Exposure of Dwelling Populations to Alpha Particles and Its Health Impact in Illar Region, Tulkarem-Palestine

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Abstract: Radon concentrations were measured using passive dosimeters SSNTD CR-39 in Illar region, Tulkarem, Palestine. The dosimeters were installed in living rooms, bedrooms, bathrooms and kitchens, which were selected randomly in the surveyed area. Indoor radon levels and the annual effective dose in houses were found to be from 4.9-116.0 Bq m-3 and 0.11-1.73 mSv y-1, respectively, with average values of 38.3 Bq m-3 and 0.96 mSv y-1. Average values of radon concentration levels in living rooms, bedrooms, bathrooms and kitchens were 14.0, 27.1, 44.45 and 69.3 Bq m-3 respectively. The corresponding average values of annual effective dose for the living rooms, bedrooms, bathrooms and kitchens were 0.35, 0.68, 1.11, 1.73 mSv y-1 respectively. Indoor radon concentration values were lower than that of the world average value of 40 Bq m-3 and lower than the level recommended by the ICRP of 100 Bq m-3. Excess lung cancer risk was calculated using US EPA occupancy factors from the measured indoor radon concentrations. The overall average values of ERR for ages 35 and 55 years were found to be 0.29 and 0.23, respectively. The ERR due to indoor radon was within the standard limits and does not pose any serious threat to the occupants of the houses investigated.

Key words: Radon concentration, alpha particles, health impact, Palestine.

1. Introduction

Radon is an invisible, odorless, and radioactive noble gas produced through the uranium decay series. Of all radon isotopes, only 222Rn (radon gas) and 220Rn (thoron) occur in significant amounts indoors [1]. Lung cancer is the most commonly diagnosed cancer and causes more deaths than any other cancer. Recent estimates suggest that lung cancer accounted for 1.2 million deaths worldwide in 2002, with about 90-95% of lung cancers arising from epithelial cells of the bronchi and bronchioles. Epidemiological studies have shown a clear link between breathing high concentrations of radon and the incidence of lung cancer. Radon inhalation is considered to be the second most frequent cause of lung cancer after cigarette smoking, with a higher incidence among men than women [2-5].

Radon gas is a naturally occurring radioactive gas, appearing mainly by the diffusion process from the point of origin following α-decay of 226Ra in natural sources such as soil, building materials, tap water, natural energy sources used for cooking like gas, coal, etc. The presence of radon in soil depends upon the
uranium contents in it and on the complex soil chemistry that varies from place to place [8, 9]. Radon diffusion and transport through different media is affected by several factors like weather conditions, radon infiltration rates, ventilation, pressure differentials, soil characteristics, and occupant behavior [10-12]. Indoor radon variations occur hourly, diurnally, and seasonally, and the concentration in air varies according to location, altitude of the houses, building materials, different room within the same house, and ventilation rate [13].

Several epidemiological studies conducted on different locations (mines, schools, dwellings, etc) showed that exposure to elevated levels of radioactive radon gas is expected to increase the risk of lung cancer. Relative risk of lung cancer is almost linear with radon exposure. Elevated concentrations of radon are not only reported within mines but also for closed indoor environment of general public houses. Measurements of radon play a serious role in assessing public health and safety in homes [7].

1.1 Cancer Survey: Palestine Case

In low and middle income countries, high quality disease registration is difficult to achieve in the setting of inadequate healthcare infrastructure and political or economic instability [14]. In the West Bank, severe restriction on the movement of Palestinian people and goods, and difficult access to health services, have negatively affected living conditions and health status, resulting in the lack of data and very limited resources, which has been exacerbated by the state of the area under occupation [5]. According to the annual health report conducted by the Palestinian Authority Ministry of Health in mid of 2012, 733 cancer cases were reported, with 90 of these cases being lung cancer. This shows that lung cancer is the second most prevalent type of cancer, second only to breast cancer [15]. Only one registered survey has been carried out in the district of Tulkarem in 2010 by An-Najah University. According to this survey, there were 200 cancer cases in Tulkarem during 2005-2008; 85 cases were males, and 115 cases were females. This survey also showed that the number of lung cancer cases was 85 for the period 2005-2008. A high percentage of these cancer cases are attributed to smoking [5]. Annually, smoking alone is directly responsible for approximately 30% of all cancer deaths in USA, and 87% of lung cancer deaths [16].

