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ASSESSMENT OF INDOOR RADON DOSES RECEIVED BY THE DWELLERS OF BALAKOT – NWFP, PAKISTAN: A PILOT STUDY

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Abstract: An indoor radon measurement survey has been carried out in the dwellings of Balakot city of North West Frontier Province of Pakistan using CR-39 based radon detectors. The main objective of this survey was to estimate radiation doses received by the dwellers of the Balakot city due to the indoor radon exposure. For this purpose CR-39 based radon detectors were installed in bedrooms and living rooms of 50 randomly selected houses. After 90 days of radon exposure, CR-39 detectors were etched for 9 h in 6 M NaOH at 70 ^{0}C and the observed track densities were related to radon concentrations. The measured indoor radon concentration ranged from 15±8 to 267±3 Bq m^{-3} and 15±8 to 205±3 Bq m^{-3} in bedrooms and living rooms, respectively. Weighted average radon concentration varied from 16±8 to 222±3 Bq m^{-3}. Based on the measured indoor radon data, the annual effective doses were found to vary from 0.30±0.20 to 5.60±0.08 mSv y^{-1}. The overall mean effective dose for the studied area was found to be 1.69 ± 0.15 mSv y^{-1}.

Keywords: indoor radon concentration, CR-39 based radon detectors, annual effective dose, mean effective dose

1. INTRODUCTION

Human beings are inevitably exposed to low level background radiations from the environment. These radiations got importance and became the subject of various studies once the health hazards related with their exposure were recognized. About 50–55% of the average annual dose received by the population from all background radiations is contributed by radon gas and its short-lived daughters alone (Durrani & Ilic, 1997; UNSCEAR, 2000). High incidence of lung cancer cases (about 30 times the normal) were found in the miners, working in the cobalt mines of Saxony (in southeastern Germany) and in pitchblende mines (in Czechoslovakia) having large concentrations of uranium (Lamarsh & Baratta, 2001). It is believed that these workers suffered from internal radiation exposure due to the inhalation of radioactive gas radon and its progenies. Several epidemiological and assessment of lung cancer risk studies have established the fact that not only the mine workers but also the general public living in the dwellings with high radon concentration may be effected by radon and its progenies (Mustafa & Vasisht, 1987; Nero, 1988). Radon is a colorless, odorless chemically inert gas and has greater ability to diffuse through rocks and soils. It can move a substantial distance from its point of origin towards the surface of the earth and enters into the open environment and houses. In open environment its radiological impacts are low, however in buildings high concentration of radon can occur due to the close environment of room. Factors' contributing towards high concentrations within close rooms includes building materials, soil underneath the building, restricted ventilation and to the lesser extent by well water (Sannappa et al., 2003; EPA, 2003).

Radon has three isotopes, namely; 1) ^{222}Rn, called radon belongs to ^{238}U decay series; 2) ^{220}Rn, called thoron belongs to thorium series; 3) ^{219}Rn called actinon belongs to ^{235}U series. Half-life of ^{222}Rn is 3.82 days, which is significantly greater than half lives of thoron (55.6 s) and actinon (3.96 s). This fact compels the researchers to give more importance to ^{222}Rn as compared to other two isotopes. The main health risk associated with exposure of radon and thoron is lung cancer. The short lived radioactive daughter products of radon (^{218}Po and ^{214}Po) emit densely ionizing alpha particles that can interact with biological tissues in the lungs leading to DNA damage. It is thought that generally occurrence of one mutation can lead to cancer and with passage of time proliferation of cells having some degree of DNA damage can greatly increase the pool of cells available for the development of cancer. One important thing associated with radon exposure and cancer is that there is no threshold value of radon concentration below which we can say that radon has no potential to cause lung cancer. This is due to the fact that even a single alpha particle can cause major genetic mutation in cell, which may occur at any level of exposure (WHO, 2009).

