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Full Length Research Paper

Monitoring of $^{222}Rn/^{220}Rn$ concentrations at the work places of Muzaffarabad, Azad Kashmir

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Thoron (^{220}Rn), due to its-short half-life of 55.5 s is unable to travel far from its point of generation. A number of studies report indoor radon (^{222}Rn) concentration in different locations of Azad Jammu and Kashmir, while no study reports indoor ^{220}Rn concentration. The CR-39 based passive alpha track detectors were used for the measurement of ^{222}Rn and ^{220}Rn concentrations at different selected workplaces of Muzaffarabad. ^{222}Rn and ^{220}Rn concentration were measured simultaneously. Alpha track detectors (ATD) were enclosed in a thin polyethylene film to exclude ^{220}Rn (closed detector) while the other ATD has a coarse metal grid and cloth covering the large entry port allowing for rapid radon gas ingress. The results showed that the measured ^{222}Rn concentration varied from 18.7 Bqm^{-3} to 160.2 Bqm^{-3} with an average value of 67.0 ± 3 $Bq.m^{-3}$. Whereas the ^{220}Rn concentration varied from 14.7 Bqm^{-3} to 100.4 Bqm^{-3} with an average value of 50.0 ± 2 Bqm^{-3}. Preliminary results show that indoor ^{220}Rn concentration is significantly higher and should be taken into consideration while calculating the dose due to radiation of natural origin.

Key words: Thoron, indoor radon, alpha track detectors, radiation dose, Azad Jammu and Kashmir.

INTRODUCTION

Radon is a radioactive element that possesses the gaseous state and is the decay product of ^{238}U. It shows non-reactive behavior while its alpha emitting daughters are harmful to the human health. Radon oozes out from its point of production to the earth surface where it resides in the environment including our homes, offices and all other workplaces especially the buildings having uncovered floors (mud floorings). Radon present in the environment is inhaled by the human as they breathe and reaches the lungs where it may decay resulting to lung cancer (if a person resides in radon-rich environment for quite a long time) and severe conditions might include death of the person. Along with ^{222}Rn, ^{220}Rn also plays an important role in the risk evaluation. Those conventional radon monitors which are also sensitive to ^{220}Rn results in over estimation of the ^{222}Rn (Tokonami et al., 2003). It has been reported that ^{220}Rn is present in considerable amount in the indoor environment (Tokonami et al., 2002). Radiation exposure due to the inhalation of ^{220}Rn progeny has been estimated to be of the order of 10 - 20% as that compared with the short-lived ^{222}Rn progenies (Yamasaki et al., 1995; Guo et al., 1992). In the past, health hazards associated with ^{220}Rn have been underestimated as compared to those associated with ^{222}Rn because of the difficulties involved in the calibration and measurement of ^{220}Rn (Tokonami, 2005; Guo et al., 1992). McLaughlin (2010) reported an overview of ^{220}Rn and its progeny in the indoor environment and comparisons are given of a range of ^{220}Rn and progeny measurement techniques both using passive and active techniques and as an example of a survey of ^{220}Rn and its airborne progeny in over 200 houses in Ireland are presented. Ramachandran and Sathish (2011) reported nationwide indoor ^{222}Rn and ^{220}Rn map for India comprising more than 5000 measurements in 1500 dwellings across the country in urban and nonurban

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locations. According to their results 20% of the total indoor inhalation dose rates are due to ^{220}Rn.

Harley et al. (2005) reported continuous ^{222}Rn and ^{220}Rn measurements at all sites for at least 1 year and the bronchial dose is reported. (1) at Fernald; (2) at the New York City National Weather Service site (3) at a private home in Bangkok used as a QC site; and (4) at a research center and rare earth development facility processing monazite (Harley et al., 2005; Pressyanov (2012) has used CDs/DVDs for retrospective measurements of ^{220}Rn and ^{222}Rn. He employs analysis of alpha tracks at (69 µm) is due both to ^{220}Rn and ^{222}Rn, while the signal at the (80 µm) is due only to ^{222}Rn.