The results of the present study shall help in establishing a baseline map of natural radiation background in the northern part of Palestine. It is interesting to mention that many researchers have studied indoor radon concentration levels in the southern part of the West Bank [17-22], but there have been no studies conducted in the northern part of West Bank specially Tulkarem district, making this study unique.

2. Materials and Methods

2.1 Study Area and Type of Dwellings

The Illar region, located in the north of Tulkarem, and famous for agriculture, was chosen for this study because it is the largest town among the villages of the Tulkarem District with regard to area and population. It is located about 238 m above sea level at lat. 32.37 N, long. 35.11 E. The weather is usually hot and humid in Illar region with a daily variation of temperature. The climate is cool from December to March, with a progressive increase in temperature in the following months [23].

The dwellings under study were built, in general, with limestone bricks, cement, sand, bricks, iron reinforcement, marble, and concrete as construction materials. Most of the houses are single story, while few of them are double story. Each house consists of at least three rooms, one or two bathrooms, and one kitchen. The walls of the dwellings are often covered with paints, bathroom walls ornamented with ceramics, kitchens designed with large marble plates. It is worthy to note that several of these materials are expected to contribute significantly to sources of indoor radon.
Most of the rooms are approximately 3 m by 4 m, with two windows and a door. Usually windows are not functional and remain closed with no additional exhausting fans, which results in poor ventilation.

2.2 Methodology

Indoor radon concentrations were measured mainly using the passive closed techniques employing high-quality CR-39 SSNTD from Pershore Moulding Ltd., UK, in the form of large sheets which were cut into 1 cm², and fixed by a double-sided solo tape at the bottom of the dosimeter. A total of 130 dosimeters were distributed inside various dwellings in the region under investigation. In each dwelling, at least five detectors were placed in different rooms, i.e., living room, bedroom, kitchen and bathroom, at a height of about 1.25 m above the floor. In each dwelling, at least two detectors were placed, with one in the living-room, one in a bedroom, one in a bathroom, and one in the kitchen. The exposure time in all sites was approximately 2.5 months. The structure of these passive radon dosimeters had been described as shown in Fig. 1 [24]. The design of the chamber ensures that all aerosols and radon decay products are deposited on the soft sponge from the outside and that only radon gas diffuses through it to the chamber. After exposure, the detectors were then collected and chemically etched using 6.25 M solution of NaOH in water bath with controlled electric heater for 4 hours at fixed temperature of 70 °C in temperature controlled etching bath (to ± 0.1 °C). After etching, the detector was washed in distilled water and allowed to air dry. The tracks were counted manually for ten randomly chosen fields of view, using an optical microscope with a magnification of 160X, to obtain an average and representative value of track density for each dosimeter. A total of 130 detectors were placed in the different sites; only 104 detectors were collected. The remaining ones (20%) were lost in the dwellings. To link the obtained track density with radon concentration, the dosimeters were previously calibrated in a standard source facility at the National Radiological Protection Board (NRPB), England.

3. Results and Discussions

3.1 The Radon Concentration

The radon concentration (activity density) measured by one detector, in units of Bq m⁻³, is given by equation [25]:

\[ C_{Rn} = \frac{C_o t_o \rho}{\rho_o t} \]  

(1)

Where \( C_o \) is the radon concentration of the calibration chamber (90 kBq m⁻³), \( t_o \) is the calibration exposure time (48 h), \( \rho \) is the measured track number density per cm² on the CR-39 detectors inside the dosimeters used in this study, \( \rho_o \) is the measured track number density per cm² on those of the calibrated dosimeters (3.31 \times 10^4 tracks cm⁻²) and \( t \) is the exposure time (1800 h).

The following radon level concentration data was obtained from 104 dosimeters collected after 75 days. The other 26 dosimeters were lost. Statistical methods were employed to analyze the collected data. The range of radon concentrations and the frequency are listed in Table 1.

Table 1 shows the frequency distribution of ²²²Rn average concentrations in 24 dwellings (86 rooms). About 76% of indoor ²²²Rn levels are found to vary between 0 and 50 Bq m⁻³. The concentrations (51-100 Bq m⁻³) were observed in 18% of the studied different

![Fig. 1 Typical CR-39 dosimeter.](image-url)
rooms. Nearly 6% of rooms show radon concentrations above 100 Bq m\(^{-3}\), with a maximum of 116.0 Bq m\(^{-3}\).

