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The Alpha Particle Doses Received by Students and Staff in Twenty Schools in the North of Hebron Region - Palestine

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Abstract: The aim of the current study was to measure indoor radon concentration levels and its resulting doses received by the students and staff in schools of the directorate of education in the north of Hebron region- Palestine, during the summer months from June to September (2018), using CR-39 detectors. In this study, a total of 567 CR-39-based radon detectors were installed in the selected schools. The average radon concentrations were found to be 90.0, 66.5 and 58.0 Bqm^{-3} in Halhul, Beit Umar and Alarrub camp schools, respectively. Based on the measured indoor radon data, the overall average effective dose for the studied area was found to be 0.31 $mSvy^{-1}$. Reported values for radon concentrations and corresponding doses are lower than ICRP recommended limits for workplaces. The results show no significant radiological risk for the pupils and staff in the schools under investigation. Consequently, the health hazards related to radiation are expected to be negligible.

Keywords: Radon concentration, Alpha particles, Annual effective dose, Schools.

PACs: 29.40.−n.

Introduction

Radon is a naturally occurring radioactive gas that is tasteless, odorless and colorless, and its decay products represent the most important source of natural radioactivity for human exposure [1]. It is the second leading cause of lung cancer in the world and the primary cause of lung cancer for individuals who have never smoked [2]. Measurement of the indoor radon level is highly desirable, because the radiation dose received by the human population due to the inhalation and ingestion of radon and its progeny contribute more than 53% of the total dose from natural sources [3].

The most important isotope of radon, in terms of environmental effects, is (^{222}Rn), which is formed from the α-decay of radium (^{226}Ra), which is a decay product of Uranium (^{238}U) [1]. ^{222}Rn has a half-life of 3.82 days, allowing it to diffuse through earth crust and into the air before decaying by the emission of α- particles into a series of short- lived radioactive progeny. However, as radon concentrations increase, the quantity that decays in the lung increases, resulting in a greater health risk [4].

Radon gas naturally dissipates from the rock and soil out to the atmosphere. Building materials, the water supply and natural gas can all be sources of radon in home and atmosphere. The concentration of atmospheric ^{222}Rn, therefore, depends on the rate of diffusion from the ground and diffusion in the air [5]. The radon gas can enter the body *via* respiring, drinking and eating. The alpha particles emitted by radon gas and other radiations emitted by its daughter

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products increase the absorbed dose in respiratory and digestion systems [6]. Exposure of persons to high concentration of radon and its short-lived progeny for a long period leads to health problems, particularly lung cancer [2].

The knowledge of radon levels in classrooms is important in assessing students and staff exposure and has a considerable public health impact, where the concentrations of indoor radon are almost always higher than outdoor concentrations. Once inside a building, radon cannot easily escape. The sealing of buildings to conserve energy reduces the intake of outside air and worsens the situation, although radon levels are generally highest in basements and ground floors, because these areas are nearest to the source and are usually poorly ventilated.

Schools may be a significant source of radon exposure for children and working staff. However, because occupancy patterns in schools differ from those in homes, the actual exposures received by each individual, or even by the entire school population, are difficult to determine. In another previous work, Dabayneh measured the radon concentration in 62 classrooms in Palestine; he claimed that the harmful levels of radon and radon progeny can accumulate in confined air spaces, such as basements and crawl spaces [7].

Our laboratory previously conducted a series of studies with the objective to determine radon concentration levels in homes, hospitals, schools, tobacco, soils and building materials [6, 9, 10-24].

The aim of the present work is to determine radon concentrations in schools in the Directorate of Education in the north of Hebron region - Palestine, during the summer months from June to September, using CR-39 track etch detectors. It is worth mentioning here that this study is part of a nationwide survey and measurement of indoor radon levels in workplaces and studies which so far have not been conducted in this region, to provide data for drawing a national radon map in Palestine.

Materials and Methods

Solid State Nuclear Track Detectors (SSNTDs) (CR-39 detectors) were installed in various rooms in twenty elementary and secondary schools in the Directorate of Education in the north of Hebron region – Palestine (Fig. 1).

