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ESTIMATION OF THE INDOOR RADON CONCENTRATION IN DWELLINGS OF THE DISTRICT KOTLI, AZAD KASHMIR – PAKISTAN

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Abstract: Environmental radiations exist everywhere and each natural substance contains trace amount of radioactive material. Radon alone contributes about 55% of total environmental radiations. Effects of these radiations on humans were firstly reported by Agricola for miners in the Erz Mountains of Eastern Europe in 1556 and in 1879 first association of lung cancer with miners were established**.** Nowadays indoor radon is believed to be second leading cause of lung cancer after smoking. Keeping in view the importance of subject indoor radon survey has been conducted in district Kotli of Azad Kashmir (Pakistan) using CN-85 based box type radon detectors. In this regard, 120 radon box type detectors were installed in a bedroom and living room of each house. The detectors were retrieved after exposing to the indoor radon for a period of 3 months and were etched in 6 N NaOH solution at 70^{o}C for 3 hours. The observed track densities were then related to the indoor radon concentration. Arithmetic and geometric means were found to be 84±6 Bq. m^{-3}, 73±6 Bq. m^{-3} and 80±6 Bq. m^{-3}, 71±7 Bq. m^{-3} in the living rooms and bedrooms, respectively. For bed rooms indoor radon concentration varied from 38±9 to 107±5 Bq. m^{-3} whilst for living rooms 52±8 to 263±3 Bq. m^{-3}. The overall mean value of the indoor radon concentration in the studied area was found to be 77±7 Bq. m^{-3}. According to the recommendations made by the Health Protection Agency, UK (200 Bq. m^{-3}), all the houses surveyed have the indoor radon concentration within the safe limits.

Keywords: CR-39 detector, Indoor radon concentration. Mean annual effective dose, Azad Kashmir.

1. INTRODUCTION

Gaseous radon isotopes (^{222}Rn, ^{220}Rn, ^{219}Rn) belong to three primordial series, namely; uranium series originating from ^{238}U, thorium series originating from ^{232}Th and actinium series originating from ^{235}U. All of these radioactive isotopes after completing their half lives (^{222}Rn with half life 3.82 d, ^{220}Rn with half life 55.6 s and ^{219}Rn with half life 3.96 s decays with emission of α-particles. In spite of equal radioactivities from chain precursor of ^{238}U and ^{232}Th, the steady state ^{220}Rn activity is always considerably less than ^{222}Rn activity. Due to the short half life of ^{220}Rn, diffusion losses in soil, while coming from its sources ^{232}Th location within earth are very large. Only decay product of ^{220}Rn which has biological significance is ^{212}Pb (half life 10.6 h), with daughters ^{212}Bi and ^{212}Po. These nuclides contribute radiation dose to the lungs that is approximately one-sixth of the dose delivered by ^{222}Rn daughters. Though, dose contribution to lungs by ^{220}Rn is less than ^{222}Rn, still its input is greater than many other back ground radiation sources. Due to very short half life, ^{219}Rn (actinon) importance is less compared to ^{222}Rn and ^{220}Rn.

Most important products of ^{222}Rn are ^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po. These short lived products having half-lives ranging from 26.8 min to 164 μs are very important in terms of human exposure (Martin, 2006). These daughter products when inhaled, deliver the bronchial radiation dose, which is implicated in bronchogenic carcinoma (NCRP, 1988). These four daughters do not exist in any environment. The two polonium isotopes, ^{218}Po and ^{214}Po are alpha emitters, and are of dosimetric interest.

Under some special occupational or environmental situations, measurement of actinon (^{219}Rn) or thoron (^{220}Rn) would be the primary concern but in normal situations only ^{222}Rn has to be seriously considered due to its relatively longer half-life (Alpen, 1988). Epidemiological studies of underground miners confirmed that high levels of exposure to radon are associated with increased lung cancer risk. Radon exposure also occurs elsewhere, especially in close environment within houses (Lubin et al., 1994).

