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ARTICLE

Indoor Radon Concentrations and Effective Dose Estimation in Dwellings of As-Salt Region in Jordan

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Abstract: Radon concentrations were measured using passive dosimeters, SSNTD CR-39 in As-Salt city and its surrounding. 300 dosimeters were distributed over the study area dwellings according to the fraction of the population. The exposure time started from April 2004 and lasted for 100 days. Radon concentrations were found to vary from region to region, ranging from 31 to 501 Bq m^{-3} with a mean value of 111 ± 4 Bq m^{-3}. The concentration of radon short-lived daughters was estimated at 44 ± 2 Bq m^{-3} or around 0.012 Working Level (WL). The ground floors were found to have the highest radon concentrations with a mean value of 118 Bq m^{-3}, while the upper floors were found to have a mean value of 96 Bq m^{-3}. Based on the use of the room, bedrooms were found to have a higher mean radon concentration than living or setting rooms; these concentrations were 117 ± 16 and 105 ± 5 Bq m^{-3}, respectively. It was found that As-Salt dweller is exposed annually to 0.49 Working Level Month (WLM) from radon gas and its short-lived daughters. Hence, a person takes on the average an annual effective dose equivalent to 2.7 mSv according to UNSCEAR and 1.9 mSv according to ICRP. This implies an expected value for lung cancer probability of 0.004%.

Keywords: Indoor radon concentration; Passive dosimeter; CR-39; Effective dose; Jordan.

Introduction

Radium is a naturally occurring radioactive element available in trace amounts throughout the Earth crust. The decay of radium leads to a series of short-lived radioactive isotopes via gaseous radon to polonium, bismuth and lead. These decay products are attached, usually, to dust particles in air shortly after they are formed. After inhalation, these products are deposited in the lung, which receives a dose from alpha radiation, emitted during subsequent decay of these products. They also emit gamma rays that increase the external human exposure.

Over the past four decades, natural radiation exposure due to radon (^{222}Rn) and its progeny inside houses has been recognized as a worldwide problem and a cause of significant lung cancer risk to the population. It is also of great importance to assess the exposure to ^{222}Rn and its progeny in houses and areas of high ^{222}Rn levels for the purposes of quality control, radioactivity monitoring of building materials and for correction measures recommendations. Previous research papers [1-6] show that ^{222}Rn, on average, in many countries contributes 50% radiation dose to the general public, including other parts of Jordan, but there is considerable variation due to underlying geology. As-Salt city and its surrounding have more than 330,000 inhabitants, which constitute about 6.5% of the Jordan's total population. The main purpose of the present study was to measure the indoor radon concentration in dwellings

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of As-Salt region, the middle part of Jordan, in order to assess whether the general public is at any risk from exposure to excessive levels of radon. Most of the dwellings in As-Salt city and its surrounding are without any compliance to regulatory standards and are typical for one family having two to three rooms. The dwellings surveyed were of different types, but were mainly made of stones with cement. The results of the present study shall help in establishing a baseline map of natural radiation background in this part of the world.

Region of the Study

As-Salt city lies to the northwest of Amman, capital of Jordan, at the latitude of 32° 00' and the longitude of 35° 30' (Fig. 1a). The structure and morphology of the study area are controlled mainly by the Dead Sea, Jordan Transform Fault that roughly bisects the area into two geomorphological provinces; the Highlands and the Ghor areas. The former has a rough topography with elevations up to 1100 m above sea level (a.s.l.). The Ghor land is, more or less, a table land with elevations between 180 and 360 m a.s.l. The prevalent kinds of stone in the study area are limestone, argillaceous, dolomitic limestone, sandstone, dolomitic sandstone and marl [7]. There is a considerable climate seasonal variation with most of the precipitation occurring during winters (December-March) with a mean annual rainfall of 350 mm. Summers (June-September) are hot (average temperature range of 17-30 °C) and winters are cold (average temperature range of 3.5-14 °C).

FIG. 1a. Map of Jordan.