A number of studies form Azad Jammu and Kashmir (Rafique et al., 2010, 2011, 2012) and other parts of Pakistan (Ali et al., 2010; Khan et al., 1991; Matiullah et al., 2003; Rahman et al., 2010a, b; Tufail et al., 1988, 1992) measurements of indoor ^{222}Rn concentration while no study was reported for ^{220}Rn concentration. To have baseline data of the ^{220}Rn concentration for the study area, simultaneous measurements of the ^{222}Rn and ^{220}Rn concentration were performed in the selected work places in the Muzaffarabad area.

Study area

Area under investigation, Muzaffarabad, is the state capital of Azad Kashmir and is located at the confluence of the Neelum and Jhelum Rivers (Figure 1). The district Muzaffarabad is bounded by the Kupwara and Baramulla districts of the Indian state of Jammu and Kashmir in the east, by North-West Frontier Province in the west, by the Neelum district Azad Kashmir in the north and by Rawalpindi /Islamabad in the south. It is at a distance of 138 km from Rawalpindi and about 76 km from Abbotabad. It is also surrounded by mountains; situated at 1250 m above sea level. The climate is mountainous, sub humid with most of the precipitation-taking place in winters. The higher reaches receive heavy snowfall during winter season.

Quality control protocol (QCP)

Careful QCP was adopted for the measurement of radon and thoron at workplaces of Muzaffarabad. To obtain reliable data from the current survey QCPs were strictly followed. QCPs included:

1. Selection of workplace sites was based upon the willingness of the owners and location of the site.
2. Before installation of the detectors they were placed in radon proof environment.
3. After exposing the detectors for a specific period, the radon exposed detectors were retrieved and carefully sealed in polythene bags and transported to the Nuclear Laboratory, Physics Department, University of Azad Kashmir for further analysis.

Selection of sampling sites

Forty workplaces were carefully selected for the current radon survey. The choice of the workplaces was based on our convenience, geographical spread and willingness of the workplace owner of the surveyed area. The CR-39 detectors were installed at the height of ~1.5 m. Detectors were installed at the following sites: Lower Chehla, Middle Chehla, Upper Chehla, Plate, Upper Addah, Ranjata, Domel, Upper Chattar, Ambore, Lower Chatter, Shaukat Line, Naluchi, Gojra, Main Shaukat Line, Tahli Mandi, C.M.H Road, Gillani Cowk, Tanga Stand, Madina Market, Khawaja Chowk Bazar, Shahnara, Suzuki Stand, Old Court, City Police Station and Main Bazar.

MATERIALS AND METHODS

Sheets of CR-39 detectors were cut into small strips of 3 cm × 3 cm. In order to measure simultaneously ^{222}Rn and ^{220}Rn concentration, pairs of high sensitivity alpha track detectors which is developed and used for measuring atmospheric radon concentration, were used (Steck et al., 1999). One of the alpha track detector (ATD) is enclosed in a thin polyethylene film to exclude ^{220}Rn (closed detector) while the other ATD has a coarse metal grid and cloth covering the large entry port allowing for rapid radon gas ingress (Figures 2 and 3). The detector (^{220}Rn and ^{222}Rn) response was measured (Steck, 2006) through multiple exposures into chambers in Laboratory (Shafer Environmental Radiation Lab, St. John University, MN, USA). The ^{222}Rn responses of the open and closed ATDs were determined in a room which contain measurable ^{220}Rn but can have constant ^{222}Rn concentration of about 1 kBqm^{-3}. The ^{222}Rn concentration in the room as measured hourly with calibrated Continuous Radon Monitors (CRM) (Durridge RAD-7). The radon response of the open ATD has also been calibrated in the national radon tests for more than ten years.

The closed detector has a response of 5.7 tracks/cm^{-2}(kBqhrm^{-3})$^{-1}$ for ^{222}Rn and less than 0.05 tracks cm^{-2} (kBq hrm^{-3})$^{-1}$ for ^{220}Rn. The open detector has a ^{220}Rn response of 5.2 tracks cm^{-2} (kBq hr.m^{-3})$^{-1}$ and a ^{222}Rn response of 0.7 tracks/cm^{-2}(kBqhrm^{-3})$^{-1}$.