The importance of radon as a source of exposure of the human lung has been given the attention and significance during last several decades. Extensive studies have been conducted at national and international level to measure and identify the high level radon and natural radioactivity regions (Ulbak et al., 1988; Tufail et al., 1988; Wrixon, et al., 1988; Tufail et al., 1992; Marcinowski, 1992; Canoba et al., 2001; Al-Jarallah et al., 2003; Kam & Bozkurt 2006; Rahman et al., 2007a,b, Rafique et al., 2009, 2010a,b, 2011a,b; Rahman et al., 2009, 2010a,b; Andras et al., 2011; Ramasamy et al., 2011). The main objective of the current study is to monitor indoor radon and to probe areas with high indoor radon concentrations in the district Kotli of Azad Kashmir, Pakistan. In order to unveil the high radon concentration areas in Azad Kashmir, systematic studies have been initiated since the last 4 years. This paper is a continuation of our previous studies with the aim to setup a base line indoor radon data for the Azad Kashmir.

2. STUDIED AREA

Kotli is a district of the Azad Kashmir covering a total area of 1862 km^2. According to the 1998 census, the population of the district Kotli is 0.558 million. The average height in the eastern and central part of the district is about 1000 m above the sea level. The rest of the area is less than 1000 m in altitude.

The climate of the district is generally hot in summer and cold in winter. The Eastern and Northern parts of the said district are dry and cold. Whereas the western areas are a little hot. June is the hottest month with the mean maximum and minimum temperature of about 38^{0}C to 25^{0}C, respectively. January is the coldest month with the mean maximum and minimum temperatures of about 18^{0}C and 5^{0}C, respectively. The mean annual rainfall is about 1300 mm, more than half of which occurs during the months of July and August.

3. QUALITY CONTROL

A meticulous quality control protocol was developed for the current survey. Protocols were strictly followed to ensure rigor of data. This quality control protocol included:

1. Selection of houses was based upon the willingness of the occupants and location of the house.

2. All the detectors were stored in radon proof conditions before installation.

3. After retrieving, the radon exposed detectors were carefully sealed in polythene bags and transported to the Nuclear Laboratory of Physics Department for analysis.

4. EXPERIMENTAL SETUP

4.1. Selection of sampling sites

Sixty houses were carefully selected for current indoor radon survey. The choice of the houses was based on our convenience, geographical spread and willingness of the dwellers of the surveyed area. CN-85 (cellulose nitrate) detectors were installed in a bedroom and living room of each house. Detectors were installed at the following sites: Kotli City (grid station), Palatar, Housing scheme (Kotli), Sarda calony, Industrial area, Damol, Sarsawa,Panjera, Tenda kala, Mandi Dehara, Maryyah Mera, Gulhar calony, Sehansa City, Charhoi, Parai, dare, Batoya, Darkote Cross, Nar Rajdani, Kotehra khanka, Khoiratta, Nikyal.

4.2. Materials and Methods

Sheets of CN-85 detectors were cut into small strips of 3cm × 3cm and were placed in box type holders (hereafter called box type radon detectors) having dimensions 3cm × 3cm ×1.14cm (see, Fig. 1).

