Research Article **Open Access**

Radon Concentrations Measurement in Dwellings of Kufa Technical Institute, Iraq Using LR-115 Nuclear Track Detector

Ali Abid Abojassim* and Afnan Ali Husain

Department of Physics, Faculty of Science, University of Kufa, Al-Najaf/ Kufa, box (221) Najaf, Iraq

Abstract

In this work, radon concentrations were measured in dwellings Kufa Technical institute, Iraq between November 2014 to February 2015 using time integrated passive radon dosimeters containing LR-115 Type II plastic track detectors. Also, we calculated the concentration of short-lived radon daughters, potential alpha energy, working level month, the annual effective dose rate, the annual equivalent dose rate and the excess lifetime cancer risk in all dwellings under study. The radon concentration in these dwelling ranges from (15.211 ± 2.745 to 32.445 ± 09.200) Bq/m3 with an average of (21.567 Bq/m3), which within the acceptable radon levels (50-150) Bq/m3 recommended by the International Commission on Radiological Protection (ICRP). The mean the excess lifetime cancer risk were found to be ranges from 35.458 to 75.633 with an average value of 50.297 per 106 persons. These values are within in the safe limits recommended by the international organizations.

Introduction

Radon is a unique natural element being found as a gas, noble, and radioactive in all of its isotopes. As gases, the isotopes are mobile and carry messages over significant distances, within the earth and in the atmosphere, but on the other side of the coin, inhalation can be a problem to one's health. The fact that radon is noble ensures that it is not immobilized by chemically reacting [1]. The decay of radon begins with uranium-238 and goes through four intermediate states to form radium-226, which has a half-life of 1,600 years. Radium-226 then decays to form radon-222 gas. Radon's half-life, 3.8 days, which provides sufficient time for it diffuse through soil and into homes, where it further disintegrates to produce the more radiologically active radon progeny ("radon daughters") [2].

The Health effects of radon, most notably lung cancer, have been investigated for several decades. Initially, investigations focused on underground miners exposed to high concentrations of radon in their occupational environment. However, in the early 1980s, several surveys of radon concentrations in homes and other buildings were carried out, and the results of these surveys, together with risk estimates based on the studies of mine workers, provided indirect evidence that radon may be an important cause of lung cancer in the general population. Recently, efforts to directly investigate the association between indoor radon and lung cancer have provided convincing evidence of increased lung cancer risk causally associated with radon, even at levels commonly found in buildings. Risk assessment for radon both in mines and in residential settings have provided clear insights into the health risks due to radon. Radon is now recognized as the second most important cause of lung cancer after smoking in the general population [2,3].

Since radon is constantly escaping from the ground, it is always present in the air, but under certain circumstances the concentration of radon in a building can be increased significantly over its normal outdoor level [4]. Most buildings have a confined air space with limited air movement and only a slow exchange with outside air. Consequently the concentration of any particulates or gases released into the building atmosphere will tend to increase above the concentration normally found in outside air. Radon can enter a building in a number of ways and once inside, the concentration of its particulate progeny will increase as the radon decays. Thus, high concentrations of radon gas in soils with high transport efficiency (i.e. loose, porous, dry soil) can lead to elevated radon concentrations in buildings [2,5].

Measurement of indoor radon is rather important because the radiation dose to human constitutes more than 60% of the total dose, including that from the natural sources [6]. Several techniques have been used to measure radon and are daughters concentration. LR-115 Nuclear Track Detector has been widely used for the measurement of time integrated radon levels in dwellings under different conditions [7-12].

The aim of the present work is to measure the indoor radon concentration and the annual effective dose in the Kufa technical Institute building of Kufa city by using SSNTDs technique LR-115 because there is no studying of radon concentration in this Institute.

Study area

Kufa city in Iraq, about 170 kilometres (110 mi) south of Baghdad, and 10 kilometres (6.2 mi) northeast of Najaf. It is located on the banks of the Euphrates River, with location of latitude (32°1'46"N), and longitude (44°23'53"E). It is located about 30 meters above the sea level, with a total area of nearly 28,824 km2 and a population of nearly 110,000 [13].

