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Assessment of indoor radon levels in some dwellings of Beit Fajjar city, Palestine

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ABSTRACT:

This study presents the indoor radon concentration levels measurements in 46 dwellings of Beit Fajjar city, West Bank, Palestine. The measurements were performed during the period of July16 to September 28, 2008, using CR-39 detectors. The indoor radon concentration levels were found to vary from 18.6 to 215.6 Bq/m3 with an average value of 78.6 Bq/m3. Most of the obtained data are below the action level of 150 Bq/m3. In 0.5% of the measurements, reported in one closed storages and badly ventilated rooms, the radon levels were found to be above 200 Bq/m3. The calculated annual effective doses were found to range from 0.64 to 3.56 mSvy−1 with an overall annual effective dose equivalent of 1.38 mSvy−1. This is an indication that the inspected zones are characterized by low radon exposure doses and no action is recommended.

Key words: Radon gas; Radon progeny; CR-39 detector; Response; Activity concentration radon dosimeter; Lung cancer; Annual effective dose; Indoor radon survey

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الملخص:

هذه الدراسة تمثل قياس تراكيز غاز الرادون في هواء عينة من المباني مكونة من 46 بناية في مدينة بيت فجار في محافظة بيت لحم في فلسطين. وقد تم تنفيذ القراءات خلال الفترة الزمنية ما بين 16 تموز إلى 28 ايلول من عام 2008، وباستخدام كواشف الحالة الصلبة للمسارات النووية نوع CR-39. بينت الدراسة أن قيم تراكيز غاز الرادون تتراوح ما بين 18.6 و 215.6 بيكرل / متر مكعب، وبمعدل 78.6 بيكرل / متر مكعب. معظم النتائج التي تم الحصول عليها أقل من مستوى التدخل 150 بيكرل / متر مكعب. فقط في 0.5% من القراءات التي سجلت في أحد المخازن المغلقة ، والأماكن سيئة التهوية، وجد أن تراكيز غاز الرادون فيها أعلى من 200 بيكرل / متر مكعب. دلت الدراسة أيضا أن قيم الجرعات السنوية الفاعلة تتراوح ما بين 0.64 إلى 3.56 ميللي سيفرت / سنة، وبمعدل كلي للجرعة السنوية المكافئة الفاعلة يساوي 1.38 ميللي سيفرت / سنة. وهذا مؤشر أن المناطق التي فحصت تتميز بمستويات تراكيز غاز رادون منخفضة، ولا تحتاج إلى إجراءات وقائية معينة

INTRODUCTION:

During the past four decades, it has been recognized that the inhalation of indoor radon-222 (222Rn) by humans is the main source of radiological hazard and probably the second most important cause of lung cancer after that of smoking (WHO, 1996; BEIR VI, 1999; UNSCEAR, 2000; EPA, 2006). The risk for cancer widely depend on the level of 222Rn and on how long a person is exposed to those levels (Darby and Hill, 2003; Matiullah et. al, 2003; WHO, 2009). In order to assess the population risk due to exposure to radon, the knowledge of the spatial distribution of indoor radon levels is of great importance.

Tremendous investigations have been conducted worldwide into direct monitoring of 222Rn and its progeny exposure, as well as direct measurements of 222Rn concentration levels and mapping (Faheem et al., 2007). At the international level, the World Health Organization (WHO) has published a series of guidelines and recommendations on the 'Environmental Health Impact Assessment'(WHO, 2007). The source and concentration level of 222Rn and its effects on human health have been extensively reported in the literature of United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000).

A radon concentration level of 150 Bq/m3 has been adopted in the United States; while a 200 Bq/m3 level has been adopted in most European countries as a reference point for radon concentration levels to the general public before mitigation before hazard takes place (ICRP 65, 1993; ICRP 68; 1994; ICRP 77, 1997). The conversion factors relating dose from exposure to radon concentration levels are described in ICRP Publication 68 (ICRP 68, 1994), where a conversion factor of 5.4 pCi/L is set to be equal to 200 Bq/m3. The UNSCEAR-2000 report estimated an average annual effective equivalent dose of 2.4 mSv to members of the public, due to natural sources (UNSCEAR, 2000). Up to 1.15 mSvy−1 is attributed to the inhalation of radon and its decay products, while the rest is due to cosmic rays, terrestrial gamma rays and radionuclides in the body (except radon) (UNSCEAR, 2000). The average effective dose due to radon corresponds to an average global population-weighted concentration of about 40 Bq/m3 indoors and 10 Bq/m3 outdoors (Magalhães, et al., 2003).

