Original Research

Higher Levels of Radon Affect Women's Fertility in Iraqi Kurdistan

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Received: 29 August 2012
Accepted: 14 January 2013

Abstract

The effect of indoor radon on the fertility of women was studied for the first time in Kurdistan. The Lowest radon was 99.94 $Bq·m^{-3}$, 94.883 $Bq·m^{-3}$ and highest radon concentrations were 360.112 $Bq·m^{-3}$ and 357.832 $Bq·m^{-3}$ in kitchens and living rooms in Sulaymania. Lowest radon was 97.886 $Bq·m^{-3}$ and 95.113 $Bq·m^{-3}$, and the highest concentrations were 360.112 $Bq·m^{-3}$ and 357.832 $Bq·m^{-3}$ in kitchens and living rooms in Erbil, respectively, which were significant ($p<0.001$). This result is above the normal limits and the action level provided by the international environmental organizations of 148 $Bq·m^{-3}$. The indoor radon concentration in Iraqi Kurdistan was high in many houses, which affects women's fertility.

Keywords: radon, fertility of women, living room, kitchen, CR-39NTDs

Introduction

Radon (^{222}Rn) is a naturally radioactive noble gas originating from the decay of uranium in soil and rocks. It is odorless, colorless, and tasteless, and only special equipment can measure it. Many factors affect the amount of radon emitted into a home such as the rocks on which the home is built and how much soil or other material covers the radon-emitting rocks. Also, concentration of radon in the atmosphere varies depending on place, time, meteorological conditions, and height above the ground. Indoor radon measurements have an increasing interest if an average person spends 80% of time in home inhalation of radon [1]. From among the naturally radioactive materials radon gas and its radioactive isotopes deserve special attention because it has the largest amount of total annual effective doses to humans [2]. The threat is not radon itself, however, but its daughter products with their short half-lives emitting alpha particles that cause more damage than radon gas [3] when the radon enters an indoor atmosphere, it accumulates in poorly ventilated rooms at levels that may pose a significant health risk to the occupants [4]. Radon and alpha particles have many effects on the body. The decay products of ^{222}Rn ($t_{1/2}$ = 3.82 d) include polonium 218 (^{218}Po, $t_{1/2}$ = 3.05 min.), lead 214 (^{214}Pb, $t_{1/2}$ = 26.8 min.), bismuth (^{214}Bi, $t_{1/2}$ = 19.7 min), and polonium 214 (^{214}Po, $t_{1/2}$ = $1.6×10^{-4}$ s), as shown in Fig. 1 [4].

The biological effects of radon are predominantly due to the alpha particle activity of ^{222}Rn and two of its solid decay products, ^{214}Po and ^{218}Po. ^{218}Po and ^{214}Po deposition in the lungs caused by the inhalation of radon damages the cell lining of airways. Exposure to radon varies according to the concentrations present in homes [5]. Radon measurements are performed in kitchens and living rooms, where women spend most of their time. CR-39 plastic track detectors in air volume of cups has emerged as the most reliable procedure for time-integrated measurement, which should be used to estimate the equivalent concentrations of radon and its progeny. Long-term measurement also is performed to estimate the activity concentrations of radon and its daughters under different environmental conditions.

This study measured indoor radon alpha activity in the Iraqi Kurdistan region and examined its health effects on the population. This study is the first work that has attempted to

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explain the damaging effects of radon and alpha particles on the uterus, which leads to weak fertility in women. Testing using CR-39 alpha-sensitive solid state nuclear track detectors, which are very economical and reliable [6], was performed for the first time in kitchens and living rooms. Knowing radon levels in buildings is important in assessing population exposure [7].

Building Characteristics

The dwellings under study were generally built with cement, clay, and limestone bricks, with walls often covered with gypsum [6]. Different materials such as cement, sandstones, bricks, iron structures, marble, and concrete were used as construction materials. Several of these materials are significant sources of indoor radon. Each house had at least two rooms and one kitchen approximately (5×4×4) m^3, with one window and one door. A room without windows is considered poorly ventilated, whereas a well-ventilated room had one or more windows [7]. Windows are usually kept closed, even in living rooms with no exhaust fans, resulting in poor ventilation [4].

