MEASUREMENT OF INDOOR RADON CONCENTRATIONS IN DIFFERENT DWELLINGS IN ARAR, SAUDI ARABIA

by

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Indoor radon concentrations in 33 dwellings in Arar city were measured using a CR-39 detector. This work is the first in the region and was done to assess the health risks. The exposure time was about 4 months, from May to September 2017. It was found that the indoor radon concentration changed in the range from 7.7 to 89.1 Bqm^{-3} with an overall average of 44.05 6.21 Bqm^{-3} while the geometric mean is 39.51 Bqm^{-3} with a geometric standard deviation of 1.67. These values are within the acceptable level set by the International Committee for Radiation Protection. The annual effective dose received by the population of Arar was reported and it varied in the range 0.16 –1.82 mSv with an average value of 0.9 0.16 mSv and the geometric mean is 0.81 mSv. The exposure to radon progeny was studied where the minimum, maximum, average, and geometric mean of exposure are 0.83$\cdot$10^{-3}, 9.63 10^{-3}, 4.76 0.67 10^{-3} and 5.05 10^{-3} WLM, respectively. Finally, for the estimation of cancer risks, the excess lifetime cancer risk was investigated. Its average value was 3.7 10^{-3} which is relatively higher.

Key words: radon concentration, indoor radon, dwelling, CR-39, Arar, Saudi Arabia

INTRODUCTION

Radon is a naturally occurring radioactive, inert and heavy gas. It is produced from the decay of ^{238}U and ^{232}Th, which are found in the Earth's crust with different amounts according to the geographical location [1]. There are three different isotopes of radon gas, which are: ^{222}Rn that is the main isotope which belongs to the ^{238}U decay series, its half-life ($T_{1/2}$) is 3.82 days, and it decays by emission of alpha particles of energy 5.5 MeV; ^{220}Rn is called thoron, it belongs to the ^{232}Th decay series and its $T_{1/2}$ = 55.6 s; ^{219}Rn is called actinon, it belongs to the ^{235}U decay series and its $T_{1/2}$ = 3.96 s. The current epidemiological investigations of occupational exposures of miners and domestic exposures of people, in general, proved the existence of the risks of lung cancer due to inhalation of radon and radon progeny [2, 3]. In addition, it is reported that radon gas in dwellings causes about 21,100 lung cancer deaths per years in the USA [4]. Radon decays into two products, ^{218}Po and ^{214}Po, and their interaction with the biological tissues in the lungs leads to DNA damage [5] which causes cell mutation that leads to cancer [6]. Radon comes from soil, building materials, and water supplies. It can penetrate through cracks and breaks in the walls and establishments inside homes where it can be accumulated to harmful levels. Inhaling of indoor radon and its progeny forms about 60 % of the total background radiation dose of human beings [7]. Radon concentration in indoor air is on average 2-10 times higher than that in the free atmosphere [8-10] and it depends on the rate of exhalation of radon from the soil and the intensity of turbulent air mixing.

The exposure to radon progeny (*EP*) is expressed in units of working level months (WLM). 1 WLM has been equal to 1 WL exposure for 170 hours, which is equivalent to 130,000 MeV alpha energy per liter air or 20.8 μJ alpha energy per m^3 air. In case of *EP* at home, assuming 7000 hours are spent indoors per year, 1 Bqm^{-3} = = 0.0044 WLM [11].

Many investigators are interested in the topic of measuring indoor radon concentrations in different regions in the world [12-14] and in Saudi Arabia [15-17]. In addition, some academic programs in Saudi Arabian universities are concerned with monitoring the radon levels in the different areas in the Kingdom [18]. The first survey of this type was in 1984 [19]. In the last decade, Alghamdi and Aleissa [15] studied the radon level in Riyadh. It was found

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that the radon concentration varied from 1 to 195 Bqm^{-3}, with an average value of 24.68 Bqm^{-3}. Al-Yami [20] measured such concentrations in the Najran region and found that it ranged from 9 to 163 Bqm^{-3} with a mean value of 49 14 Bqm^{-3}. The average radon concentration in low ventilated rooms in Jeddah was 46.80 8.80 Bqm^{-3} [21] but in Al-Madinah Al-Munawarah the average radon concentration was 21 2.5 Bqm^{-3} [16]. In Al-Kharj, it was 114 41 Bqm^{-3} [17]. Despite the previously mentioned literature, more surveys are still needed to add new building types and other geographic locations to the radon database.

This study intends to find the indoor radon concentration in various dwellings in Arar city. Such an estimation was carried out using a CR-39 detector as an instance of alpha-particle etched track detectors. It is worth mentioning that the present work is the first of its kind in this region and has been done to assess the health risks. In addition, the annual effective dose (*H*) received by the population of Arar was assessed. The exposure to radon progeny (*EP*) and excess lifetime cancer risk (*ELCR*) were reported as well. Finally, this work enriches the radon survey in the main cities of Saudi Arabia.