In Palestine, due to a specific type of dwelling construction, the use of concrete bricks, concrete, sand, cement, gypsum and many types of stones is very common; considering the geological characteristics, and population density, measurements of 222Rn levels are important in public health issues. Historically, the effort and dedication of two research groups, from different institutions: Al-Quds University and Hebron University have published approximately 90% of the radon data in the West Bank, Palestine. Previous studies were carried out in Hebron province, Jerusalem, and in Ramallah provinces (Hassan, 1996; Abu-Samreh, 2000; Dabayneh,2006; Leghrouz et al.,2007; Dabayneh, and Awawdeh, 2007; Leghrouz, et al. , 2011). Therefore, it is of great importance to extend previous work to collect representative data to the indoor 222Rn levels in Palestinian territories. This is a preliminary investigation for the radon concentration levels in Beit Fajjar city dwellings. The study is motivated by the fact that a few radon concentration data are available in Bethlehem dwellings and no radon measurements were performed in Beit Fajjar city before.

The primary purpose of this study was to assess the radon levels to which residents in Beit Fajjar city are exposed in order to determine the need for remedial action to protect the dwelling residents. However, this study is part of a nationwide survey and measurement of indoor radon levels in workplace and residential buildings, so far, has not been conducted in Palestine.

THE SITE

Beit Fajjar is a Palestinian city located 14 kilometers south of Bethlehem city in the Bethlehem Governorate, in the central West Bank (ARIJ, 2009). The city is located at 31°37′29.03″ N latitude and 35°09′20.19″E longitude as shown in Figure 1.

There is title variation in dwelling styles in Beit Fajjar city, depending on the economic and social level of the population. In general, no air conditioning systems are used in family houses. The primary economic sectors of the city are agriculture and stone-cutting; the city has 52 stone-cutting factories (saws) which supply the famous granite stones used in the construction of many houses in Israel and the Palestinian Territories
(http://www.bethlehem-city.org/index-1.php?)