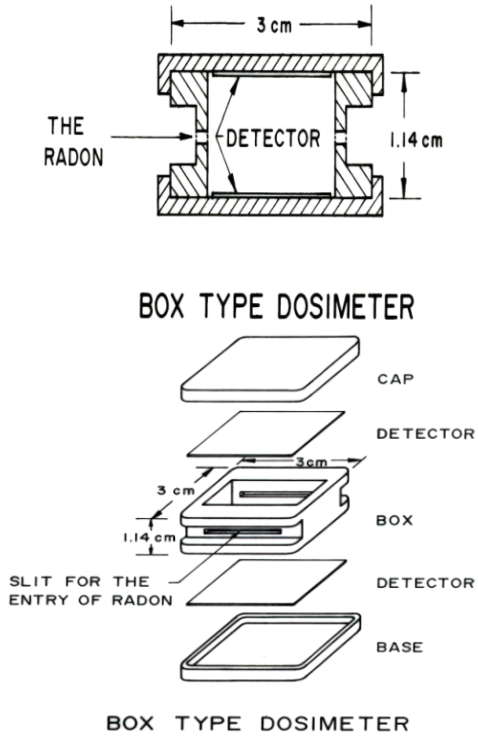

Figure 1. Schematic representation of the CR-39 based box type radon detector

CN-85 detector was chosen because of its high sensitivity to alpha particles in the energy range of 0.1- 6 MeV. For the sake of convenience, the surveyed district of Kotli was divided into four zones (Kotli, Sehansa, Charhoi and Khoiratta+FatehPur). As mentioned earlier, selection of the houses was based upon their geological spread, locality and design of the houses as well as willingness and cooperation of the occupants. The above-mentioned box type radon detectors were installed at head heights (i.e. ~ 1.5m) in a bedroom and living room of each house of selected 60 houses in district Kotli and were allowed to expose to indoor radon for 90 days. After exposure, the detectors were retrieved from the houses and etched in a 6N NaOH solution at 70°C for 3 hours. After the background correction, track densities were related to the radon concentrations (Bq. m^{-3}) using a calibration factor of 0.0092 tracks $cm^{-2}.h^{-1}$ = 1Bq. m^{-3} of ^{222}Rn (Khan et al., 1991).

5. RESULTS AND DISCUSSIONS

After determining concentration of indoor radon, weighted averages were calculated for all houses. Weighted average indoor radon concentration for each house was calculated using the following formula.

$$\bar{N}_{Rn} = 0.4N_{Rn_{liv}} + 0.6N_{Rn_{bed}} \quad (1)$$

Where, $\bar{N}_{Rn}$ is weighted average value of radon concentration, $0.4N_{Rn_{liv}}$ is radon concentration in living room and $0.6N_{Rn_{bed}}$ is radon concentration in bedroom. Equation (1) is formulated on the basis of interviews conducted with residents of the area. From these interviews, approximate time spent in a day by the residents in bed room and living room was estimated. According to interviews conducted, occupants spent ~60% of their indoor time in their bedrooms and 40% time in living rooms. The results obtained are shown in tables 1-3.

Table 1 shows results of the indoor radon concentrations in Kotli city. In Kotli city, indoor radon concentration varies from 38±9 to 85±6 Bq. m^{-3} in bed rooms and 58±7 to 263±3 Bq. m^{-3} in living rooms. Minimum value of the indoor radon concentration in bed room were found in house no. 9 and 11 in Damol region and housing scheme, whilst maximum concentration in bed rooms were found in house no. 19 in the region of Marryyah. Similarly minimum value of indoor radon concentration in living room were found for house no. 6 situated near high way road in Kotli whilst maximum concentration in living rooms were found in house no. 15 situated in industrial area of the city.

Table 2 shows results of the indoor radon concentrations in Sehansa and Chahroi regions. In Sehansa, indoor radon concentration varies from 63±7 to 104±5 Bq. m^{-3} in bed rooms and 52±8 to 104±5 Bq. m^{-3} in living rooms. Minimum value of indoor radon concentration in bed room was found for house no. 1whilst maximum concentration in bed rooms was found in house no. 6. Minimum value of indoor radon concentration in living room was found for house no. 10 whilst maximum concentration in living rooms was found in house no. 4. In Chahroi, radon concentration varied from 53±7 to 107±5 Bq. m^{-3} in bed rooms and 63±7 to 162±4 Bq. m^{-3} in living rooms. Minimum value of indoor radon concentration in bed rooms was found in house no. 7 in Kotehra khanka area whilst maximum concentration in bed rooms was found in house no. 6 in Chahroi city. Minimum value of indoor radon concentration in living room was found in house no. 10 of Nar Rajdani area whilst maximum concentration in living rooms was found in house no. 2 of Sehansa city. Results for Khoiratta and FatehPur regions are listed in table 3. As may be seen from table 3, indoor radon concentration varies from 48±8 to 104±5 Bq. m^{-3} in bed rooms and 53±7 to 119±5 Bq. m^{-3} in living rooms. Minimum value of indoor radon concentration in bed rooms was found for house no. 5 in Nikyal (palani) region whilst maximum concentration in bed rooms was observed in house no. 3 of Khoratta region. Minimum value of indoor radon concentration in living rooms was found for house no. 10 situated in Nikyal whilst maximum concentration in living rooms was found in house no. 9 situated in Nikyal (Maryyah).