EXPERIMENTAL WORK

Integrated indoor radon measurements were performed for thirty-three dwellings of Arar city, fig. (1), in randomly selected homes. Arar is located at 30°59' N 41°1' E at approximately 546 m above sea level. It is the northern border province capital. It is to the far north of Saudi Arabia on the Iraqi border. CR-39 track etched detectors (TASTRACK) were used for indoor radon level measurements. This is in accordance with the National Radiological Protection Board (NRPB) Measurements Protocol [22]. The density of used CR-39 ($C_{12}H_{18}O_7$) is 1.3 gcm^{-3} and its thickness is about 0.5 mm. CR-39 sheets were cut into pieces of dimensions 1.0 cm × 1.0 cm before use. In the present work, CR-39 films are fixed on the bottom of plastic cups of 10 cm height and 5 cm diameter and the cup was filtered through a filter membrane. This method is called "Filtered Setup", fig. (2). The filtered setup has been calibrated in a homemade radon calibration system [23]. The exposure time in all the dwellings was about four months from May to September 2017. After irradiation the detectors in the houses, the rate of track density were calculated after etching the detector, the radon concentration was determined in each house. In the present work, we have apartments and detached houses. They were built using sand, cement, bricks, marble, and concrete as construction materials. Each house has two to four rooms with common walls and, in some cases, interconnecting doors. Most of the buildings were air-conditioned. The climate in Arar is classified as hot desert climate so, energy saving has led to the tighter sealing of windows and doors, so the radon concentration must be very significant. The humidity levels in this period of time were 12-41 %, and the temperature range was 22-46 °C. After collecting the detectors (samples) from the dwellings, they were chemically etched at first using a 6.25 M sodium hydroxide solution at 70 °C for 6.5 hours. A water path of stabilizing temperature (accuracy 0.5 °C) was utilized in the etching process. The collected samples were inserted in bottles with tight lids to ensure the constancy of the etching solution concentration. The samples were grasped at the same depth in the etchant solution. Then, they were immersed in running water for a reasonable time interval to remove all etchant products from the surfaces. At last, the samples were painstakingly dried and afterward utilized for analysis. An optical microscope fitted with a magnification of 40-100 X was used for estimation of the track diameter. Such a microscope was associated with a web digital camera to catch images of the sample using the microscope and was saved on a laptop. To analyze the tracks after calibration, a commercial software (Lumenera INFINITY ANALYZE software) was used.

The radon concentration (C_{Rn}) in Bqm^{-3} is calculated according to the following relation

$$C_{\mathrm{Rn}} \quad \frac{\rho}{Kt_o} \tag{1}$$

where *K* is the calibration factor (tracks cm^{-2}/Bqm^{-3} day), the quantity used to convert the observed track density rates to the activity concentrations, is the average track density (track cm^{-2}) and t_o is the exposure time (day) [24, 25]. Indeed, the calibration factor *K* could be found using the calibration device described in a previous work [23].

The annual effective dose (*H*), in units of mSvy, to the inhabitants of the investigated city due to radon and its progeny is calculated by applying the following equation

$$H \quad C_{\mathrm{Rn}} FOTDF_{\mathrm{A}} \tag{2}$$

where *F* is the equilibrium factor between radon and its progeny [26]. According to UNSCEAR for typical residential environments, an average value of 0.4 was taken [27]. *O* is the occupancy factor taken as 0.8, *T* – the time in hours in a year and *D* – the dose conversion factor whose value to the public is 4 mSv/*WLM*. F_A – the annual correction factor whose value is 0.81 [15].

The exposure to radon progeny (EP), in units of WLM, is related to the radon concentration in Bqm^{-3} by the eq. [28]

$$EP \quad \frac{C_{\mathrm{Rn}} F}{3700} \tag{3}$$

The excess lifetime cancer risk (ELCR) gives the probability of developing cancer over a lifetime at a

