



Life Time Cancer Risk Evaluation Due to Inhalation of Radon Gas in Dwellings of Al-Diwaniyah Governorate, Iraq

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 10-05-2021

Revised: 09-06-2021

Accepted: 15-07-2021

Key Words:

Inhalation of radon gas
Annual effective dose
Cancer risks
CR-39 alpha detector

ABSTRACT

Radon is a radioactive natural gas that tends to concentrate in indoor homes and has major health consequences, the most serious of which is the ability to cause lung cancer. This research involves measuring indoor radon concentrations in different types of homes (non-smokers and smokers) in Al-Diwaniyah, Iraq, as well as assessing radon concentrations in cigarette samples acquired from Iraqi markets. nuclear track detectors were used to measure radiological parameters to determine annual effective dose levels and the associated cancer risk (CR-39). The average indoor radon concentrations, annual effective dose, and increased cancer risk attributable to the inhalation of indoor radon were $22.93 \pm 3.67 \text{ Bq.m}^{-3}$, $0.58 \pm 0.08 \text{ mSv.y}^{-1}$ and $2.2 \times 10^{-3} \pm 0.35$ respectively, for non-smokers home. For smokers' home, these parameters were $29.77 \pm 5.24 \text{ Bq.m}^{-3}$, $0.75 \pm 0.12 \text{ mSv.y}^{-1}$, and $2.89 \times 10^{-3} \pm 0.50$, respectively. The value of radon gas in cigarette samples ranged from 24.16 ± 2.55 to $33.91 \pm 5.13 \text{ Bq.m}^{-3}$. The obtained results have been compared with limits recommended by International Commission on Radiological Protection (ICRP) and found to be within allowed limits.

INTRODUCTION

Humans are exposed to large levels of internal and external radiation on a daily basis without even realizing it. Radiation exposure is defined as the introduction of radionuclides into the human body through the consumption of contaminated water and food, inhalation of contaminated air, or contact with contaminated soil and air (Aswood et al. 2019, Salih et al. 2019, Al-Gharabi & Al-Hamzawi 2020). According to the National Council on Radiation Protection (NCRP) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), natural radiation in the environment is the major source of radiation exposure. One of these radiation sources is radon, a colorless, odorless gas with high toxicity and three naturally occurring isotopes: ^{222}Rn , ^{219}Rn , and ^{220}Rn . Radon-222 occurs naturally in minute quantities as an intermediate step in the normal radioactive decay chains through which thorium and uranium slowly decay into lead and various other short-lived radioactive elements. Radon itself is the immediate decay product of radium (Ra). Its most stable isotope, ^{222}Rn , has a half-life of only 3.8 days, making it one of the rarest elements. Hence, radon represents the most harmful and important natural isotopes of the radioactive element, making it one of the rarest elements (Okeji & Agwu 2012). Radon undergoes radioactive decay when it releases ionizing radiation and forms "daughter" elements, known as decay products. It is

the release of radiation from this decay process that leads to exposure and health risks from radon. During the decay process, radon normally decays to short-lived nuclides called radon daughters, producing harmful particles, including alpha particles, as well as beta and gamma rays. Once these particles enter the body and destroy most of the living cells passing through them. Because radon can enter the human body through ingestion or inhalation, the absorbed dosage of radon into the body will increase, and because people spend so much time in their homes, their exposure to internal radon will be higher. As a result, there will be more illnesses related to environmental exposures due to indoor radon exposure (Sharma & Virk 2001). Also, because of the dangers of the radioactive gas radon in homes. The International Agency for Research on Cancer classed it as a carcinogen, malignant, and high-risk substance (IARC 1988). Even though there are three distinctive isotopes of radon produced in the natural decay series, the most important one is ^{222}Rn ($T_{1/2} = 3.82 \text{ d}$), which is a progeny of ^{226}Ra . Radon decays by alpha particle emission, while also generating gamma rays with very low probability (<0.08%). Together with its mainly short-lived daughters, radon's contribution to the world annual dose from background radiation is on the level of 1.2 mSv, representing roughly 50% of the overall dose (UNSCEAR 1988)

Many researchers have studied radon and its impact on human health through thorough investigations of indoor

exposure rates, annual effective dose, and residents' lifetime cancer risk (Aswood et al. 2020, Warner et al. 1996, Al-Hamzawi et al. 2019). The goal of this study is to determine the indoor radon concentration and annual effective inhalation in the homes tested in Al-Diwaniyah, Iraq's southern governorate. As a result, using the effective approach of CR-39 solid state alpha track detectors with decay emitters, determine the lifetime cancer risk of residents.

