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Monitoring of Indoor Radon and Assessment of Lung Cancer Risk to Population of Beit Ummar City in Palestine

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Background: Radon exposure is the second leading cause of lung cancer after cigarette smoking. The individuals exposed to radon in their homes prove that radon is a major environmental carcinogen.

Material & Methods: Radon concentrations were measured using CR-39 passive dosimeters in Beit Ummar city. 150 dosimeters were distributed over the study area dwellings according to the fraction of the population. The exposure started from October 2014 and lasted for 90 days. The city was divided into five sectors with six categories for each; corridor, kitchen, living room, saloon, bedroom and store. The influence of floor number and building type was introduced.

Results: Obtained results have recorded relatively high radon concentration in 73% of the studied houses. This is explained due to several factors such as poor ventilation, construction materials, and continuous usage of heating during this period and age of the building. Different parameters were calculated based on the measurements of track density of the distributed dosimeters in order to estimate the risk of radiation exposure; those parameters are: radon concentration (C_{Rn}), exposure to radon progeny (E_P), indoor annual effective dose (AED) and number of lung cancer cases per year per million persons (LCC).

Conclusion: The results showed that the radon concentrations and the resulting doses in the monitored chambers exceed the safe limits recommended by the WHO and EPA in some aspects. Therefore, health risk due to radon is possible.

Key words: Radon, Beit Ummar city, annual effective dose, lung cancer cases.

Introduction

Radon (^{222}Rn) exposure is the second leading cause of lung cancer after cigarette smoking. Studies concerning occupationally radon exposed miners and direct observation from the individuals exposed to radon in their homes prove that radon is a major environmental carcinogen (1, 2). The radioisotope ^{222}Rn which produced from the decay of ^{238}U is the main source (approximately 65%) of internal radiation exposure to human life due to breathing it and its progenies present in the dwellings (3). Worldwide average annual effective dose of ionizing radiation from natural sources is estimated to be 2.4 mSv, of which about 1.0 mSv is due to radon exposure (1). Thus, the hazard of ^{222}Rn is prominent due its long half-life (3.83 days), while the other isotopes such as ^{220}Rn and ^{219}Rn which produced from ^{232}Th and ^{235}U are less significant because of their much shorter half-life; therefore, ^{222}Rn is by far the most dominant hazardous radionuclide. The main natural sources of indoor radon are soil, building materials, water born transport and natural energy sources, which contain traces of ^{238}U (4). This health risk comes from the fact that the radon gas and its airborne daughters can seep up from the ground and build up in enclosures like dwellings.

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The long-term and large scale passive measurements of radon and its progeny in the dwellings have been receiving the greater attention due to its harmful effects to the human beings. It is a well-documented fact that the pathological effects like the respiratory functional changes and the occurrence of lung cancer may be caused by the long exposure of a person with high radon concentration and its short-lived daughter products (5). As a result, nationwide measurements of radon concentration levels inside dwellings (indoor) have received numerous interests from research professionals and are continuously presented all over the world (6). It is also of great importance to assess the exposure to ^{222}Rn and its progeny in houses and areas of high ^{222}Rn levels for the purposes of quality control, radioactivity monitoring of building materials and for correction measures recommendations (7).

In Palestine, some surveys have been carried out concerning radon concentration and radon exhalation from building materials in dwellings, (8-15). Due to lack of specific information about radon concentration in dwellings in Beit Ummar city; this study takes this region to provide a baseline for Palestine in the radon world atlas.

The aim of the present work is the estimation of radon concentration in some dwellings and its related risks such as risk of inhalation of radon gas by the populations inside the dwellings, exposure to radon progeny, annual effective dose and lung cancer cases per year per million people. Furthermore, the study aimed to find variation in radon concentration for different floors, and for old and new buildings.

Study Design

This study assessed the indoor radon concentrations and risk of cancer in 35 selected old and new dwelling in five main sites in Beit Ummar city which is located in the northern part of Hebron governorate, Palestine (*Figure-1*). The targeted dwellings were made of marble stone, cement, sand, iron, granite, and concrete. Several of them were covered with gypsum. Many of these materials are significantly contributes to the indoor radon emission. Most of these dwellings have only one door and one or two windows for each. Furthermore, the ventilation conditions are poor as there are no exhaust fans. Also, the population using heating with wood in this period of the year.