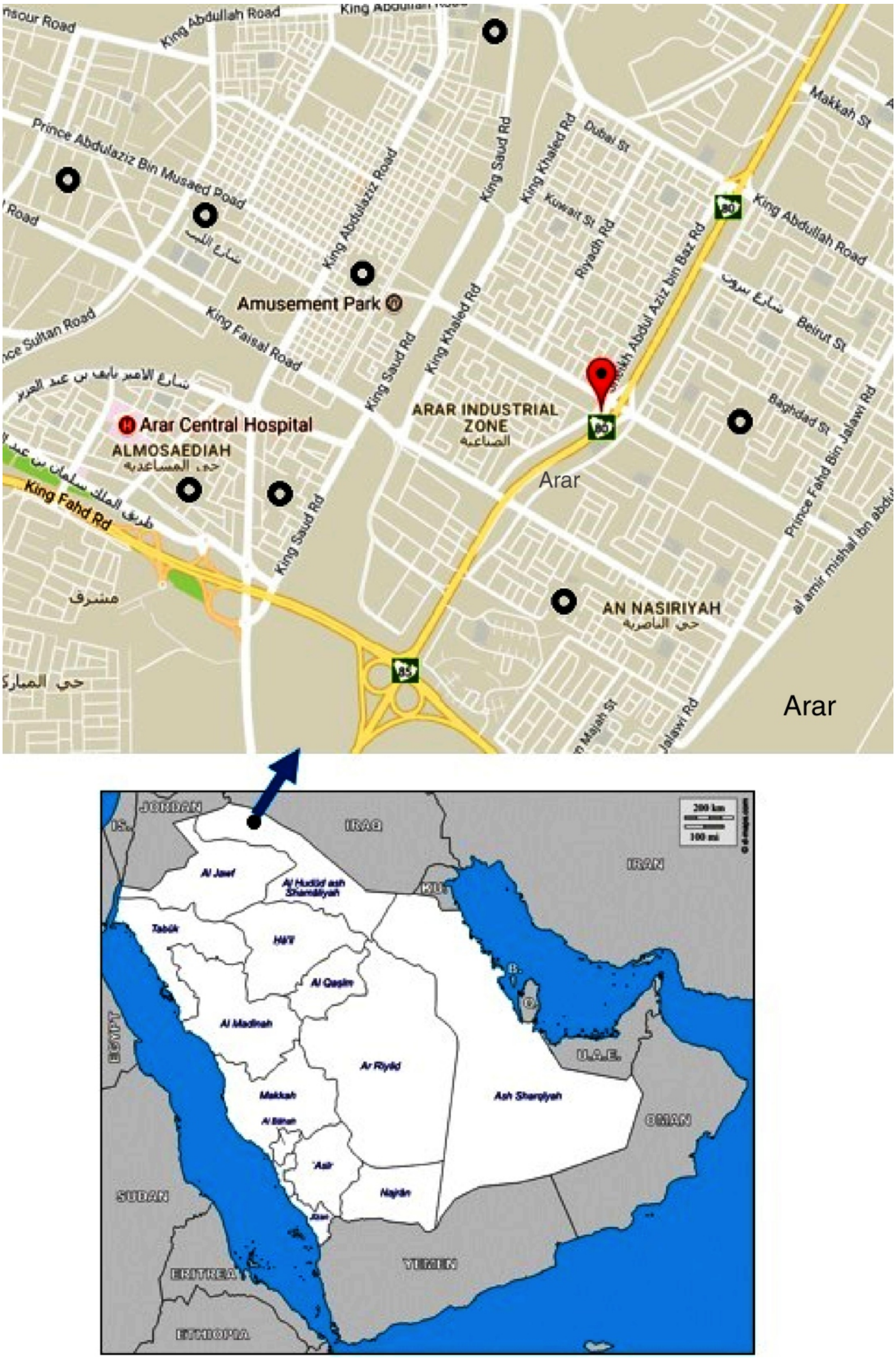

Figure 1. The map of the investigated area in this work (taken from https://time.is/map/Arar) (the black circles are the location of the investigated dwellings)

given exposure level. It is displayed as a value representing the number of additional cancers expected in a given number of individuals with exposure to a cancer-causing agent at a given dose. It depends on H as in the following equation

$$ELCR = HDLRF \tag{4}$$

where DL is the average of lifelife span (estimated to be 74.5 years in Saudi Arabia), RF is the fatal cancer risk per Sievert (5.5 10^{-2} Sv) recommended by ICRP 103 [29].

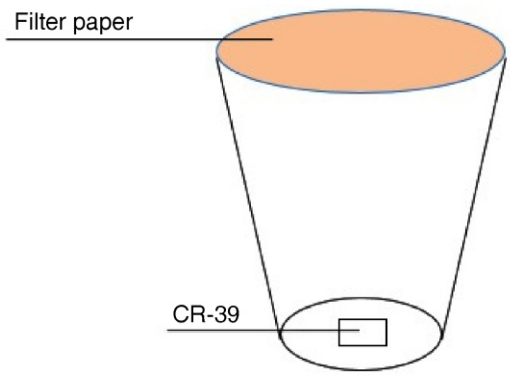

Figure 2. Schematic diagram of the geometry of the CR-39 radon detector used

RESULTS AND DISCUSSIONS

The code, geographic location, storey level, ventilation and altitude from sea level of the different samples (dwellings) are presented in tab. 1. The concentration of radon recorded in all dwellings at the 33 locations of Arar city is shown in fig. 3. It was observed that C_{Rn} varied from 7.7 Bqm^{-3} in the location 10 km from Arar (S27) to 89.1 Bqm^{-3} in An Nasiriyah (S8) with an average value of 44.05   6.21 Bqm^{-3}, which is slightly higher than the world average of 39   2.3 Bqm^{-3} [7]. The geometric mean is also calculated and its value is 39.51 Bqm^{-3} with a geometric standard deviation of 1.67. Thirteen dwellings have C_{Rn} values less than the worldwide weighted average. The radon concentrations, in general, are within the acceptable region set by the ICRP, which is (0-300) Bqm^{-3} [30] and the safe limit of 150 Bqm^{-3} set by the Environmental Protection Agency (EPA) of the USA [31]. The higher values of C_{Rn} in some locations may originate from the soil and rocks that are found around the dwelling that accumulates indoors. In addition, people's habits represent a significant parameter.