In the light of the above-mentioned facts a large number of studies have been conducted at international and national levels including Pakistan to measure indoor radon concentration and to create public awareness about radon and its hazards (Israeli, 1985; Carta et al., 1994; Yu et al., 1997; Virk & Sharma, 2000; Canoba et al., 2001; Srivastava et al., 2001; Roth et al., 2002; Sannappa et al., 2003; Miles, 2005; Tufail et al., 1988, 1992a, 1992b; Khan et al., 1991; Matiullah et al., 2003; Ahmad et al., 1998; Rehman et al., 2006; Rahman et al., 2006, 2007; Rafique et al., 2008, 2009, 2010; Rahman et al., 2009, 2010a, 2010b). In most of studies radon concentrations for residential area are found to be within safe limits. This study presents the results of radon survey carried out in the Balakot city of the North West Frontier Province of Pakistan. Balakot city was severely damaged in 08th Oct. 2005 earthquake. After earthquake, construction in and around the Balakot city was banned because of the propinquity of active fault lines. Majority of the houses were destroyed in the earthquake and there were few pre-earthquake houses have been left. With the government help and advice, people have constructed prefabricated buildings in the Balakot city.

2. AREA UNDER STUDY

Balakot is situated in North West of the Muzaffarabad and is a city of the district Manshera, North West Frontier Province of Pakistan (NWFP). It is located along the Kunhar River and lies on the survey of Pakistan toposheet No. 43 F/6. The studied area lies in the humid region in the access of monsoon. In various parts of the area, there is a small scale variation in the humidity and rain fall due to the change in altitude. The climate of Balakot is moderate to cold, but in winter season the weather goes to colder one and mountains of the area are covered with snow. However, in summer the climate remains moderate and pleasant. The Balakot city was badly destroyed during the 08th Oct. 2005 earthquake. The two types of rocks i.e. sedimentary and metamorphic rocks are exposed in the Balakot and the surrounding area. The geological rock formations present in the area include; the Precambrian Tanol Formation, Cambrian Muzaffarabad Formation, Carboniferous Chushal Formation and the Early Paleocene to Miocene sedimentary sequence. Geological map is shown in figure 1.

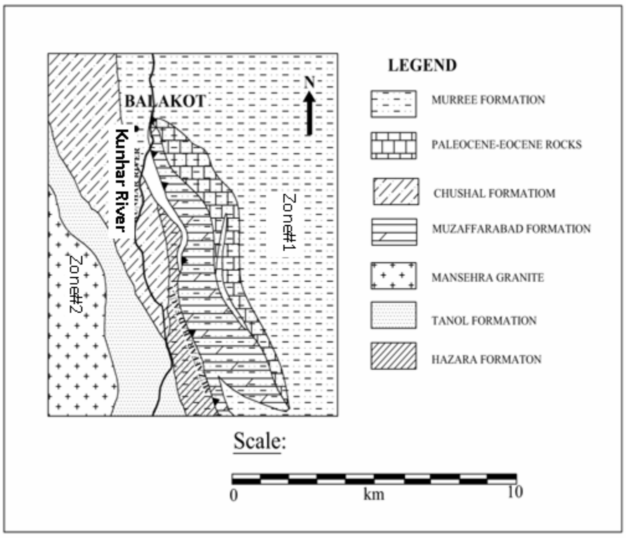

Figure 1. Geological Map of the Balakot city showing different formations in the studied area. (Modified after Bossart et al., 1984)

Most of the houses surveyed in the Balakot city were made up of shelters and CGI (corrugated galvanized iron) sheets. There were very few houses with no windows and in most of houses one or two windows in each room. The floors of these houses were made up of concrete (the mixture of cement and sand) and plywood sheets were used in ceiling. Some of the houses were built from bricks and blocks. Bricks are made of cement and clay whereas blocks were made of cement, sand and gravels. Sand is usually taken from the banks of the both sides of river Kunhar. A small number of houses were made of mud with wooden roofs. These houses have a poor ventilation system, but majority of houses surveyed had good ventilation system.

