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RESEARCH ARTICLE

STUDY OF RADON CONCENTRATION AND THE ASSOCIATED HEALTH EFFECTS IN SELECTED HOSPITALS IN THE SOUTHERN PART OF WEST BANK – PALESTINE

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ABSTRACT

Indoor radon concentrations (C_{Rn}), potential alpha energy concentrations (*PAEC*), exposure to radon progeny (E_P), annual absorbed dose (D_{Rn}), annual equivalent dose to the lung (H_E) and lung cancer cases per million person (*LCC*) were estimated in nine hospitals of the southern part of West Bank-Palestine, by using time-integrated passive radon detectors. Solid State Nuclear Track Detectors (SSNTD) technique were used for the measurements and carried out in the hospitals for an average exposure time of 75 day. The obtained mean values of C_{Rn} in those hospitals are ranges from 78 to 187 Bqm^{-3}, with highest mean value is recorded in Al- Etimad hospital, and the lowest is in Shaheera hospital. In addition, the estimated mean of D_{Rn} to both workers and patients ranges from 0.98 mSv y^{-1} to 2.34 mSv y^{-1}. The LCC risk for different rooms in the area under investigation varies from 8 per million person to 68 per million person. The results show that the mean C_{Rn} and the resulting doses not exceed the reference level recommended by ICRP (2010) in all hospitals. Therefore, health risk due to radon is a few possibilities. The results conclude that the ventilation condition is the major but not the only factor affects the results. Poor ventilated buildings showed the maximum annual effective dose on the other hand the number of floor has insignificant difference.

INTRODUCTION

The study of health effects of exposure to low-level alpha radiation emitted particles from radon (^{222}Rn) in dwellings and general environment has been received a continuing attention as the radon has been found to be a ubiquitous indoor radioactive air pollutant to which all people are exposed (Proctor, 1995). Exposure due to natural radiation is of great importance due to its largest contribution (nearly 55%) to the total collective radiation dose to the world population (UNSCEAR, 2000). The major contribution of doses of normal background regions arises from the inhalation of ^{222}Rn and their short - lived progeny (Anil *et al.*, 2014). When radon gas is inhaled, densely ionizing alpha particles emitted by depositing short-lived decay products of radon (^{218}Poand ^{214}Po) can interact with biological tissue in the lungs leading to DNA damage (WHO, 2009). A relationship between lung cancer and inhalation of radon and its decay products has been demonstrated. Hence, monitoring of radon in different rooms is important from the point of view of radiation hygienic (Sharma *et al.*, 2014). An individual's risk of lung cancer infection from radon depends mainly on three factors; the level of radon concentration, duration of exposure and individual's smoking habits. Risk increases as an individual is exposed to higher levels of radon over a longer period of time.

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Smoking combined with radon is an especially serious health risk. The risk of death from lung cancer due to radon is much larger for smokers than nonsmokers. If the radiation protection community wants to reduce radon-related mortality, then it needs to focus on ordinary people exposed at moderate concentrations, especially smokers, rather than just on people exposed at high concentrations who have the time and inclination to measure the radon concentration in their homes. Most people killed by radon-induced lung cancer would never have developed the disease if they hadn't also smoked. Absolute risk for life-long smokers about 25 times greater than for life-long non- smokers (John Hunt, 2014). Children have been reported to have greater risk than adults for certain types of cancer from radiation because of their lung shape and rate of breathing (EPA, 1993; Megbar and Bhardwaj, 2014). The workers in hospitals may inhale air polluted with radon and its short-lived progeny, which can enter the lungs during inhalation and then undergo them to radioactive decay thereby. This in turns may cause physical damage which leading to chemical damage and ultimately biological damage. The continuous damage which produced by alpha particles emitted from radon in the lungs may cause cancer. The knowledge of radon levels in building is extremely important in assessing population exposure. Radon in indoor spaces may originate from exhalation from rocks and soils around the building or from construction materials used in walls, floors, and ceilings (Thabayneh *et al.*, 2012; Thabayneh *et al.*, 2015).