The annual effective doses (H) received by the population of Arar have also been found and presented in tab. 2. These doses vary from 0.16 to 1.82 mSv with an average of 0.9   0.16 mSv and the geometric mean is 0.81 mSv. These doses do not exceed the ICRP limit, which is 3-10 mSv [26]. About 21 locations have annual effective doses under 0.97 mSv.

Table 1. The code, geographic location, storey level, ventilation and altitude of the different dwellings of Arar

Sample code	Location	Storey level	Ventilation of the dwellings	Altitude [m]
S1	Al-mesaedya Al-gharbia	Ground	Ventilated	544
S2	Al-mesaedya Al-gharbia	Ground	Ventilated	544
S3	Al-mesaedya Al-gharbia	Ground	Ventilated	544
S4	Al-mesaedya Al-gharbia	Ground	Not ventilated	544
S5	Al-mesaedya Al-gharbia	Ground	Ventilated	544
S6	An Nasiriyah	2^{nd}	Ventilated	549
S7	An Nasiriyah	2^{nd}	Ventilated	549
S8	Al-mesaedya Al-sharkia	Ground	Not ventilated	539
S9	Al-mesaedya Al-sharkia	Ground	Ventilated	539
S10	Al-mohamadya	1^{st}	Ventilated	538
S11	Al-mohamadya	1^{st}	Ventilated	538
S12	Al-khaledya	Ground	Ventilated	546
S13	10 km from Arar	2^{nd}	Ventilated	547
S14	Al-mohamadya	1^{st}	Ventilated	538
S15	Al-mohamadya	1^{st}	Ventilated	538
S16	Badanah	1^{st}	Ventilated	541
S17	Badanah	1^{st}	Ventilated	541
S18	Al-mohamadya	2^{nd}	Ventilated	541
S19	Al-mohamadya	2^{nd}	Ventilated	541
S20	Al-khaledya	1^{st}	Ventilated	549
S21	Al-mohamadya	2^{nd}	Ventilated	541
S22	Al-khaledya	Ground	Not ventilated	546
S23	Al-Salehya	3^{rd}	Ventilated	556
S24	Al-Salehya	3^{rd}	Ventilated	556
S25	25 km from Arar	2^{nd}	Ventilated	533
S26	10 km from Arar	2^{nd}	Ventilated	547
S27	Midtown of Arar	2^{nd}	Ventilated	544
S28	Al-mesaedya Al-gharbia	1^{st}	Ventilated	547
S29	25 km from Arar	Ground	Ventilated	527
S30	Midtown of Arar	2^{nd}	Ventilated	544
S31	Al-mesaedya Al-sharkia	1^{st}	Ventilated	542
S32	Al-mesaedya Al-sharkia	1^{st}	Not ventilated	542
S33	Al-mesaedya Al-gharbia	1^{st}	Ventilated	547

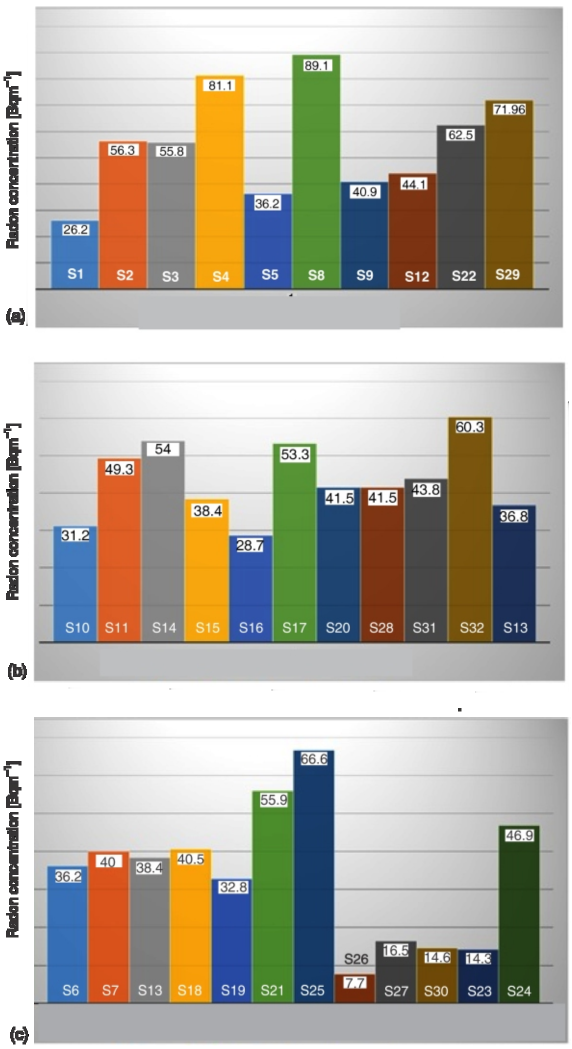

Figure 3. The concentration of radon recorded in (a) ground (S1-S5 Al-mesaedya Al-gharbia, S8, S9 Al-mesaedya Al-sharkia, S12, S22 Al-khaledya, S29 25 km from Arar); (b) first (S10, S11, S14, S15 Al-mohamadya, S16, S17 Badanah, S20 Al-khaledya, S28, S33 Al-mesaedya Al-gharbia, S31, S32 Al-mesaedya Al-sharkia): (c) second and third-storey levels (S6, S7 An Nasiriyah, S13 10 km from Arar, S18, S19, S21 Al-mohamadya, S25 25 km from Arar, S27, S30 Midtown of Arar, S23, S24 Al-Salehya)

