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Indoor exposure assessment of radon in the elementary schools, Palestine

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► ***Original article***

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ABSTRACT

Background: Many public health agencies rank residential radon exposure as the second leading cause of lung cancer after cigarette smoking. It has been shown that the risk coefficient for lung cancer is higher for children than that for adults. Therefore, indoor radon measurements were carried out in the elementary schools of Tulkarem province, West Bank, Palestine. ***Materials and Methods:*** Two hundred and thirty solid state nuclear track detectors (SSNTDs) type CR-39 were distributed in the classrooms of 20 elementary schools in Tulkarem province area. About thirty of them were used for quality assurance purposes. The CR-39 detectors were exposed in the schools for three months during the school summer holiday from May 2012 to August 2012 and then collected and etched in Sodium Hydroxide (NaOH) 6.25 N solution at 75 °C for 6 h. The tracks were counted manually at the digital microscope. ***Results:*** The indoor radon levels were generally low, ranging from 3.48 to 210.51 Bq/m^3 (Becquerel per cubic meter), with a mean radon concentration (mean±SE; standard error) of 40.42± 2.49 Bq/m^3. The average annual radon effective dose was assessed to be (mean±SE) 0.17 ± 0.01 mSv/y (milliSievert per year) while the excess lifetime lung cancer risk was approximately 0.09%. The results obtained indicate that the indoor radon concentration was significantly affected by the floor level of the classroom (negatively correlated) and the school building age (positively correlated). ***Conclusion:*** The radon concentration and the resulting dose in the schools were within the reference levels of the International Commission on Radiological Protection (ICRP). Better ventilation is recommended to decrease the risk to the minimum.

Keywords: *Indoor radon, schools, CR-39, effective dose, lung cancer risk.*

INTRODUCTION

Radon has long been recognized as a cause of lung cancer, and in 1988, the International Agency for Research on Cancer (IARC) and the World Health Organization (WHO) [1, 2] classified radon as a human lung carcinogen. Moreover, numerous public health agencies rank residential radon exposure as the second leading cause of lung cancer after cigarette smoking [2, 3]. However, it is well known that human exposure to radioactivity comes mainly from natural sources, being radon and its progeny breathed in the air responsible for more than 50% of the annual dose received from natural radiation [4]. Radon (^{222}Rn) is a noble radioactive gas generated by disintegration of radium (^{226}Ra) which is present in soil, water and building materials [5, 6].

Exposures to radon and its short-lived decay

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products at concentrations typically found indoors, deliver a dose to the sensitive cells of the lung corresponding to a dose of 1.3 milliSievert per year (mSvy) out of the total effective dose (2.4 mSvy) [4]. However, due to the enhanced sensitivity in children. The ICRP estimates that for youth, the risk coefficient for lung cancer from inhaled radon daughters is about a factor of two (among those age < 20 years) to four (age < 10 years) times higher than that for adults [7]. However, for most children and staff, the school is actually the second most likely exposure after their home environment given the time spent in each location (6 hours compared to at least 12 hours per day) [8]. Moreover, most of the data related to lung cancer involves radiation exposure during childhood because children have small lung volumes and high breathing rates. Therefore, they are more sensitive to ionizing radiation than at older ages [9]. Thus, a number of radon surveys have been performed in schools in many parts of the world [7, 10-16].

It has been recognized that an increase in radon concentration of 100 Becquerel's per cubic meter (Bq/m^3) is associated with approximately a 16% increased chance of contracting lung cancer. Tulkarem province has the second highest prevalence of lung cancer compared with other districts in the West Bank [18]. Therefore, indoor radon evaluation will help researchers quantify radon exposures and identify opportunities to address radon as a specific risk factor for lung cancer among this vulnerable population of students.

Results of this study will be used to estimate the effective dose for the pupils and teachers from radon and it will provide an important database about the radiation hazard from indoor radon in Tulkarem province. Which help to supply the radon map of Palestine.

MATERIALS AND METHODS

Study area and characteristics

Tulkarem province is a 246 km^2 area located in the central part of Palestine and in the extreme northwest of the West Bank, and nearly 15km east of the Mediterranean Sea [19]. The district lies between 40 to 500 m above sea level and is entirely within a fertile zone [20]. The population density is about 682 person/km^2. There are 88 elementary schools in Tulkarem: 75 governmental schools host 35 045 pupils, six United Nation Relief and Work Agency (UNRWA) schools host 3850 pupils and seven private schools host 685 pupils. Overall, the schools host 39 580 children whose ages range from 6-16 years. Approximately 1940 teachers serve these students.