The typical dosimeter is shown in Fig. 2 [2, 10]. Five detectors were used for the determination of background track density. This track density was subtracted from all the measurements before the determination of radon concentration. The CR-39-based radon detector was calibrated according to the standard source facility at the National Radiological Protection Board (NRPB), UK [6, 7]. Following this technique, dosimeters were prepared and distributed in three sites (Halhul, Beit Umar and Alarrub camp) in Hebron region. The detectors were installed in the classrooms, teachers' office, director's office, kitchens, stores, laboratories, libraries, corridors, bathrooms, canteens, … etc. In each room two passive detectors were installed ~ 1.25 –1.5 m above the ground. The first detector was placed 0.5 m behind the door to prevent air currents and the second detector was placed against the windows.

The schools of the studied area, as almost all Palestinian schools, are structures of masonry (concrete and brick) from inside and stones from outside, where rooms are ventilated only by operable windows (natural ventilation).

The main zones and the statistical information on detectors and schools in the Directorate of Education in the north of Hebron region - Palestine, during the summer season, are exhibited in Table 1.

Three months later; i.e., after 90 days of exposure, the detectors were collected and chemically etched in a 6.25 M, NaOH solution at 72±2 ^{0}C and 8 h etching time to reach high resolution latent tracks [2, 8]. The detectors were washed by distilled water and then dried out. The number of tracks per cm^2 in each detector was counted manually using an optical microscope of 160 times magnification (160×). The tracks were counted trice for each detector and the average was calculated [2].

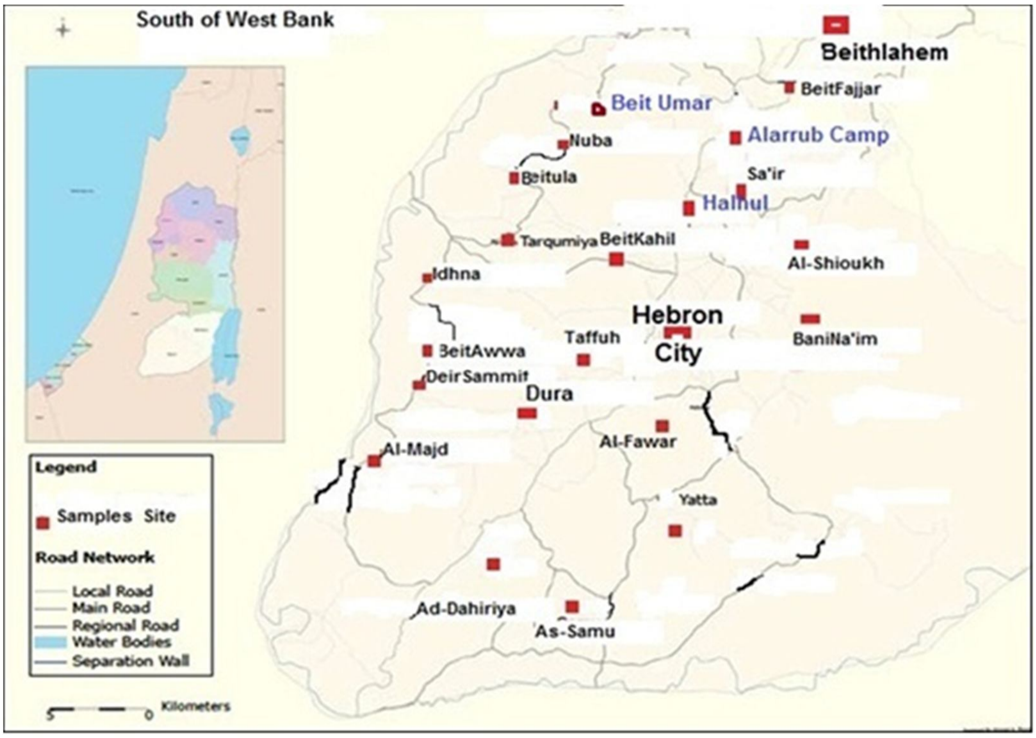

FIG. 1. West Bank geographical map showing the studied region.