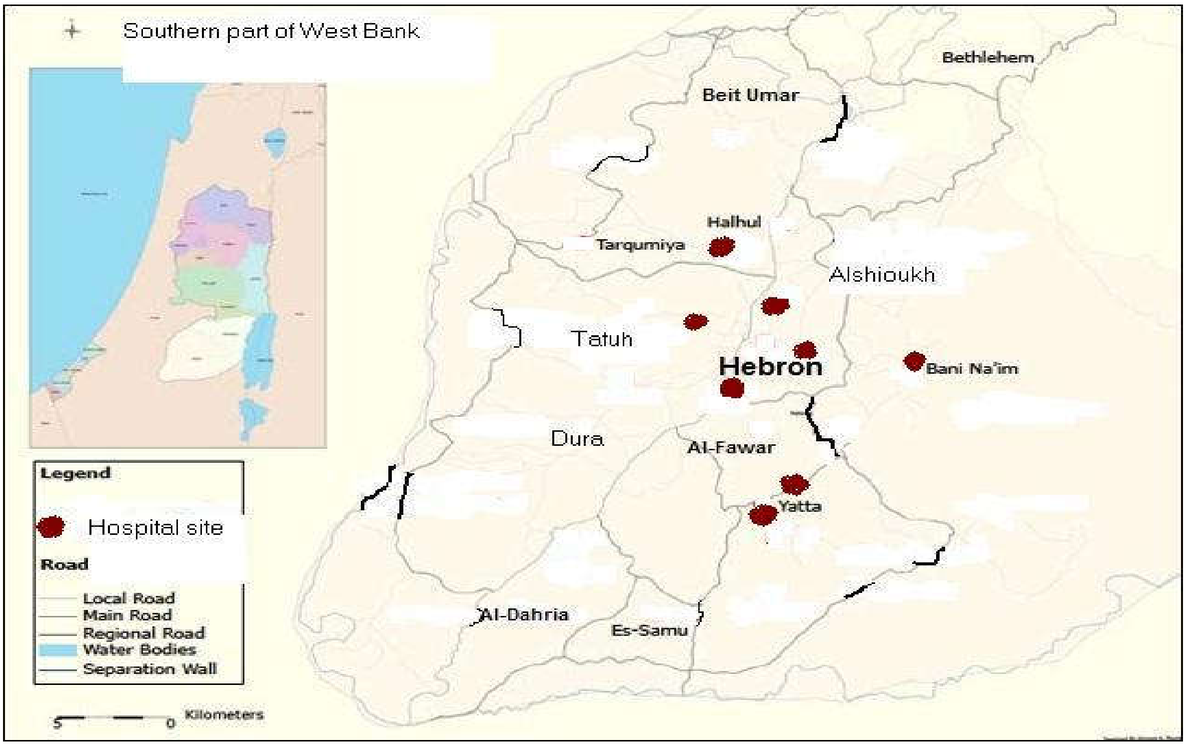

Fig. 1. Map shows the locations of the studied hospitals

Once settle inside the building; the radon cannot easily be rid of it. The sealing of buildings to conserve energy reduces the intake of outside air and worsens the hazard of radon. Good ventilation, reduce radon concentrations inside the buildings. Radon levels are generally high in cellars and basements, this is because these areas are closed to the natural sources of radon (soil of the ground), and are usually poorly ventilated. Radon can seep out from the ground and accumulates in confined spaces, such as basements, caves, mines, etc. High concentrations of radon can also be found in buildings because they are usually at a slightly lower pressure than the surrounding atmosphere and so tend to suck in radon (from the soil) through cracks or gaps in the floor (Mansour *et al.*, 2014; Hamori *et al.*, 2004). In the USA, radon is reported to be responsible for 15, 000 –20,000 lung cancer deaths per year (Bochicchio, 2005). The risk is reported to be proportional to the radon level down to EPA's action level of 4 $pCi\ell^{-1}$ and probably below this level (Somlai *et al.*, 2009; Zakariya *et al.*, 2013). In this study, together with measuring the indoor radon concentration; other highly-related parameters are considered to estimate the risk of inhalation of radon gas by the workers inside the hospitals, these parameters are: potential alpha energy concentration, equilibrium factor between radon and its daughter, annual effective dose and effective dose equivalent.