3. EXPERIMENTAL METHODOLOGY

Time integrated radon concentrations were measured by using CR-39 based radon detectors in the dwellings of the Balakot city. For the sake of convenience, the city was divided into two Zones. The part of the city lying at the left bank of Kunhar river was considered as Zone -1 (consisting of Mohallah Ziarat upper Garlat, Mohallah Ghandak, Khawas, Nala Khawas) and other part at the right bank of the river was called Zone -2 (consisting of Narrah, upper Narrah, Katha Khawas). Majority of population of city lies in Zone -1. Large sheets of CR-39 detectors were cut into small strips (having dimensions 3 × 3 cm^2) and then fixed in a box type dosimeters with dimensions 3 × 3 ×1.14 cm^3 (see, Figure 2).

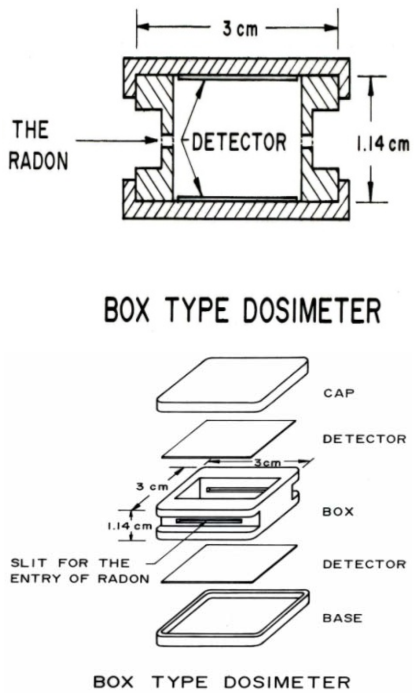

Figure 2. Schematic representation of the CR-39 based box type radon detector.

Two detector strips were placed at two opposite walls of the holder. The design of this type of radon detector ensures that all the aerosols and radon decay products are kept outside and only radon diffuses into the sensitive volume of the chamber. The detectors were placed at a height of five feet from the ground in the bedrooms and living rooms of each house (all in the ground floor storey). After 90 days of indoor radon exposure, CR-39 detectors were etched in a 6M NaOH solution at 70^{o}C for 9 h and counted under an optical microscope. After the background correction, track densities were related to the indoor radon concentrations (Bq m^{-3}) using a calibration factor of 0.0092 tracks $cm^{-2}.hr^{-1}$ = 1 Bq m^{-3} (Rafique et al. 2010).

4. RESULTS AND DISCUSSION

As mentioned earlier, indoor radon concentrations was measured in 50 dwellings of the Balakot city. Results are shown in figures 3-5. Figure 3 shows results of the indoor radon concentrations in Zone -1 (situated at left bank of the Kunhar River) and Figure 4 shows radon concentration values for Zone - 2 (at right bank of the Kunhar river). Minimum, Maximum, Arithmetic Mean (A.M), Geometric Mean (G.M) and Geometric Standard Deviation (G.S.D) are depicted in figure 5. In Zone - 1, radon concentration varies from 15±8 to 205±3 Bq m^{-3} in living rooms and 17±8 to 251±3 Bq m^{-3} in bed rooms.

Assuming that occupants spent ~55% of their indoor time in their bedrooms and 45% time in living rooms (Pinel et. al., 1995), weighted average indoor radon concentration for each house was calculated using the following formula. Weighted average radon concentration = (0.45×radon concentration in living room+ 0.55× radon concentration in bedroom).

Weighted average radon concentration for Zone - 1 was found to vary from 16±8 to 231±3 Bq m^{-3}. A.M for the bedrooms and living rooms came out to be 73 and 54 Bq m^{-3}, respectively. G.M values for the bedrooms and living rooms are 61 and 46 Bq m^{-3}, respectively. G.S.D for Zone -1 has value of 1.69.

In Zone - 2, indoor radon concentration varies from 15±8 to 267±3 Bq m^{-3} in bedrooms, and from 40±6 to 166±3 Bq m^{-3} in living rooms. Weighted average radon concentration for Zone - 2 varied from 28±7 to 222±3 Bq m^{-3}, A.M for bedrooms and living rooms have the values 77 and 70 Bq m^{-3}, respectively whereas G.M values for the bedrooms and living rooms are 71 and 58 Bq m^{-3}, respectively. G.S.D value for Zone - 1 is 1.32. Overall weighted average indoor radon concentration for the Balakot city came out to be 67 Bq m^{-3}.