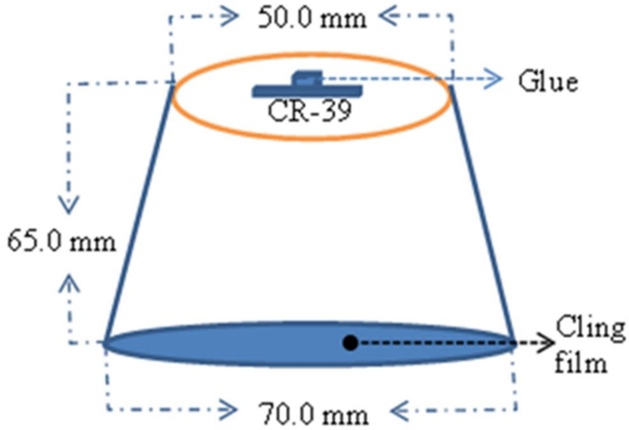

FIG. 2: CR-39 dosimeter.

TABLE 1. Number of the schools, rooms and dosimeters distributed in the area under investigation.

Zone	No. of schools	No. of rooms	No. of dosimeters distributed	No. of dosimeters lost	No. of dosimeters collected
Halhul	10	118	262	28	234
Beit Umar	9	129	270	29	241
Alarrub Camp	1	16	35	8	27
Total	20	263	567	65	502

Results and Discussion

The Indoor Radon Concentrations

The track density, ρ, is generally defined as the average number of scratches in section divided by the section area. The obtained track densities were converted into indoor radon concentration levels, C_{Rn}, in Bqm^{-3} by applying the following calibration formula [2]:

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

where C_0 is the radon concentration of the calibration chamber (90 $kBqm^{-3}$), t_0 is the calibration exposure time (48 h), ρ is the measured track number density per cm^2 on the CR-39 detectors inside the used dosimeters, ρ_o is the measured track number density per cm^2 on those of the calibrated dosimeters (3.3 × 10^4 tracks cm^{-2}) and t is the exposure time (2160 h).

The radon concentration levels data were assessed from 502 dosimeters over a total of 567 as 65 detectors were lost. The range of radon concentrations and the frequency distributions of indoor ^{222}Rn in twenty schools (263 rooms) are listed in Table 2.

TABLE 2. Range and frequency of radon concentrations of selected schools in the 3 investigated zones in the area under investigation.

Zone	Frequency range (Bqm^{-3})			
	0 - 49	50-99	100-199	≥ 200
Halhul	36	154	28	16
Beit Umar	79	145	14	3
Alarrub Camp	8	19	----	---
Total	123	318	42	19
%	24.5	63.3	8.4	3.8

As can be seen from Table 2, about 24.5% of indoor ^{222}Rn levels are found to vary between 0 and 29 Bqm^{-3}. Radon concentration levels between 50 and 99 Bqm^{-3} were observed in 63.3% of the studied classrooms, while about 8.4% are found to vary between 100 and 199 Bqm^{-3}. Nearly 3.8% of rooms show radon concentrations ≥ 200 Bqm^{-3}, with a maximum value of 306.4 Bqm^{-3}.

The results show that the concentrations in 12.2% of the studied rooms are above the reference level of 100 Bqm^{-3} assigned by WHO [23]. The minimum, the maximum and the average concentrations of ^{222}Rn in the investigated rooms in 20 schools in 3 different zones are listed in Table 3.

TABLE 3. Statistical parameters of the ^{222}Rn concentrations (C_{Rn}) in different rooms of schools.