MATERIALS AND METHODS

This study addresses the indoor radon concentrations and risk of cancer in nine selected hospitals in four main regions (Hebron, Halhul, Yatta and Bani Naim) in the southern part of West bank – Palestine, which is illustrated in Figure 1. The hospitals are: Alya Governmental Hospital, Al Ahli Private Hospital, Al Mizan private Hospital, Naser Hospital, Red Crescent Hospital, Abu AL Hassan Alqasem Hospital, Bani Naim Hospital for childbirth and surgery, Al- Etimad Hospital and Shaheera Hospital for childbirth.

Radon concentrations are measured by using Solid State Nuclear Track Detector (SSNTD) (CR-39 detectors), which supplied by Pershore Mouldings, Ltd., UK. The typical dosimeter consists of a plastic cup in the form of frustum cone having dimensions of 7.0 cm diameter orifice, 5.0 cm diameter base and 6.5 cm depth. The detector (1.0 × 1.0 cm in size) is fixed by blue-tag to the bottom of the dosimeter. The top of the cup was covered with a permeable cling film, which is commercially available over the shelf (polyethylene foil of ~1 mm in thickness), to allow only radon gas to pass through the film and to exclude other radon progeny, particulates and alpha emitters particles from entering the dosimeter (Figure 2). The dosimeters were suspended at a height of about 1.8 m from the ground during autumn season (October to December 2014) in hospitals' rooms; each of them consists of several floors. The detector exposure registers α-tracks attributable to airborne radon gas and its α-emitting progeny. When α-particle penetrates the detector, the particle causes damage along its path, the damage is then made visible by chemical etching. The etching produces a hole in the detector along the path of the particle. The hole can be easily observed in a light transmission microscope with moderate magnification. The detector film detects α-particles from both ^{222}Rn and its daughters during the time of exposure in the indoor environment of a dwelling (Khan *et al.*, 1990). After 75 exposure day, the CR-39 detectors were collected and chemically etched in a 6.25 NaOH solution using a water bath at 70 °C for 6hours. The etched films were washed with distilled water and after that got dried (Jazzar and Thabayneh, 2014). Alpha-particle track measurements per cm^2 produced by the decay of ^{222}Rn and its daughters were conducted using an optical microscope of 160 x magnification power. The track density was converted into radon concentration in Bqm^{-3} using the calibration factor. The CR-39 radon detector was calibrated in a standard source facility at the National Radiological Protection Board (NRPB), UK (Miles and Strong, 1989).

RESULTS AND DISCUSSION

Radon concentration

The indoor radon concentrations in units of Bqm^{-3}, were measured by applying the following calibration formula (Jazzar and Thabayneh, 2014):

$$\left[C_{Rn} = \left(\frac{C_0 t_0}{\rho_0}\right)\frac{\rho}{t} = k\ \frac{\rho}{t} \qquad (1) \right]$$

Where C_o is the radon concentration of the calibration chamber (90 $kBqm^{-3}$), to which the calibration exposure time (48 hr), ρ is the measured track number density per cm^2 on the CR-39 detector inside the dosimeter which is used in this study, ρ_o is the measured track number density per cm^2 on those of the calibrated dosimeters which is equal 3.31×10^4 $track.cm^{-2}$and t is the exposure time (1800 hr). The following indoor radon concentration data is obtained from 219 dosimeters which are successfully collected out of 270 dosimeters after 75 days. Statistical methods are implemented to analyze the collected data.