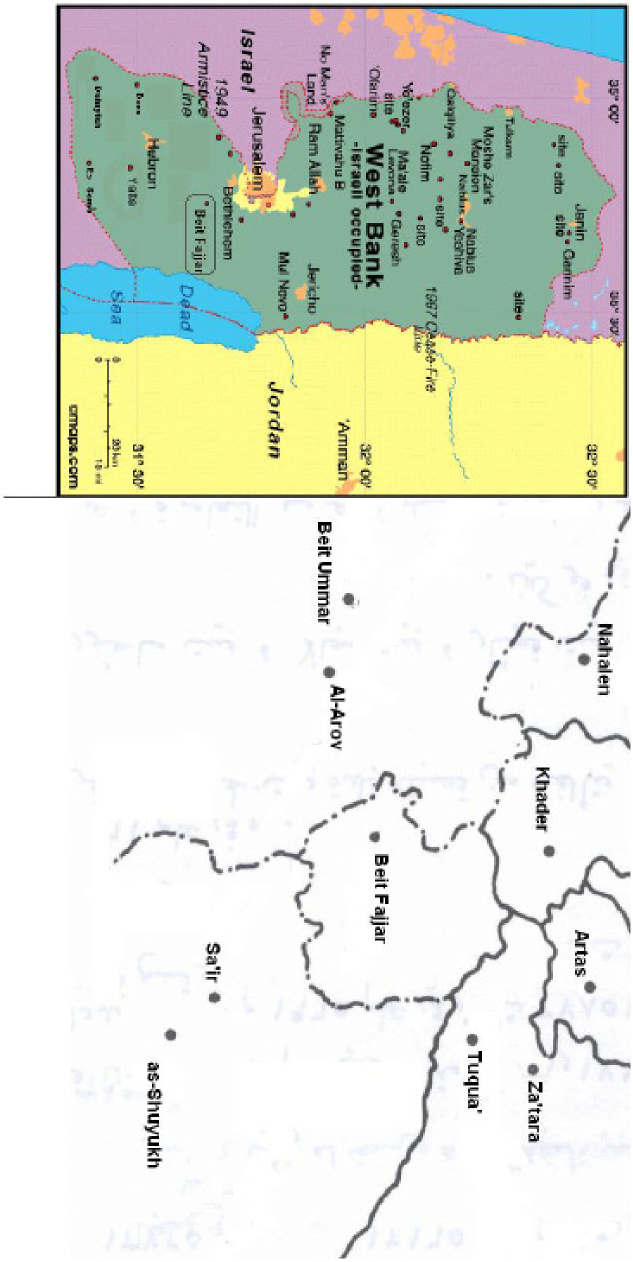

Figure 1. Map of the West Bank where Beit Fajjar Location is marked by an oval (http://www.infoplease.com/atlas/country/westbank.html, Jan 1,2011).

EXPERIMENTAL METHODOLOGY

The measurement of the indoor radon concentration levels has been carried out using the so- called long time-integrated passive radon dosimeters of closed can technique containing CR-39 solid state track nuclear track detectors (SSNTDs). This type of detector is a convenient device as it is sensitive to alpha particle with energies varied from about 0.1 to more than 20 MeV.

The high-quality of CR-39 as material detector, were of 500 µm thickness and provides from Pershore Modeling Ltd., UK, in the form of large sheets (~30cm×20 cm) (Kullab et al.,2001). The sheets were cut into small pieces, to be used as detectors, of size 1 cm×1 cm, these were used to build the dosimeters that were installed inside dwellings. The general description of a CR-39 dosimeter can be found elsewhere (Al-Bataina et al., 1997, Kullab et al., 2001; Abumurad et al., 2005; Abusamreh 2005). The typical dosimeter shown in Figure 2 consists of a plastic cup in the form of frustum cone having dimensions of 70.0 mm diameter orifice, 50.0 mm diameter base and 65.0 mm depth. The detector was 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 ~100 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. The structure of these passive radon dosimeters had been described elsewhere (Abumurad et al., 1994; Al-Bataina et al., 1997;Hadad et al., 2007). This type of dosimeter has been used for routine measurements of radon concentrations levels in soil, dwellings, and in water (Abumurad et al., 1994; Al-Bataina et al., 1997; Kullab et al., 2001; Abumurad et al., 2005).

In this study, the measurements were performed during the period 16/7/2008 to 28/9/2008. A total number of 213 dosimeters were installed in the inspected 46 dwellings of the city, which was divided into five sites: the east, the north, the west, the south, and the downtown. The dwellings include 39 houses, one pharmacy, two stores, two labs, and one office. All dosimeters were fixed at a level of 0.8 meter above the ground except in living room where dosimeters were placed 1.5 m above the floor, over any furniture piece available in the room and left in position for 75 days.

By the end of the test period, a total of 194 detectors were collected, the rest were damaged or lost, and returned to a laboratory after being sealed for reading. The CR-39 detectors were detached from the cups, and etched in a 6.25% NaOH solution at 72±2 0C and 8 h etching time in order to reach high resolution latent tracks. This process is well established with a protocol that is highly reliable (Espinosa and Gammage, 2003). After etching, the detector was washed in distilled water and allowed to dry in air. The number of tracks over a surface was counted manually using an optical microscope of 150 times magnification (150×).