Experimental method for radon detection and measurement based on counting of alpha particle which emitted from radon. The plastic track detector (CR- 39) was used to record alpha tracks. Dwellings were selected randomly some of these were ventilated and others were unventilated. This plastic track detector film of size 1cm × 1cm and then fixed in a flat position at the bottom of a plastic cup and were held in place by a small piece of glue-tape, as shown in Figure 2. The twin cup dosimeters were suspended between autumn and winter seasons (October 2014 to January 2015) in dwellings consisting of two floors at a height of about 1.8 m from the ground.

Detectors were exposed to alpha particles 90 day, and then these detectors were collected and etched in 6.25 NaOH for 6 hours under constant temperature bath (70±1 °C). After a thorough washing they were scanned for track density measurements using optical microscope at a magnification of 160×. All α-particles that reach the CR-39 detectors were registered as bright track holes (13, 15).

Results

Radon Concentration

Radon concentration (*activity density*) which measured by each detector, in unit of Bqm^{-3}, is given by the following equation (15):

$$C_{Rn} = \left(\frac{C_o t_o}{\rho_o}\right)\frac{\rho}{t} = \mathrm{k}\,\frac{\rho}{\mathrm{t}} \qquad (1)$$

Where C_o is the radon concentration of the calibration chamber (90 kBqm^{-3}), t_o is the calibration exposure time (48 hours), ρ is the measured track number density per cm^2 on the CR-39 detectors inside the dosimeters used in this study, ρ_o is the measured track number density per cm^2 on those of the calibrated dosimeters (3.31×10^4 tracks cm^{-2}) and t is the exposure time in hours (2160 hours). At the end of exposure period, 116 dosimeters have been collected while the other 34 dosimeters were lost. Table-1 show the range of radon concentration, the corresponding number of dosimeters and the frequency of each range. The distribution frequency of radon concentration levels in each area in the city are summarized in Table-2. Distribution of Radon concentration levels according to building type (*old and new*) are listed in Table-3. Distribution of radon concentration levels according to floor number and statistics analysis of the data are listed in Table-4. Indoor radon concentration levels for different rooms and statistics analysis of the data are listed in Table-5. This Table includes: The minimum (Min), the maximum

(Max), the mean (Mean) and the standard deviation (SD) of the radon levels obtained for each room type in two floors in all directions.

Table-1: Range and frequency of radon concentrations of selected rooms in the region under investigation.

Frequency Range (Bqm^{-3})	No of Detectors	Percentage
0-50	6	5.2%
51-100	26	22.4%
101-150	38	32.8%
151-200	24	20.7%
201-250	8	6.9%
251-300	10	8.6%
301-350	0	0.0%
> 350	4	3.4%
Total	**116**	**100%**

The results in *Table-1* are depicted as in *Figure-3*. It is shown that the maximum frequency of 32.8% is obtained in the frequency range 101-150 Bqm^{-3} is an indication that the frequency distributions are skewed to the lower radon levels. Referring to Table 2 and Figure 4; the mean value of radon concentration along all directions is above the world average radon concentration (100 Bqm^{-3}) (16). Therefore it's possible that there will be a health risk to the inhabitants of those homes resulting from inhalation of radon. radon concentration levels were found to vary from 49 to 292 Bqm^{-3} with mean value of 146 Bqm^{-3} in the north east site, from 48 to 246 Bqm^{-3} with mean value of 131 Bqm^{-3} in the north west site, from 50 to 380 Bqm^{-3} with mean value of 156 Bqm^{-3} in the south east site western site, from 67 to 357 Bqm^{-3} with mean value of 144 Bqm^{-3} in the south west site and from 100 to 293 Bqm^{-3} with an a mean value of 172 Bqm^{-3} in the west site.