The exposure to radon progeny (*EP*) is calculated by using eq. (3) taking the equilibrium factor (*F*) to be 0.4 and the results are presented in tab. 2. The minimum, maximum and average values of EP are $0.83\ 10^{-3}$, $9.63\ 10^{-3}$ and $4.76\quad 0.67\ 10^{-3}$, respectively while the geometric mean is $5.05\ 10^{-3}$ WLM. The excess lifetime cancer risk (*ELCR*) values found by applying eq. (4) are reported in tab. (2) as well. They ranged from $0.6\ 10^{-3}$ to $7.5\ 10^{-3}$ with an average value of $3.7\ 10^{-3}$. It should be mentioned that all the sites exceed the world average of $0.29\ 10^{-3}$ [32] which supports this study and demonstrates the importance of measuring radon concentrations.

Table 3 represents the effect of the storey level on C_{Rn}, *H*, *EP*, and *ELCR*. It is obvious that, as the storey level increases, these parameters decrease. This is due to the heavy nature of radon gas. It can not reach higher storey levels and consequently, the soil is excluded as a reason for radon accumulation. So the type of building materials and ventilation rate are the main causes of such accumulation in these higher storey levels. In other words, there is a positive relationship between the nearness to the soil and the values of these parameters.

Table 2. Annual effective dose, exposure to radon progeny and excess lifetime cancer risks in the different dwellings of Arar

Sample number	Annual effective dose [mSv]	Exposure to radon progeny, (WLM) $\times 10^{-3}$	Excess lifetime cancer risk $\times 10^{-3}$
S1	0.53	2.83	2.20
S2	1.15	6.09	4.71
S3	1.14	6.03	4.67
S4	1.66	8.79	6.80
S5	0.74	3.91	3.03
S6	0.74	3.91	3.03
S7	0.82	4.32	3.35
S8	1.82	9.63	7.45
S9	0.83	4.42	3.42
S10	0.64	3.37	2.61
S11	1.00	5.33	4.12
S12	0.90	4.77	3.69
S13	0.79	4.15	3.22
S14	1.10	5.84	4.52
S15	0.79	4.15	3.22
S16	0.58	3.10	2.40
S17	1.09	5.76	4.46
S18	0.83	4.39	3.39
S19	0.67	3.55	2.75
S20	0.85	4.49	3.47
S21	1.14	6.04	4.67
S22	1.28	6.76	5.22
S23	0.29	1.55	1.20
S24	0.96	5.07	3.92
S25	1.36	7.20	5.57
S26	0.15	0.83	0.65
S27	0.34	1.78	1.38
S28	0.85	4.49	3.47
S29	1.47	7.78	6.02
S30	0.30	1.58	1.22
S31	0.89	4.74	3.66
S32	1.23	6.52	5.05
S33	0.75	3.98	3.08

Table 3. The influence of the storey level on radon concentration, annual effective dose, exposure to radon progeny and excess lifetime cancer risks

Storey level	Total no. of dwellings	Average radon concentration [Bqm^{-3}]	Average annual effective dose [mSv]	Average exposure to radon progeny, (WLM) $\times 10^{-3}$	Average excess lifetime cancer risks $\times 10^{-3}$
Ground	10	56.4	1.15	6.1	4.72
1st	11	43.5	0.89	4.7	3.65
2nd & 3rd	12	34.2	0.70	3.7	2.86

To understand qualitatively radon and its associated risks, it is important to study the relation between C_{Rn} and its statistical distribution. To construct a probability distribution for each C_{Rn} and also H in this work, the Gaussian distribution function, $G(x)$, was used which is given by [33]

$$G(x)\mathrm{d}x \quad \frac{1}{\sqrt{2\pi\sigma^2}} \exp \frac{(x \quad m)^2}{2\sigma^2} \mathrm{d}x \tag{5}$$

where $G(x)$ dx represents the probability of the value of x (x here represents C_{Rn} or H) to lie between x and x + dx, m and σ^2 are the distribution average and variance, respectively. Figure 4 shows the frequency distribution of C_{Rn} (Bqm^{-3}) and H for 33 dwellings of the investigated area. It can be seen that most states (more than 70 % of all the dwellings) have C_{Rn} between 30-70 Bqm^{-3}. In addition, 58 % have H in the range 0.8-1.7 mSv per year and about 12 % exceeds 1.4 mSv per year.