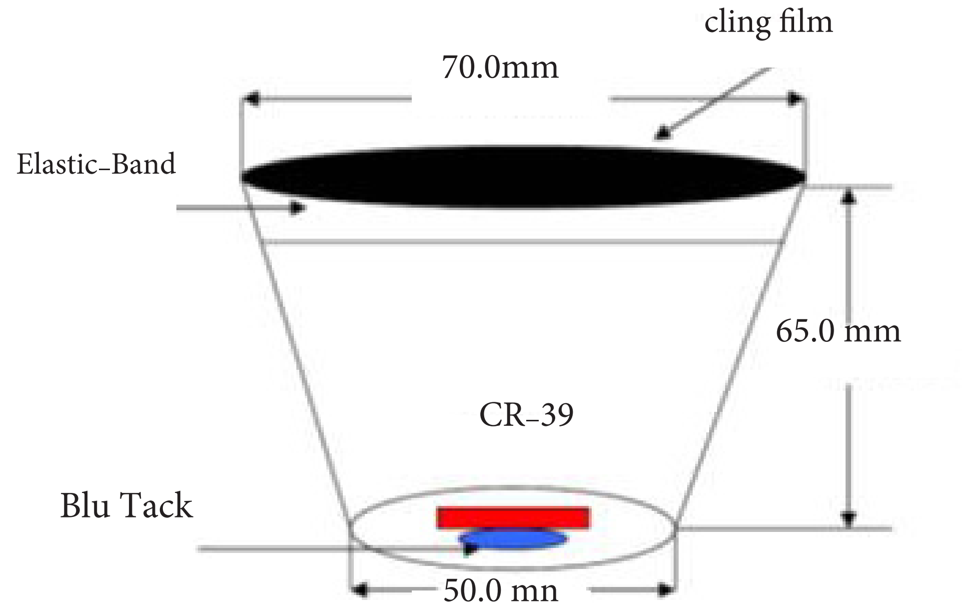

Figure 2. Typical CR-39 dosimeter (Abu-Samreh, 2005).

CALCULATIONS OF THE CONCENTRATIONS LEVELS

To relate the density of recorded tracks to radon concentration the dosimeters were previously calibrated (Al-Bataina et al., 1997).The calculated number of tracks per area was employed to calculate the radon concentration level of the site tested in Bqm-3 using the following calibration equation (Al-Bataina et al., 1997; Kullab et al., 1997; Kullab et al., 2001;Abumurad et al., 2005):

$$C_{Rn} = \frac{C_0 t_0 \rho}{\rho_0 t} \qquad (1)$$

where C_o, ρ_o, and t_o are the concentration (90 kBq/m^3), tracks density (3.3 × 10^4 tracks/cm^2) and the calibration exposure time (48 h), respectively. C_{Rn}, ρ, and t (75 days) are the concentration level, tracks density and exposure time of the measured ^{222}Rn, respectively. Using these quantities, then equation (1) in units of kBq/tracks can be written as:

$$C_{Rn} = 5.47\rho \qquad (2)$$

Equation (2) was used to calculate the radon levels in this study.

DOSE ESTIMATION

The annual mean effective dose E (mSv y^{-1}) expected to be received by people in the residential places as well as workplaces due to the indoor ^{222}Rn and its progeny can be estimated using the following equation (UNSCEAR, 2000):

$$E = C_{R} \times F \times H \times T \times D \qquad (3)$$

where C_{Rn} is the ^{222}Rn concentration (Bq/m^3), F is an equilibrium factor (0.4), H is the occupancy factor (0.8) , T is the hours in a year (8760 h y^{-1}) and D is the dose conversion factor (9.0×10^{-6} mSv h^{-1}/ Bq m^{-3}), which is the effective dose received by adults per unit activity of ^{222}Rn per unit volume of air per hour. The occupancy factors for the studied residential and workplace were estimated by personal interviewing of workers of the private/public offices and dwellings.

Substituting these values in equation (3), the effective dose received by the human lungs as given by equation (3) can be simplified into:

$$E = 0.0173\ C_{R} \qquad (4)$$

RESULTS AND DISCUSSION

The reported data for radon levels in this study were obtained from the collected dosimeters from Beit Fajjar dwellings after exposure time of 75 days during the summer of the year 2008. A grand total of 194 measurements have been successfully achieved. The collected data were analyzed statistically where the arithmetic average, geometric average, standard deviations were calculated.