Kufa city has a desert climate characterized by extreme heat during the day, an abrupt drop in temperature at night, and slight, erratic rainfall. The weather in kufa city is dry and hot in summer; cold and less rainy in winter. Temperature is moderate in winter at 18°C and 42°C in summer. Najaf does not have a seaport. Its lands are flat and leveled in areas linked to waters from the Euphrates River and higher in the southern portions of the desert areas, extending to the republic of Iraq [13,14]. The dwelling of Kufa Technical institute were built

*Corresponding author: Ali Abid Abojassim, Department of Physics, Faculty of Science, University of Kufa, Al-Najaf/ Kufa, box (221) Najaf, Iraq, Tel: 07809644332; E-mail: ali.alhameedawi@uokufa.edu.iq

using different materials, such as cement, sand stones and bricks, iron structure, marble, and concrete. Several of these materials contribute significantly to indoor radon emission. We put tracks of LR-115 detector in living which has been measuring about 7 m x 4 m x 4 m, with one window and one door.

In this study we calculated the radon concentration for dwellings in Kufa Technical institute which are divided in to eight region as shown in Figure 1. Table 1 showed the sites of measurement in studied area for taking samples.

Martials and Methods

Methodology

Thirty one dosimeters, were prepared and distributed inside the underground levels of the dwellings in Kufa Technical institute. These locations are chosen to be representative of the whole region. Experimental methods for radon detection and measurements are based on alpha-counting of radon and its daughters. The plastic track detector (LR-115 type II) is a cellulose nitrate film of 12 μm thickness manufacture by Kodak Path, France. Due to its ruggedness and a fine window for recording alpha particles emanating from radon progeny, it is highly useful for integrated measurements from few days to several months [15]. These plastics films of size 1 cm x 1 cm were hung in the ceiling at distance 1 m above the earth of room. After the exposure period of 120 days, the detectors were etched for 120 minutes in 2.5 N NaOH solution maintained at 60°C. The etched detectors were washed with distilled water and finally dried in air and count the number of tracks by the track counting technique, which was performed using an optical microscope. The calibration factor for dosimeters exposed for range from (4-28) day to Radium ^{226}Ra (Radon source) of activity 3.3 kBq was calculated to be (0.0216 ± 0.0033) [(Bq.d. m^{-3}) per (track.cm^{-2})]. The value is approximately the same as that reported in many works [15-17].
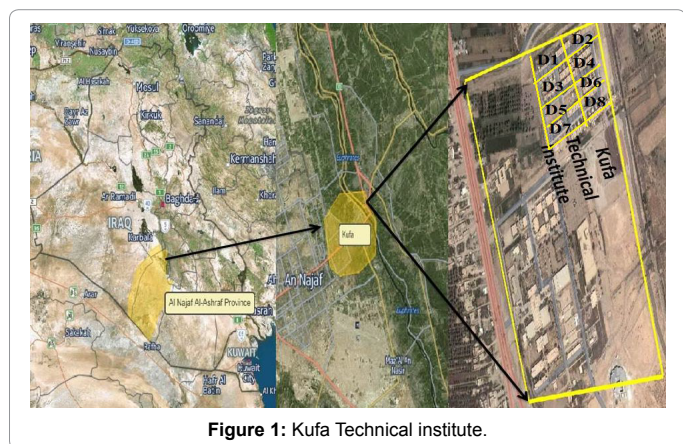

Figure 1: Kufa Technical institute.

Measurement of radon concentration

The tracks density is measured by using equation (1) [18]:

$$Track\ density\left(\frac{track}{cm^2}\right) = \frac{Average\ number\ of\ total\ tracks}{view\ field\ of\ Area} \quad \text{......................(1)}$$

Radon concentrations (C_{Rn}) in present work are determined by the equation [19-21]:

$$C_{Rn}\left(\frac{Bq}{m^3}\right) = \frac{C_0\left(\frac{Bq.day}{m^3}\right)}{\rho_{o\left(\frac{track}{cm^2}\right)}}\frac{\rho_{\left(\frac{track}{cm^2}\right)}}{t(day)} \quad (2)$$

$\frac{C_0\left(\frac{Bq.day}{m^3}\right)}{\rho_{o\left(\frac{track}{cm^2}\right)}}$ is calibration factor for dosimeters exposed (it gives (0.0216 ± 0.0033) [(Bq.day/m^3) per (track/cm^2)].