Differences of indoor radon concentration in bed room and living rooms ($|\Delta| = |\text{Living Room} - \text{Bed Room}|$) have been observed. For the region Palatar, Housing Scheme and Industrial area, reported indoor radon in living rooms are significantly higher than the values for bedrooms. Although the geology of living and bedrooms is same for above mentioned areas but there were significant differences regarding ventilation. Also in these living rooms floors were muddy with crawls and fissures. In few living rooms even peoples use to cook and wash crockery's. For cooking purpose peoples of the area use natural gas or wood, leading considerable amount of smoke within the living rooms.

To get clearer picture of the variation observed in the indoor radon levels, a frequency distribution graph is plotted in figure 2. Graph follows lognormal distribution. Figure 2 show that none of the surveyed house has radon concentrations below 40 Bq. m^{-3}. Percentage of houses having indoor radon levels between 41-50, 51-60, 61-70, 71-80, 81-90, 91-100, 101-110, 111-120, 121-130, 131-140, 141-150 Bq. m^{-3} are 1.85%, 7.4%, 26%, 33.33%, 20.37%, 3.7%, 3.7%, 0%, 1.85%, 0%, 1.85%. Majority of the houses surveyed (53.70%) have radon concentrations between 61 to 80 Bq. m^{-3}.

To find geometrical spread in the observed data arithmetic, geometric mean and geometric standard deviation have been calculated. The arithmetic mean estimates the average probability of detrimental health effects associated with indoor radon data. A.M and G.M in living rooms are found to be 84±6 and 80±6 Bq. m^{-3} whereas for bed rooms A.M and G.M have been found to be 73±6 and 71±7 Bq. m^{-3}. The overall weighted average (mean) value for indoor radon concentration was found as 77±7 Bq. m^{-3}. Overall G.S.D for the studied was found as 1.17.

In figure 3, current indoor radon survey results have been compared with the data published in the open literature. At national level average indoor radon concentration reported for the Kotli district (77±7 Bq. m^{-3}) matches with (with in small differences) studies reported in references (Ali et al., 2010; Matiullah et al., 2003; Rafique et al., 2011b; Rahman et al., 2007a,b). Comparison with the international data suggests that the average measured indoor radon concentration values for the district Kotli is higher than those reported for the UK (20 Bq. m^{-3}), USA (46 Bq. m^{-3}), India (Assam, 42 Bq. m^{-3}, Himachal, 45 Bq. m^{-3}), Saudi Arabia (16 Bq. m^{-3}), Denmark (53 Bq. m^{-3}), Brazil (82 Bq. m^{-3}) and world average of 44 (Bq. m^{-3}) (Wrixon et al., 1988; Marcinowski 1992; Ulbak et al., 1988; UNSCEAR, 1982). On the other hand, indoor radon concentration values obtained from the current survey are less than the values reported for some other parts of the world like Finland (120 Bq. m^{-3}), Kenya (100 Bq. m^{-3}), China (120 Bq. m^{-3}), Meghalaya, 68 Bq. m^{-3} (Castren, 1994; Mjones, 1993; UNSCEAR, 1982; Dwivedia et al., 2005).

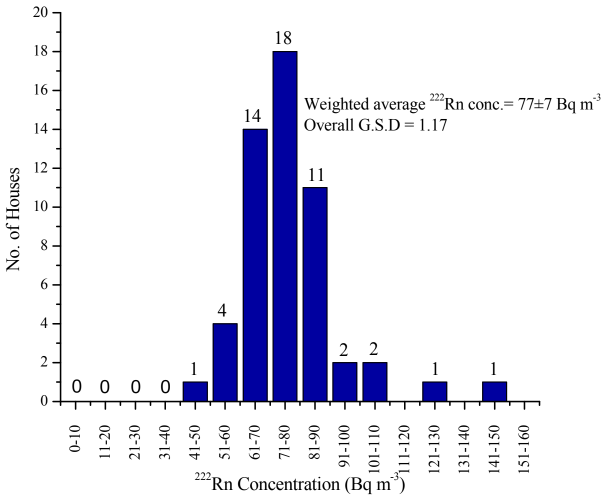

Figure 2. Frequency distribution of indoor radon concentration in district Kotli.