Zone	Halhul	Beit Umar	Alarrub Camp
Rooms Type	C_{Rn} (Bqm^{-3}) Min Max Av.	C_{Rn} (Bqm^{-3}) Min Max Av.	C_{Rn} (Bqm^{-3}) Min Max Av.
Classrooms	37.5 257.0 80.3	25.2 286.0 65.2	35.0 93.0 49.2
Administration and Teacher rooms	32.5 306.4 109.6	35.7 164.6 79.3	51.9 64.5 58.2
Bathrooms	46.5 99.5 73.4	20.5 93.2 52.4	----- ----- 55.5
Kitchens	45.5 84.5 62.2	16.6 107.1 58.4	52.0 60.0 56.0
Stores	52.5 305.2 110.6	34.2 164.6 79.4	60.9 91.7 76.3
Computer and scientific labs and libraries	48.1 289.0 103.6	35.6 99.0 64.6	----- ----- 52.5
Total Average	90.0	66.5	58.0

The data presented in Table 3 shows that the average indoor radon concentrations obtained varied from 62.2 Bqm^{-3} (in kitchens) to 110.6 Bqm^{-3} (in stores) in Halhul zone; from 52.4 Bqm^{-3} (in bathrooms) to 79.4 Bqm^{-3} (in stores) in Beit Umar zone and from 49.2 Bqm^{-3} (in classrooms) to 76.3 Bqm^{-3} (in stores) in Alarrub camp, with overall average values of 90.0, 66.5 and 58.0 Bqm^{-3}, respectively. Generally speaking, almost 83% of average values are below the reference level [23], for the remedial action to be taken, and all the average values are higher than the world average radon concentration of 40 Bqm^{-3} [3].

According to the data in Table 3, the differences between the minimum and maximum of indoor concentration levels in the surveyed schools are relatively high. This large variation is mainly due to the difference in the ventilation methods used, the difference in the school's altitude and the difference in the number of floors. Small values of concentration levels are generally reported in schools newly built under the supervision of Western countries (USA, Germany) and Japan as donations for Palestinian pupils.

Table 4 shows the average concentrations of ^{222}Rn and other radiological effects, in the schools in three zones in different floors of the regions under investigation. Fig. 3 shows the comparison of radon average concentrations in different floors in the studied regions.

The first floor is generally characterized by a high radon concentration level compared to the other floor levels. This may be due to several reasons. Firstly, upper floors have better ventilation than lower ones. Secondly, the chances for radon to reach upper floors are very small compared to its chances to reach lower ones. Finally, the radon exhalation rates from the ground decrease fast as going to higher floors. However, there is a large variation in the radon concentration levels within the same floors, especially the ground and the first floors.

We can see from Tables 4 and 5 that radon concentration was found to be higher in old schools, poorly ventilated, rather than in newly constructed schools, having good ventilation. In addition, a higher concentration of radon in lower floors in comparison to values measured in higher floors, is observed. The ground floor of such schools is directly constructed on top of soil with a coating of concrete, which allows more radon to diffuse inside the rooms because of the higher porosity of the construction materials used.

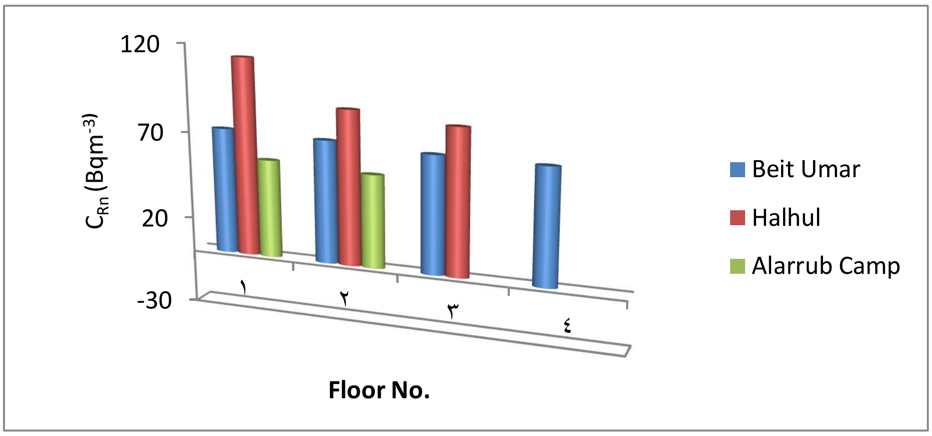

FIG. 3: Comparison of the average radon concentrations in different floors in the studied zones.