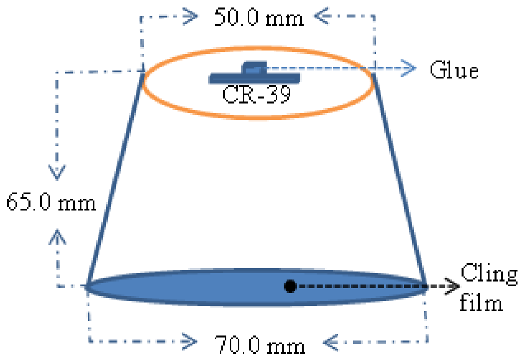

Fig. 2. CR-39 Dosimeter

Table 1. Distribution of measured radon concentration levels in each hospital

Hospital	Radon concentration (Bqm^{-3})				
	No. of detectors	Min.	Max.	Mean	SD
Al-Mizan	29	35	295	150	66
Red Crescent	39	33	287	144	68
Al-Ahli	59	49	298	178	67
Alya	27	40	268	137	68
Abu AL Hassan Alqasem	21	67	297	159	65
Shaheera	9	33	121	78	30
Naser	18	67	252	151	53
Bani Naim	8	45	230	119	75
Al-Etimad	9	103	294	187	58

The main parameters are the minimum, maximum; mean and standard deviation of radon concentrations in all hospitals are listed as shown in Table 1 and Figure 3. The present survey shows that the mean indoor radon concentration obtained varies from 78 Bqm^{-3} in Shaheera hospital to 187 Bqm^{-3}in Al-Etimad hospital. The mean results for all hospitals have been found lower than the reference level (300 Bqm^{-3}) as recommended by ICRP (ICRP, 2010).56% of the collected records are higher than the action level of 148 Bqm^{-3} as recommended by EPA(EPA, 1993). As a result, the mean value for all hospitals is higher than the world average radon concentration of 40 Bqm^{-3}as recommended by UNSCEAR (UNSCEAR, 2000). The indoor radon concentrations in the studied hospitals are categorized according to the floor number versus hospitals as shown in Table 2. According to this, the obtained mean values are vary from 92 to 202 Bqm^{-3} with overall mean of 158 Bqm^{-3} in underground floor (F-1), from 33 to 187 Bqm^{-3} with overall mean of 146.4 Bqm^{-3} in ground floor (GF), from 84 to 277 Bqm^{-3} with overall mean of 143 Bqm^{-3} in first floor (F1), from 120 to 192 Bqm^{-3} with overall mean of 154.8 Bqm^{-3} in second floor (F2), from 151 to 163 Bqm^{-3} with overall mean of 157 Bqm^{-3} in third floor (F3), and from 116 to 164 Bqm^{-3} with overall mean of 140 Bqm^{-3} in fourth floor (F4). The GF and F1 are generally characterized by a high mean radon concentration level compared with the other floors; this can be interpreted due several reasons, such as: Firstly, the upper floors have better ventilation than the lower ones. Secondly, the chance for radon to reach upper floors is very small as compared to that in lower ones. Thirdly, the radon exhalations rates from the ground are decreasing fast as going to higher floors. However, there is a large variation in the radon concentrations within the same floor, especially in underground, ground and the first floor.