MATERIALS AND METHODS

Collection and Preparation of Samples

The present work was to determine the cancer risk and estimate the annual effective dose due to inhalation of indoor radon through measuring the indoor radon levels in the dwellings of Al-Qadisiyah, Iraq. This study included 60 subjects (20 non-smokers dwellings and 20 smokers' dwellings, in addition to 20 cigarette samples collected from Iraqi

markets), Table 1 includes the collected data and information on locations, codes, types of cigarettes, and other data. The CR-39 nuclear track detector was primarily employed in this study, with a thickness of around 500 m (Tasl Company, UK). The detectors were carefully cut into little pieces with dimensions of (1.51.5) cm² so that they could be used immediately. The storage in this study covers non-smokers' and smokers' houses, which was accomplished by exposing nuclear reagents to the indoor air openly to detect radon concentrations in the residences and determine the health risks associated with them. CR-39 was cultivated on the walls of Al-Diwaniyah governorate houses, at a distance of 150 cm from the ground, with a double-sided tape, and specific codes were placed on it, taking into consideration the date of cultivating (Obed et al. 2018). The closed tube technique (Poly Vinyl Chloride) PVC-tube was used to store the cigarette samples for analysis. It was developed with length, thickness, and diameter measurements of 10.5 cm,

Table1: Database dwellings (non-smokers and smokers) and cigarettes samples in this study.

Studied Samples	Location	Code and number of samples
Non- smokers' dwellings	Al- Karama	N ₀₁ -N ₀₄
	Al-Wehda	N ₀₅ -N ₀₈
	Al-Jazayir	N ₀₉ -N ₁₂
	Al- Euruba	N ₁₃ -N ₁₆
	Al- Jumhuri	N ₁₇ -N ₂₀
Total		20
Smokers' dwellings	Al- Karama	S ₀₁ -S ₀₄
	Al-Wehda	S ₀₅ -S ₀₇
	Al-Jazayir	S ₀₈ -S ₁₃
	Al- Euruba	S ₁₄ -S ₁₇
	Al- Jumhuri	S ₁₈ -S ₂₀
Total		20
Cigarettes	Type of cigarettes	
	KENT SILVER	C ₀₁ -C ₀₂
	OSCAR	C ₀₃ -C ₀₄
	SUMER	C ₀₅ -C ₀₆
	PINE	C ₀₇ -C ₀₈
	ASPEN	C ₀₉ -C ₁₀
	BON	C ₁₁ -C ₁₂
	MAC	C ₁₃ -C ₁₄
	MIAMI	C ₁₅ -C ₁₆
	MASTER	C ₁₇ -C ₁₈
ESSE BLACK	C ₁₉ -C ₂₀	
Total		20

2 mm, and 2.1 cm, respectively, to ensure that only radon reaches the CR-39 detector and no other gases (Salih et al 2019). The cigarette samples were dried in an electric oven for 15 minutes at 150°C. The samples were then pulverized and sieved many times with a hand mill (mortar) to generate a homogeneous dry powder. After that, 10 gm of sample powder was placed in the bottom of the tube, a CR-39 detector was installed by adhesive tape at the bottom of the tube cover, and the forms were stored as a whole from March 24, 2020, to June 22, 2020; this is equivalent to 90 days to ensure the radionuclides in the samples reach equilibrium state (Fig. 1a, b). After 90 days, all detectors and samples of cigarettes were collected from the homes for process etching of the CR-39 detectors using NaOH etching solution in a water bath to reveal the latent tracks on the CR-39 arising from the radon indoor decay process. At 70°C for 8 h, a 6.25 mol.L⁻¹ of this solution was used (Fig. 1c). Then, the pathways of the alpha particles (latent tracks) that emerge on the surface of the CR-39 detectors are traced using an optical microscope with a magnification of 400X and a divided lens with a known area (Fig. 1d, e). The equation below is used to measure the density of latent tracks (Showard & Aswood 2020)

$$\rho\left(\frac{tr}{cm^2}\right) = \frac{\text{Average number of total tracks (N)}}{\text{(Area of view field (A))}} \quad \dots (1)$$