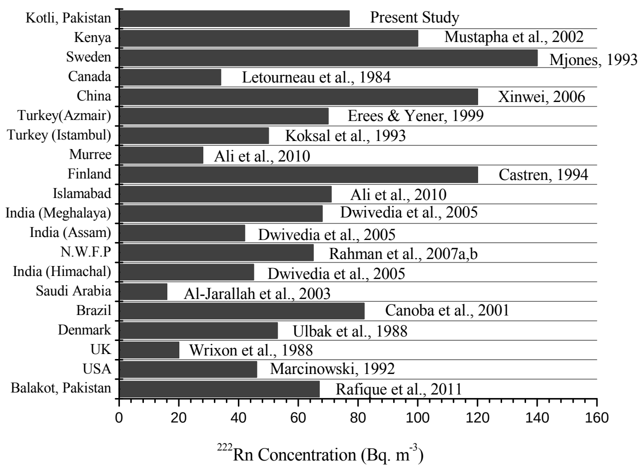

Figure 3. Comparison of indoor radon concentration in district Kotli with data available in literature.

Table 1. Indoor radon concentration in bedrooms and living rooms of the studied houses of the Kotli city region

House No.	Indoor Radon concentration (Bq. m^{-3})				Weighted Average radon concentration (Bq. m^{-3}) $\bar{N}_{Rn} = 0.4N_{Rn_{liv}} + 0.6N_{Rn_{bed}}$
	Location of Houses	Living Room	Bed Room	$\lvert\Delta\rvert = \lvert \text{Living Room} - \text{Bed Room} \rvert$	
1	Kotli City (grid station)	75±6	74±6	1	74±6
2	Palatar	149±4	63±7	86	97±6
3	Housing Scheme	82±6	42±9	40	58±8
4		58±7	69±7	11	65±7
5	Sarda calony	97±5	76±6	21	84±6
6	Near High way road	58±7	69±7	11	65±7
7	Industrial area	79±6	65±7	14	71±7
8	Sarda calony	61±7	68±7	7	65±7
9	Damol	69±7	38±9	31	50±8
10	Industrial area	94±6	73±6	21	81±6
11	Housing scheme	77±6	38±9	39	54±8
12	Sarsawa,Panjera	63±7	79±6	16	73±6
13	Tenda kala	77±6	81±6	4	79±6
14	Mandi Dehara	86±6	70±6	16	76±6
15	Industrial area	263±3	67±7	196	145±5
16	Sarda calony	65±7	81±6	16	75±6
17	Maryyah	73±6	65±7	8	68±7
18	Darang	67±7	76±6	9	72±6
19	Maryyah	78±6	85±6	7	82±6
20	Mera	60±7	69±7	9	65±7
21	Gulhar calony	65±7	50±8	15	56±8

Minimum and maximum indoor radon concentration along with arithmetic mean.

Location	Radon Concentration (Bq. m^{-3})		A.M	G.M	G.S.D
	Minimum value	Maximum value			
Bed Room	38±9	85±6	67±7	65±7	1.13
Living Room	58±7	263±3	86±6	79±6	1.19

Table 2. Indoor radon concentration in bedrooms and living rooms of the studied houses of Sehansa and Charhoi region

House No.	Indoor Radon concentration (Bq. m^{-3})				Weighted Average Radon Concentration (Bq. m^{-3}) $\bar{N}_{Rn} = 0.4N_{Rn_{liv}} + 0.6N_{Rn_{bed}}$
	Location of Houses	Living Room	Bed Room	$\lvert\Delta\rvert = \lvert \text{Living Room} - \text{Bed Room} \rvert$	
Sehansa					
1	Sehansa City	74±6	63±7	11	67±7
2		56±7	103±5	47	84±6
3		65±7	102±5	37	87±6
4		104±5	74±6	30	86±6
5		94±6	72±6	22	81±6
6		99±5	104±5	5	102±5
7		79±6	65±7	14	71±7
8		55±7	76±6	21	68±7
9		66±7	92±6	26	82±6
10		52±8	74±6	22	65±7

Minimum and maximum indoor radon concentration along with arithmetic mean.