CR-39NTDs

The CR-39 technique was used to determine alpha particles and radon concentration. This technique was previously used to study indoor radon levels in different dwellings. The CR-39 SSNTD is diglycol carbonate ($C_{12}H_{18}O_7$). The detectors used in the present study are the ideal detectors produced by Intercast Europe SRL (43100 Parma, Italy) [8]. The rectangular part of the NTD is a film approximately 1.5×1 cm^2 [9] and 700 μm thick. The Intercast CR-39 has a low background for a small etching process during its use in radon dosimetry. The sensitivity of CR-39 enables it to register low energy alphas [10].

Chamber Design

The tube used in this study consisted of a PVC tube (2.1 cm wide and 10.5 cm long). The end of this tube was open and covered with a permeable cling film. The design of this radon detector ensured that only radon diffused into the sensitive volume of the chamber, such that all aerosols and radon decay products were kept outside [11, 12].

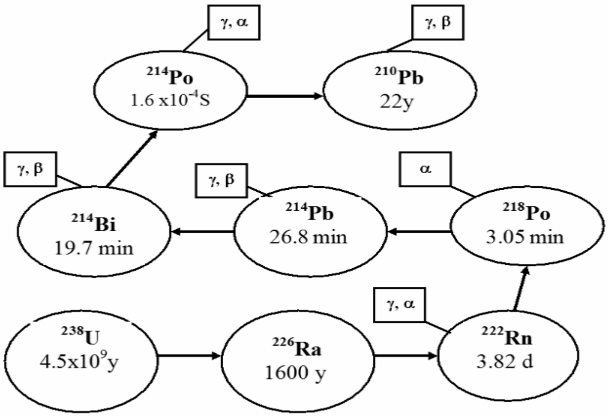

Fig. 1. The decay products of ^{222}Rn.

Methodology

Indoor ^{222}Rn concentrations were studied in 30 houses, which were carefully chosen depending on the situation of the women patients. The tube technique was utilized using one that was 2.1 cm wide and 10.5 cm long. A typical 15.0×10.0×0.7 mm CR-39 dosimeter was used. The study was performed from 11 July 2011 to 11 August 2011. Measurement of radon concentrations was conducted in kitchens and living rooms on the ground floor of all the houses. There was usually no difference between the physical or structural materials used in these rooms. The main difference we noted was that living rooms were larger in size and had more windows than did the kitchens. A total of 120 CR-39 detectors were installed in kitchens and living rooms, with two detectors per house. The design of this radon detector is illustrated in Fig. 2. Each detector was attached in a flat position to the bottom of a plastic container using a small piece of tape or glue. In the middle of the cover was a circular opening 1 cm in diameter, which was covered by a thin soft sponge approximately 0.5 cm thick. This sponge protected the detector by keeping out dust and ensured that all aerosols, as well as radon decay products, were kept outside, with only radon diffusing into the sensitive volume of the chamber [7].

The mobile number of the can and some instructions to keep it from being opened were written on the outside bottom of each can. The dates of distribution and collection also were written on the side of each can and recorded in a notebook (Fig. 2). The detectors were placed at a height of approximately 1.5 cm [13] from the floor. The dosimeters in houses were not removed for 60 d.

Detector Etching

The detector surface showed radiation damage along a trajectory when crossed by a charged alpha particle [14]. Chemical etching is an essential step in NTDs [15], with chemical or electrochemical etching frequently used to enlarge latent tracks in dosimetry [16]. The detectors were

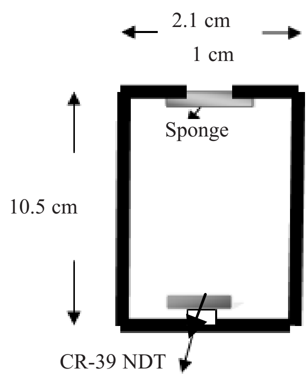

Fig. 2. Diagram of the radon detector.

Table 1. Average indoor radon concentration in kitchen and living room in 2 governorates in the Iraqi Kurdistan region.

Location	Type of room	Average radon concentration $Bq \cdot m^{-3}$		Average annual effective dose $mSvy^{-1}$	
		Minimum	Maximum	Minimum	Maximum
Erbil	Kitchen	97.886	364.412	2.466	9.183
	Living room	95.113	358.552	2.396	9.035
Sulaymania	Kitchen	99.947	360.112	2.518	9.017
	Living room	94.883	357.832	2.391	8.254

collected after 60 d of exposure and etched separately with 6.25 N NaOH at a temperature of 70.0ºC±0.5ºC for 8 hours to enhance the damage tracks [14]. The detectors were then removed from the etching solution and immediately rinsed with distilled water. Track densities registered on the CR-39 were determined using an optical microscope [11].

