عالمياً، وهذا يعني أنه لا توجد خطورة على الساكنين في المباني موضوع الدراسة.

الكلمات المفتاحية: الجرعة الفعالة السنوية، نسبة الانبعاث، الرادون الداخلي، تقنية العلبة المغلقة، يافع.

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