As reported by Steck et al. (1999), the statistical uncertainty in the individual ATDs is approximately 10%. Since the closed detector's track density depends on ^{222}Rn exposure alone while the open detector's track density reflects the ^{222}Rn and ^{220}Rn. Hence, the ^{220}Rn exposure uncertainty depends on the ^{222}Rn exposure as well as the ^{220}Rn exposure. The CR-39 obtained from Pershore Molding was cut into small pieces and were used in this study. In order to obtain background tracks 5% detector were etched and counted and thus background track density of the sheet was obtained. The formula was set in MS Excel; ^{222}Rn and ^{220}Rn concentrations were calculated (Steck et al., 1999).

Cylindrical shaped dosimeters were specially designed to place the CR-39 pieces to deploy at the selected workplaces. The geometry of the dosimeters used in the present study is shown in Figure 2.

One end of the dosimeters were sealed with the aluminum sheets while the other end were covered with the same aluminum sheets having a hole of diameter 2.5 cm at the center (as can be seen in a of Figure 2). The holes were created to provide the path for air to enter into the dosimeter. Bags of a porous cloth named *"Markene"* having length and width of 18 and 11 cm, respectively

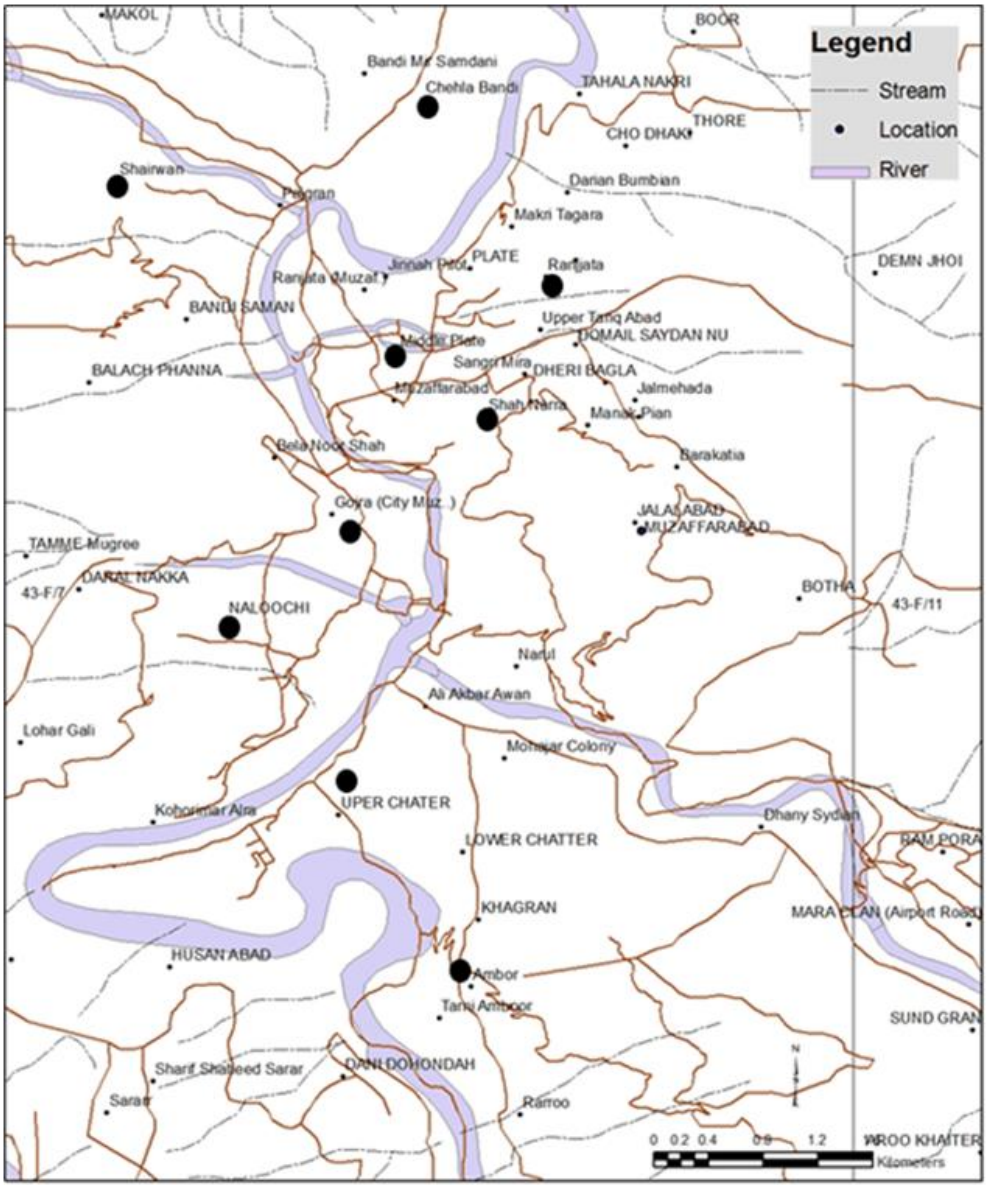

Figure 1. Map of study area.

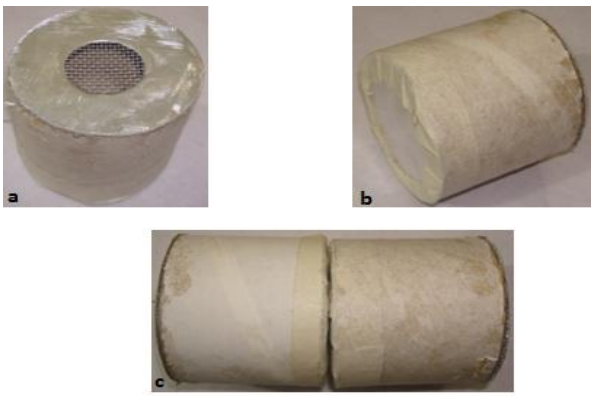

Figure 2. Sectional view of $^{222}Rn/^{220}Rn$ dosimeters.

were designed to pack the dosimeters and to save them for the desired period of time at the places of their installations.

The dosimeters were categorized into two parts based on the measurement of ^{222}Rn and ^{220}Rn. Half of the dosimeters (40 out of 80) were covered with polythene bags (named; *Packed*) so that, only ^{222}Rn can enter and remaining half of them were kept bare (named; *Unpacked*) for the measurement of all the radiations present in the air. Each Markene bag consisted of two dosimeters (*Packed* and *unpacked*) having a seal on it (Figure 3).