Location	Radon Concentration (Bq. m^{-3})		A.M	G.M	G.S.D
	Min.	Max.			
Bed Room	63±7	104±5	83±6	81±6	1.07
Living Room	52±8	104±5	74±6	72±6	1.09

Charhoi					
11	Charhoi	87±6	67±7	20	75±7
12		162±4	69±7	93	106±6
13	Charhoi (Parai)	74±6	83±6	9	79±6
14	Charhoi(Darhi)	77±6	69±7	8	72±7
15	Charhoi (dare)	93±6	68±7	25	78±7
16	Charhoi city	156±4	107±5	49	127±5
17	Kotehra khanka	90±6	53±7	37	68±7
18	Darkote	86±6	65±7	21	73±7
19	Charhoi (Batoya)	72±6	82±6	10	78±6
20	Nar Rajdani	63±7	85±6	22	76±6
21	Darkote Cross	85±6	69±7	16	75±7
22		70±6	67±7	3	68±7
23	Kotehra khanka	95±6	75±6	20	83±6

Minimum and maximum indoor radon concentration along with arithmetic mean

Location	Radon Concentration (Bq. m^{-3})		A.M	G.M	G.S.D
	Min.	Max.			
Bed Room	53±7	107±5	74±7	73±7	1.07
Living Room	63±7	162±4	93±6	89±6	1.12

Table 3. Indoor radon concentration in bedrooms and living rooms of the studied houses of Khoiratta and Charhoi region

House No.	Indoor Radon Concentration (Bq. m^{-3})				Weighted Average Radon Concentration (Bq. m^{-3}) $\bar{N}_{Rn} = 0.4N_{Rn_{liv}} + 0.6N_{Rn_{bed}}$
	Location of Houses	Living Room	Bed Room	$\lvert\Delta\rvert = \lvert \text{Living Room} - \text{Bed Room} \rvert$	
1	Khoiratta	82±6	96±6	14	90±6
2		95±6	70±6	25	80±6
3		67±7	104±5	37	89±6
4		74±6	59±7	15	65±7
5	Nikyal (palani)	79±6	48±8	31	60±7
6	Nikyal (palani)	67±7	89±6	22	80±6
7	Nikyal (Maryyah)	92±6	54±7	38	69±7
8	Nikyal (Maryyah)	74±6	67±7	7	70±6
9	Nikyal (Maryyah)	119±5	79±6	40	95±6
10	Nikyal	53±7	68±7	15	62±7

Minimum and maximum indoor radon concentration along with arithmetic mean.

Location	Radon Concentration (Bq. m^{-3})		A.M	G.M	G.S.D
	Minimum value	Maximum value			
Bed Room	48±8	104±5	73±6	71	1.09
Living Room	53±7	119±5	80±6	78	1.08

6. CONCLUSIONS

To conclude, indoor radon concentrations have been measured in the dwellings of the district Kotli. A.M and G.M values for indoor radon concentrations were measured in living rooms and bed rooms. Followings results are drawn from current study,

1) Indoor radon concentration for bed rooms varied from 38±9 to 107±5 Bq. m^{-3} whilst for living rooms concentration varied from 52±8 to 263±3 Bq. m^{-3}.

2) For living rooms A.M and G.M values of indoor radon concentrations were found as 84±6 Bq. m^{-3}, 73±6 Bq. m^{-3}. Similarly for bed rooms reported values are 80±6 Bq. m^{-3}, 71±7 Bq. m^{-3}.

3) Weighted Average indoor radon values varied from 50 to 145 Bq. m^{-3}.

4) Overall mean value of indoor radon concentration for studied area was found as 77±7

Bq. m^{-3}.

5) Since there is no local criterion therefore current study results are compared with the recommendations made by the Health Protection Agency, UK (200 Bq. m^{-3}) and World Health Organization (WHO, 100 Bq. m^{-3}). On comparing results obtained from current survey with recommendations made by the Health Protection Agency, UK (200 Bq. m^{-3}) all the houses surveyed are within the safe limits.

6) Whilst comparison with WHO (100 Bq.m^{-3}) recommendations shows that 7.4% houses have elevated values of indoor radon concentrations. To conclude, indoor radon concentration in the Kotli is low and does not pose any threat to the occupants of the studied area.

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