Measuring Procedures

Nuclear track detectors were used to measure the integrated concentrations of radon in As-Salt region. The technique used is based on a closed can containing the CR-39 SSNTD from Pershore Moulding Ltd., U.K. The schematic diagram of the chamber is shown elsewhere [3, 8-9]. To distribute the dosimeters fairly, As-Salt region was divided into 11 sub regions, adopting the formal division of the greater municipality of As-Salt (Fig. 1b), and they were weighted for the fraction of the number of their population to the total number of As-Salt population. In each region, the choice of the dwelling where the measurements were conducted was random. The dosimeters were distributed in the specified locations starting from April 2004 and collected after the assigned period of 100 days. Every participating dwelling has got two dosimeters; one in the living room and the other in the bedroom, at a height of 1.5 m from the floor. 300 dosimeters were distributed in this study, 254 among them were collected at the end of the period and the remaining 46 were lost for different reasons. The retrieved dosimeters were chemically etched in 6.25 N NaOH, at a temperature of (80 ± 1) °C for 4 hours; these conditions give about 85% detection efficiency [10]. An optical microscope of 25× was used to count the number of tracks per cm^2 within the exposed dosimeters. The tracks were counted randomly all over the detector surface for at least 20 fields of view to obtain an average and representative value of track density for each dosimeter. The measured track densities formed on the analyzed NTDs were converted into radon concentrations (Bq m^{-3}) using the calibration factor of (8.5 tracks cm^{-2} per kBq h m^{-3}) by adopting an exposure period of 100 days. Then the equilibrium equivalent concentration (EEC) was derived by multiplying the radon concentrations (Bq m^{-3}) by an equilibrium factor (F) of 0.4. The potential alpha energy concentration (PAEC), which was used as a measure of decay product concentration, was obtained in the standard unit of working level (WL) by multiplying EEC by 5.57×10^{-9}. Finally, the PAEC to which the worker is exposed was multiplied by the time of exposure in working months of 170 hours, giving the potential alpha energy exposure (PAEE) in units of working level month (WLM). The lower limit of detection was empirically estimated as 3 times the standard deviation of the non-irradiated dosimeters. The equivalent value of this limit in terms of radon concentration was found to be 0.25 Bq m^{-3}.

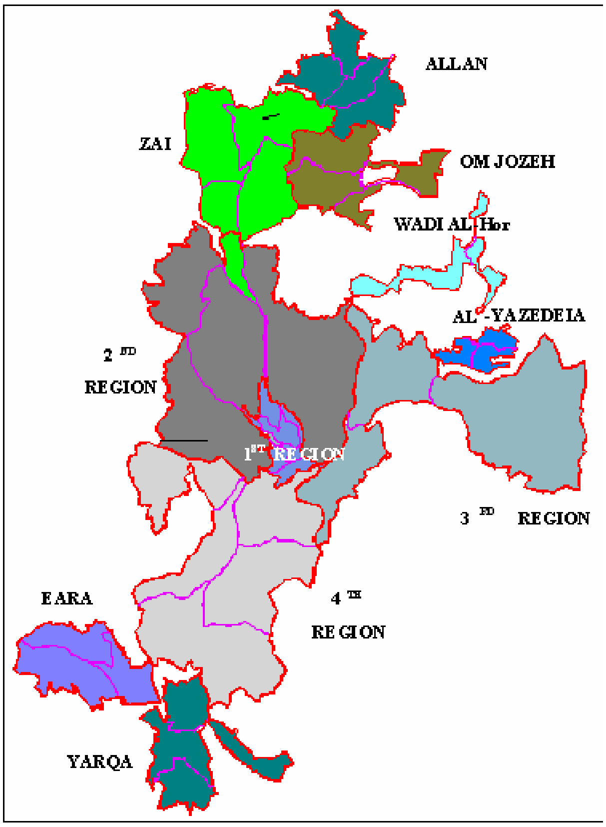

FIG. 1b. Map of the study area.

In order to derive the effective dose of exposure to radon and its progeny for a given time spent in a house if an equilibrium factor of 0.4 is assumed, 1 Bq h m^{-3} is equivalent to 3×10^{-6} mSv [11]. Moreover, the estimated exposure to airborne radon daughters has to be translated into an effective dose equivalent. Deposition and retention of radon daughters in lung are influenced mainly by the size distribution of the carrier aerosol, the fraction of unattached radioactivity, the breathing rate of the subject and biological and physiological factors. Following the suggestions made by UNSCEAR (1982) [12], a breathing rate of 0.8 m^3 h^{-1} during indoor residence time will lead to a dose conversion factor of 0.061 mSv per Bq m^{-3}. On the other hand, according to ICRP 65 (1993) [11] dose conversion convention, the effective dose per unit of exposure at home is 4 mSv per working level month (WLM), which is based on a working month. It is defined as the amount of radioactive exposure an individual receives if he is exposed to 1 WL of radon for one working month (170 hours), considering the occupancy factor 0.8. Then, 1-year exposure introduces 41 WM [13].