CALCULATIONS

After the density of the tracks was calculated, the concentrations of indoor radon in dwellings of (non-smokers and smokers) were calculated, thus the radiation doses and lifetime cancer risk due to inhalation of radon can be determined, and from the same equation, we can calculate radon concentration for cigarettes samples. Therefore, the equation used to measure radon concentration (C_{Rn}) is given by the following relationship (Aswood et al. 2018):

$$C_{Rn}\left(\frac{Bq}{m^3}\right) = \frac{\rho}{k \times t} \quad \dots (2)$$

k: calibration factor which equals to 0.212 (tr.cm⁻²)/ d. (Bq.m⁻³);

t: exposure time (90 d).

The formula used to measure the annual effective dose (AED) is (Obed et al. 2018):

$$AED\left(\frac{mSv}{y}\right) = C_{Rn} \times F \times O \times T \times DCF \quad \dots (3)$$

C_{Rn} : radon concentration Bq.m⁻³;

F: equilibrium factor (0.4);

O: occupancy factor (0.8);

T: indoor occupancy time in a year (8760 h.y⁻¹);

DCF: dose conversion factor (9.0×10⁻⁶ mSv.h⁻¹. (Bq.m⁻³)). Based upon calculated values of (AED), excess lifetime cancer risk (ELCR) is calculated using the following equation (Obed et al. 2018):

$$ELCR = AED\left(\frac{mSv}{y}\right) \times DL(y) \times RF\left(\frac{1}{Sv}\right) \quad \dots (4)$$

DL: life expectancy (70 y);

RF: risk factor (0.055 1.Sv⁻¹)

RESULTS AND DISCUSSION

Table 2 summarizes indoor radon concentrations in non-smokers' and smokers' homes, as well as radon concentrations in cigarettes samples, in the Al-Diwaniyah governorate. The highest value of indoor radon concentration in non-smokers' households was 26.33 4.31 Bq.m⁻³ (N₀₁ sample) and the lowest value was 16.75 1.08 Bq.m⁻³ (N₁₀ sample). These were found in Al-Karama and Al-Jazayir

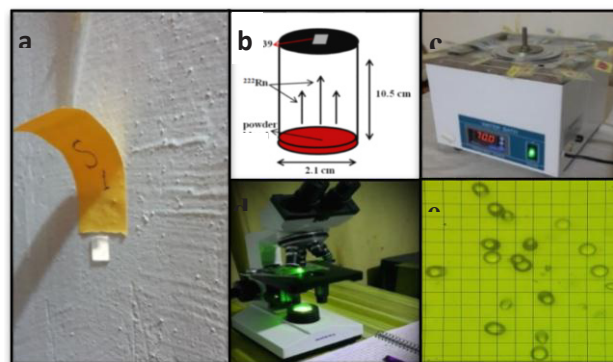


Fig. 1: The storage of detectors in dwellings and cigarettes samples(a, b), water bath with the detectors(c), optical microscope (d), the tracks of radon on the detectors under a microscope (e).

localities respectively. Also, the highest and lowest values of indoor radon concentration for smokers' homes were $32.94 \pm 5.33 \text{ Bq.m}^{-3}$ (S_{07} sample) and $25.22 \pm 4.66 \text{ Bq.m}^{-3}$ (S_{04} sample), found in Al-Wehda and Al- Karama areas, respectively. For cigarettes samples, the radon concentration varied from $22.88 \pm 3.54 \text{ Bq.m}^{-3}$ (C_{18}) sample to $33.91 \pm 5.13 \text{ Bq.m}^{-3}$ in the (C_{08}) sample. The average value of indoor radon gas in non-smokers' and smokers' homes are 22.93 ± 3.67 and $29.77 \pm 5.24 \text{ Bq.m}^{-3}$, respectively. While the average value of radon levels in cigarette samples is $29.34 \pm 4.42 \text{ Bq.m}^{-3}$.