ρ=track density (number of tracks/cm^2) of distributed detectors,

t= exposure time (days) of distributed detectors.

Calculation of EEC, PAE and WLM

The track density on the detector is related to the potential alpha energy (PAE) concentration expressed in Working Level (WL) units. WL is the concentration of any combination of radon progeny corresponds to 1.3×10^5 MeV of PAE per liter of air [22]. The resulting concentration of short-lived radon daughters expressed in term of an equilibrium-equivalent radon concentration (EEC), is related to the activity concentration of radon (C_{Rn}) by the equation (3) [22,23]:

$$EEC\left(\frac{Bq}{}\right) = C_{Rn} \times F \quad \text{.................(3)}$$

where F is an equilibrium factor which is equal 0.4 in indoor air [22,23].

The Potential Alpha Energy (PAE) concentration calculated in mWL using equation (4) [22]:

$$PAE(mWL) = \frac{EEC}{3700} \quad \text{.................(4)}$$

Exposure to indoor ^{222}Rn in terms of working level month (WLM) for indoor has been calculated using the following equation:

$$WLM = WL\frac{8760}{170} \quad \text{.................(5)}$$

Estimated the Excess Lifetime Cancer Risk (ELCR)

Indoor radon has been determined to be the second leading cause of lung cancer after tobacco smoking [24]. Radon effective dose value describes the harmful effects of radon on the human body; therefore, it is necessity to calculate the radon dose from radon concentration. There are large uncertainties in dosimetric assessments and epidemiological

No.	Location Symbol	Number of Track		Coordinates		Range of alt(m)
		distributed	collected	Lat.(deg)	Long. (deg)	
1	D1	4	4	32.061271	44.404522	26-25
2	D2	4	4	32.061521	4.405205	26-25
3	D3	4	4	32.061754	44.405899	26-25
4	D4	4	4	32.060883	44.404706	26-25
5	D5	4	4	32.061088	44.405394	26-25
6	D6	4	4	32.061310	44.406121	26-25
7	D7	4	4	32.060628	44.405618	25-24
8	D8	4	3	32.060882	44.406337	26-25

Table 1: Sites of measurements in studied area for taking samples.

aspects for the conversion of a radon exposure to a radon dose [25]. We used UNSCEAR's radon dose conversion factor as it lies between dosimetric and epidemiological dose conversions [26,27]. UNSCEAR suggests that in estimating the effective doses, the following factors are applied [28]:

- An indoor radon decay product equilibrium factor of $E_f = 0.4$

- A radon effective dose coefficient factor of $C_f = 9$ nSv/(Bq h m^{-3})

- An indoor occupancy factor of $O_f = 0.8$, which is the fraction time that people spend indoors, but not essentially in their homes. It means, during one year ($T = 365 \times 24$ h), people spend about 8,760 h at indoor spaces like home and office.

So, the equation for annual absorption dose (D_{Rn}) due to radon concentration is:

$$D_{Rn}\left(\frac{mSv}{y}\right) = E_f \times C_f \times O_f \times C_{Rn} \times T \dots\dots\dots\dots(6)$$

where C_{Rn} is the radon concentration in Bq/m^3 scale. By using this equation, annual radon effective dose has been calculated.

In the biological effect of radiation, to calculate the annual equivalent dose, two types of weighting factors are needed in order to estimate the level dose. A radiation weighting factor and a tissue weighting factor. The radiation weighting factor (W_R) for alpha particles is 20 as recommended by ICRP [29] and a tissue weighting factor (W_T) is applied. The weighting factor that used in this study is 0.12 [30,31]. The annual equivalent dose was then calculated using the following equation [32].

$$H_E\left(\frac{mSv}{y}\right) = D_{Rn} \times W_R \times W_T \dots\dots\dots\dots(7)$$

Where H_E (mSv/y) is the annual equivalent dose, D_{Rn} is the annual effective dose, W_R is radiation weighting factor and W_T is tissue weighting factor.