The climate of Tulkarem province is subtropical, with rainfall limited to the winter. The average temperature in the winter ranges from 8 to 16 °C, while the average temperature in the summer ranges from 17 to 30 °C [21]. The district is mainly covered by sedimentary carbonate rocks such as limestone, dolomite, marl and chalk.

Sample size and settings

A stratified random sampling technique was used to select a sample from all 88 elementary schools in Tulkarem province. The classification and distribution of schools prepared by the Directorate of Education in the Tulkarem province was used in the selection process as these records are the most accurate. We selected 20 schools for the study from all the elementary schools of Tulkarem province (N=88) as follows: (A) schools were first stratified by location into three subgroups (city schools, village schools and refugee camp schools); (B) a proportional random sample were taken from each stratum depending on the number of schools in each stratum.

Radon measurements in schools

Radon concentrations were determined using solid state nuclear track detectors (SSNTDs). The specific detector used (CR-39, poly allyldiglycol carbonate, named PADC) is the most popular member of the SSNTD family. It was selected because of its good sensitivity, stability against various environmental factors, and high degree of optical clarity [22, 23]. A large sheet of CR-39 was supplied by Intercast Co, Parma-Italy (http://www.df.unibo.it/macro/intercast). The

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sheet was 1.0 mm in thickness and there was a mark on the front surface to avoid the possibility of tracks on the back surface by correctly handling and positioning the detectors. The CR-39 sheet was cut into square shapes sized 1.5 × 1.5 cm by a special hand cutter and a serial number was engraved on each detector in Arabic numerals for ease of identification. Then the detector was inserted flat into the bottom of a conical plastic cup held in place by a small piece of blu-tac to reduce any error that might be caused by its movement. The mouth of the pot was completely covered with a single layer of cling film that was held by an elastic band. The radon dosimeter developed in this study is shown in figure 1.

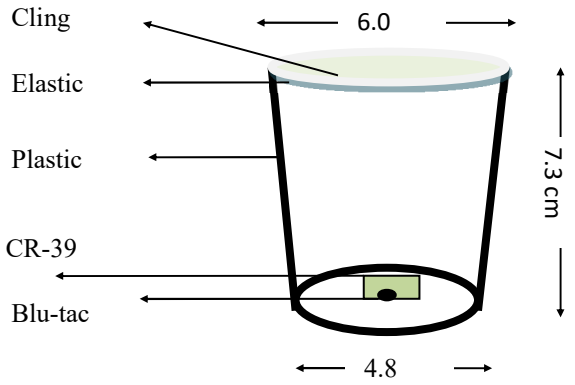

Figure 1. Schematic diagram of the radon CR-39 dosimeter placement (Single column fitting image).

RESULTS

Two hundred and thirty dosimeters were prepared and distributed in the selected schools at the frequently occupied classrooms. About 10 classrooms from all floor levels were randomly selected in each school. The dosimeters were hung on the wall at least 1.5 m above the floor and at least 10 cm from any objects. About 30 dosimeters were used for quality assurance purposes to ensure that measurement results were reliable. They were left in place for 90 days (from May to August 2012) during the summer school holidays, in demi-close conditions. After the exposure, the detectors were detached from the dosimeters and were processed in the standard procedure, as follows. The dosimeters were first chemically etched in 6.25 N solution of sodium hydroxide (NaOH; CAS 1310-73-2, Merck Millipore, Germany) at a temperature of 75 °C for 6 hours. Next, the detectors were washed for 30 minutes with running cold water, then with distilled water and finally with a 50% water/alcohol solution. For measuring radon concentrations that are dependent on the track density, was used a digital optical microscope with built-in camera and with 400 X magnification power (Optika Company, Italy).

The calculated track densities (TD) after background subtraction were converted into radon concentrations (CRn) in Bq/m^3 using the calibration factor (F) supplied by the manufacturer, where every track per cm^2 per day on the CR-39 detectors corresponds to an exposure of 12.3 Bq/m^3 of radon concentration, divided by the exposure time (Δt) in day (91 days for all detectors). That is [16]:

$$C_{Rn} = \times \quad (1)$$

The Environmental Protection Agency (EPA) guidance [24] for quality assurance has been adopted to make sure that the results of the present study are reliable, accurate and precise. Therefore, we measured duplicates (10% of all detectors) and we used blank measurements (5% of detectors).

Estimation of the effective dose and the lifetime risk

It is a common practice in radon surveys to convert the radon concentration to dose, and in the case of schools to calculate the annual effective dose for the students and the teachers. Together, the selected schools host about 8140 students and 455 teachers. The problem is that the mean radon concentration takes also into account the radon concentration when the school is closed. For this, the estimated effective doses may be overestimates as the classrooms are closed during nights, weekends and holidays [14, 25].