Table 2 summarizes the results of indoor radon concentration levels measured in different compartments of 24 different houses in Illar region. The data shows that the indoor concentration obtained in the present investigation varies from 4.9 to 39.8 Bq m\(^{-3}\), with an average value of 14 Bq m\(^{-3}\) in living rooms, and from 4.4 to 93.1 Bq m\(^{-3}\), with an average value of 27.1 Bq m\(^{-3}\) in bed rooms, and from 10.3 to 116.0 Bq m\(^{-3}\), with an average value of 44.4 Bq m\(^{-3}\) in bathrooms, and from 36.9 to 102.5 Bq m\(^{-3}\), with an average value of 69.3 Bq m\(^{-3}\) in kitchens. The overall average of the measured indoor radon concentration level inside dwellings of Illar region is found to be 38.3 Bq m\(^{-3}\), which is much lower than the recommended ICRP acceptable radon level of 100 Bq m\(^{-3}\) [26], and world average radon concentration of 40 Bq m\(^{-3}\) [27]. This study was done during the summer, in which the average radon level is expected to be lower than during winter season.

From the tabulated data in Table 2, it is clear that there is a notable difference between the minimum and maximum concentrations of average radon level in the dwellings of Illar. The lowest concentration (4.9 Bq m\(^{-3}\)) was found in the living room, whereas the highest concentration was found in the bathroom (116.0 Bq m\(^{-3}\)). Table 2 shows that the average radon concentration in bedrooms is higher than that in living rooms in the investigated regions. This may be attributed to poor ventilation rates in bedrooms, while living rooms of the houses have large windows, open areas, and good ventilation.

The results indicate that in all the dwellings we investigated, radon concentrations in some compartments, like kitchens and bathrooms, were significantly higher than the radon concentrations measured in living rooms and bedrooms. Although kitchens and bathrooms are constructed mainly from the same 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, in particular, is used extensively in place of the paint commonly used in living room and bedrooms [28]. Previous reports have indicated that ceramic is a potential source of radon, where radon mainly emerges from the decay of thorium and uranium in these materials [11]. Another factor explaining the high levels of radon and radon inhalation rates in these compartments is the poor state of ventilation due to the relatively narrow openings. The use of natural gas in houses and the supply of kitchens and bathrooms with water originated from underground sources are a potential source of indoor radon [19]. 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.

Therefore, we strongly recommend that better ventilation be considered in these houses to keep radon concentration levels low. Additional studies should be

<table>
<thead>
<tr>
<th>Room</th>
<th>Frequency range (Bq m(^{-3}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-50</td>
</tr>
<tr>
<td>Living rooms</td>
<td>42</td>
</tr>
<tr>
<td>Bed rooms</td>
<td>18</td>
</tr>
<tr>
<td>Bath rooms</td>
<td>14</td>
</tr>
<tr>
<td>Kitchens</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>79</td>
</tr>
<tr>
<td>%</td>
<td>76%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Compartments</th>
<th>No. of rooms</th>
<th>No. of detectors</th>
<th>(C_{206}) (Bq m(^{-3}))</th>
<th>Min</th>
<th>Max</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living rooms</td>
<td>24</td>
<td>42</td>
<td>4.9</td>
<td>39.8</td>
<td>14.0</td>
<td></td>
</tr>
<tr>
<td>Bed rooms</td>
<td>22</td>
<td>22</td>
<td>4.4</td>
<td>93.1</td>
<td>27.1</td>
<td></td>
</tr>
<tr>
<td>Bath rooms</td>
<td>21</td>
<td>21</td>
<td>10.3</td>
<td>116.0</td>
<td>44.4</td>
<td></td>
</tr>
<tr>
<td>Kitchens</td>
<td>19</td>
<td>19</td>
<td>36.9</td>
<td>102.5</td>
<td>69.3</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>86</td>
<td>104</td>
<td>Total average</td>
<td>38.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
carried out during other seasons, in which the ventilation of various dwellings is different.