Table 3 shows the annual effective dose (AED) and excess lifetime cancer risk (ELCR) associated with radon inhalation in non-smokers' and smokers' homes. The average (AED) in non-smokers' and smokers' homes were $0.58 \pm 0.08 \text{ mSv.y}^{-1}$ and $0.75 \pm 0.12 \text{ mSv.y}^{-1}$, respectively. The average values of ELCR in non-smokers' and smokers' homes were 2.23 ± 0.35 and 2.89 ± 0.50 , respectively. These results show that the radon concentrations in non-smokers' homes are lower than the concentrations in smokers' homes and cigarettes samples due to many reasons, including the ventilation factor, air extractor, design and modernity of construction, etc.

Therefore, it was found that smoking had a clear effect on increasing radon concentrations.

Table 4 shows a comparison of the current study's indoor radon concentration (C_{Rn}) and annual effective dose (AED) with those of previous studies in different locations. Except for Babylon in Iraq, and Japan, the current indoor radon levels are lower than all the values of previous studies. The indoor radon concentration range is well under the EPA's permitted limit (148 Bq.m^{-3}) (EPA 2003). Table 4 shows that the current values of annual effective dose (AED) in non-smokers' homes are lower than those of previous studies, with the exception of Baghdad and Babylon in Iraq and Japan. However, the annual effective dosage range is within the ICRP permissible limit (3mSv.y^{-1}) (ICRP 1993). Fig. 2 provides a comparison of the average values of ELCR of non-smokers' homes in the current study with the results of previous studies. Except for Baghdad, Iraq, the results in this study are less than all the results of the previous studies. The extra lifetime cancer risk range, on the other hand, is less than the EPA's permitted levels (EPA 2003). In general, an estimate of the excess lifetime cancer risks due to inhalation radon was obtained

Table 2: Radon gas concentrations (Bq.m^{-3}) in studied samples.

Non-smokers' dwellings		Smokers' dwellings		Cigarettes samples	
SC	Indoor radon	SC	Indoor radon	SC	Radon content
N_{01}	26.33 ± 4.31	S_{01}	32.11 ± 4.62	C_{01}	32.33 ± 5.02
N_{02}	24.18 ± 3.29	S_{02}	30.24 ± 5.50	C_{02}	31.22 ± 5.61
N_{03}	20.47 ± 4.85	S_{03}	28.46 ± 5.03	C_{03}	27.91 ± 5.92
N_{04}	20.75 ± 5.11	S_{04}	25.22 ± 4.66	C_{04}	26.11 ± 2.02
N_{05}	24.89 ± 2.13	S_{05}	31.17 ± 5.99	C_{05}	31.87 ± 5.11
N_{06}	23.72 ± 2.62	S_{06}	27.09 ± 2.19	C_{06}	30.01 ± 5.83
N_{07}	24.42 ± 5.08	S_{07}	32.94 ± 5.33	C_{07}	$33.73.16 \pm$
N_{08}	26.30 ± 4.51	S_{08}	32.41 ± 5.81	C_{08}	33.91 ± 5.13
N_{09}	25.59 ± 3.06	S_{09}	32.16 ± 5.60	C_{09}	24.19 ± 4.01
N_{10}	16.75 ± 1.08	S_{10}	27.25 ± 4.19	C_{10}	23.92 ± 3.43
N_{11}	22.82 ± 4.03	S_{11}	29.19 ± 6.33	C_{11}	25.33 ± 1.44
N_{12}	20.24 ± 5.05	S_{12}	28.01 ± 5.43	C_{12}	24.16 ± 2.55
N_{13}	24.91 ± 4.02	S_{13}	27.31 ± 1.44	C_{13}	33.03 ± 5.65
N_{14}	23.28 ± 3.12	S_{14}	31.11 ± 6.54	C_{14}	31.39 ± 2.55
N_{15}	21.17 ± 5.17	S_{15}	29.32 ± 4.65	C_{15}	32.56 ± 5.98
N_{16}	22.82 ± 2.19	S_{16}	31.17 ± 4.55	C_{16}	31.04 ± 7.44
N_{17}	20.24 ± 2.31	S_{17}	29.68 ± 5.98	C_{17}	24.89 ± 3.17
N_{18}	23.68 ± 3.81	S_{18}	28.77 ± 7.44	C_{18}	22.88 ± 3.54
N_{19}	22.56 ± 3.61	S_{19}	32.35 ± 6.43	C_{19}	33.49 ± 5.19
N_{20}	23.52 ± 4.18	S_{20}	29.52 ± 7.13	C_{20}	32.76 ± 6.12
Mean \pm S.D	22.93 ± 3.67		29.77 ± 5.24		29.34 ± 4.42