The comparison of our results with those of neighboring regions in Saudi Arabia is presented in tab. 4. It is obvious that the average C_{Rn} in Arar is larger than in Al-Jauf and Hafr Al-Batin regions, this may be attributed to the effect of soil and construction materials. Since there is phosphate ore present largely in this area which is one of the major sources of natural radon gas [34]. Finally, tab. 5 presents the comparison between the average C_{Rn} and the published data in the neighboring countries. It is clear that the value of average C_{Rn} in Arar is higher than its value in Egypt and Syria while it is lower than the values in Turkey, Iraq, and Jordan.

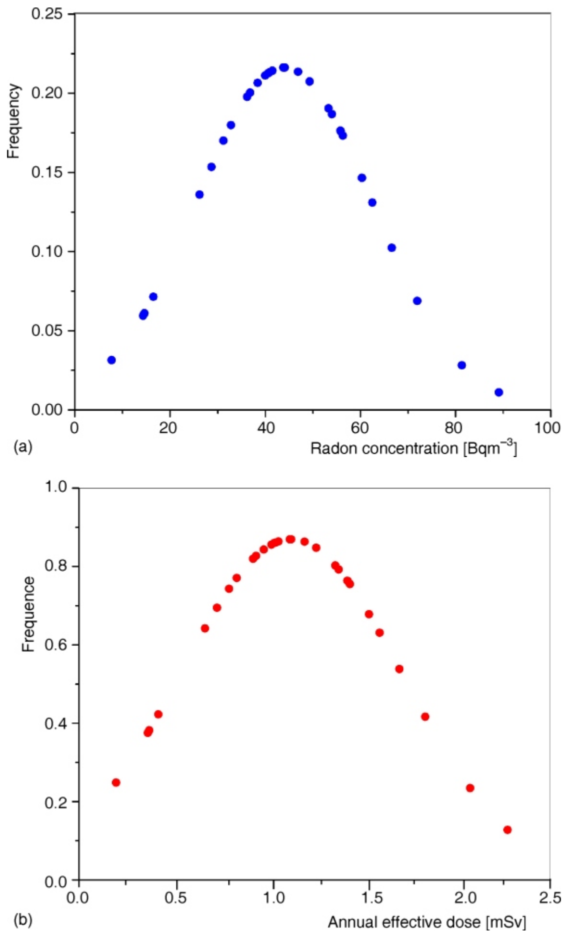

Figure 4. The frequency distribution of radon concentration and annual effective dose

Table 4. A comparison of present results with those of neighboring regions

Region	Number of measured samples	Average radon concentration [Bqm^{-3}]	Reference
Arar	33	44.05 6.21	Present work
Al-Jauf	136	35 30	[35]
Hafr Al-Batin	85	20 2.7	[36]

Table 5. Average radon concentrations in dwellings in the nearest countries

Country	Average radon concentration [Bqm^{-3}]	Reference
Arar	44.05 ± 6.21	Present work
Turkey	81	[37]
Iraq	116.8	[38]
Syria	45	[39]
Jordan	56.7	[40]
Egypt	9	[41]

CONCLUSIONS

The radon concentrations in different dwellings of Arar, Saudi Arabia, were measured and it was found that: C_{Rn} varied from 7.7 to 89.1 Bqm^{-3} with an average value of 44.05 6.21 Bqm^{-3} which is within the acceptable level set by the ICRP. More than 70 % of all the dwellings have C_{Rn} between 30-70 Bqm^{-3}. The higher values of C_{Rn} in some locations originate from the soil and rocks that are found around the dwelling that gets accumulated indoors due to poor ventilation. The annual effective doses (H) received by the population of Arar vary from 0.16 to 1.82 mSv with an average value of 0.90 0.16 mSv. These doses are within the acceptable level set by the ICRP. The exposure to radon progeny was investigated and the minimum, maximum and average values of EP are 0.83 10^{-3}, 9.63 10^{-3}, 4.76 0.67 10^{-3} WLM, respectively. EP depends on the equilibrium factor and C_{Rn}. The excess lifetime cancer risk values were in the range from 0.6 10^{-3} to 7.5 10^{-3} with an average value of 3.7 10^{-3}. As the storey level increases, C_{Rn}, H, EP and $ELCR$ decrease which refers to the heavy nature of radon gas. In higher storey levels the accumulation of radon is mainly due to the type of building materials and the ventilation rate. Finally, the average C_{Rn} in Arar is larger higher than in the Al-Jauf and Hafr Al-Batin regions.

NOMENCLATURE

C_{Rn} – radon concentration
D – dose conversion factor whose value to the public is 4 mSv/WLM
DL – average duration of life (life expectancy)
ELCR – excess lifetime cancer risk
EP – exposure to radon progeny
F – equilibrium factor between radon and its progeny
H – annual effective dose
K – calibration factor (tracks $\mathrm{cm}^{-2}/\mathrm{Bqm}^{-3}$. day)
O – occupancy factor taken as 0.8
RF – fatal cancer risk per one sievert
T – time in hours in a year
t_{o} – exposure time (day)
WLM – working level months

Greek symbol

ρ – average track density (track cm^{-2})

AUTHORS' CONTRIBUTIONS

The manuscript was written by S. El-Gamal and A. M. Abdalla. The figures were prepared by A. M. Abdalla and S. El-Gamal. The survey was organized by the two authors. The detectors were distributed and collected by S. El-Gamal and raw experimental data was carried out by A. M. Abdalla. The two authors analyzed, discussed the results and reviewed the manuscript.