TABLE 4. Comparison of the present study results in the schools with those of other studies.

Country	C_{Rn} (Bqm^{-3})	Reference
Palestine:		
- Tarqumia schools	34	[7]
- Tulkarem schools	40	[25]
- Bethlehem schools	125	[26]
- North-east of Hebron	71	[2]
- North of Hebron schools	74	Present study
Jordan	77	[27]
Algiers	26	[28]
Kuwait:		
- 1st Floor	16	[29]
- 2nd Floor	19	
Saudi Arabia	75	[30]
Greece	231	[31]
Pakistan:		
- Kashmir schools	78	[32]
- Punjab schools	52	[33]
Tunisia	27	[34]
Nigeria	45	[35]
Portugal	400	[36]
ICRP action level, 1993	200	[37]
UNSCEAR, 2000	40	[3]
WHO	100	[23]

TABLE 5. The ^{222}Rn concentrations levels (C_{Rn}), the annual effective dose (E_{Rn}), the lifetime risk (LTR) and the radon content of the lung air (H_{lung}) belonging to different floors in the surveyed schools.

Zone	Floor No.	C_{Rn} (Bqm^{-3}) Min Max Av.	E_{Rn} ($mSvyr^{-1}$) Min Max Av.	LTR ($\times 10^{-4}$) Min Max Av.	H_{lung} ($\times 10^{-8}$) ($Svyr^{-1}$) Min Max Av.
Halhul	1	53.5 289.0 113.3	0.22 1.20 0.47	12.5 67.3 26.3	4.3 23.1 9.1
	2	37.5 306.4 88.2	0.16 1.27 0.37	8.7 71.4 20.6	3.0 24.5 7.1
	3	32.5 248.5 83.0	0.14 1.03 0.34	7.6 57.9 19.4	2.6 19.9 6.6
Beit Umar	1	20.5 325.2 72.0	0.09 1.35 0.30	4.8 75.8 16.8	1.6 26.0 5.8
	2	48.6 286.0 70.0	0.20 1.19 0.29	11.3 66.6 16.3	3.9 22.9 5.6
	3	35.7 101.4 67.0	0.15 0.42 0.28	8.3 23.6 15.6	2.9 8.1 5.4
	4	16.6 81.0 66.0	0.07 0.34 0.27	3.9 18.9 15.4	1.3 6.5 5.3
Alarrub Camp	1	35.0 93.0 56.0	0.15 0.39 0.23	8.2 21.7 13.1	2.8 7.4 4.5
	2	38.0 91.7 53.0	0.16 0.38 0.22	8.9 21.4 12.3	3.0 7.3 4.2
Total Average		74.3	0.31	17.3	6.0

The observed variations of radon concentrations among various regions can be attributed to many factors, such as the geological structure of the site, the various types of building materials used for the construction of the schools, the number of floors, painting and ventilation rates and the aging effect on the building. Other variations of the radon concentration levels may be attributed to human activities, such as opening windows and doors. Human activities are definitively different for schools from those for homes. Schools in Palestine mainly are operated from 5 to 6 hours and closed for the rest of the day. In addition, except for weekends, there are also long periods in the year when schools are closed, especially during summer holidays. When schools are closed, an increase of radon concentration is expected due to poor ventilation. Accordingly, indoor radon concentrations in schools are expected to be higher than in houses.

The relatively high concentrations found in some rooms may be due to the structure of the soil and rocks, which consist mainly of limestone. Also, it may be due to the geological and topographical nature of the school site. Finally, the general results obtained were less than the ICRP standard level, the standard reference level set by WHO and the US EPA for the USA assigned level in general [23, 24].

For the sake of comparison, the radon concentration levels were compared with those of other schools in different countries. The obtained radon concentration levels in the region under consideration are within the majority results of some other national and international areas, as can be seen in Table 4.