Table-2: Distribution of measured radon concentration levels in each area

Direction	*Radon concentration levels (Bqm^{-3})*				
	NE	**NW**	**SE**	**SW**	**W**
Min	49	48	50	67	100
Max	292	246	380	357	293
Mean	146	131	156	144	172
SD	56.7	64.3	91	101	68

***NE**: North East, **NW**: North West, **SE**: South East, **SW**: South West, **W**: West, **SD**: Standard Deviation.*

Table-3: Distribution of Radon concentration levels according to building type

Building Type	Old Building	New Building
No of detectors	64	52
Min	67	48
Max	357	380
Mean	154	147
SD	78.8	71.4

The influence of type of building (*old, new*) is listed in *Table-3* and depicted in *Figure-5*. The indoor radon concentration level with mean value 154 Bqm^{-3} was recorded in old buildings and 147 Bqm^{-3} for new ones. In both types of buildings, the measured mean value of radon levels are above the world average radon concentration. This unsafe distribution may be due to the poor ventilation as well as the buildings' characteristics and their usage. Therefore, a proper ventilation system is recommended in order to reduce the indoor radon levels especially in the old buildings.

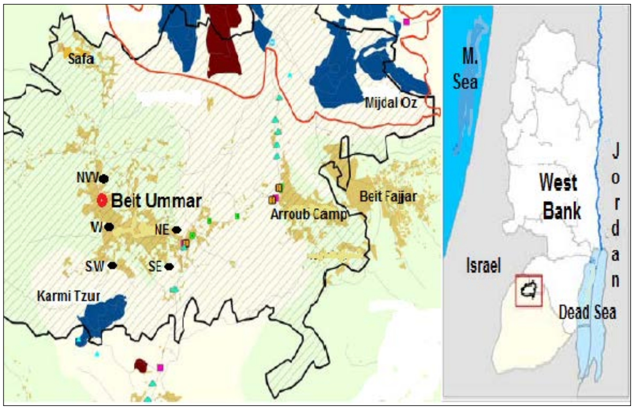

Figure-1: Location of Beit Ummar City

The indoor radon concentration levels were found to vary from 67 to 357 Bqm^{-3} in old buildings and from 48 to 380 Bqm^{-3} in new buildings. The mean values of the obtained results in Bqm^{-3} are as follows: 154 and 147 in old and new buildings, respectively. *Table-4* and *Figure-6* showing that the mean concentration of radon decreases as the floor number increase due better ventilation in upper floors than it in lower ones and decaying the chance for radon to reach upper floors compared with lower ones. The results in *Table-5* are depicted in *Figure-7*.

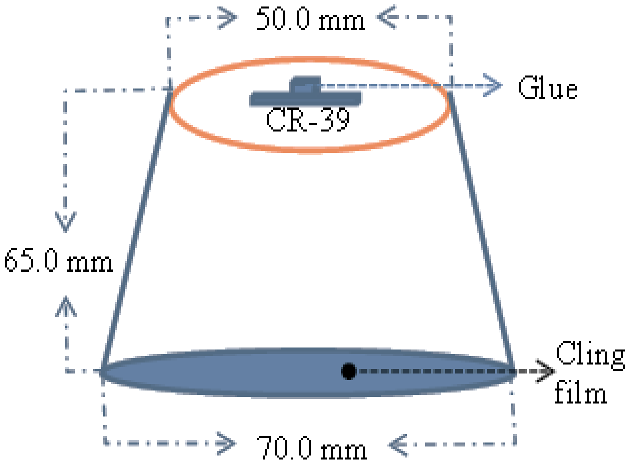

Figure-2: CR-39 Dosimeter

The results show the distribution of radon concentration in different rooms in dwellings in Bqm^{-3}. The results show that the indoor radon concentration levels are relatively high in kitchens, stores and saloons compared with bedrooms, living rooms and corridors. These results make sense due to bad ventilation and natures of usage in chambers suffer high levels in radon concentration. The indoor radon concentration levels were found to vary from 48 to 164 Bqm^{-3} in corridors, from 103 to 380 Bqm^{-3} in kitchens, from 67 to 190 Bqm^{-3} in living rooms, from 114 to 278 Bqm^{-3} in saloons, from 76 to 182 Bqm^{-3} in bed rooms, and from 83 to 357 Bqm^{-3} in stores. The mean values of the obtained results in Bqm^{-3} are as follows: 90 in corridors, 214 in kitchens, 115 in living rooms, 179 in saloons, 119 in bed rooms, 199 in stores.