Results and Discussion

The frequencies of radon concentration in the surveyed dwellings are plotted in Fig. (2a). From this figure, it can be seen that the frequency distribution looks lognormal-like, as is the case in most other national radon surveys [3, 8]. Moreover, Table 1 summarizes the results of radon levels in 127 houses in the investigated regions. The results indicate a random concentration arithmetic mean of 111 ± 4 Bq m^{-3} with the higher data frequency for values between 60-85 Bq m^{-3}. The measured concentrations were below the action level (< 200 Bq m^{-3}) as reported by ICRP (1993) [11]. Actually, about two thirds of the measured concentrations were lower than 110 Bq m^{-3}. The observed variations of radon concentrations among various regions can be attributed to many factors like the geological structure of the site, the various types of building materials used for the construction of the dwellings, the heating systems and ventilation rates, the aging effect on the building as well as the social habits of the dwellers. As an example, the third region has a feature that most of its dwellings are villas; their dwellers keep the windows closed to keep the elegant furniture away from dust and save energy in both cases of cooling or heating.

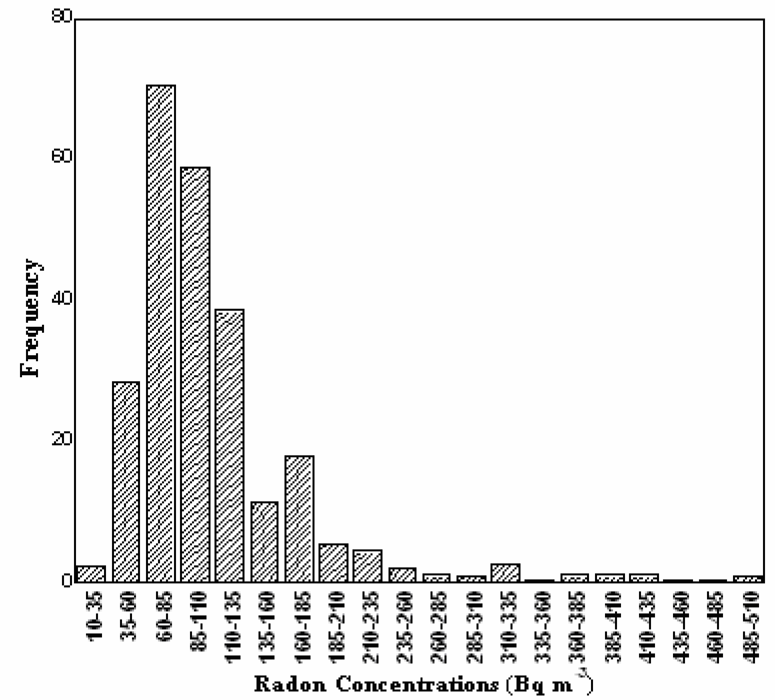

FIG. 2a. Frequency distribution of radon concentrations.

TABLE 1. Radon concentrations in As-Salt region.

Subregion	No. of Dosimeters	Minimum (Bq m^{-3})	Maximum (Bq m^{-3})	Mean ± σ (Bq m^{-3})
1st	50	34	431	116 ± 10
2nd	98	31	364	105 ± 5
3rd	22	39	392	136 ± 22
4th	20	39	187	101 ± 9
Zai	10	48	501	152 ± 47
Om Jozeh	8	52	168	101 ± 14
Wadi Al-Hor	4	84	129	103 ±13
Al-Yazedeya	4	134	168	151 ± 17
Yarqa	14	43	213	117 ± 16
Eara	10	50	174	103 ± 12
Allan	14	48	154	86 ± 7
Total	254	39	331	111 ± 4

σ: Standard Error of the Mean.

Preliminary statistics of data for each subregion showed that it was reasonable to divide data into two groups depending on the floor level of the dwelling; ground floor and upper floors (first floor, second floor…etc.). The mean radon concentration for the ground floor was 119 ± 17 Bq m^{-3}, while it was 96 ± 9 Bq m^{-3} for the upper floors. The soil underneath the dwelling is the main radon source for the ground floor house, while the building materials are one of the main contributors at higher floors. In addition, the upper floors are usually more ventilated; their altitudes are higher than any borders or enclosures, which shut the airflow out. In some cases, the ground floors are more ancient than the upper floors. The exhalation of radon from walls, floors and ceilings in the older dwellings is higher than that in modern dwellings because of the cracks and defective joints in walls and floors, due to age and poor maintenance.