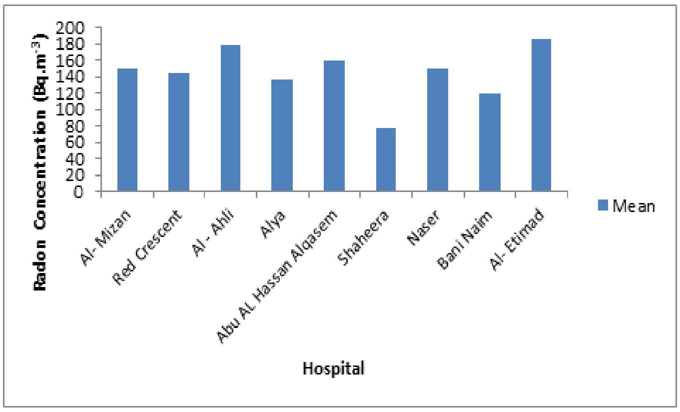

Fig. 3. Distribution of mean indoor radon concentrations in each hospital

The range of results and mean values of the indoor radon concentration levels in different compartments (x-ray, Administrative, Doctor, Reception, Pharmacy, Surgical operations, Laboratory, Stores, Patients, and Kitchens) are presented in Table 3. The results indicate that the mean values of indoor radon concentration levels in x-ray rooms, stores and kitchens are significantly higher than that measured in the other rooms. The lowest mean values are found in surgical operations, patients and laboratory rooms. Nevertheless, the highest indoor radon concentration (299 Bqm^{-3}) is recorded in a kitchen room in Al-Mizan hospital and (298 Bqm^{-3}) is measured in a non-ventilated store in Al-Ahli hospital, while (294, 295 and 297 Bqm^{-3}) are recorded in X-ray rooms in Al-Etimad, Al-Ahli and Abu AL Hassan Alqasem hospitals, respectively. High values in these rooms and in all hospitals in general, can be attributed to different factors; mainly of the bedrock geology as well as building characteristics and ventilation regime due to keeping closed windows for long time compared with other rooms. Moreover, an elevated indoor radon concentration in renovated buildings may also result from using new sealed double glass windows. On one hand, this type of windows saves energy, while on the other hand, this result in reduced ventilation rates, which leading to increase indoor radon concentration.

Table 2. Distribution of radon concentration levels according to floor number in each hospital

Floor Hospital	Radon concentration levels (Bqm^{-3})																	
	F -1			GR			F 1			F2			F3			F4		
	Min	max	mean	min	max	mean	min	max	mean	min	max	mean	min	max	mean	min	max	mean
Al-Mizan	68	295	150	70	262	162	54	170	129	35	224	146	---	---	---	98	235	164
Red Crescent	63	281	160	52	287	141	111	246	153	33	211	120	91	228	151	41	182	116
Al–Ahli	49	279	164	80	295	179	277	277	277	133	298	192	147	179	163	---	---	---
Alya	202	202	202	43	257	123	71	230	130	40	268	161	---	---	---	---	---	---
Abu AL Hassan Alqasem	78	297	172	95	277	167	67	205	124									
Shaheera	---	---	---	33	33	33	46	121	84									
Naser	---	---	---	67	252	160	92	120	104									
Bani Naim	45	230	92	109	197	166	---	---	---									
Al-Etimad	---	---	---	103	294	187	---	---	---									

Table 3. Indoor radon concentration levels for different rooms in each hospital

Hospital	Patients			Store			Laboratory			Administrative			X-ray		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Al-Mizan	54	219	111	104	235	163	68	191	125	168	262	215	78	241	135
Red Crescent	33	246	128	41	281	134	52	287	169	186	186	186	75	228	150
Al–Ahli	96	266	175	90	298	173	80	139	109	80	245	162	74	295	213
Alya	40	268	143	69	202	119	43	73	61	85	230	157	66	257	156
Abu AL Hassan Alqasem	92	185	125	103	200	156	78	231	154	67	205	136	149	297	211
Shaheera	46	100	69	33	121	77	58	58	58	101	101	101	---	---	---
Naser	101	165	127	120	148	134	---	---	---	67	237	172	188	188	188
Bani Naim	190	230	210	60	109	85	49	49	49	197	197	197	---	---	---
Al-Etimad	103	183	147	139	139	139	176	176	176	---	---	---	238	294	266
Hospital	Surgical operations			Doctor			Pharmacy			Kitchen			Reception		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Al-Mizan	35	224	150	114	127	119	70	70	70	295	295	295	---	---	---
Red Crescent	97	182	141	---	---	---	234	234	234	176	234	209	---	---	---
Al–Ahli	---	---	---	49	213	147	---	---	---	96	96	96	---	---	---
Alya	---	---	---	175	175	175	---	---	---	---	---	---	---	---	---
Abu AL Hassan Alqasem	118	118	118	---	---	---	87	277	182	113	190	151	---	---	---
Shaheera	86	86	86	98	98	98	---	---	---	---	---	---	---	---	---
Naser	92	120	106	---	---	---	133	133	133	230	230	230	114	252	166
Bani Naim	---	---	---	---	---	---	45	45	45	75	75	75	---	---	---
Al-Etimad	---	---	---	---	---	---	---	---	---	---	---	---	161	233	197