The effective dose in mSv/y at any location depends upon the occupancy factor. The occupancy factor for the students and the

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teachers of Tulkarem elementary school was calculated using the following equation:

$$30\ h\ /wk \times 37\ wk\ /yr = 1110\ h\ /yr \quad (2)$$

Thus, the school occupancy factor (H)

= 1110h / 8760h = 13%.

The expected annual effective doses received by the students and the teachers of the surveyed areas were calculated using equation (4), the UNSCEAR model (2000, 2009) [26].

$$E = C_{Rn} \times H \times F \times D \times T \quad (3)$$

Where C_{Rn}: is the radon concentration (Bq/m^3)

H: is the occupancy factor (0.13)

F: is the equilibrium factor (0.4)

T: is hours in a year (8760)

D: is the dose conversion factor (91×0^{-6} m Sv/ h per Bq/ m^3).

The estimate of lifetime risk used in the ICRP Publication 115 [1] was the lifetime excess absolute risk (LEAR) associated with a chronic exposure scenario, expressed in number of deaths 10^{-4} per Working Level per Month (WLM). The ICRP concluded that a LEAR of 5×10^{-4} per WLM should now be used as the nominal probability coefficient for radon and radon progeny induced lung cancer, replacing the ICRP Publication 65 value of 2.8×10^{-4} per WLM [1].

$$LEAR = WLM/life \times 5 * 10^{-4} \quad (4)$$

Data analysis

The data analysis is also based on the different parameters that may affect indoor radon concentration levels mainly: geographic location, school building age and floor level. The statistical t-test (unpaired t-test, two-tailed) was used to investigate if the mean radon concentrations of these study parameters were significantly different from each other. A *P*-value of less than 0.05 was always considered significant. The statistical package for social sciences (SPSS) software program, version 17, was used for data entry and analysis.

RESULTS

Results of indoor radon concentration measurements are summarized in table 1. The indoor radon levels in Tulkarem province elementary schools were generally low, ranging from 3.48 to 210.51 Bq/m^3, with a mean radon concentration (mean±SE; standard error) of 40.42± 2.49 Bq/m^3, and the standard deviation (SD) was 34.58 Bq/m^3. As shown figure 2, nearly 85% of the detectors had radon concentrations less than 60 Bq/m^3 while about 4% exceeded 150 Bq/m^3.

Table 1. Summary analysis of the average radon concentrations, average effective dose and average lifetime risk over different classifications.

Classification	No. of Dosimeters	Mean±SE of Radon Concentration Bq/m^3	Effective Dose±SE (mSv/y)	Lifetime Risk±SE *10^{-4}
Tulkarem Province	193	40.42 ± 2.49	0.17 ± 0.01	9.42 ± 0.58
Tulkarem City	31	40.16 ± 6.02	0.16 ± 0.02	9.36 ± 1.40
Tulkarem Camps	55	35.07 ± 3.91	0.14 ± 0.02	8.18 ± 0.91
Al Shaarawih V.	45	48.84 ± 5.30	0.20 ± 0.02	11.39 ± 1.24
Al Kafriaat V.	30	52.07 ± 9.34	0.21 ± 0.04	12.14 ± 2.18
Wad Al Shaeer V.	32	27.08 ± 2.11	0.11 ± 0.01	6.31 ± 0.49
Government	129	43.84 ± 3.28	0.18 ± 0.01	10.22 ± 0.76
UNRWA	55	35.07 ± 3.91	0.14 ± 0.02	8.18 ± 0.91
Private	9	24.03 ± 4.69	0.10 ± 0.02	5.60 ± 1.09
Ground Floor	107	50.20 ± 4.01	0.21 ± 0.02	11.70 ± 0.93
First Floor	72	29.73 ± 1.88	0.12 ± 0.01	6.93 ± 0.44
Second Floor	14	20.57 ± 5.37	0.08 ± 0.02	4.79 ± 1.25
New Building	99	35.52 ± 2.85	0.15 ± 0.01	8.28 ± 0.67
Old Building	94	45.58 ± 4.08	0.19 ± 0.02	10.62 ± 0.95