The Radiological Effects of Radon

The Effective Dose in Schools

To obtain the annual effective dose (E_{Rn}), due to the indoor radon and its progeny received by the pupils and staff, one has to take into account the conversion coefficient from the absorbed dose and the occupancy factor. According to the UNSCEAR 2000 report [3], the effective dose at any location depends upon the occupancy factor. The occupancy factor for the students and the teachers of north Hebron schools was calculated using the following equation:

$$5.5\frac{\text{h}}{\text{day}} \times 5\frac{\text{day}}{\text{wk}} \times 36\frac{\text{wk}}{\text{yr}} = 990\frac{\text{h}}{\text{yr}} \qquad (2)$$

Thus, the school occupancy factor (H_s) = 990h / 8760h = 0.113.

The expected annual effective doses received by students and teachers in the surveyed areas were calculated by using Eq. (3), the UNSCEAR model [3, 25] as shown below:

$$E_{Rn}(mSvy^{-1}) = C_{Rn} \times H_s \times F \times D \times T \qquad (3)$$

where C_{Rn} is the radon concentration (Bqm^{-3}), H_s is the occupancy factor (0.113), F is the equilibrium factor (0.4), T is hours in a year (8760) and D is the dose conversion factor (9.1×0^{-6} mSv/ h per Bqm^{-3}).

By using Eq. (3) and Table (4), the results for the average annual effective dose in all schools are as follows: from 0.34 $mSvy^{-1}$ (in third floor) to 0.47 $mSvy^{-1}$ (in first floor) in Halhul zone; from 0.27 $mSvy^{-1}$ (in fourth floor) to 0.30 $mSvy^{-1}$ (in first floor) in Beit Umar zone; and from 0.22 $mSvy^{-1}$ (in second floor) to 0.23 $mSvy^{-1}$ in (in first floor) in Alarrub camp.

In recent reports, UNSCEAR and WHO [3, 23] recommended that the action levels of radon should be set around 1.3 and 2.5 $mSvy^{-1}$, respectively. Based on these recommendations, it has been observed that all of the annual effective doses show lower values than the action levels. Therefore, the results show no significant radiological health risk to the students and staff. We think that this low effective dose value may reflect the very low occupancy rate as students and teachers spend just 11.3% of the year in the schools.

The Lifetime Risk

The estimate of lifetime risk used in the ICRP Publication 115 [38] is the lifetime excess absolute risk (LTR) associated with a chronic exposure scenario, expressed in a number of deaths 10^{-4} per Working Level per Month (WLM). According to the ICRP, an LTR 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 [25, 38].

$$LTR = \frac{WLM}{Life} \times 5\times10^{-4} \quad (4)$$

The students and staff of the schools in the north of Hebron region are subjected to the total average of a lifetime lung cancer risk of about 17.3% to chronic exposure to indoor radon. Another study in Palestine reported a lifetime lung cancer risk variation of 0.02% to 0.09% [25, 39].

The Annual Equivalent Dose to the Lungs

The annual effective dose to lung, H_E, is calculated using an equation of the form [40]:

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

where W_R is the radiation weighting factor for alpha particles ($W_R = 20$) and W_T is the tissue weighting factor for the lung ($W_T = 0.12$).

In case the radon content of the lung air is taken into account, Eq. (5) reduces to [3]:

$$H_{lung}(Sv) = 8 \times 10^{10}\, C_{Rn}\, (Bqm^{-3}). \quad (6)$$

The total average value of radon content in the lung air (H_{lung}) is 6×10^{-8} Svy^{-1} in the region under investigation. The results show no significant radiological risk for pupils and staff in the schools in this region [41].

Conclusions

The results of the present research led to the following conclusions: the average radon concentrations for the three zones were found to be 90.0, 66.5 and 58.0 Bqm^{-3} in Halhul, Beit Umar and Alarrub camp schools, respectively. The total average annual effective dose due to the radon received by the pupils and staff in the studied area was 0.31 $mSvy^{-1}$.

Since most radon comes from the ground, the highest concentrations of radon are found in ground floor rooms compared to values measured in the first and upper floors. Variations in radon concentration from one room to another in the same floor level may be explained by human activities. As the annual mean effective dose for students and staff at the schools is consistent with the normal dose as regarded by ICRP and WHO recommendations, health hazards related to radiation are expected to be negligible.

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