Table-4: Distribution of Radon concentration levels (*in* Bqm^{-3}) according to floor number.

Floor No.	F_0	F_1
No of detectors	54	62
Min	48	49
Max	380	357
Mean	168	136
SD	83.6	64.2

This prominent variation in radon concentration can be explained as follows: the rooms with radon levels are kept closed most of the time. Although kitchens are constructed mainly from the skeletal building materials (*concrete and cement blocks*), the finishing materials used In such compartments largely differ from that used in other locations within the same apartment. Ceramic and granite in particular, are used extensively in place of the paint commonly used in living room and bedrooms (15). Previous reports have indicated that ceramic and granite are potential sources of radon, where radon emerges from the decay of thorium and uranium in these materials (17). The use of natural gas in houses and supply of kitchens are a potential source of indoor radon (15).

The observed variations of radon concentrations among various dwellings can be attributed to many factors, like geological structure of the sites, the various types of building materials used for the construction of the houses, the heating systems, ventilation rates, and the effect of aging on the buildings, as well as the social habits of the inhabitants.

In general, the measured mean radon levels in most rooms are above the world average radon concentration (100 Bqm^{-3})(16). ICRP recommends an action level of 200 Bqm^{-3}(3). Comparing the results obtained from the present survey, indoor radon concentration levels in most rooms are below the action level. In many houses, indoor radon concentration levels are higher than the limit of 148 Bqm^{-3} recommended by EPA for United States (18).

Table-5: Indoor radon concentration levels for different rooms in Beit Ummar city.

No. of detectors	**Radon concentration (Bqm^{-3})**					
	16	18	26	18	20	18
Type of room	*Corridors*	*Kitchens*	*Living rooms*	*Saloons*	*Bed rooms*	*Stores*
Min	48	103	67	114	76	83
Max	164	380	190	278	182	357
Mean	90	214	115	179	119	199
SD	43	90	37	69	33	85

Table-6: The mean values of (CRn), (Ep), (AED) and (LCC) in different rooms in the Beit Ummar city.

Room	C_{Rn} (Bqm^{-3})			*Ep* ($WLMY^{-1}$)			*AED* ($mSvyr^{-1}$)			*LCC*($\times 10^{-6}$)		
	Min	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Corridor	48	164	90	0.22	0.73	0.40	1.20	4.10	2.25	22	74	41
Kitchen	103	379	214	0.46	1.70	0.96	2.58	9.48	5.35	46	171	96
Living room	67	190	115	0.30	0.85	0.51	1.66	4.76	2.88	30	86	52
Saloon	114	278	179	0.51	1.24	0.80	2.85	6.96	4.48	51	125	81
Bed room	76	182	119	0.34	0.81	0.53	1.89	4.54	2.98	34	82	54
Store	83	357	199	0.37	1.60	0.89	2.07	8.93	4.98	37	161	90

The Radiation Exposure

Exposure to radon progeny (E_P) is then related to average radon concentration C_{Rn} by expression (19, 20):

$$E_P(WLMY^{-1}) = \frac{8760\times n\times F_R\times C_{Rn}}{170\times 3700} \qquad (2)$$

where n is the fraction of time spent indoors which is equal to (0.8) , F_R is the equilibrium factor between radon and its progeny (0.4), 8760 is the number of hours per year ,170 is the number of hours per working month. As it can be seen from Table 6, the highest value of exposure to radon progeny (E_P) found in kitchens which is equal to (0.1.70 $WLMY^{-1}$), while the lowest value found in corridors which is equal to (0.22 $WLMY^{-1}$). The mean values of (E_P) in corridors, kitchens, living rooms, saloons, bedrooms and stores are 0.40, 0.96, 0.51, 0.80, 0.53 and 0.89 $WLMY^{-1}$, respectively. All the results of (E_P) in indoors dwellings in Beit Ummar city were lower than lower limit of recommended NCRP range (1-2 $WLMY^{-1}$) (21).According to the UNSCEAR report, annual effective dose *AED* ($mSvy^{-1}$) to the public from ^{222}Rn and its progeny is estimated using the following equation (1):