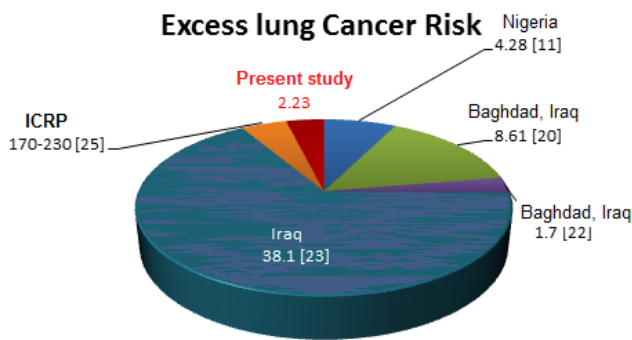


Fig. 2: A comparison between average excess lifetime cancer risk (ELCR) in non-smokers dwellings in the present study with previous studies.

inside the dwellings of Al-Diwaniyah, Iraq, in spite of Fig. 3 showed that the high the indoor radon values, the annual effective dose and the excess lifetime cancer risk in the dwellings of smokers compared to non-smokers, but the results showed that all these values were within the internationally allowable limits. Finally, the findings showed that higher radon concentrations in cigarettes samples were associated

with higher radon concentrations in smokers' houses. As a result, there is an elevated risk of cancer throughout one's lifetime (ELCR). The ratio of non-smokers' calculated values to smokers' calculated values was 0.77 percent.

CONCLUSION

The findings show that non-smokers' indoor radon concentrations (CRn), annual effective dose (AED), and excess lifetime cancer risk (ELCR) are all lower than smokers' homes. However, high values in some dwellings could be owing to building materials and types, or insufficient ventilation and air extractors, among other things. Furthermore, a positive relationship exists between the increase in indoor radon concentrations in smokers' homes and the increase in radon concentrations in cigarette samples. As a result, the annual excess lifetime cancer risk (ELCR) in smokers' homes will increase. The current study shows that the measured levels of radon gas in Al-Diwaniyah, Iraq, are within the global permitted limit, indicating that these havens are moderately protected. The intake of natural indoor radon gas in homes poses no significant risk to people.

Table 3: Annual effective dose (AED) and excess lifetime cancer risk (ELCR) from indoor radon of non-smokers and smokers' dwellings.