The excess lifetime cancer risk (ELCR) per million persons per year (MPY) was calculated using formula in Ref [33].

$$ELCR = H_E \times DL \times RF \dots\dots\dots\dots(8)$$

Where, DL is the Duration of Life (70 y) and RF is the Risk Factor (0.055 Sv^{-1}) recommended by the ICRP [29].

Results and Discussions

The minimum, maximum values and the average of radon ^{222}Rn gas concentrations for each monitored dwelling is reported in Table 2. The average radon concentration in dwellings was 21.567 Bq/m^3, this variation in radon concentration is fundamental related with type of construction and age of the building, the minimum and maximum values for indoor radon concentration were found in sample (T10) and sample (T19) which equal to 15.211 ± 2.745 Bq/m^3 and 32.445 ± 09.200 Bq/m^3 respectively. The variable from one region to another due to different concentration of uranium in different regions, these results are within the radon levels (50-150) Bq/m^3 which are recommended by ICRP [34]. The values of equilibrium equivalent concentration (EEC), potential alpha energy (PAE) and monthly work level (MWL) of the study area are given in Table 3. The average values of equilibrium equivalent concentration, potential alpha energy concentration and monthly work level for each of the 31 samples were 8.630 Bq/m^3, 2.332 mWL and 0.120 respectively. Table 4 shows the values of annual effective dose (D_{Rn}), annual equivalent dose (H_E) and the excess lifetime

No.	Sample Code	Radon Concentrations (Bq/m³)		
		Minimum	Maximum	Average ± S.D
1	T1	20.131	28.296	23.545 ± 3.850
2	T2	18.664	23.417	20.308 ± 6.976
3	T3	15.784	23.964	19.655 ± 11.303
4	T4	20.491	26.998	22.266 ± 10.001
5	T5	17.027	24.075	19.608 ± 9.9663
6	T6	16.530	20.333	19.097 ± 5.483
7	T7	14.268	26.032	20.150 ± 16.168
8	T8	16.931	21.729	18.962 ± 7.572
9	T9	23.476	31.211	27.647 ± 11.301
10	T10	14.248	16.342	15.211 ± 2.745
11	T11	14.391	20.574	16.939 ± 9.251
12	T12	14.531	19.662	17.930 ± 7.291
13	T13	13.735	20.105	16.292 ± 8.713
14	T14	17.031	25.635	20.958 ± 12.048
15	T15	13.996	18.301	16.208 ± 7.436
16	T16	12.897	23.648	18.220 ± 13.899
17	T17	15.155	25.059	21.084 ± 13.871
18	T18	14.178	22.134	17.450 ± 10.661
19	T19	25.173	38.949	32.445 ± 09.200
20	T20	20.309	35.739	25.653 ± 11.724
21	T21	21.139	29.772	26.859 ± 15.024
22	T22	21.981	39.121	29.845 ± 12.392
23	T23	20.000	27.245	22.924 ± 10.048
24	T24	21.015	23.153	22.140 ± 2.818
25	T25	20.686	23.907	21.799 ± 4.587
26	T26	17.793	24.908	21.635 ± 9.461
27	T27	17.715	26.773	20.442 ± 13.424
28	T28	15.444	31.474	24.983 ± 11.724
29	T29	20.326	26.691	23.209 ± 8.329
30	T30	14.347	29.600	23.519 ± 10.633
31	T31	16.602	26.674	21.888 ± 15.11
	Average	17.6127	25.855	21.567

Table 2: Observed radon concentrations at different places in study area.

cancer risk per million persons per year (ELCR). The annual effective dose, the annual equivalent dose received by the residents of the study area varied from 0.383 mSv/y to 0.818 mSv/y with an average of 0.544 mSv/y and from 0.921 mSv/y to 1.964 mSv/y with an average of 1.306 mSv/y respectively. The high value of the annual effective dose in this study were (0.818) mSv/y. This value was lower than the permissible limits recommended by world health organization (WHO) [35] which it is equal (1-3) mSv/y. According to ours estimations, Table 4 shows the radon induced lung cancer risk for all dwelling in Kufa Technical institute was found and ranges from 35.458 to 75.633 with an average value of 50.297 per 10^6 persons. In general, these estimates indicated that the dwelling under study are characterized by low radon exposure dose, so the people who live in those dwelling are subject to relatively low risk factor for radon induced lung cancer. In general the low levels of radon concentration in these buildings can be attributed to the following reasons such as the good ventilation systems in most places and the good geometric designs, all walls are painted and most locations have covered floors and there are no cracks in the building basement.