To get a clearer picture of the variation observed in the indoor radon levels, a frequency distribution graph is plotted in figure 6. Graph follows lognormal distribution, as most of the radon surveys have observed. Figure 6 show that 4% of houses have radon concentrations below 20 Bq m^{-3} and 12% between 21-40 Bq m^{-3}. Majority of the houses surveyed (44%) have radon concentrations between 41 to 60 Bq m^{-3} while 24% of the houses have radon concentration between 61 to 80 Bq m^{-3} and 10% between 81 to 100 Bq m^{-3}.

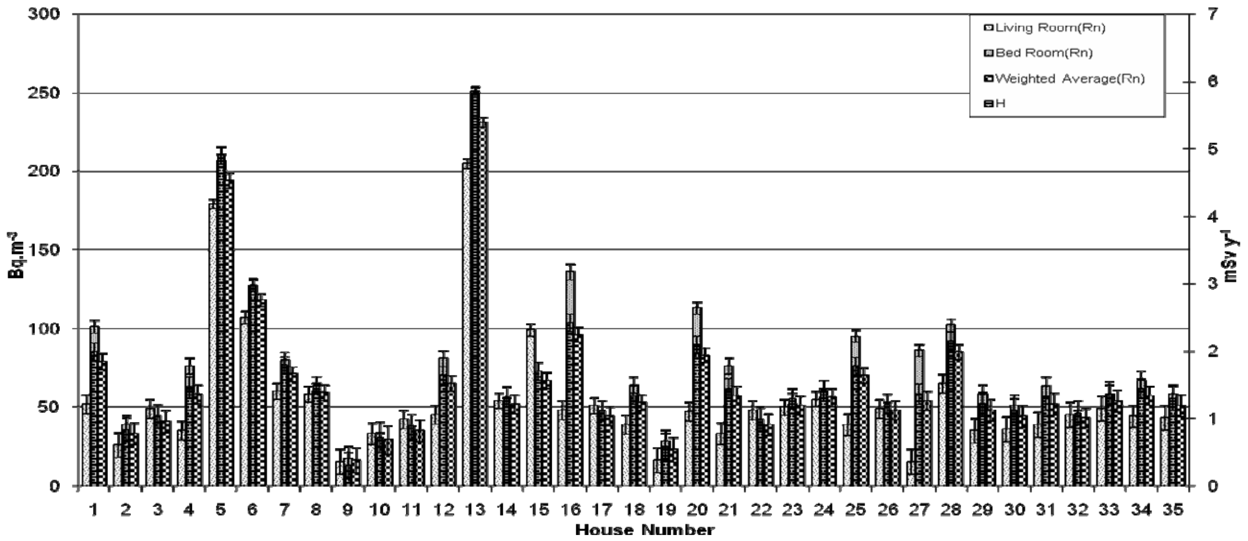

Figure 3. Indoor radon concentration and resulting doses in the houses of Zone-1 (Balakot city)