Scanning of the Detectors

An optical microscope was used at 400 × magnification to measure each detector's track density per cm^2, indicating radon concentration [17]. The area of the fields of view must be determined and kept constant throughout the scanning and counting processes [3]. During the scanning process, the sample must be carried carefully from its corner and must not be touched by bare hands [8].

Statistical Analysis

Statistical Package for the Social Sciences (SPSS) version 20 was used to analyze the results of the current study, using Wilcoxon Signed Rank test and noting differences between living rooms and kitchens.

Measurement of Indoor Radon Concentration and Excessive Lifetime Cancer Risk (ELCR)

After background correction, the track densities and concentrations of indoor radon gas in Bq/m^3 were calculated using the formula in reference [1]. Radon progeny concentration (WL) was calculated using the formula in reference [7]. The annual effective dose of the population in Iraqi Kurdistan as a result of the exposure to radon decay products was determined using the following formula:

$$E\ (annual\ effective\ dose) = A_{Rn} \times F \times O \times DCF$$

...where, A_{Rn} is the radon concentration ($Bq \cdot m^{-3}$), F is an equilibrium factor (0.4), O is the occupancy factor (7000 h), and DCF is the dose conversion factor (9.0 nSv $Bq \cdot m^{-3} \cdot h^{-1}$). From the effective dose (H in $mSv \cdot y^{-1}$), the excess lifetime cancer risk (*ELCR*) for the living room and kitchen was calculated using formula in, using the following formula:

$$ELCR = H \times DL \times RF$$

...where: DL is the duration of life (70 y) and RF is the risk factor (0.055 Sv^{-1}) recommended by the ICRP.

The values of the calculated annual effective doses of radon were found to vary from 2.391 $mSvy^{-1}$ to 9.017 $mSvy^{-1}$ in living rooms and 2.518 $mSvy^{-1}$ to 9.075 $mSvy^{-1}$ in kitchens. The radon concentrations and risks estimated from the 60 location in dwellings surveyed are presented in Tables 2 and 3.

Result and Discussion

This study is the first attempt to examine the radon levels in two rooms in the same houses in different locations in the Iraqi Kurdistan region by relating the fertility of women to the inhaled radon progeny gas in the air. The level of radon and its progeny in the air are governed by different parameters such as atmospheric conditions, seasonal situations (different ventilation and exhalations by soil), local geology, building features (types of building materials used, height of the considered floor, orientation of the house), and the habits of the occupants. Radon that enters the lungs is distributed by the blood to different parts of the body, including the uterus. Thus, radon levels affect the fertility of women. Women in Kurdistan are exposed to indoor radon in the home because they spend most of their time at home with poor ventilation.

In this study, indoor radon concentrations were measured in the kitchens and living rooms of 30 locations in the Iraqi Kurdistan region in each governorate. The data were determined depending on the age of the house, ventilation conditions, and the type of building materials used [18]. The results are listed in Table 1.

Indicating that the radon levels are different in different rooms of the same house. Higher radon levels registered in the kitchen than in the living room. This discrepancy can be explained by the difference in ventilation rates, the nature of the soil beneath each room, and particular geological considerations. Table 1 shows that there is linearity in all locations between radon concentrations and the effective dose on the biological samples (uterus). The mean as well as the minimum and maximum values variated, as listed in Table 1.

Table 1 shows that the radon levels in the kitchen vary from 99.947 $Bq \cdot m^{-3}$ to 364.412 $Bq \cdot m^{-3}$, with an average activity of 187.215 $Bq \cdot m^{-3}$. By contrast, indoor radon levels in the living room vary from 94.883 $Bq \cdot m^{-3}$ to 358.552 $Bq \cdot m^{-3}$. The minimum, maximum, and average values of indoor radon concentrations, as well as the annual effective dose per dwelling across two cities, were different and are

Table 2. Evaluation of indoor radon air concentrations in living rooms and kitchens with excess lifetime cancer risk (ELCR) in dwellings in Kurdistan-Iraqi region of Sulaymania.