The results obtained are shown in Table 1, Table 2, Table 3, and Table 4. In Table 1, the number of collected dosimeters, N, the range of radon levels, the frequencies for each direction, the arithmetic mean, and the annual effective dose for all the investigated dwellings are exhibited for each location in the city. The number of distributed dosimeters (N) in rooms of the investigated dwellings and the corresponding detailed range, and the frequency of radon concentration levels of a 194 detectors collected from the ones distributed in buildings are summarized in Table 2. Indoor radon concentration levels and statistics analysis of the data including the annual effective dose in different rooms are listed in Table 3. This table includes: The minimum (M_{in}), the maximum (M_{ax}), the arithmetic mean (AM), the standard deviation (SD), and the geometric mean (GM) of the radon levels obtained for each room type in a certain floor in a certain direction. Table 4 reports the distribution of radon concentration summary statistics in buildings, calculated as the average radon concentration in a certain floor, together with a table summarizing its main parameters.

Table 1. The frequencies of the radon concentration levels for each direction of the city.

Part of the city	Frequency range (Bq/m^3)					N	AM	E
	0-49	50-99	100-149	150-200	>200		(Bq/m^3)	(mSvy^{-1})
Eastern	8	40	5	1	1	55	94.4	1.63
Northern	6	14	5	1	--	26	73.2	1.27
Western	11	23	6	--	--	40	78.8	1.36
Southern	8	34	9	--	--	51	86.6	1.50
Downtown	2	19	1	--	--	22	75.7	1.31
AM = Arithmetic Mean, E = Annual effective dose								

Table 2. The range and the frequency of radon concentration levels of a 194 detectors collected from the ones distributed in buildings (houses, class rooms, stores, etc,--) located in Beit Fajjar city.

Direction: Eastern							
Floor No.	Room type	Frequency range (Bq/m^3)					N
		0-49	50-99	100-149	150-200	>200	
1	Salon	4	18	3	--	--	25
	Living room	3	1	--	--	--	4
	Bathroom	6	20	1	1	--	28
	Bedroom	6	30	5	--	--	41
	Kitchen	3	16	5	--	--	24
	Balcony	--	1	--	--	--	1
	Shop	--	2	--	--	--	2
	Clinic	--	1	--	--	--	1
	Pharmacy	--	1	--	--	--	1
	Storage	--	--	--	1	--	1
	Stairwell	1	--	--	--	--	1
	Hall	--	1	--	--	--	1
	Office	--	1	--	--	--	1
2	Salon	1	5	2	--	1	9
	Bathroom	3	6	8	--	--	17
	Bedroom	--	20	--	--	--	20
	Kitchen	4	5	--	--	--	9
	Balcony	--	1	--	--	--	1
	Stairwell	--	1	--	--	--	1
	Corridor	1	--	--	--	--	1
	Hall	2	1	--	--	--	3
	Living room	--	1	1	--	--	2
Total		**34**	**132**	**25**	**2**	**1**	**194**

Table 3. The minimum (M_{in}), the maximum (M_{ax}), the arithmetic mean (AM), the standard deviation (SD), and the geometric mean (GM) of the radon levels obtained for each room type in the survey.

Room type	First Floor						Second floor					
	Indoor concentration levels (Bq/m^3)					E	Indoor concentration levels (Bq/m^3)					E
	M_{in}	M_{ax}	AM	SD	GM	(mSvy^{-1})	M_{in}	M_{ax}	AM	SD	GM	(mSvy^{-1})
Saloon	18.6	125.8	69.4	33.5	66.3	1.20	50.9	215.6	102.8	54.6	101	1.78
Living	48.7	65.0	56.3	33.3	42.2	0.99	--	144.0	--	--	--	2.49
Bed	38.3	117.1	75.0	34.6	63.5	1.12	54.7	97.9	77.8	29.4	65.4	1.21
Bath	33.4	161.9	70.4	36.5	68.1	1.22	46.0	77.7	60.9	30.8	56.7	1.05
Kitchen	32.8	140.1	66.3	29.6	63.1	1.15	38.3	91.9	71.7	37.3	67.4	1.24
Hall	53.6	65.6	59.6	26.3	54.8	1.03	37.8	59.6	48.7	28.6	44.7	0.84
Passage	--	--	--	--	--	--	44.3	--	--	--	--	0.77
Balcony	98.6	--	--	--	--	1.71	52.0	--	--	--	--	0.90
Stairwell	64.6	--	--	--	--	1.12	48.1	--	--	--	--	0.83
Storage	--	151.0	--	--	--	2.61	--	--	--	--	--	--
Clinic	54.7	--	--	--	--	0.95	--	--	--	--	--	--
Shop	58.0	97.9	78.0	38.1	68.1	1.35	--	--	--	--	--	--