Depending on the use of the room, data for the floor itself can be divided into two groups; bedroom and living room. It is shown in Fig. (2b) that the mean radon concentration in bedrooms is higher than that in living rooms in most investigated regions. This may be attributed to the reduction in the ventilation rates in bedrooms. As it is noticeable in Fig. (2b), the radon concentration levels in some regions like the third region have higher values in living rooms than those in bedrooms at the opposite to the normal estimations. This is probably because these dwellings were built using the modern style; the bedrooms are upstairs with less radon concentrations.

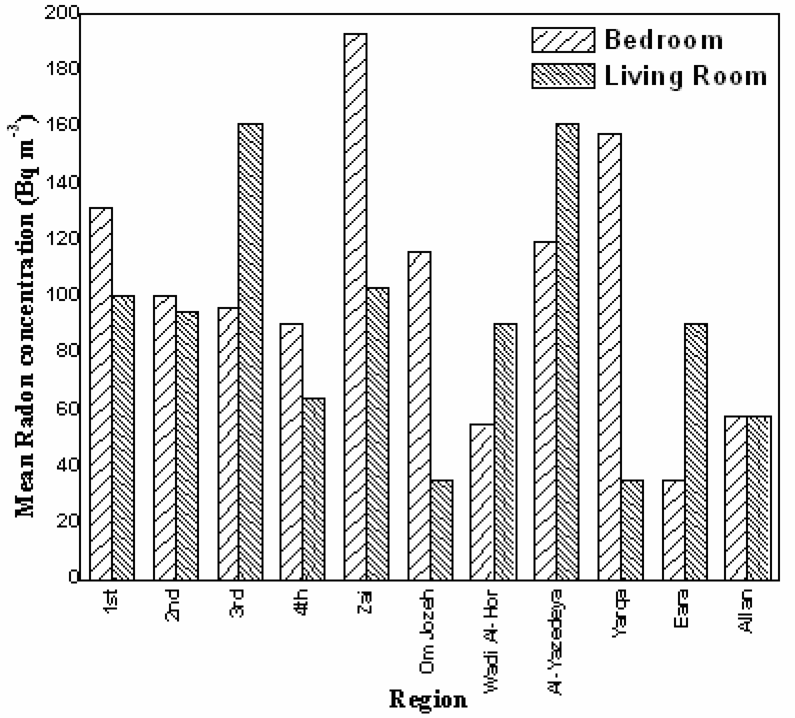

FIG. 2b. Comparison of radon mean concentrations in bedrooms and living rooms in the studied regions.

The radon concentration in As-Salt area is slightly higher in comparison to the major of other national and international areas as can be seen in Table 2. This may be due to the structure of the soil and rocks, which consist mainly of limestone. In addition, it may be due to the geological and topographical nature of As-Salt area, having many flexions and faults due to its mountainous nature [7], and the excavation activity of the earth crust because of building and road construction purposes. There is another intervening factor to influence the survey results and rise up the radon concentration. This factor is the fact that the majority of participants in the survey are employees; this implies that their dwellings are kept closed during the work time when they are outside the house. This may be an important factor in raising the radon concentration levels due to lack of ventilation.

TABLE 2. Radon concentration levels in local and non-local regions.

Country (Region)	Indoor Radon Concentration* (Bq m^{-3})	Reference No.
Jordan (As-Salt)	111 ± 4	Present Study
Jordan (Amman)	41	Khatibeh, A. et al., 1997
Jordan (Zarqa)	31	Khatibeh, A. et al., 1997
Jordan (Irbid)	44	Abumurad, K. and Al-Omari, R., 2008
Jordan (Soum)	144	Abumurad, K. and Al-Tamimi, M., 2005
Syria	44	Othman, I. et al., 1996
Saudi Arabia	16	Al-Jarallah et al., 2003
Egypt	9	Kenawy, M. and Morsy, A., 1991
Iran	82	Sohrabi, M. and Solaymanian, A., 1988
Brazil	82	Canoba, A. et al., 2002
Canada	34	Létourneau, E.G. et al., 1984
China	24	Zuoyuan, W., 1992
Denmark	53	Ulbak, K. et al., 1988
Finland	120	Castrén, O., 1994
France	62	Rannou, A. and Tymen, G., 1989
Mexico	38	Segovia, S. et al., 1993
Poland	41	Biernacka, M., 1992
Sweden	108	Swedjemark, G.A. et al., 1993
UK	20	Wrixon, A.D. et al., 1988
USA	46	Marcinowski, F., 1992
Population-weighted average	44	UNSCEAR, 2000

* Arithmetic mean values.