N	Location	Concentrations of radon in living rooms ($Bq{\cdot}m^{-3}$)	ELCR (MPY^{-1}) in living rooms	Concentrations of radon in kitchens ($Bq{\cdot}m^{-3}$)	ELCR (MPY^{-1}) in kitchens
1	Eiskan	94.883	9.205	99.947	9.697
2	Khurmal	97.514	9.460	107.664	10.445
3	Chamchamal	99.766	9.678	105.546	10.239
4	Shekhan	101.519	9.848	123.534	11.985
5	Darbandikhan	103.431	10.033	125.429	12.169
6	Rzgary	114.374	11.096	124.457	12.074
7	Bakhteary	123.316	11.964	139.300	13.513
8	Reaea	123.863	12.016	130.973	12.707
9	Takea	134.861	13.082	137.195	13.309
10	Kalar	136.624	13.255	145.655	14.129
11	Khalakan	137.726	13.362	146.821	14.244
12	Bazean	140.791	13.659	143.231	13.894
13	Kfry	146.878	14.250	155.473	15.084
14	Sharawany	161.118	15.631	170.123	16.505
15	Zaraeen	168.726	16.366	172.476	16.732
16	Toymalek	170.105	16.501	181.158	17.579
17	Said sadiq	173.524	16.836	182.156	17.672
18	Penjween	186.119	18.056	193.157	18.739
19	khormal	211.281	20.497	231.651	22.474
20	Zargata	216.631	21.017	220.563	21.398
21	Bardarash	232.114	22.518	240.118	23.292
22	Mawat	242.155	23.492	263.101	25.525
23	Dukan	243.168	23.592	249.671	24.223
24	Qaladza	243.569	23.746	261.511	25.371
25	Halabjay taza	258.142	25.045	267.662	25.968
26	Rania	290.626	28.193	304.654	29.556
27	Mamostayan	326.034	31.727	329.136	31.931
28	Sulaymania	327.572	31.780	341.552	33.137
29	Arbat	343.091	33.286	353.754	34.321
30	Halabjay kon	357.832	34.715	360.112	34.938
Ave.		190.245	18.463	200.259	19.428

listed in Table 1. There was no significant difference in radon concentration when houses were compared, but the indoor radon levels in the kitchen were higher than those in the living room.

This study found that the indoor radon levels are within the acceptable ICRP limits. However, indoor radon levels of a few of the dwellings were above the recommended limits of the US EPA. The yearly mean effective radon dose was 4.795 mSv in the living room, lower than the 5.1633 $mSvy^{-1}$ in the kitchen. Both values are within the gauging limit of 3 to 10 $mSvy^{-1}$ for recommended action [18]. These values were expected because of poor ventilation. In cold climates, buildings are designed to be thermally efficient and are therefore poorly ventilated, allowing radon gas to build up to a high level.

Data presented in Tables 2 and 3 shows the relationship between radon concentrations in the living room and kitchen with ELCR in dwellings in the Iraqi Kurdistan region.

Table 3. Evaluation of indoor air radon concentrations in living rooms and kitchens with excess lifetime cancer risk (ELCR) in a dwellings in Kurdistan-Iraqi region of Erbil.

N	Location	Concentrations of radon in living rooms ($Bq·m^{-3}$)	ELCR (MPY^{-1}) in living rooms	Concentrations of radon in kitchens ($Bq·m^{-3}$)	ELCR (MPY^{-1}) in kitchens
31	Shorsh	95.113	9.2259	97.886	9.4949
32	Kas-Nazan	98.644	9.5684	102.326	9.9256
33	Shaqlawa	99.896	9.6899	106.894	10.3687
34	Salahadden	100.533	9.7517	114.224	11.0797
35	Nazanen	109.521	10.6230	119.174	11.5598
36	Holy- Zatd	116.804	11.3290	124.479	12.0746
37	Kareat- Zanko	124.871	12.1120	129.973	12.6073
38	Nawato dw	125.563	12.1790	132.195	12.8229
39	Erbil Center	132.960	12.8970	136.387	13.2295
40	Khalefan	136.921	13.2810	140.231	13.6024
41	Rzgary	138.781	13.4610	142.643	13.8363
42	Aeen-Kawa	143.279	13.8980	148.855	14.4389
43	Saed -Taqan	148.121	14.3670	153.348	14.8747
44	Sarsang	162.765	15.7880	166.923	16.1915
45	Qshtapa	167.098	16.2080	174.156	16.8931
46	Makhmur	171.554	16.6400	180.258	17.4850
47	Shaqlawa	177.824	17.2480	187.776	18.2142
48	Haji-Omaran	190.179	18.4470	196.158	19.0273
49	Rawanduz	213.201	20.6800	224.383	21.7651
50	Barzan	224.656	21.7916	230.673	22.3752
51	Harer	233.324	22.6324	241.176	23.3940
52	Taq-Taq	239.231	23.2054	248.273	24.0824
53	Shekholla	244.667	23.7327	254.511	24.6875
54	Prdea	257.239	24.9521	262.591	25.4713
55	Ronaki	278.152	26.9807	265.162	25.7207
56	Koya	305.996	29.6816	323.431	31.3728
57	Barsren	320.691	31.1070	336.156	32.6071
58	Deana	329.234	31.9357	344.071	33.3748
59	Eiskan	346.671	33.6270	352.564	34.1987
60	Sedakan	358.552	34.7795	364.412	35.3479
Ave.		193.068	18.7276	200.043	19.4041