M_{in}=Minimum measured radon level, M_{ax}= Maximum measured radon level AM = Arithmetic Mean, E=Annual effective dose

Table 4. The frequencies of the radon concentration levels variations with the floor number.

Floor number	N	Radon concentration levels (Bq/m^3)					AM (Bq/m^3)	E (mSvy^{-1})
		0-49	50-99	100-149	150-200	> 200		
1	131	23	92	14	2	--	93.6	1.62
2	63	11	39	11	--	1	85.4	1.48

N=number of dosimeters; AM=arithmetic average; E=annual effective dose

As it can be seen from Table 1, the maximum frequency obtained in the frequency range 50- 99 Bq/m^3 and an indication that the frequency distributions are skewed to the lower radon levels in the frequency range 100- 149 Bq/m^3. Radon concentration levels were found to vary from 18.6 to 215.6 Bq/m3 with an average of 78.6 Bq/m^3. The radon concentration levels were found to vary from 40 to 176 Bq/m^3 in the eastern site; from 38 to 156 Bq/m^3 in the northern site; from 48 to 185 Bq/m^3 western site ; and from 46 to 161 Bq/m^3 in the southern, respectively. Indoor radon concentration levels in down town of Beit Fajjar city varied from 75 to 164 Bq/m^3. The average radon concentration in all rooms was above the world average radon concentration (40 Bq/m^3) (UNSCEAR, (1993).

According to Table 3, The obtained results in dwellings were as follows: the indoor radon concentration levels were found to vary from 18.6 to 215.6 Bq/m^3 in salons, from 48.7 to 144.0 Bq/m^3 in living rooms, from 38.3 to 117.1 Bq/m^3 in bedrooms, from 33.4 to 161.9 Bq/m^3 in bathrooms, from 32.8 to 140.1 Bq/m^3 in kitchens, from 48.1 to 64.6 Bq/m^3 in stairwells, from 37.8 to 65.6 Bq/m^3 in halls, from 58.0 to 97.9 Bq/m^3 in shops, from 52.0 to 98.6 Bq/m^3 in balconies and from 69.5 to 76.6 Bq/m^3 in classrooms. The average values of the obtained results in Bqm^{-3} are as follows: 125.8 Bq/m^3 in saloons, 63.4 Bq/m^3 in living rooms, 75.3 Bq/m3 in balconies 78.6 Bq/m^3 in bedrooms, 112.4 Bq/m^3 in bathrooms, 88.7 Bq/m^3 in kitchens, and 56.4 Bq/m3 in stairwells. It was found that the highest mean of concentration was located in the eastern site where an average value of 94.6 Bq/m^3 was reported. The average radon level in the southern part was found to be 86.6 Bq/m^3 and the lowest mean was found in the kindergarten school where an average value of 64.8 Bq/m^3 of radon level was measured. The measured average radon levels are all above the world average radon concentration (40Bqm^{-3}) (UNSCEAR, (1993), ICRP recommends an action level of 200 Bq/m^3 (ICRP 65, 1993; Denman et al., 2004). Comparing the results obtained from the present survey, the indoor ^{222}Rn concentration levels were below the action level. In a few houses, indoor radon concentration levels were higher than the limit of 148 Bq/m^3 recommended by EPA for United States (EPA, 2004).