REFERENCES

[1] Cothern, Richard C., *et al*., Environmental Radon. Springer Science & Business Media, New York, 2013
[2] Axelsson, G., *et al*., Lung Cancer Risk from Radon Exposure in Dwellings in Sweden: How Many Cases can be Prevented if Radon Levels are Lowered, *Cancer Causes Control, 26* (2015), 4, pp. 541-547
[3] Kreuzer, M., *et al*., Lung Cancer Risk at Low Radon Exposure Rates in German Uranium Miners, *Br J Cancer, 113* (2015) ,9, pp. 1367-1369
[4] ***, WHO Handbook on Guidelines for Drinking-Water Quality (Vol. 1, pp. 19-209), World Health Organization Publication, France, 2008
[5] Sinitsky, M. Y., The Cytokinesis-Block Micronucleus Assay on Peripheral Blood Lymphocytes as a Prospective Biological Test-System to Estimate the Influence of Radon on the Human Organism: Recent Progress and Future Prospects, *Open. J. Genet.,* 4, (2014), 1, pp. 1-7
[6] Zeeb, H., Shannoun, F., World Handbook on Indoor Radon, A Public Health Perspective, World Health Organization, 2009
[7] ***, Sources and Effects of Ionizing Radiation, United Nation Scientific Committee on the Effects of Atomic Radiation, UNSCEAR, United Nations, New York, 2000
[8] Papachristtodoulou, C. A., *et al*., Exposure to Indoor Radon and Natural Gamma Radiation in Public Workplaces in North- Western Greece, *Radiat. Meas., 45* (2010), 7, pp. 865-871
[9] Segovia, N., *et al*., Environmental Radon Studies in Mexico, *Environ. Geochem. Health., 29* (2007), 2, pp. 143-153
[10] Zamazk, B., Vaupotic, J., Coping with Radon Problem in a Private House, *Build. Environ., 42* (2007), 10, pp. 3685-3690
[11] ***, Protection Against Radon-222 at Home and Work, International Commission on Radiological Protection, ICRP Publication 65. Ann. ICRP. 23 (2), Pergamon Press, Oxford, UK, 1993
[12] Turhan, S., *et al*., Health Hazards Due to the Exposure to Radon in Schools of the Cappadocia Region, *Nucl Technol Radiat, 32* (2017), 2, pp. 174-179
[13] Tareen, A. D. K., *et al*., Soil Gas Radon Mapping of Muzaffarabad City, Pakistan, *Nucl Technol Radiat, 31* (2016), 3, pp. 291-298
[14] Stojanovska, Z., *et al*., Prediction of Long-Term Indoor Radon Concentrations Based on Short-Term Measurements, *Nucl Technol Radiat, 32* (2017), 1, pp. 77-84
[15] Alghamdi, A. S., Aleissa K. A., Influences on Indoor Radon Concentrations in Riyadh, Saudi Arabia, *Radiat. Meas., 62* (2014), March, pp. 35-40
[16] Mohamed, R. I., *et al*., Measurements of Radon Gas Concentrations in Dwellings of Al-Madinah Al-Munawarah Province in Saudi Arabia, *Radiat. Prot. Dosim., 158* (2014), 2, pp. 156-161
[17] Maghraby, A. M., *et al*., Estimation of the Residential Radon Levels and the Population Annual Effective Dose in Dwellings of Al-Kharj, Saudi Arabia, *J. Radiat. Res. Appl. Sci.. 7* (2014), 4, pp. 577-582
[18] Alharbi, W. R., Abbady, A. G. E., Radon Concentrations in Soil and the Extent of Their Impact on the Environment, *Natural Sci.. 5* (2013), 1, pp. 93-98
[19] Abu-Jarad, F., AI-Jarallah, M. I., Radon Activity in Saudi House, *Nucl. Tracks Radiat. Meas., 8* (1984), 1-4, pp. 395-398
[20] Al-Yami, S. H., Comparative Study of Radon Concentration in Houses and Soil in Najran Region, Saudi Arabia, *J Mater. Sci. Eng., 5* (2011), January, pp. 76-79
[21] Abdallah, A. M., *et al*., Radon Exhalation and Natural Radiation Exposure in Low Ventilated Rooms, *Radiat. Phys. Chem., 81* (2012), 11, pp. 1710-1714
[22] Sainz, C., *et al*., Comparative Risk Assessment of Residential Radon Exposures in Two Radon-Prone Areas, Stei (Romania) and Torrelodones (Spain), *Sci. Total Environ., 407* (2009), 15, pp. 4452-460
[23] Abdalla, A. M., Al-Hajry, A., Radon Irradiation Chamber and its Applications, *Nucl. Instr. Meth. Phys. Res., A 786* (2015), June, pp. 78-82.
[24] Matiullah, Determination of the Calibration Factor for CR-39 Based Indoor Radon Detector, *J. Radioanal. Nucl. Chem., 298* (2013), 1, pp. 369-373
[25] Sutej, T., *et al*., Response of Track-Etch Dosimeters to Environmental Radon, *Int. J. Radiat. Appl., Instrument, Part D, Nucl. Tracks Radiat. Meas. 15* (1988), 1-4, pp. 547-550
[26] ***, Effects of Ionizing Radiation, UNSCEAR 2008 Report volume II: Annex E. United Nations Scientific Committee on the Effects of Atomic Radiation, New York, 2008
[27] Abo-Elmagd, M., *et al*., External and Internal Exposure to Natural Radiation Inside Ancient Egyptian Tombs in Saqqara, *Radiat. Meas., 41* (2006), 2, pp. 197-200
[28] ***, Recommendations of the International Commission on Radiological Protection, International Commission on Radiological Protection, ICRP Publication 103. Ann ICRP 37 (2-4) 2007