Based on these limited results obtained from a limited number of houses, as well as the measurements conducted only in one season, radiation doses received by the inhabitants could not be accurately determined. However, some crude estimates of the mean annual effective dose equivalent were determined as shown in Table 3. Table 3 shows the equilibrium equivalent concentration of radon (EEC) in units of Bq m^{-3}, which is the product of radon concentration C by the equilibrium factor F. It corresponds to a concentration of radon for which the radon daughters in equilibrium with radon have the same potential alpha energy as the actual daughter concentration of interest. The PAEC was also derived and shown in Table 3 (in mWL) along with the PAEE in units of WLM. Risk estimation, on the other hand, can be done by adopting a mean absolute risk factor of 0.9×10^{-4} per WLM [7]. As it can be seen from Table 3, the inhabitant of As-Salt area is exposed to an annual mean value of 0.49 WLM. This produces an annual effective dose equivalent to 2.71 and 1.95 mSv according to UNSCEAR (1982) [12] and ICRP 65 (1993) [11], respectively. These doses correspond to an average risk of 0.4×10^{-4}. This means that the dose due to radon may cause 4 lung cancer cases among each 100,000 inhabitants of As-Salt city per year.

Published data by the Ministry of Health in Jordan indicates that the number of lung cancer cases in As-Salt area was 15 per 100,000 inhabitants during the year 1998 [14]. Thus, one may deduce that lung cancer cases due to smoking and other factors are 11 per 100,000 inhabitants annually. It can be seen from Table 4 that As-Salt area has a high percentage of lung cancer from all types of cancer in comparison to other cities. This seems to agree with the high radon concentration levels in As-Salt area compared to other areas.

TABLE 3. Summarized data of EEC, PAEC, PAEE, annual effective dose and mean risk estimation for each region.

Region	EEC (Bq m^{-3})	PAEC (mWL)	PAEE (WLM)	Annual effective dose (mSv)		Mean estimated risk $\times 10^{-4}$
				(a)	(b)	
1st	46 ± 4	12	0.5	2.0	2.8	0.4
2nd	42 ± 2	11	0.5	1.8	2.6	0.4
3rd	54 ± 9	14	0.6	2.4	3.3	0.5
4th	40 ± 3	11	0.4	1.8	2.5	0.4
Zai	61 ± 18	16	0.7	2.7	3.7	0.6
Om Jozeh	40 ± 5	11	0.4	1.8	2.4	0.4
Wadi Al-Hor	41± 5	11	0.4	1.8	2.5	0.4
Al-Yazedeya	60 ± 7	16	0.7	2.6	3.7	0.6
Yarqa	47 ± 6	12	0.5	2.0	2.8	0.5
Eara	41 ± 5	11	0.4	1.8	2.5	0.4
Allan	34 ± 3	92	0.4	1.5	2.1	0.3
Average	44 ± 2	12 ± 1	0.5	2.0	2.7	0.4

(a) According to ICRP 65 (1993), and (b) According to UNSCEAR (1982).

TABLE 4. Lung cancer percentage in males from all types of cancer (1998 statistics of the Ministry of Health, Jordan).

Governorate	Amman	Irbid	Zarqa	As-Salt	Al-Mafraq	Madaba	Ma’an	Aqaba
Lung Cancer in males %	9.1	12.2	12.4	17.6	9.7	9.5	6.6	7.1

Conclusions

Radon gas concentration levels inside houses of As-Salt area were found to have an average value of 111 ± 4 Bq m^{-3} during April to July of the year 2004. Concentration of radon short-lived daughters was estimated to be 44 ± 2 Bq m^{-3} or around 0.012 WL. It was found that the average exposure of dwellers in As-Salt area is annually 0.49 WLM due to radon gas and its short-lived daughters. This corresponds to an annual effective dose equivalent of 2.7 mSv according to UNSCEAR (1982) [12] and 1.9 mSv according to ICRP 65 (1993) [11]. This also implies an expected value for lung cancer probability of 0.004%, which means that 4 out of each 100,000 dwellers on the average become infected by lung cancer caused by radon inhalation. Even though this is not a high dose, but based on the ALARA principle, it is advisable to reduce the dose. An increase in ventilation rate would probably reduce the concentration level. For future work, it is recommended to extend the survey during other periods of the year in order to have a better representative value for the annual average. It is also recommended to study the radon concentration levels in soil and water in the same region of this study. Finally, the concentration levels as a function of the elevation of houses, due to the mountainous nature of As-Salt area, deserve to be studied.

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