Table 5 summarizes the comparison between our results with those conducted in other countries. It seems that our results are near or around the other results [35-44].

Conclusions

In conclusion, we found that the radon levels in Dwellings of Kufa

No.	Sample Code	EEC (Bq/m³)	PAE (mWL)	WLM
1	T1	9.418	2.545	0.131
2	T2	8.123	2.195	0.113
3	T3	7.862	2.124	0.109
4	T4	8.906	2.407	0.124
5	T5	7.843	2.119	0.109
6	T6	7.638	2.064	0.106
7	T7	8.060	2.178	0.112
8	T8	7.584	2.049	0.105
9	T9	11.058	2.988	0.154
10	T10	6.084	1.644	0.084
11	T11	6.775	1.831	0.094
12	T12	7.172	1.938	0.099
13	T13	6.516	1.761	0.091
14	T14	8.383	2.265	0.116
15	T15	6.483	1.752	0.090
16	T16	7.288	1.969	0.101
17	T17	8.433	2.279	0.117
18	T18	6.980	1.886	0.097
19	T19	12.978	3.507	0.181
20	T20	10.261	2.773	0.142
21	T21	10.743	2.903	0.149
22	T22	11.938	3.226	0.166
23	T23	9.169	2.478	0.127
24	T24	8.856	2.393	0.123
25	T25	8.719	2.356	0.121
26	T26	8.654	2.338	0.120
27	T27	8.176	2.209	0.113
28	T28	9.993	2.701	0.139
29	T29	9.283	2.509	0.129
30	T30	9.407	2.542	0.131
31	T31	8.755	2.366	0.122
	Average	8.630	2.332	0.120

Table 3: Values of (EEC), (PAE) and (MWL) in all samples of studied area.

No.	Sample Code	D_{Rn} (mSv/y)	H_E (mSv/y)	ELCR (10⁻⁴)
1	T1	0.594	1.425	54.886
2	T2	0.512	1.229	47.340
3	T3	0.495	1.190	45.818
4	T4	0.561	1.348	51.905
5	T5	0.494	1.1872	45.709
6	T6	0.481	1.156	44.517
7	T7	0.508	1.220	46.972
8	T8	0.478	1.148	44.203
9	T9	0.697	1.674	64.449
10	T10	0.383	0.921	35.458
11	T11	0.427	1.025	39.487
12	T12	0.452	1.085	41.797
13	T13	0.411	0.986	37.978
14	T14	0.528	1.268	48.856
15	T15	0.408	0.981	37.783
16	T16	0.459	1.103	42.473
17	T17	0.531	1.276	49.149
18	T18	0.440	1.056	40.678
19	T19	0.818	1.964	75.633
20	T20	0.647	1.553	59.800
21	T21	0.677	1.626	62.612
22	T22	0.752	1.807	69.572
23	T23	0.578	1.388	53.439
24	T24	0.558	1.340	51.611
25	T25	0.549	1.319	50.816
26	T26	0.545	1.309	50.434
27	T27	0.515	1.237	47.653
28	T28	0.630	1.512	58.238
29	T29	0.585	1.405	54.103
30	T30	0.593	1.424	54.826
31	T31	0.552	1.325	51.024
	Average	0.544	1.306	50.297

Table 4: Values of annual effective dose, annual equivalent dose and the excess lifetime cancer risk in all samples of studied area.

Country	Indoor radon concentration (Bq/m³)	Reference
Saudi Arabia	21-34	[36]
Iraq	61.2	[37]
Serbia	20	[38]
Yemen	42	[39]
Brazil	40	[40]
India	15-41	[41]
Poland	32	[42]
Saudi Arabia	6-24	[43]
Korea	34.1	[44]
Study area	15-32	---------

Table 5: Comparison between our results with international studies.