These bags were then installed at the selected workplaces for the period of three months (June 2010 to August 2010). Each bag was suspended at an average height of 5 feet from the ground level. Care was taken during their installation such that they were installed on the Ground floor of each workplace. Number of the dosimeter and the date of installment were written on each bag and their corresponding names of places followed by the building structure (floor, roof, walls etc.) were noted on the catalog book.

Figure 3. View of Packed dosimeters.

Further, the installed detectors were regularly monitored for every fortnight to check whether they are present at their respective places or not. It is very important to note, while discussing the experimental setup that the selected workplaces covered the whole city of Muzaffarabad from *Ranjata* to *Tahli Mandi* and *Naloochi* (East to West), *Chehla* to *Ambore* (North to South) and the old city.

After the completion period of exposure, the detectors were retrieved and were extracted from the dosimeters, etched chemically. The CR-39 detector sheets were immersed in the beakers (containing NaOH) with the help of metallic hooks and then the beakers were placed in the Shaking Bath (mention the speed of shaking bath) which was filled with 5 L of tap water heated up to 70°C for 8 h. The equipment was covered with a lid to avoid the evaporation of both etchant and the water. During the etching process, the Shaking Bath was adjusted to minimize the variation of temperature throughout the whole etching. It was done by shaking the equipment along with being heated to a certain temperature.

After the completion of etching, detectors were washed under the tap water and were cleaned with a soft cloth. After the cleaning of all the detectors, they were viewed one by one under the optical microscope (*Labomade;* with eye piece of magnification 40 x and objective lens of 10 x) to a magnification of 400 x ($M = m_1 \times m_2 = 40 \times 10 = 400$) (include some the exposed film photos). Each detector was read for tracks produced by alpha particles from one end to the other. The calculations were made in the following way; the track densities were calculated by employing the formula (Rafique et al., 2010a, b);

Track density = Total no. of tracks per Field of View (FOV) /Area.