Results

Participant Laboratory Characteristics

Sixty participants agreed to be involved in the current study, and their laboratory characteristics are shown in Table 4.

Differences in Participants' Laboratory Results in Kitchens and Living Rooms

Significant differences were found between kitchens and living rooms, where kitchen laboratory results had higher medians than results of living rooms using Wilcoxon Signed Rank test, as shown in Table 5.

Table 4. Participants' laboratory characteristics.

Laboratory outcomes	N	Mean (±SD)	Median
Living room conc. radon	60	191.657±80.016	169.42
Living room AAD	60	4.831±2.017	177.21
Living room WL	60	20.728±8.656	4.27
Living room LTR	60	1.916±0.800	4.47
Living room CPPP	60	86.899±36.374	18.31
Living room AEq D	60	96.610±40.348	19.16
Living room ELCR	60	18.595±7.766	10.25
Kitchen conc. radon	60	200.151±80.506	10.72
Kitchen AAD	60	5.044±2.029	10.25
Kitchen WL	60	21.634±8.707	10.72
Kitchen LTR	60	2.001±0.805	4.27
Kitchen CPPP	60	90.782±36.505	4.47
Kitchen AEqD	60	100.874±40.574	17.08
Kitchen ELCR	60	19.416±7.810	17.19

Data presented in Table 6 compared indoor radon concentrations in kichens and living rooms with other countries.

Conclusion

In this work, an indoor radon survey of 60 locations of women (30 for each location) with reproductive ailments in the Iraqi Kurdistan region was performed. The concentrations of indoor radon were high in a number of houses, affecting the fertility of the women occupants. The highest concentration of radon and highest annual effective dose calculated in the kitchen and living room were 364.412 Bq·m^{-3} and 9.183 mSvy^{-1}, respectively, and measured in Sedakan. The lowest concentration of radon and lowest annual effective dose was 94.883 Bq·m^{-3} and 2.391 mSvy^{-1}, respectively, and measured in Dukan. Generally, radon levels were higher in kitchens than in living rooms.

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Table 5. Differences of participants' laboratory results between kitchen and living rooms.

Variable	Difference		No.	Mean Rank	Z value	p value
Conc. of radon	Kitchen – living room	Negative Ranks	1	48.00	-6.383	<0.001
		Positive Ranks	59	30.20		
		Ties	0			
Negative Ranks			1	48.00	-6.383	<0.001
WL	Kitchen – living room	Negative Ranks	1	48.00	-6.383	<0.001
		Positive Ranks	59	30.20		
		Ties	0			

Table 6. The comparission of the indoor radon concentration in kichen and living room with other countries.

Location	Con. Bq·m^{-3}		Type of detector	References	
	Kitchen	Living room		Author	years
Nigeria	-	255	CR-39NTDs	Obed	2011
Swazilad	-	162	CR-39 NTDs	Farid	1992
India	82.29	40.10	HS71512 Radon gas detector	Kadam	2010
Pakistan	-	23	CR-39 NTDs	Rafique	2011
Pakistan	-	62	CR-39 NTDs	Mansour	2005
Pakistan	-	38-141	CR-39 NTDs	Rahman	2012
Iraq	187.215	184.212	CR-39 NTDs	Salih (this study)	2011

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