Technical institute are within the internationally acceptable values and there is no health risks. The average equals to (21.567) Bq/m³. The averageof reading were lower than the permissible limits recommended by ICRP. Also, it is found that all radiation parameters in this study such as potential alpha energy, equilibrium-equivalent radon concentration, working level month, the annual effective dose, the annual equivalent dose rate and the excess lifetime cancer risk per million persons per year rate depend upon many factors inside the dwellings. Ventilation plays an important role as far as the problem is concerned. Computed data indicates that region is safe without posing significant radiological threat to population.

References

1. Banjanac R, Dragić A, Grabež B, Jokovic D, Markushev D, et al. (2006) In Indoor radon measurements by nuclear track detectors :applications in secondary school. Physics, chemistry technology 4: 93-100.

2. http://www.lung.org/associations/charters/midland-states/assets/pdfs/program-misc/kentucky-radon-report.pdf.

3. http://nuclearsafety.gc.ca/pubs_catalogue/uploads/February-2011-Info-0813-Radon-and-Health-INFO-0813_e.pdf.

4. NCRP National Council on Radiation Protection and Measurements (1987) Exposures of the population in the United States and Canada from natural background radiation. Bethesda, Maryland (NCRP Report No. 94).

5. Borgoni R, Tritto V, Bigliottoand C, de Bartolo D (2002) A Geostatistical Approach to Assess the Spatial Association between Indoor Radon Concentration, Geological Features and Building Characteristics. Int J Environ Res Public Health 8: 1420-1440.

6. UNSCEAR (1998) United Nations Scientific Committee on the Effect of Atomic Radiation. United Nations New York.

7. Pundir A, Kamboj S, Singh R (2014) Estimation of indoor Radon, Thoron and their progeny levels in some dwellings of District Yamuna Nagar of India using SSNTD". Nature and Science 12: 94-97.

8. Al-Mosuwi WH, Subber ARH (2013) Indoor Radon Concentration in the Basra Sport City, Basra, Iraq. Journal of Basrah Researches (Sciences) 39: 150-157.

9. Verma D, Khan MS (2014) Assessment of indoor radon, thoron their progeny in dwelling of Bareilly city of northern India using track etch detectors. Rom. Journ. Phys 59: 172-182.

10. Gupta M, Mahur AK, Verma KD (2012) Indoor radon levels in some dwellings surrounding the National Thermal Power Corporations (NTPCs), India. Advances in Applied Science Research 3: 1262-1265.

11. Abd-Elzaher M (2012) An Overview on Studying 222Rn Exhalation Rates using Passive Technique Solid-State Nuclear Track Detectors. American Journal of Applied Sciences 9: 1653-1659.

12. Singha P, Singha P, Singha S, Sahoob BK, Saprab BK, et al. (2015) A study of indoor radon, thoron and their progeny measurement in Tosham region Haryana, India. Journal of Radiation Research and Applied Sciences 8: 226-233.

13. Trudy R (1996) "Najaf". Global Security. R etrieved 2009-09-13.

14. Trudy R (1996) Najaf. Global Security.

15. Eappen KP, Mayya YS (2004) Calibration factors for LR-115 (type-II) based radon thoron discriminating dosimeter. Radiation Measurements 38: 5-17.

16. Pundir A, Kamboj S, Singh R (2014) Estimation of indoor Radon, Thoron and their progeny levels in some dwellings of District Yamuna Nagar of India using SSNTD. Nature and Science 12: 94-97.

17. Duggal V, Rani A, Mehra R (2014) A study of seasonal variations of radon levels in different types of dwellings in Sri Ganganagar district, Rajasthan. Journal of Radiation Research and Applied Sciences 7: 201-206.

18. Lymburner D (2003) Another Human Experiment. DU Education Project, Metal of Dishonor, International Action Center, NewYork, 45-98.

19. Al-Kofahi M, Khader B, Lehlooh A, Kullab M, Abumurad K, et al. (1992) Measurement of Radon-222 in Jordanian Dwellings. International Journal of Radiation Applications and Instrumentation. Part D. Nuclear Tracks and Radiation Measurements 20: 377-382.

20. Khader B (1990) Radon-222 Concentration in the Air of the Dwellings in Irbid Region- Jordan. Yarmouk Univ., Irbid M. Sc. Thesis.

21. Corporation T, Lane W, Creek W, Fleischer R (1981) Passive Integrating Radon Monitor for Environmental Monitoring. Health Phys 40: 693-702.