The tracks densities were then converted to radon concentrations (Bqm^{-3}) by using the calibration factors as follows:

For calculation of ^{222}Rn concentration, calibration factor of 19.6 $tracks.mm^{-2}.d^{-1}/37$ Bqm^{-3} was used. For calculation of ^{220}Rn concentration, calibration factor of 33.533 $tracks.mm^{-2}.d^{-1}/37$ Bqm^{-3} (Steck et al., 1999; Steck, 2006).

RESULTS AND DISCUSSION

As mentioned earlier, from the observed track densities ^{222}Rn and ^{220}Rn concentration levels were calculated using the calibration factor given by Steck et al. (1999). Having determined the ^{222}Rn, ^{220}Rn concentrations, arithmetic mean (AM) and standard deviations (SD) were calculated. Minimum and maximum indoor ^{222}Rn and ^{220}Rn concentration levels observed in different selected locations are shown in Figure 4. Concentration variations of different selected work places were also calculated.

From the Table 1, it is clear that ^{222}Rn concentration varied from 18.7 to 160.2 Bqm^{-3} with an average value of 67.0 ± 34 Bqm^{-3}, ^{220}Rn concentration varied from 14.7 Bqm^{-3} to 100.4 Bqm^{-3} while the average value was 49.9 ± 21) Bqm^{-3}, respectively.

In the Chehla area the variation of indoor ^{222}Rn varied from 84.7 to 122.3 Bqm^{-3} with an average of 102.5 Bqm^{-3} while ^{220}Rn concentration varied from 24.8.0 to 56.9 Bqm^{-3} with an average value of 41.9 Bqm^{-3}. In the plate, Upper Addah, Upper Addah Khashkhar (Ranjata), Domel and Upper Chattar area minimum value of ^{222}Rn concentration of 41.5 Bqm^{-3} was found in Upper Addah area and maximum value of 109.5 Bqm^{-3} was observed in the Upper Chattar area, whilst the average in this area was 63.4 Bqm^{-3}, similarly ^{220}Rn concentration varied in these locations form 23.4 Bqm^{-3} to 100.4 Bqm^{-3} which were observed in upper Chattar and Domel having an average of 50.0 Bqm^{-3}.

Five dosimeters were placed in the selected locations of Ambore area Muzaffarabad where indoor ^{222}Rn concentration varied form 18.7 Bqm^{-3} to 122.0 Bqm^{-3} having an average of 56.3 Bqm^{-3} while ^{220}Rn varied form 30.6 Bqm^{-3} to 52.9 Bqm^{-3} having an average value of 43.3 Bqm^{-3}.

Six dosimeters were installed in the selected workplaces of Main Shaukat Lines, Tahli Mandi, C.M.H Road, Bank Road, Gillani Chowk and Taanga Stand area where minimum value of ^{222}Rn is 25.5 Bqm^{-3} and a maximum value of 83.01 Bqm^{-3} with an average of 51.1 Bqm^{-3}, similarly ^{220}Rn concentration varied from 40.3 to 80.5 Bqm^{-3} with an average of 62.4 Bqm^{-3}.