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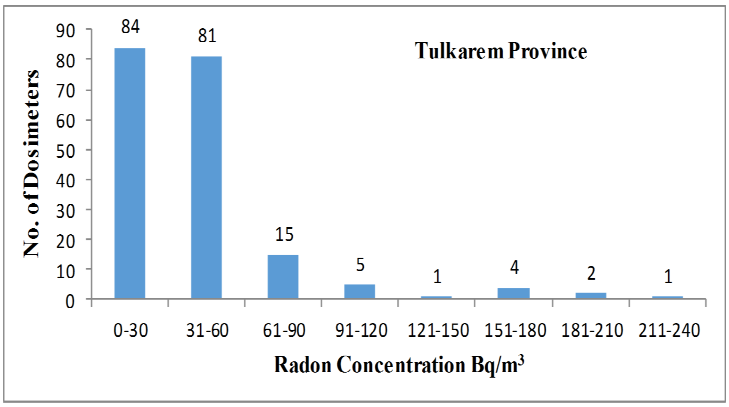

Figure 2. Radon concentration distribution by number of dosimeters in the Tulkarem province area (Single column fitting image).

The effective dose due to indoor radon at the elementary schools of Tulkarem province was found to be 0.17 ± 0.01mSv/y.

The LEAR which estimates the lifetime risk factor for radon induced lung cancer among teachers in Tulkarem province elementary schools was worked out to be about (9.42± 0.58) ×10^{-4}.

In this survey, the area of Tulkarem province was divided into five regions in order to evaluate the effects of geographic location on indoor radon concentration. For the purpose of statistical evaluation we organized the administrative divisions of Tulkarem municipality as follows: Tulkarem city in the west region of the province, Tulkarem camps in the middle, Al Shaarawih Villages in the north region, Al Kafriaat Villages in the south and Wad Al Shaeer Villages in the east region.

The average radon concentrations for each region of the five regions respectively, were: 40.16 Bq/m^3, 35.07 Bq/m^3, 48.84 Bq/m^3, 52.07 Bq/m^3 and 27.08 Bq/m^3 as shown in table 2.

The probable effects of the age of the school buildings were studied. For this purpose, we classified the schools into two groups: less than or equal 15 years old and at least 50 years old. The age range for the schools monitored was 4-79 years; 11 schools were less than 15 years old. About 51% of the detectors were distributed among these newer schools with mean ±SE radon concentration of 35.52 ± 2.85 Bq/m^3. For the nine schools which were older than 50 years (49% of the detectors), the mean ±SE concentration was 45.58 ± 4.08 Bq/m^3.

The variations in radon concentration by floor level were consistent with our expectation that radon exposures are higher on the lower levels (negative correlation); findings are presented in table 2. The mean ±SE radon concentrations in the ground, first and second floors are: 50.20 ± 4.01 Bq/m^3, 29.73 ± 1.88 Bq/m^3 and 20.57 ± 5.37 Bq/m^3, respectively. The maximum values are 210.51 Bq/m^3, 84.93 Bq/m^3 and 73.06 Bq/m^3, respectively.

The quality assurance measurements were computed with an average relative percent difference (ARPD). The ARPD for each duplicate pair which exceeded 148 Bq/m^3 was found to be 11.54%, well under the EPA-recommended threshold of 25% [24]. Also for those with an average pair of less than 148 Bq/m^3, the difference in readings was less than 18.5 Bq/m^3 for all pairs with one exception.

In the present study, the maximum result of blank measurements (unexposed detectors) was 6.79 Bq/m^3. Therefore, the background radiation was very low. If any of the blank measurements had been equal to or greater than 37 Bq/m^3, then the accuracy would have been considered questionable according to EPA [24].

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respectively.

The quality assurance measurements were computed with an average relative percent difference (ARPD). The ARPD for each duplicate pair which exceeded 148 Bq/m^3 was found to be 11.54%, well under the EPA-recommended threshold of 25% [24]. Also for those with an average pair of less than 148 Bq/m^3, the difference in readings was less than 18.5 Bq/m^3 for all pairs with one exception.

In the present study, the maximum result of blank measurements (unexposed detectors) was 6.79 Bq/m^3. Therefore, the background radiation was very low. If any of the blank measurements had been equal to or greater than 37 Bq/m^3, then the accuracy would have been considered questionable according to EPA [24].

DISCUSSION

Average indoor radon concentration, effective dose and lifetime risk

The results obtained from the 193 CR-39 detectors indicate that the mean±SE radon concentration in Tulkarem province elementary schools was 40.42 ± 2.49 Bq/m^3, which is statistically indistinguishable from the worldwide average indoor radon concentration of 39 Bq/m^3 and within the level reported previously from studies in Palestinian homes and work places [11, 27-30]. (table 3) Results do vary across studies, however, because geology is a key determinant of radon levels. We conclude that radon levels in Tulkarem schools are within normal limits and below the 148 Bq/m^3 action level of schools set by the international environment organizations [8].