22. Gupta M, Mahur AK, Verma KD (2012) Indoor radon levels in some dwellings surrounding the National Thermal Power Corporations (NTPCs), India. Advances in Applied Science Research, 3: 1262-1265.

23. Khan MSA, Tariq M, Rawat RBS (2012) Preliminary Measurements of Radon Radiations in (Bare Mode) In Rampur District of Western U.P. (India). IOSR Journal of Applied Physics, 1.

24. Marley F, Denman AR, Philips PS (1998) Studies of radon and radon progeny in air conditioned rooms in hospitals. Radiation Protection Dosimetry 5: 273-276.

25. Chen J (2005) A review of radon doses. Radiation Protection Management 22: 27-31.

26. WHO (2009) World Health Organization, Sets radon action level of 2.7 - less lung cancer risk than EPA 4.0. Global Press Release Distribution.

27. IARC (1988) International Agency for Research on Cancer. Summaries & Evaluations, 43.

28. UNSCEAR (2000) United Nations scientific committee on the effect of atomic radiation sources, effects and risks of ionizing radiation. New York: United Nations.

29. https://www.oecd-nea.org/rp/reports/2011/nea6920-ICRP-recommendations.pdf

30. Mossadegh N, Karimian A, Shahhosseini E, Mohammadzadeh A, Sheibani Sh (2011) Experimental simulation of personal dosimetry in production of medical radiations by research reactor. Radiat Prot Dosimetry 147: 267-271.

31. Issa E (2007) Determination of the conversion factor for the estimation of effective dose in lungs, autography and cardiac procedures Thesis for Master of Science in Medical Radiation Physics.

32. Alberigi S, Pecequilo BR, Lobo HA, Campos MP (2004) Assessment of effective dose from radon levels for tour guides at several galleries of Santana cave Southern Brazil, with CR-39 Preliminary results Radiation. Radiat Prot Dosimetry 145: 252-255.

33. Obed RI, Ademola AK, Ogundare FO (2011) Radon measurements by nuclear track detectors in dwelling Oke- Ogun area, South- Western, Nigeria. Radiation. Protection Dosimetry 148: 475-481.

34. ICRP (1993) Protection Against Radon-222 at Home and at Work. Ann ICRP 23 (2).

35. WHO (2009) WHO handbook on indoor radon - a public health perspective.

36. Abu-Jarad F, Islam MA (1993) A passive radon detector survey in a three-story laboratory building. Nuclear Tracks and Radiation Measurements 22: 257-258.

37. Tawfiq NF (1996) Study Comparssion in Some of Organic and Inorganic Track Detectors and Applications in Environment. Ph.D thesis, University of Al-Mustansiriyah.

38. Antanasijević R, Aničin I, Bikit I, Banjanac R, Dragić A, et al. (1999) Radon measurements during the building of a low-level laboratory. Radiation Measurements 31: 371-374.

39. Khayrata AH, Al-Jarallahb MI, Fazal-ur-Rehmanb X, Abu-Jaradc F (2003) Indoor radon survey in dwellings of some regions in Yemen. Radiation Measurements 36: 449-451.

40. Magalhaes MH, Amaral ECS, Sachett I, Rochedo ERR (2003) Radon-222 in Brazil: an outline of indoor and outdoor measurements. Journal of Environmental Radioactivity 67: 131-143.

41. Shaikh AN, Ramachandran TV, Vinod Kumar A (2003) Monitoring and modelling of indoor radon concentrations in a multi-storey building at Mumbai, India. J Environ Radioact 67: 15-26.

42. Mnich Z, Karpińska M, Kapała J, Kozak K, Mazur J, et al. (2004) Radon concentration in hospital buildings erected during the last 40 years in Białystok, Poland. Journal of Environmental Radioactivity 75: 225-232.

43. Qahtani M, Jarallah MI, Rehman F(2005) Indoor radon measurements in the Women College, Dammam, Saudi Arabia. Radiation Measurements 40: 704-706.

44. Yoon S, Chang B, Kim Y, Byun J, Yun J (2010) Indoor radon distribution of subway stations in a Korean major city. Journal of Environmental Radioactivity 101: 304-308.