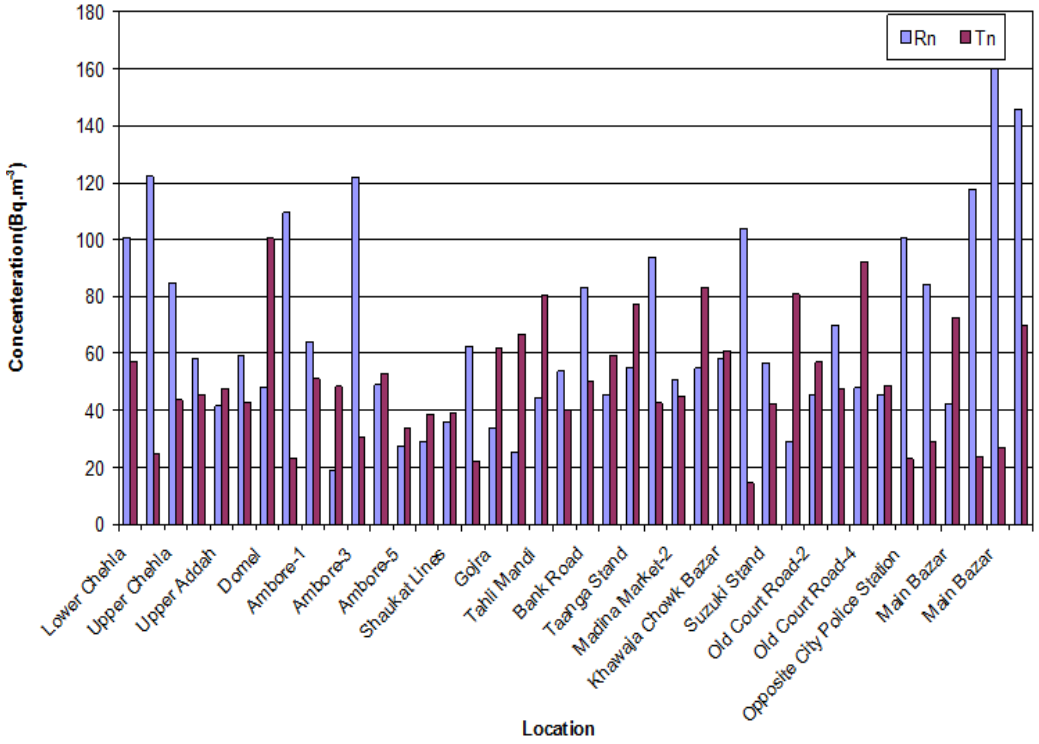

Figure 4. ^{222}Rn-^{220}Rn concentrations at the selected locations (Bqm^{-3}).

In Madina Market area three dosimeters were installed in different workplaces where ^{222}Rn concentration varied from 51.0 to 93.8 Bqm^{-3} with an average of 66.5 Bqm^{-3} while ^{220}Rn varied from 42.6 to 83.1 Bqm^{-3} with an average value of 57.0 Bqm^{-3}. Five dosimeters were installed in different locations of Old Court Road area where ^{222}Rn showed variations from 29.3 to 69.8 Bqm^{-3} with an average of 47.6 Bqm^{-3}, while ^{220}Rn varied from 47.5 to 92.2 Bqm^{-3} with an average of 65.2 Bqm^{-3}.

Similarly five dosimeters were installed in different workplaces of Main Bazar, which is a commercial area where ^{222}Rn varied from 42.6 to 160.2 Bqm^{-3} having an average of 108.4, while ^{220}Rn varied from 23.0 to 72.3 Bqm^{-3} having an average of 40.9 Bqm^{-3}.

The study conducted for 114 Houses in Minnesota and Iowa (Steck, 2006) homes, where, the arithmetic mean for ^{222}Rn of 210.0 and 35.0 Bqm^{-3} was reported, ^{222}Rn concentration reported for Minnesota is higher than the reported values of the current study (67.0 and 50.0 Bqm^{-3} for ^{222}Rn and ^{220}Rn, respectively), while ^{220}Rn concentration is lower than the values reported in this study. A maximum concentration of 510.0 Bqm^{-3} was reported by Steck (2006) for a basement in Minnesota, USA.

ICRP (ICRP Publication 50, 1987) in its publication addressing ^{220}Rn decay products (TDP) where assumed Dose Conversion Factor (DCF) was 0.52 based on dosimetric approach available in 1987. UNSCEAR (1988) report uses value of 0.42 Sv per Jhm^{-3} to all the organs considering occupancy of 100%, and for 80% occupancy the lung dose was 0.35 Sv per Jhm^{-3}. IAEA (1996) basic safety standards assumed a DCF equal to 0.48 Sv per Jhm^{-3}. In the 1996 Council Directive of the European Union, a DCF of 0.5 Sv per Jhm^{-3}. In ICRP 65 the DCF for Thoron Decay Progeny (TnDP) is 0.3 and 0.4 Sv per Jhm^{-3} for dwellings and work places, respectively (Nuccetelli and Bochicchio, 1998). The annual effective dose from ^{220}Rn and its progenies was evaluated to be up to 9% of that of ^{222}Rn and its progenies (UNSCEAR, 2000). As the half-life of ^{220}Rn progeny: ^{212}Pb, 10.64 h is much longer than that of ^{222}Rn progeny, and the alpha energy emitted from ^{220}Rn progeny is high (^{212}Po, 8.78 MeV), the effective dose per unit equilibrium equivalent concentration of ^{220}Rn progeny is nearly 4.4 times higher than that of ^{222}Rn progenies. It is not possible to use only the concentration of the gas in dose evaluation, since the concentration is strongly dependent on the distance from the source (UNSCEAR, 1993). Using the equilibrium equivalent concentrations, the annual effective dose may be derived as:

Indoors: 0.3 Bqm^{-3} (EEC) × 7000 h × 40 nSv (Bqhm^{-3})$^{-1}$ = 0.0084 mSv
Outdoors: 0.1 Bqm^{-3} (EEC) × 1760 h × 40 nSv (Bqhm^{-3})$^{-1}$ = 0.007 mSv

The value of 40 nSv (Bqhm^{-3}) is for equilibrium equivalent concentrations of ^{220}Rn, for evaluating exposures both

Table 1. Indoor ^{222}Rn and ^{220}Rn concentration at selected workplaces of Muzaffarabad.

S/N	Place	Latitude	Longitude	^{222}Rn (Bqm^{-3})	^{220}Rn (Bqm^{-3})
1	Lower Chehla	N 34° 23′ 5″	E 73° 23′ 15″	100.4	56.9
2	Middle Chehla	N 34° 23′ 14″	E 73° 27′ 54″	122.3	24.8
3	Upper Chehla	N 34° 23′ 20″	E 73° 28′ 1″	84.7	43.8
4	Plate	N 34° 22′ 33″	E 73° 28′ 3″	58.5	45.8
5	Upper Addah	N 34° 22′ 21″	E 73° 28′ 15″	41.5	47.7
6	Khashkhar (Ranjata)	N 34° 22′ 20″	E 73° 28′ 51″	59.5	42.6
7	Domel	N 34° 21′ 17″	E 73° 28′ 14″	48.1	100.4
8	Upper Chattar	N 34° 20′ 44″	E 73° 28′ 19″	109.5	23.4
9	Ambore-1	N 34°19′ 52″	E 73° 28′ 7″	64.2	51.1
10	Ambore-2	N 34° 19′ 59″	E 73° 28′ 5″	18.7	48.4
11	Ambore-3	N 34 °19′ 42″	E 73° 28′ 17″	122.0	30.6
12	Ambore-4	N 34° 19′ 40″	E 73° 28′ 19″	49.1	52.9
13	Ambore-5	N 34° 20′ 2″	E 73° 28′ 56″	27.4	33.5
14	Lower Chattar	N 34° 20′ 43″	E 73° 27′ 58″	29.3	38.5
15	Shaukat Lines	N 34° 21′ 46″	E 73° 27′ 53″	35.9	39.3
16	Naloochi	N 34° 20′ 57″	E 73° 27′ 37″	62.6	22.1
17	Gojra	N 34° 21′ 16″	E 73° 27′ 42″	34.0	62.1
18	Main Shaukat Lines	N 34° 21′ 56″	E 73° 28′ 31″	25.5	66.9
19	Tahli Mandi	N 34° 22′ 12″	E 73° 27′ 49″	44.4	80.5
20	C.M.H Road	N 34° 22′ 21″	E 73° 28′ 5″	53.8	40.3
21	Bank Road	N 34° 22′ 4″	E 73° 28′ 8″	83.1	50.5
22	Gillani Chowk	N 34° 22′ 4″	E 73° 28′ 14″	45.3	59.3
23	Taanga Stand	N 34° 22′ 4″	E 73° 28′ 20″	54.7	77.1
24	Madina Market-1	N 34° 22′ 13″	E 73° 28′ 11″	93.8	42.6
25	Madina Market-2	N 34° 22′ 14″	E 73° 28′ 5″	51.0	45.1
26	Madina Market-3	N 34° 22′ 18″	E 73° 28′ 13″	54.7	83.1
27	Khawaja Chowk B	N 34° 22′ 15″	E 73° 28′ 18″	58.5	60.8
28	Shahnara	N 34° 22′ 12″	E 73° 28′ 26″	104.0	14.7
29	Suzuki Stand	N 34° 22′ 5″	E 73° 28′ 15″	56.6	42.2
30	Old Court Road-1	N 34° 22′ 9″	E 73° 28′ 20″	29.3	80.7
31	Old Court Road-2	N 34° 22′ 9″	E 73° 28′ 21″	45.3	57.1
32	Old Court Road-3	N 34° 22′ 9″	E 73° 28′ 21″	69.8	47.5
33	Old Court Road-4	N 34° 22′ 9″	E 73° 28′ 22″	48.1	92.2
34	Old Court Road-5	N 34° 22′ 9″	E 73° 28′ 22″	45.3	48.8
35	Opposite City Police Station	N 34° 22′ 10″	E 73° 28′ 19″	100.4	23.0
36	Main Bazar	N 34° 22′ 9″	E 73° 28′ 16″	84.1	29.1
37	Main Bazar	N 34° 22′ 9″	E 73° 28′ 15″	42.6	72.3
38	Main Bazar	N 34° 22′ 9″	E 73° 28′ 15″	117.6	23.9
39	Main Bazar	N 34° 22′ 9″	E 73° 28′ 15″	160.2	27.1
40	Main Bazar	N 34° 22′ 9″	E 73° 28′ 15″	145.7	69.8
Average				67.0	50.0
Min				18.7	14.7
Max				160.2	100.4
Std D				34.5	20.7