Individual houses showed a large variation. In some houses higher mean radon concentration values were found in bathrooms and kitchens as compared to living rooms in first floor, and in living rooms and saloons as compared to bed rooms in second floor. This variation may mainly be attributed to the ventilation of the rooms. The ventilation influence on radon concentration is also observed on these results. The radon concentration levels were found to be higher in closed places and in houses closed most of the time. This may be explained by the fact that rooms with high radon levels are probably kept closed most of the times. For instance, people are keeping balconies closed most of the day in order to avoid stone dust, emerging from stone saws, entering their homes. As a result, the radon concentration levels in such balconies are expected to be high and this is reflected on the concentration levels in houses as a whole.

We found that radon concentrations were below 100 Bq/m^3 in 85% of the studied houses. This is an indication that during this time the dwellings were well ventilated. The variation in indoor radon levels of the city may be due to the ventilation as well as the building characteristics and their uses as an office, store, shop etc. Therefore, a proper ventilation system may be set up in the buildings, especially in the basements in order to reduce the indoor radon levels.

In general, radon concentration levels were found to vary from one dwelling to another but having the same trend in the radon concentration levels. In each building, the average of the radon concentrations in a floor was used to determine floor-to-floor variation in those buildings with more than one detector per floor. Standard deviation (SD) of floor means for each building with more than two floors was used to study variation between floors. Higher SD values occur in the same building where the first floor is characterized by a high radon concentration level with respect to the second floor level. Table 4 shows that radon concentration decreases as the floor number increases. This may be due to: Firstly, upper floors have better ventilation than the lower ones. Secondly, the chances for radon to reach upper floors are very small compared to its chances to reach lower ones.

The annual effective doses were found to range from 0.64 to 3.56 mSv y^{-1} with an average value of 1.38 mSv y^{-1}. In the first floor the annual effective doses were found to be 1.62 mSv y^{-1}, and in second floor, the annual effective doses were found to be 1.48 mSv y^{-1}. These values are less than the recommended action levels in dwellings (3–10 mSv y^{-1}) (ICRP 65, 1993). In addition, according to the findings of this study, the inhabitants of Beit Fajjar city may receive on the average an annual radon dose equivalent 1.38 mSv y^{-1}. Hence, the inhabitants of Beit Fajjar region are subjected on the average to a lung cancer risk of about 0.0032% according to a mathematical model proposed by Cross (1992) (Cross, 1992).

CONCLUSIONS

The overall average radon concentration level in Beit Fajjar city was found to be about 78.6 Bq/m3 during the summer season. The average annual radon effective dose was estimated to be 1.38 mSv y^{-1}. According to these estimates the risk factor for radon induced lung cancer was estimated to be about 0.0032%. Radon concentration levels and annual effective doses were found to be within recommended limits. 98% of the studied dwellings at Beit Fajjar city are radiology safe; as the measured radon concentration levels are below the recommended action level of 200 Bq/m3. Only 0.5% of the rooms were identified having radon levels higher than the 200 Bq/m^3. The measured ^{222}Rn concentration levels were highest in first followed by the second, third and fourth floor. All the estimated ef-

fective doses delivered to the inhabitants due to the indoor radon were found to be less than the lower limit of ICRP recommended action levels of 3–10 mSv yr^{-1}.
It is worth mentioning that remedial measures should be undertaken in a dwelling whenever the average annual radon concentration exceeds 200 Bq/m^3 in a residential area. This can be solved by increasing the ventilation rate, closing cracks and openings, and painting walls.
In conclusion, Beit- Fajjar dwellings, in general are characterized by low radon exposure dose and radon levels in different areas below the action levels recommended by international foundations (UNSCEAR, 1993). Accordingly, the city of Beit Fajjar, as a place to live in and/or to visit, is considered as one of the lowest cities in radon levels in Palestine (Abu-Samreh, 2000; Dabayneh,2006; Leghrouz et al.,2007; Dabayneh, and Awawdeh, 2007; Leghrouz, et al. , 2011; Leghrouz et al., 2012).

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