$$AED(mSvy^{-1}) = C_{Rn}\times \mathrm{F_R}\times \mathrm{H}\times \mathrm{T}\times \mathrm{D} \qquad (3)$$

where H is the occupancy factor (0.8), T is the number of hours per year (8760 hy^{-1}) and D is the dose conversion factor (9.0×10^{-6} $mSv(Bqm^{-3}\ h)^{-1}$), which is the effective dose received by adults per unit ^{222}Rn activity per unit of air volume (1). From equation (3) and Table (6), the annual effective dose in Beit Ummar city dwellings is ranged from 1.20 to 9.48 mSv y^{-1} with a mean value of 5.34 mSv y^{-1}; the least value recorded in corridors, while the largest one recorded in kitchens. The results were as follows: from 1.20 to 4.10 mSv y^{-1} with a mean value of 2.25 mSv y^{-1} in corridors; from 2.58 to 9.48 mSv y^{-1} with a mean value of 5.35 mSv y^{-1} in kitchens; from 1.66 to 4.76 mSv y^{-1} with a mean value of 2.88 mSv y^{-1} in living rooms; from 2.85 to 6.96 mSv y^{-1} with a mean value of 4.48 mSv y^{-1} in saloons; from 1.89 to 4.54 mSv y^{-1} with a mean value of 2.98 mSv y^{-1} in bed rooms and from 2.07 to 8.93 mSv y^{-1} with a mean value of 4.98 mSv y^{-1} in stores.

In its recent reports of ICRP and WHO (16,19), it has recommended that the action levels of radon in dwellings should be set around of 1.3 and 2.5 mSv y^{-1}, respectively. On the basis of these recommendations, it has been observed that most of the dwellings monitored for indoor radon concentration show higher values than the action levels. Therefore it is possible that there will be a health risk to the inhabitants of those homes resulting from inhalation of radon.

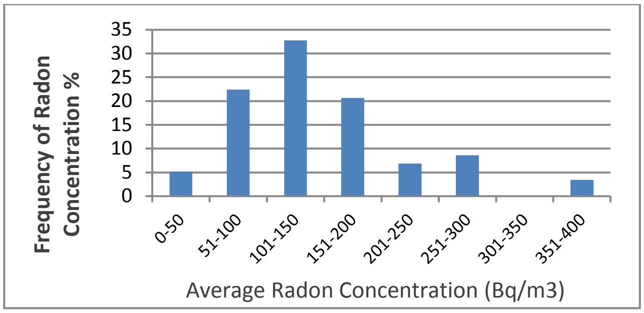

Figure-3: Distribution of frequencies of measured radon levels in the whole region.

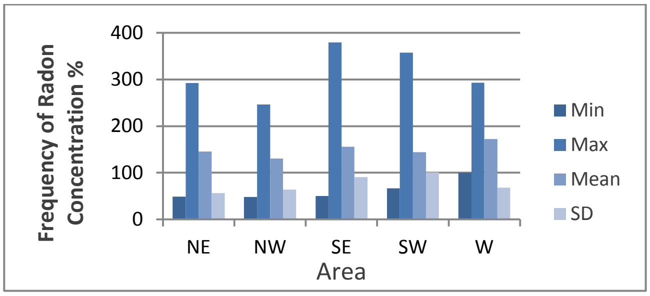

Figure-4: Distribution of measured Radon levels in each area.