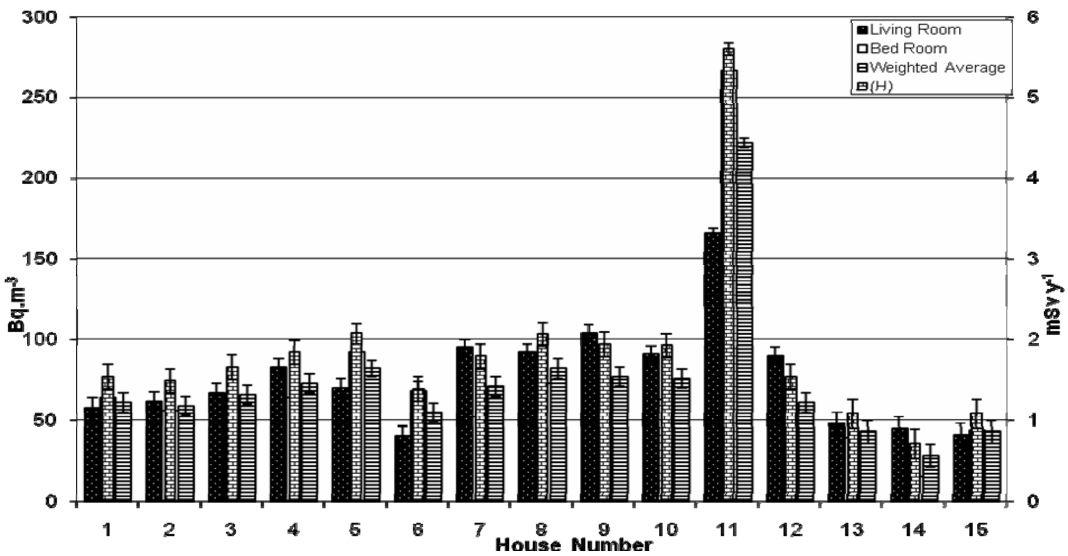

Figure 4. Indoor radon concentration and resulting doses in the houses of Zone-2 (Balakot city)

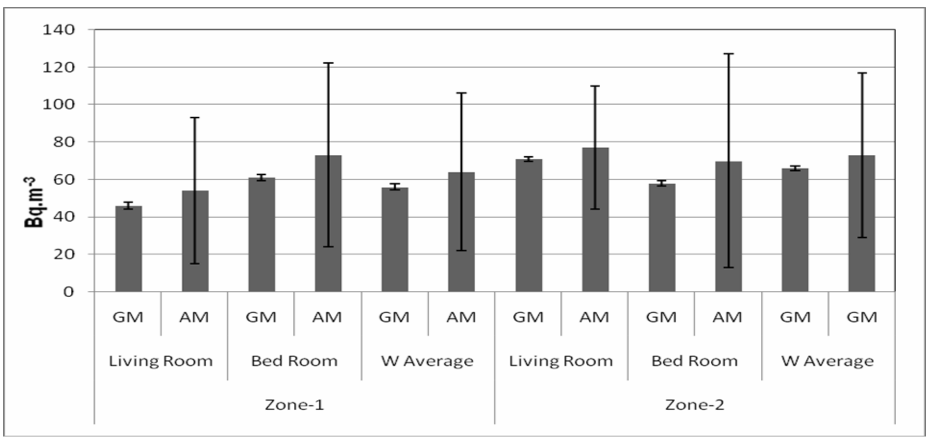

Figure 5. Geometric and arithematic means, radon weighted averages of Zon-1 and 2 of Balakot City.