[29] ***, Lung Cancer Risk from Radon and Progeny and Statement on Radon, International Commission on Radiological Protection, ICRP Publication 115, *Ann ICRP, 40* (2010), 1, pp. 1-64
[30] Gray, P. C. R., *et al*., Communicating About Risks to Environment and Health in Europe, Springer Science & Business Media, 2013
[31] Taskin, H., *et al*., Radionuclide Concentrations in Soil and Lifetime Cancer Risk Due to Gamma Radioactivity in Kirklareli, *Turk. J. Environ. Radioact., 100* (2009), 1, pp. 49-53
[32] Song, G., *et al*., Indoor Radon Levels in Selected Hot Spring Hotels in Guangdong, China, *Sci Total Environment, 339* (2005), 1-3, pp. 63-70
[33] Tsoulfanidis, N., Measurement and Detection of Radiation, 2nd ed., Taylor & Francis, New York, 1995
[34] Liu, D. H. F., Liptak, B. G., Hazardous Waste and Solid, CRC Press, Boca Raton, Fla., USA, 1999
[35] Al-Jarallah, M. I., Fazal-ur-Rehman, Indoor Radon Concentration Measurement in the Dwellings of Al-Jauf Region of Saudi Arabia, *Radiat. Prot. Dosim., 121* (2006), 3, pp. 293-296
[36] Al-Jarallah, M. I., *et al*., Indoor Radon Measurements in Dwellings of four Saudi Arabian Cities, *Radiat. Meas., 36* (2003), 1-6, pp. 445-448
[37] Celebi, N., *et al*., Indoor Radon Measurements in Turkey Dwellings, *Radiat. Prot. Dosim., 167* (2015), 4, pp. 626-632
[38] Tawfiq, N. F., *et al*., Indoor Radon Concentration in Various Dwellings of Baghdad, Iraq, *Int. J. Phys., 3* (2015), 5, pp. 202-207
[39] Othman, I., *et al*., Measurement of Radon in Syrian Houses, *J. Radiol. Prot., 16* (1996), 1, pp. 45-50
[40] Abumurad, K., *et al*., A Survey of Radon Levels in Jordanian Dwellings during an Autumn Season, *Radiat. Prot. Dosim., 69* (1997), 3, pp. 221-226
[41] Katase, A., Shimo, M., Radon and Thoron in the Human Environment: *Proceedings*, 7th Tohwa University International Symposium, World Scientific, Singapore, 1998

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МЕРЕЊА КОНЦЕНТРАЦИЈЕ РАДОНА У ЗАТВОРЕНОМ ПРОСТОРУ СТАМБЕНИХ ОБЈЕКАТА У ГРАДУ АРАРУ У САУДИЈСКОЈ АРАБИЈИ

Коришћењем CR-39 детектора измерена је концентрација радона у затвореном простору у 33 стамбена објекта у граду Арару. Рад је први ове врсте у региону и спроведен је у циљу процене здравственог ризика. Период мерења је износио око четири месеца, од маја до септембра 2017. године. Измерена је промена концентрације радона у затвореном простору у опсегу од 7.7 до 89.1 Bqm^{-3}, са средњом вредношћу од 44.05 6.21 Bqm^{-3}, геометријском средином од 39.51 Bqm^{-3} и геометријском стандардном девијацијом од 1.67. Ове вредности су унутар прихватљивих граница које је успоставила Међународна комисија за заштиту од зрачења. Приказана је годишња ефективна доза коју прими становништво Арара и налази се у опсегу 0.16-1.82 mSv, са средњом вредношћу од 0.9 0.16 mSv и геометријском средином од 0.81 mSv. Испитано је и излагање потомцима радона са минималном, максималном, средњом вредношћу и вредношћу геометријске средине од 0.83 10^{-3}, 9.63 10^{-3}, 4.76 0.67 10^{-3} и 5.05 10^{-3} WLM, респективно. На крају, ради процене ризика за настанак карцинома, испитан је дугорочни ризик за настанак карцинома, чија је средња вредност релативно увећана и износи 3.7 10^{-3}.

Кључне речи: радон, концентрација радона, радон у затвореној средини, стамбени објекат, CR-39