Table 3 shows radon concentration levels in different regions in Palestine along with the present study. It is obvious that the result of our study is around or lowers than the average radon concentration in Palestinian dwellings in all studied regions. In order to compare radon levels in different regions of Palestine and the study region, some factors have to be considered. Illar region lies in the northwestern part of the West Bank and has relatively high humidity during the summer. It is also characterized by spacious houses with many opening, occupied by large families. In addition, it is customary to exchange many visits with neighbors. These factors may induce good air circulation, which may reduce the indoor radon concentration levels, which explains why regions in the middle and south of Palestine have high radon levels in comparison with Illar region.

3.2 The Annual Effective Dose

According to the UNSCEAR report, annual effective dose \( AED \) (mSv y\(^{-1}\)) to the public from \(^{222}\)Rn and its progeny is estimated using the following equation [8]:

\[
AED = C_{Rn} \times F \times H \times T \times D
\]  

Where \( C_{Rn} \) is the \(^{222}\)Rn concentration (Bqm\(^{-3}\)), \( F \) is an equilibrium factor (0.4), \( H \) is the occupancy factor (0.8), \( T \) is hours in a year (8,760 h y\(^{-1}\)) and \( D \) is the dose conversion factor \( (9.0 \times 10^{-6} \text{ mSv Bqm}^{-3} \text{ h}^{-1}) \), which is the effective dose received by adults per unit \(^{222}\)Rn activity per unit of air volume. The annual effective dose depends only on the \( C_{Rn} \). The annual effective doses due to radon exposure are also provided in Table 4. The data shows that the average value of the annual effective dose is equivalent to the corresponding measured radon concentration, were: 0.35, 0.68, 1.11 and 1.73 mSv y\(^{-1}\), in living rooms, bedrooms, bathrooms and kitchens, respectively. In all the dwellings surveyed, the total average annual effective dose is 0.96 mSv y\(^{-1}\) and these values are less than the recommended global action levels in dwellings of 1.3 mSv y\(^{-1}\) assigned by ICRP and Gonzalez [29, 30].

3.3 Exposure Parameters

3.3.1 The Average Exposure rate

The average radon daughter exposure rate is based on EPA determinations that: (1) on average, people spend 70% of their time indoors at home (occupancy factor, \( \Omega = 0.75 \)) and (2) in homes, the average equilibrium fraction for radon daughters is \( F = 0.5 \). Taken together with the estimated average radon concentration of \( C_{Rn}=1.25 \text{ pCi L}^{-1} \) in the U.S. The estimated average exposure rate is [4]:

\[
\omega = C_{Rn}[F \times 0.01 \text{ WLM(pCi L}^{-1})^i \Omega \times 51.6 \text{ WLM(WLy}^{-1})^j]
= (1.25 \text{ pCi L}^{-1})[0.75 \times 0.5 \text{ WLM(pCi L}^{-1})^i \Omega \times 51.6 \text{ WLM(WLy}^{-1})^j]
= 0.242 \text{ WLM y}^{-1}
\]

EPA’s previous risk estimate was \( 2.24 \times 10^{-4} \) per WLM with an etiologic fraction of about 8.5% [4].

3.3.2 Mathematical Models to Calculate the Relative Lung Cancer Risk

The following mathematical models, as proposed by BEIR IV, 1999, were used for calculating relative lung cancer risk [3, 7]:

\[
RLCR = 1 + \beta \omega
\]

### Table 3 Radon concentration levels (Average value) in different regions in Palestine.

<table>
<thead>
<tr>
<th>Region</th>
<th>Average radon concentration (Bq m(^{-3}))</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gaza Strip</td>
<td>38</td>
<td>[12]</td>
</tr>
<tr>
<td>Hebron University</td>
<td>30</td>
<td>[17]</td>
</tr>
<tr>
<td>Tarqumia Schools</td>
<td>34</td>
<td>[18]</td>
</tr>
<tr>
<td>Dura city</td>
<td>69</td>
<td>[19]</td>
</tr>
<tr>
<td>BeitFajjar city</td>
<td>79</td>
<td>[22]</td>
</tr>
<tr>
<td>Bethlehem city</td>
<td>125</td>
<td>[31]</td>
</tr>
<tr>
<td>Illar region</td>
<td>38</td>
<td>Present work</td>
</tr>
</tbody>
</table>