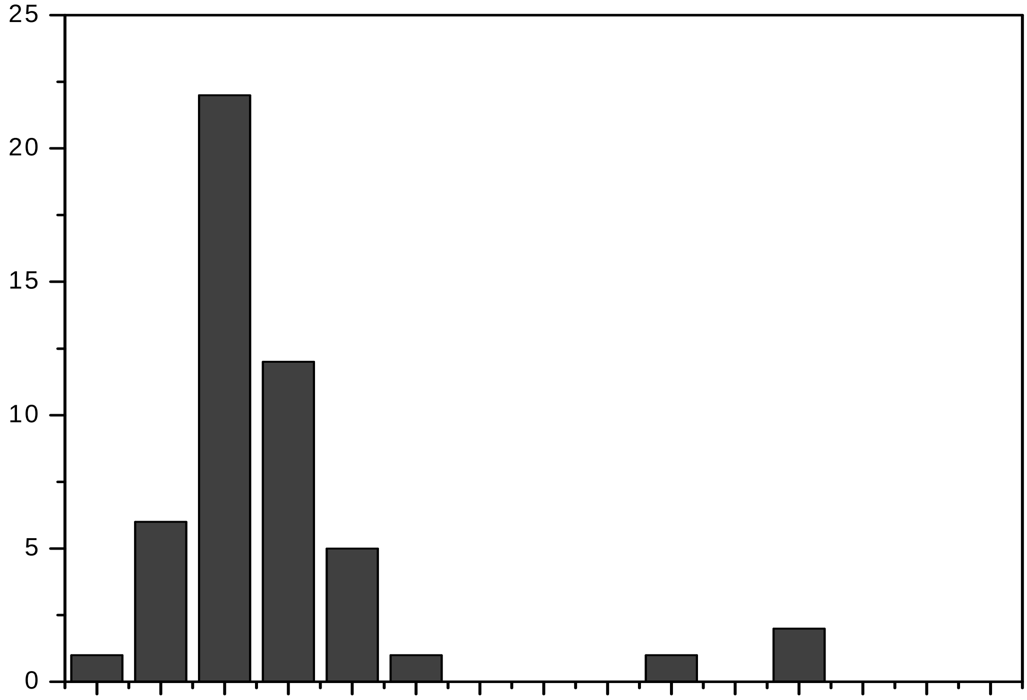

Figure 6. Frequency distribution of the indoor radon concentration observed in the Balakot city.

Only 2% of the houses have radon concentration within the ranges 101 to 120 Bq m^{-3} and 181 to 200 Bq m^{-3} overall 4% of houses surveyed have radon concentrations above Heath Protection Agency (UK) recommended level of 200 Bq m^{-3}.

The two highest values of the radon concentrations in bedrooms 251±3 and 267±3 Bq m^{-3} were found in house No.13 in Mohallah Ghandak of Zone -1 and house No.11 in upper Narrah of Zone - 2 whereas in living rooms highest radon concentration values of 205±3 and 166±3 Bq m^{-3} were found in house No. 13 (Mohallah Ghandak) of Zone 1 and house No. 11 (upper Narrah) of Zone - 2. As mentioned earlier, majority of the houses surveyed were built after the devastating 08th Oct. 2005 earthquake. Most of the houses surveyed in the Balakot were made up of shelters and CGI sheets. Their floors were made of thick concrete slabs with no cracks underneath the floor, this may lead to minimizing the radon contribution factor from the building materials and from soil underneath the dwellings. It may be one of the reasons that majority of the surveyed houses have indoor radon concentration below the ICRP (1993) recommended level of 200 Bq m^{-3}. On the other hand, older houses with poor ventilation system and muddy floor were found to have higher indoor radon concentration. Due to the cold climatic conditions people keep the doors and windows closed. This might have caused higher indoor radon concentration in some of the houses surveyed. To summarize, elevated radon levels have been found only in those houses with older buildings made up of blocks, stones, muddy walls and having concrete roofs.

5. DOSE ESTIMATION

For the estimation of average annual effective dose (H) ($mSv.y^{-1}$) received by the inhabitants of the studied area due to the indoor radon and its progeny, the following model of UNSCEAR (2000) was adopted.

$$H = C \times F \times O \times T \times D \qquad (1)$$

Table 1. A.M[*], G.M[**] and G.S.D[***] of indoor radon concentration in the houses of Zone 1 & 2 (Balakot).

Reference	Location	Results (Mean Indoor Radon Concentration Bq m^{-3})
Tufail et al. (1988)	Islamabad, Rawalpindi, Pakistan	23 to 83 Bq m^{-3} (Bed rooms), 20 to 74 Bq m^{-3} (Kitchens), 16 to 56 Bq m^{-3} (Sitting rooms)' 12 to 49 Bq m^{-3} (TV Lounges)
Tufail et al. (1992b)	Lahore, Pakistan	28 to 93 Bq m^{-3} (Bed rooms), 23 to 86 Bq m^{-3} (Kitchens), 21 to 82 Bq m^{-3} (Sitting rooms)' 20 to 69 Bq m^{-3} (TV Lounges)
Matiullah et al. (2003)	Southern Punjab, Pakistan	Bedrooms: 20, 20, 26, 28, 34, 42, 47 Bq m^{-3} and sitting rooms: 24, 26, 27, 26, 37, 40, 43 Bq m^{-3}
Khan et al. (2005)	Fatima Jinnah Women University, Rawalpindi, Pakistan	Ranges from 31 to 213 Bq m^{-3} for old buildings. and 27 to 143 Bq m^{-3} for new buildings.
Akram et al. (2005)	Skardu, Pakistan	Radon level ranges from 76 to152 Bq m^{-3} with an average value of 111 Bq m^{-3}
Rahman et al. (2007)	NWFP and FATA, Pakistan	Yearly arithmetic mean of 76 ± 37 and 68 ± 25 Bq m^{-3} in bedrooms and drawing rooms respectively
Rahman et al (2009)	Punjab	Average radon concentration values in Jhelum, Chakwal, Rawalpindi and Attock districts of the Punjab Province 55±13 Bq m^{-3}.
Rafique et al. (2010)	Poonch, Azad Kashmir	Average radon concentrations for living and bed rooms for district poonch are reported as, 83±3, 93±3 Bq m^{-3}.
Al-Jarallah et al., 2003	Saudi Arabia	16
Canoba, A. et al., 2002	Brazil	82
Ulbak, K. et al., 1988	Denmark	53
Wrixon, A.D. et al. 1988	UK	20
Marcinowski, F., 1992	USA	46
UNSCEAR, 2000	UNSCEAR, 2000	44
Current study (Balakot City)	Pakistan	67