Table 4. The mean values of *(PEAC)*, *(E_p)*, *(D_{Rn})*, *and (H_E)* for different rooms in each hospital+

Hospital	PEAC ($\times 10^{-3}$)(WL)			Ep ($WLMY^{-1}$)			D_{Rn}($mSvy^{-1}$)			H_E ($mSvy^{-1}$)		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Al-Mizan	3.8	31.9	16.2	0.16	1.32	0.67	0.44	3.69	1.88	1.05	8.86	4.50
Red Crescent	3.6	31.0	15.6	0.15	1.28	0.64	0.42	3.59	1.81	0.99	8.62	4.33
Al–Ahli	5.3	32.2	19.2	0.22	1.33	0.79	0.62	3.73	2.22	1.47	8.95	5.35
Alya	4.4	28.9	14.8	0.18	1.20	0.61	0.50	3.35	1.71	1.22	8.04	4.11
Abu AL Hassan Alqasem	7.2	32.1	17.2	0.30	1.33	0.71	0.84	3.72	1.99	2.00	8.92	4.77
Shaheera	3.5	13.1	8.5	0.15	0.54	0.35	0.41	1.52	0.98	0.99	3.64	2.35
Naser	7.2	27.2	16.3	0.30	1.12	0.67	0.84	3.15	1.89	2.00	7.54	4.53
Bani Naim	4.8	24.8	12.9	0.20	1.02	0.53	0.56	2.87	1.50	1.35	6.89	3.59
Al-Etimad	11.1	31.7	20.2	0.46	1.31	0.83	1.29	3.67	2.34	3.10	8.81	5.61

Table 5. The values of lung cancer cases (*LCC*)for different rooms in each hospital

Hospital	*LCC($\times 10^{-6}$)*		
	Min	Max	Mean
Al-Mizan	8	67	34
Red Crescent	8	65	33
Al-Ahli	11	68	40
Alya	9	61	31
Abu AL Hassan Alqasem	15	67	36
Shaheera	8	27	18
Naser	15	57	34
Bani Naim	10	52	27
Al-Etimad	23	66	42

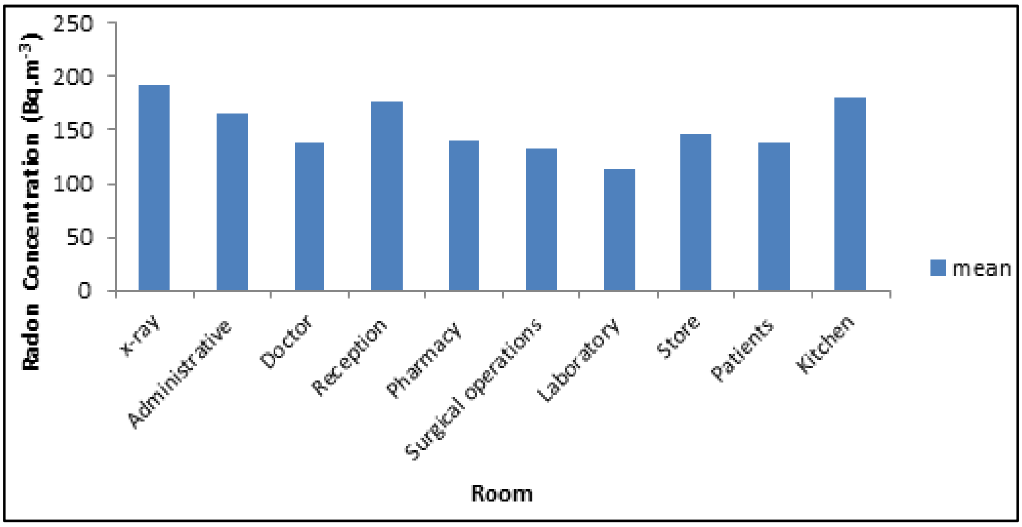

Fig. 4. Comparison of mean indoor radon concentrations between different rooms

Furthermore, central heating in winter which is constantly used, this leads to high indoor radon concentration. Moreover, there are some other sources of radiation in laboratories and radiology imaging centers which may increase the concentration of alpha particles in these rooms, such as usage of some radiated materials especially as in nuclear medicine. A comparison of mean values of indoor radon concentrations in different rooms in the studied hospitals is shown in Figure 4.