### Table 4 The annual effective dose (AED) of different dwellings in Illar region.

<table>
<thead>
<tr>
<th>Compartments</th>
<th>Min</th>
<th>Max</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living rooms</td>
<td>0.12</td>
<td>1.0</td>
<td>0.35</td>
</tr>
<tr>
<td>Bedrooms</td>
<td>0.11</td>
<td>2.33</td>
<td>0.68</td>
</tr>
<tr>
<td>Bathrooms</td>
<td>0.26</td>
<td>2.90</td>
<td>1.11</td>
</tr>
<tr>
<td>Kitchens</td>
<td>0.92</td>
<td>2.56</td>
<td>1.73</td>
</tr>
<tr>
<td>Total</td>
<td>Total Average</td>
<td>0.96</td>
<td></td>
</tr>
</tbody>
</table>
Where $\beta \omega$ estimates the excess relative risk (ERR), $\omega$ is the exposure and $\beta$ estimates the increment in ERR for unit change in the exposure $\omega$ [3].

A modified mathematical form of the model for ERR specifies that the excess relative risk depends on time-since-exposure, attained-age, and rate of exposure (concentration) according to the formula [4]:

$$ERR = \beta \left[ \omega_{5-14} + 15-24 \omega_{15-24} + 25+ \omega_{25+} \right] \phi_{age} Y Z$$

(5)

Exposure at any particular age has 4 components: exposure in the last 5 years (excluded as not biologically relevant to the cancer risk) and exposures in 3 windows of past time, namely 5-14, 15-24 and 25 or more years previously. Those exposures are labeled as $w_{5-14}$, $w_{15-24}$ and $w_{25+}$, respectively, and each is allowed to have its own relative level of effect, $\theta_{5-14}$, $\theta_{15-24}$, and $\theta_{25+}$, respectively. These parameters detail how relative risk depends on time-since-exposure, and $\phi_{age}$ describes the dependency on attained age. The $Y Z$ ranging from 1 for radon concentrations below 0.5 WL to 0.11 for concentrations above 15 WL, define the dependency on exposure rate. This formula can be simplified by noting that $Y Z$ is almost always equal to 1, because residential exposure rates are almost always below 0.5 WL. Letting $\beta^* = \beta \phi_{age}$, and using the (unadjusted) parameter estimates from BEIR VI given in $(15-24 =1, 15-24 = 0.78, 25+ = 0.51)$, the formula for the excess relative risk may then be expressed as [4]:

$$ERR = \beta^* \left[ \theta_{5-14} + 0.78 \theta_{15-24} + 0.51 \theta_{25+} \right]$$

(6)

Where $\beta^* = 0.0768$ for attained age ($x$) < 55 year
= 0.0438 for 55 year $\leq x$ < 65 year
= 0.0223 for 65 year $\leq x$ < 75 year
= 0.0069 for $x \geq 75$ year.

From the measured average indoor radon concentrations, excess relative risk (ERR) was calculated using the US EPA for the area under study [4]. For Illar region, the variations in the values of ERR are mentioned in Table 5, for US EPA occupancy factor with 35 and 55 year ages, ERR in living rooms varies from 0.04 to 0.30 and 0.03 to 0.24, with average values of 0.11 and 0.08, respectively. In bedrooms, the values vary from 0.03 to 0.70 and 0.03 to 0.56, with average values of 0.21 and 0.16, respectively. In bathrooms the values vary from 0.08 to 0.87 and 0.06 to 0.70, with average values of 0.33 and 0.27, respectively, and in kitchens the values vary from 0.28 to 0.77 and 0.22 to 0.62, with an average value of 0.52 and 0.42, respectively. The total average values of ERR for 35 and 55 years are 0.29 and 0.23, respectively. ERR values are higher for the 35 year age group compared to 55 year age group.