The present study is the first attempt to evaluate the risk related to radon presence in Tulkarem schools. To validate these findings, the total number of locations measured should be expanded in the future.

There are some high radon sites (4%) which had concentrations above 148 Bq/m^3. These high radon sites may be due to radon gas diffusion from the earth through the noticeable cracks on the floors and the walls of the classrooms, since all these classrooms were located in the ground floor level. While it is known that cracks through the building shell, caused by shrinkage or by ground packing, provide important routes of radon gas entry [7].

The effective dose value of 0.17 ± 0.01mSv/y is very low compared to the global limit of 1.3 mSv/y proposed by UNSCEAR [4]. We think this low effective dose value may reflect the very low occupancy rate as the students and the teachers spend just 13% of the year in the schools. In other studies, the occupancy factor of the students was 14% [25], 18% [14] and was overestimated at 80% in another study [9].

Table 2. Radon concentrations distributed by different categories (region, building age and floor level).

Category	Min	Max	Mean ± SE
Region			
City	6.87	186.75	40.16 ± 6.02
Camps	5.18	163.00	35.07 ± 3.91
Al Shaarawih Villages	10.27	168.09	48.84 ± 5.30
Al Kafriaat Villages	6.87	210.51	52.07 ± 9.34
Wad Al Shaeer Villages	3.48	54.39	27.08 ± 2.11
Building Age			
New (< 15 yrs)	5.18	186.75	35.52 ± 2.85
Old (> 50 yrs)	3.48	210.51	45.58 ± 4.08
Floor Level			
GF	3.48	210.51	50.20 ± 4.01
F1	5.18	84.93	29.73 ± 1.88
F2	5.18	73.06	20.57 ± 5.37

SE: Standard error of the mean; SD: Standard deviation; GF: ground floor; F1: First floor; F2: Second floor.

Table 3. Comparison of the present study results in the schools with previous studies.

Country (region)	Reference	Mean ± SE Radon concentration (Bq/m^3)
Palestine (Tulkarem)	Present study	40.4 ± 2.5
Palestine (Hebron)	(11)	34.1
Jordan (Amman)	(10)	76.8
Iraq (Iraqi Kurdistan)	(12)	97.0 ± 27.0
Saudi Arabia (Zulfi)	(13)	74.7 ± 3.0
Tunisia (Tunis)	(15]	26.9
Nigeria (Oke-Ogun)	[16)	45.0 ± 27.0
Italy (Parma)	(7)	30.0 ± 19.0
Greece (Xanthi)	(14)	231.0

SE: Standard error of the mean.

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However, low occupancy is offset by age; children younger than 12 years old must have a dose multiplier of 1.5 due to their sensitivity to ionizing radiation [31].

The teachers of the elementary schools in Tulkarem province are subjected on the average to a lifetime lung cancer risk of about 0.09% associated to a chronic exposure to indoor radon. While in another study in Nablus City, Palestine, reported a lifetime lung cancer risk variation of 0.02% to 0.09% [28].

Effects of geographic location, building age and floor level

Radon concentrations measured in the five regions show small differences between regions. This may be due to similar soil and rock formation throughout, with the exception of Wad Al Shaeer Villages where the radon concentration was significantly lower than the other regions.

Age of the building was significantly associated with radon concentrations (t-test *P*-value = 0.045). The differences may be due to cracks in the floors and the walls of the older buildings schools as well as poor painting. It is reasonable to expect that older buildings are likely to have larger and more numerous cracks than modern ones [7]. Differences in building materials likely influence the indoor radon concentrations.

As expected, radon concentration levels were negatively correlated with floor level. The difference between ground floors and second floors was highly statistically significant (t-test, *P*-value < 0.001). Differences in air exchange rate with the outdoor environment likely contribute to this correlation and confirm the influence of soil as the main source of indoor radon [5, 6, 32-34].

CONCLUSION

This study provides preliminary data about indoor radon levels in the elementary schools in Palestine as the baseline for a wider future national survey throughout the West Bank. Our results indicate that the radon concentrations in the study schools were similar to the U.S. intervention radon level of 150 Bq/m^3. The average annual effective dose that students and teachers were exposed to was lower than the global limit of 1.3 mSv/y. However, although complying with the international standards, the risk level is high (about 10^{-3} a level which is clearly unacceptable in conventional environmental health risk assessment). Therefore, we strongly recommend that better ventilation rate to these schools must be considered. This is consistent with the ALARA (As Low As Reasonably Achievable) principle, whereby reasonable efforts are made to maintain radiation exposures as low as possible.

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Conflicts of interest: *none to declare.*

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