The radiological effects

The exposure to radon radiation is normally expressed as working level (WL), which represents the total radiated energy of α-particles. In other words, working level is a measure of the concentration of radon progeny, based on the pooled average indoor radon concentration and can be calculated using the reverse-variance-weighted method for determining the expected exposure to radon in various indoor environments (Bodansky, 1989; Ravikumar and Somashekar, 2014).

In this study, to estimate the effective dose of ^{222}Rn progeny in hospitals, it is necessary to know the potential alpha energy concentration (*PAEC*) in terms (mWL) units, which can be calculated as follows (Ahmed *et al.*, 2012):

$$PAEC\ (WL) = \frac{C_{Rn}\ F_R}{3700} \qquad (2)$$

Where (F_R) is the equilibrium factor between radon and its progeny and it is equal to (0.4) as suggested by UNSCEAR (UNSCEAR, 2000).

The potential alpha energy concentration (*PAEC*) in the surveyed hospitals is summarized in Table 4. The data show that the highest value of *PAEC* levels is recorded in Al–Ahli hospital (32.2 mWL) with mean value of 19.2 mWL, while all hospitals have mean value of *PAEC* levels more than 10 mWL except Shaheera hospital. As a result, the overall values of indoor *PAEC* are lower than the recommended threshold of (53 mWL) which reported in UNSCEAR (UNSCEAR, 1993). The exposure to radon progeny (E_P) is then related to the average indoor radon concentration C_{Rn} by following expression (Mansour *et al.*, 2014; ICRP,1994):

$$E_P(WLMY^{-1}) = \frac{8760 \times n \times F_R \times C_{Rn}}{170 \times 3700} \qquad (3)$$

Where *n* is the fraction of time spent indoors which are equal to (0.8), 8760 is the number of hours per year and 170 represents the number of hours per working month. As it can be seen from Table 4, the highest mean value of exposure to radon progeny (E_P) is found in Al-Etimad hospital which is equal to (0.83 WLMY^{-1}), while the lowest value is found in Shaheera hospital which is equal to (0.35 WLMY^{-1}). The mean values of (E_P) in Al-Mizan, Red Crescent, Al-Ahli, Alya, Abu AL Hassan Alqasem, Shaheera, Naser, Bani Naim, Bani Naim and Al-Etimad are 0.67, 0.64, 0.79, 0.61, 0.71, 0.35, 0.67, 0.53 and 0.83 WLMY^{-1}, respectively. All mean results of (E_P) in indoors rooms in the studied hospitals are lower than the lower limit of the recommended range (1-2 WLMY^{-1}) (Ismail and Jaafar, 2010). According to the UNSCEAR report, the annual absorbed dose D_{Rn} in (mSvy^{-1}) to the public due to ^{222}Rn and its progeny is estimated using the following equation (UNSCEAR, 2000; Zakariya *et al.*, 2013):