A comparison of the results of the present study with the data available for excessive relative lung cancer risk at international level has been carried out. Several epidemiological studies have been performed at the international level in different parts of the world to assess relative risk of cancer due to radon exposure. For example, Goran et al. carried out a study in Sweden and reported the relative risk of lung cancer as 1.3 (95% confidence interval, 1.1 to 1.6) for average radon concentrations of 3.8 to 10.8 pCiL$^{-1}$ (140 to 400 Bqm$^{-3}$), and 1.8 (95% confidence interval, 1.1 to 2.9) at concentrations exceeding 10.8 pCi L$^{-1}$ [32]. Rafique et al. reported the total average values of ERR for US

<table>
<thead>
<tr>
<th>Compartments</th>
<th>$C_{Rn}$ (Bqm$^{-3}$)</th>
<th>$C_{Rn}*$ (pCiL$^{-1}$)</th>
<th>$w$ (WLM$^{-1}$)</th>
<th>(35 year age)</th>
<th>(55 year age)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living rooms</td>
<td>4.9</td>
<td>39.8</td>
<td>14.0</td>
<td>0.13</td>
<td>1.08</td>
</tr>
<tr>
<td>Bedrooms</td>
<td>4.4</td>
<td>93.1</td>
<td>27.1</td>
<td>0.12</td>
<td>2.52</td>
</tr>
<tr>
<td>Bathrooms</td>
<td>10.3</td>
<td>116</td>
<td>44.4</td>
<td>0.28</td>
<td>3.12</td>
</tr>
<tr>
<td>Kitchens</td>
<td>36.9</td>
<td>102.5</td>
<td>69.3</td>
<td>1.22</td>
<td>2.77</td>
</tr>
<tr>
<td>Total Average</td>
<td>38.3</td>
<td>1.04</td>
<td>0.20</td>
<td>0.29</td>
<td>0.23</td>
</tr>
</tbody>
</table>

* 37 Bqm$^{-3} = 1$ pCiL$^{-1}$. 

Table 5 The indoor radon concentration levels, $C_{Rn}$ (in Bqm$^{-3}$ and in pCiL$^{-1}$), the average radon daughter exposure rate ($w$), and the excess relative risk (ERR) of different dwellings in Illar region.
EPA occupancy factor for ages 35 and 55 years as 0.59 and 0.45, respectively [7]. Faheem et al. reported the total average excess lung cancer risk for the 35-54 y age group residents to be 0.53 [33]. Ruosteenoja conducted a survey on men from a rural area in Finland, for population sample of 238 lung cancer patients and 434 controls. The RR for highest radon exposure (= 265 Bqm⁻³) was 1.23 (95% Confidence Interval, 0.71-2.13) compared to the lowest radon level (< 109 Bqm⁻³) [34].

Lung cancer risk reported by Tomotaka et al., associated with indoor radon levels of 25-49, 50-99 and 100 or more Bq m⁻³, was found to be 1.13 (95% confidence interval; 0.29-4.40), 1.23 (0.16-9.39) and 0.25 (0.03-2.33), respectively [35]. Létourneau et al. [36] carried out a case control-study related to radon exposure in Winnipeg, Manitoba, Canada including 738 lung cancer patients and 738 controls. RRs of 0.97 (95% CI, 0.81-1.15) and 0.93 (0.71-1.11) per unit of cumulative radon exposure were observed for bedroom (3750 Bqm⁻³·y) and basement (5,000 Bqm⁻³·y) respectively.

On the whole, average excess lung cancer risk for the 35 and 55 year age groups for different dwellings in Illar region was found 0.29 and 0.23, respectively. We conclude that the estimated ERR values of this survey are lower than those reported for other parts of world.

4. Conclusions

Radon concentration in dwellings of the Illar region in Palestine has been measured, and annual effective doses received by the inhabitants of the surveyed area have been estimated from the measured radon concentration. The minimum average value of radon concentration was found in living rooms, while the maximum average value was in kitchens, which may be attributed to the difference in quality of ventilation for the two types of compartments. The high radon level in some bathrooms and kitchens suggests that building materials and room structure influence the indoor radon levels. The improvement of ventilation in these rooms could reduce radon concentration. The annual effective doses from radon inhaled from indoor air are lower than the ICRP recommended limits. Therefore, we conclude that radon level in most of the dwellings of the Illar are within the limits as proposed by ICRP and WHO.

From the measured indoor radon concentrations, excess lung cancer risk was calculated using US EPA occupancy factors. The overall average excess lung cancer risk for the studied area for the 35 and 55 year age groups was found to be 0.29 and 0.23, respectively. The ERR due to the indoor radon is within the limits and does not pose any serious threat to the occupants. The high incidence of cancers in the area may be attributed to chemicals used in agriculture, smoking, and pollutions from Israeli chemical factories surrounding Tulkarem.

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