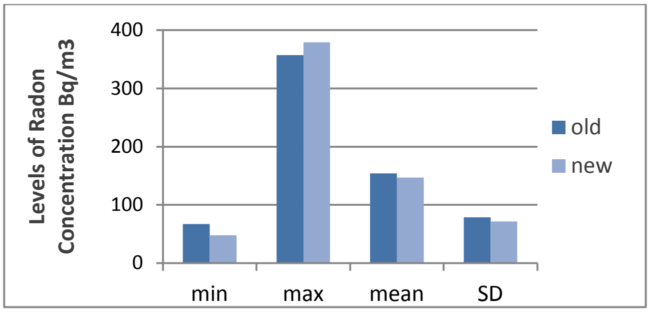

Figure-5: Distribution of Radon concentration to building type.

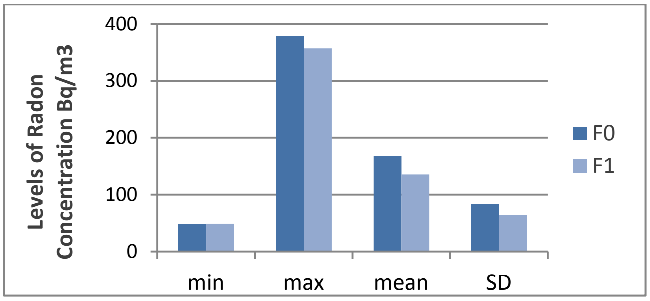

Figure-6: Distribution of Radon concentration floor number.

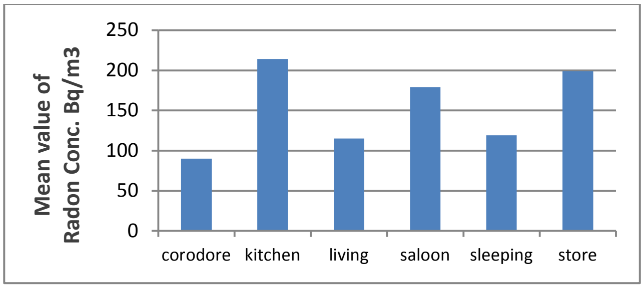

Figure-7: Mean indoor radon concentration levels for different rooms in Beit Umar city

Lung Cancer Cases

Radon decays quickly, giving off tiny radioactive particles. When inhaled, these radioactive particles can damage or distort the cells in the lung. Long-term exposure to radon can lead to lung cancer. The lung cancer cases per year per million person (*LCC*) is estimated by using the risk factor lung cancer induction 18×10^{-6} mSv^{-1} and can be obtained using the following relation (20, 22)

$$LCC = AED \quad (mSvy^{-1})\times18\times10^{-6}(\mathrm{mSv})^{-1} \qquad (4)$$

According to this study, the radon induces lung cancer risks. In the study area, it is found that *LCC* ranged between 22 and 171 per million person per year with mean value of 96.5 per million persons per year. The results found to vary from 22 to 74 per million person per year in corridors; from 46 to 171 per million person per year in kitchens; from 30 to 86 per million person per year in living rooms; from 51 to 125 per million person per year in saloons; from 34 to 82 per million person per year in bedrooms and from 37 to 161 per million person per year in stores. The mean values of (*LLC*) in corridors, kitchens, living rooms, saloons, bedrooms and stores are: 41, 96, 52, 81, 54 and 90 per million persons per year, respectively. These values are less than the lower limit of the range (170-230) per million person which recommended by the ICRP 1993 (3).

Conclusion

Indoor radon concentrations have been measured inside dwellings in Beit Ummar city using passive dosimeters CR-39 detectors in winter season 2014 to 2015. We found that radon concentrations were higher than 100 Bqm^{-3} in 73% of the studied houses. The mean indoor radon concentration decreases as the floor level increases. This concentration in old buildings is higher than that in new ones. Kitchens and stores show the maximum radon concentrations which may be due to the contribution of poor ventilation, construction materials, the uses of heating constantly during that period, age of the buildings and radon exhalation from the ground.

The annual effective dose has been calculated from radon concentration to carry out the assessment of the variability of expected radon exposure of the population due to radon and its progeny. The lung cancer cases per year per million persons have been calculated where the values are less than the lower limit of the range (170-230) per million persons recommended by the (ICRP, 1993). The results of the present work provide an additional database on indoor radon level in Palestine.

Conflict of Interest

The authors declare that no conflict of interest exists in publishing this article.

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