[*]A.M= Arithmetic Mean, **G.M=Geometric Mean, ***G.S.D= Geometric Standard Deviations

where C stands for weighted average indoor radon concentration in Bq m^{-3}, F (0.4, taken for indoor inhabitants) for equilibrium equivalent concentration (EEC) factor, O for occupancy factor (0.8 as taken in UNSCEAR 2000 report), T for time (8760 h.y^{-1}), and D for dose conversion factor (9 nSv.h^{-1} per Bq.m^{-3}).

For Zone - 1 doses due to the indoor radon exposure range from 0.30±0.20 to 5.83±0.08 mSv y^{-1}. Minimum value of the dose has been observed in house No. 9 in Mohallah Ziarat (upper Garlat), whilst maximum value has been found in house No. 13 in Mohallah Ghanak.

For Zone – 2, doses due to the indoor radon exposure range from 0.71±0.18 to 5.60±0.08 mSv y^{-1}. Minimum value of dose is observed in house No. 14 in Katha Kawas and maximum value is found in house No. 11 in Upper Narah. The overall mean indoor radon dose has been found to be 1.69±0.16 mSv y^{-1}. The observed values of doses due to indoor radon exposure for the Balakot city are less than the recommended action levels (3-10 mSv y^{-1}) (ICRP, 1993). The present values have been compared with the data published for Pakistan and other parts of the world. At national level average indoor radon concentration reported for the Balakot city (67 Bqm^{3}) matches with (with in small differences) studies carried out by Tufail et al. (1992a, 1992b), Matiullah et al. (2003), Khan et al. (2005), Rahman et al, (2007), Rahman et al. (2009) and Rafique et al. (2010). The maximum mean value of the indoor radon concentration in Pakistan (111 Bq m^{-3}) has been reported for Skardu City by Akram et al (2005). A comparison of the current results with data reported for other parts of the world is made in Table 5. Comparison with the international data suggests that the average measured indoor radon concentration values for Balakot city are higher than those reported for the UK (20 Bq m^{-3}), USA (46.25 Bq m^{-3}), Saudi Arabia (16 Bq m^{-3}), Denmark (53 Bq m^{-3}) and world average of 44 Bq m^{-3}(Wrixon, A.D. et al. 1988; Marcinowski, F., 1992; Al-Jarallah et al., 2003; Ulbak, K. et al., 1988; UNSCEAR, 2000). 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 (e.g. 82 in Brazil 98.4 Bq m^{-3} in Kastamonu, Turkey) (Canoba et al., 2001; Kam et al., 2006).

6. CONCLUSION

Indoor radon concentrations have been measured in the dwellings of Balakot city. Overall mean indoor radon concentration for Balakot city has been found to be 67 Bq.m^{-3}. Majority of the houses have indoor radon concentration below the ~200 Bq.m^{-3}. Only 4% of the houses surveyed have indoor radon concentrations within the range of 221-240 Bq m^{-3}. These houses with higher indoor radon concentration had muddy floors, poor ventilation systems and cracks in foundations produced due to earthquake. Annual mean effective dose due to the indoor radon has been found 1.69±0.16 mSv y^{-1} which is less than the lower limit of the recommended action level (3–10 mSv). To conclude, indoor radon concentration in the Balakot city is low and does not pose any threat to the occupants of the city.

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