$$D_{Rn}(mSvy^{-1}) = C_{Rn} \times F_R \times H \times T \times D \qquad (4)$$

Where H is the occupancy factor (0.4), T is hours in a 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 (UNSCEAR, 2000). From eq. (4) and Table (4); the mean values of the annual absorbed dose in the studied hospitals is ranges from 0.98 mSv y^{-1} (Shaheera hospital)to 2.34 mSv y^{-1} (Al-Etimad hospital). The results are as follows: from 0.44 to 3.69 mSv y^{-1} with mean value of 1.88 mSv y^{-1} in Al-Mizan hospital, from 0.42 to 3.59 mSv y^{-1} with mean value of 1.81 mSv y^{-1} in Red Crescent hospital, from 0.62 to 3.73 mSv y^{-1} with mean value of 2.22 mSv y^{-1} in Al-Ahli hospital, from 0.51 to 3.35 mSv y^{-1} with mean value of 1.71 mSv y^{-1} in Alya hospital, from 0.84 to 3.72 mSv y^{-1} with mean value of 1.99 mSv y^{-1} in Abu AL Hassan Alqasem hospital, from 0.41 to 1.52 mSv y^{-1} with mean value of 0.98 mSv y^{-1} in Shaheera hospital, from 0.84 to 3.15 mSv y^{-1} with mean value of 1.89 mSv y^{-1} in Al-Naser hospital, from 0.56 to 2.87 mSv y^{-1} with mean value of 1.50 mSv y^{-1} in Bani Naim hospital and from 1.29 to 3.67 mSv y^{-1} with mean value of 2.34 mSv y^{-1} in Al-Etimad hospital. In its recent reports of

ICRP (John Hunt, 2014; ICRP, 2010); it has been recommended that the reference levels of radon in indoor rooms should be set around 5 mSv y^{-1}. On the basis of this recommendation, it has been observed that most of the hospitals rooms monitored for indoor radon concentration show lower values than the action levels. Therefore, the health risk due to radon is a few possibilities. To calculate the annual equivalent dose (H_E), one has to apply a tissue and radiation weighting factors according to ICRP (ICRP, 1991).When concerned with annual absorbed dose, one has to apply a tissue weighting factor in addition to the radiation weighting factor. According to ICRP (ICRP, 1991); the tissue weighting factor for lung is $W_T = 0.12$; the radiation weighting factor for alpha particles is $W_R = 20$ (Jing Chen, 2005). The annual equivalent dose is estimated by using the following equation (Nsiah-Akoto *et al.*, 2011):

$$H_E(mSvy^{-1}) = D_{Rn} \times W_R \times W_T \quad (5)$$

As it shown in Table 4, the highest mean annual equivalent dose recorded in Al-Etimad hospital (5.61 $mSvy^{-1}$), and the lowest mean annual equivalent dose is 2.35 $mSvy^{-1}$ in Shaheera hospital.

The lung cancer cases

Radon decays quickly, giving off tiny radioactive particles. When inhaled, these radioactive particles can damage the cells that line the lung. Long-term exposure to radon can lead to lung cancer, the only cancer proven to be associated with inhaling radon. 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 obtained using the relation (Mansour *et al.*, 2014; Battawy *et al.*, 2013):

$$LCC = D_{Rn} \ (mSvy^{-1}) \times 18 \times 10^{-6} (\mathrm{mSv})^{-1} \quad (6)$$

As it shown from Table 5, the radon induced lung cancer risks for different rooms in the area under investigation is found to vary from 8 per million person (in Shaheera and Red Crescent hospitals) to 68 per million person (in Al-Ahli hospital). The mean values of (*LLC*) in Al-Mizan, Red Crescent, Al-Ahli, Alya, Abu AL Hassan Alqasem, Shaheera, Naser, Bani Naim and Al- Etimad hospitals are: 34, 33, 40, 31, 36, 18, 34, 27 and 42 per million persons per year, respectively. These values are less than the lower limit of the range (170-230) per million person recommended by the ICRP (ICRP, 1993).

Conclusion

This work assesses the WLM for workers and patients in nine hospitals in the southern part of West Bank – Palestine. Indoor radon concentrations have been measured inside different hospitals (multi-storey and rooms with a variety of usage) in autumn season. The present survey shows that the mean indoor radon concentration for most hospitals have been found lower than the reference level (300 Bqm^{-3}) as recommended by ICRP (2010). 56% of them are higher than the reference level of 148 Bqm^{-3} as recommended by EPA (1993). To estimate the health effects of radon and its progeny, many of the radiological effects in the surveyed hospitals were calculated. The annual absorbed dose and the annual equivalent dose have been calculated 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.

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