Non-smokers' dwellings			Smokers' dwellings		
SC	AED in (mSv.y ⁻¹)	ELCR×10 ⁻³	SC	AED in (mSv.y ⁻¹)	ELCR×10 ⁻³
N ₀₁	0.66±0.10	2.56±0.41	S ₀₁	0.81±0.11	3.12±0.44
N ₀₂	0.61±0.08	2.35±0.31	S ₀₂	0.76±0.13	2.94±0.53
N ₀₃	0.52±0.12	1.99±0.47	S ₀₃	0.72±0.12	2.76±0.48
N ₀₄	0.52±0.12	2.02±0.49	S ₀₄	0.64±0.11	2.45±0.45
N ₀₅	0.63±0.05	2.42±0.20	S ₀₅	0.79±0.15	3.03±0.58
N ₀₆	0.6±0.06	2.3±0.25	S ₀₆	0.68±0.05	2.63±0.21
N ₀₇	0.62±0.12	2.37±0.49	S ₀₇	0.83±0.13	3.20±0.51
N ₀₈	0.65±0.11	2.55±0.43	S ₀₈	0.81±0.14	3.15±0.56
N ₀₉	0.65±0.07	2.49±0.29	S ₀₉	0.81±0.14	3.12±0.54
N ₁₀	0.42±0.02	1.63±0.10	S ₁₀	0.69±0.10	2.65±0.40
N ₁₁	0.58±0.10	2.22±0.39	S ₁₁	0.74±0.15	2.84±0.61
N ₁₂	0.51±0.12	1.97±0.49	S ₁₂	0.71±0.13	2.72±0.52
N ₁₃	0.63±0.10	2.42±0.39	S ₁₃	0.69±0.03	2.65±0.13
N ₁₄	0.59±0.07	2.26±0.30	S ₁₄	0.78±0.16	3.02±0.63
N ₁₅	0.53±0.13	2.06±0.50	S ₁₅	0.74±0.11	2.85±0.45
N ₁₆	0.58±0.05	2.22±0.21	S ₁₆	0.79±0.11	3.03±0.44
N ₁₇	0.51±0.05	1.97±0.22	S ₁₇	0.75±0.15	2.88±0.58
N ₁₈	0.60±0.09	2.30±0.37	S ₁₈	0.73±0.18	2.79±0.72
N ₁₉	0.57±0.09	2.19±0.35	S ₁₉	0.82±0.16	3.14±0.62
N ₂₀	0.59±0.10	2.28±0.40	S ₂₀	0.74±0.17	2.87±0.69
Ave.	0.58±0.08	2.23±0.35		0.75±0.12	2.89±0.50

Table 4: A comparison between average indoor radon concentration (C_{Rn}) and annual effective dose (AED) in non-smokers homes in the present study with previous studies.

No.	C_{Rn} (Bq.m ⁻³)	AED (mSv.y ⁻¹)	Country	References
1	4.18	0.11	Babylon, Iraq	Obaed & Aswood (2020)
2	176.15	1.114	Ibadan, Oyo State, Nigeria	Obed et al. (2018)
3	25.52	0.64	Pirayiri- Palakkad, India	Ramsiya et al. (2013)
4	-	3	ICRP	ICRP (1993)
5	148	-	EPA	EPA (2003)
6	45.487	0.478	Bagdad, Iraq	Al-Alawy and Fadhil (2016)
7	143.77	-	Kurdistan, Iraq	Ismail and Jaafar (2010)
8	6.1	0.45	Japan	et al. (2003)
9	27.83	0.70	Al-Diwaniyah, Iraq	Present study

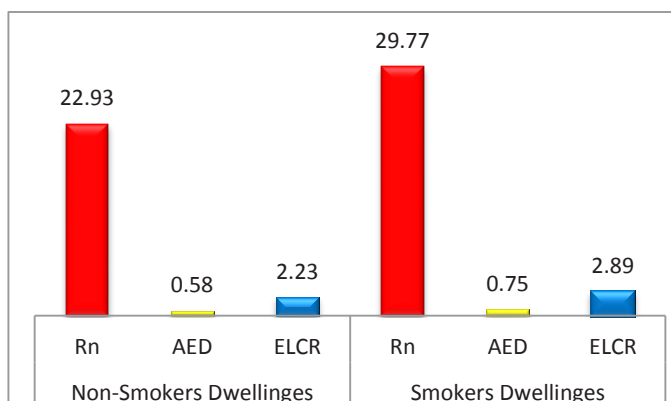


Fig. 3: Average values for indoor radon concentration (Bq.m⁻³), annual effective dose (mSv.y⁻¹), and excess lifetime cancer risk of non-smokers and smokers' dwellings.

ACKNOWLEDGEMENTS

The authors acknowledge, with gratitude, the assistance received from the Department of Physics, University of Al-Qadisiyah-Iraq. They would also like to extend their heartfelt appreciation to the dwellings that participated in the survey and their assistance to complete and succeed this research work.

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