indoors and outdoors (ICRP Publication 50, 1987). The dose to organs other than lungs due to the transfer of ^{212}Pb from the lungs is significant due to the long half-life of ^{212}Pb. Due to the unit exposure to ^{220}Rn progeny, about 20% of the dose that they receive from the same exposure to ^{222}Rn progeny (Guo et al., 2001).

Measurements of natural radiation were carried out in cave dwellings distributed in the Chinese loess plateau.

Those dwellings are located in Shanxi and Shaanxi provinces. Measurements were conducted in 202 dwellings among 193 dwellings, indoor radon concentrations ranged from 19 to 195 Bq m^{-3} with a geometric mean (GM) of 57 Bq m^{-3}, indoor thoron concentrations ranged from 10 to 865 Bq m^{-3} with a GM of 153 Bq m^{-3}, and indoor equilibrium equivalent thoron concentrations ranged from 0.3 to 4.9 Bq m^{-3} with a GM of 1.6 Bq m^{-3} (Tokonami, 2005). There results are higher as compared to the present study.

Similarly Ramola et al. (2005) reported ^{222}Rn and ^{220}Rn in the environment of Kumaun Himalayas. The reported dose rates due to ^{222}Rn and ^{220}Rn and their decay products ranged from 0.04 to 1.89 µSv/h, lower than the ICRP recommended value of 200 Bqm^{-3}. Ramola and Ramachandran (2000) reported data from about 100 houses which show that concentrations of indoor radon and thoron vary from 10.3 to 190.5 Bq m^{-3} and 1 to 144.6 Bq m^{-3}, respectively.

Yamada et al. (2006) reported indoor radon measurements were carried out in cave dwellings of the Chinese loess plateau in Gansu province using two types discriminative monitor for radon and thoron and selective monitor for thoron decay products. The arithmetic mean concentrations of indoor radon and thoron were 91 and 351 Bq m^{-3}, respectively, which is much higher than the present study.

The results of the study conducted in different workplaces of Muzaffarabad Azad Jammu and Kashmir Pakistan using the passive CR-39 detectors shows that ^{220}Rn cannot be ignored during the measurement of the indoor ^{222}Rn concentration as in some cases its concentration is high and delivers dose to such an extent which when added to the dose delivered by ^{222}Rn, may exceeded the limits defined by the US, EPA or NRPB, UK.

In the past, health hazards associated with ^{220}Rn have been underestimated as compared to those associated with ^{222}Rn because of the difficulties involved in the calibration and measurement of ^{220}Rn (Tokonami, 2005).

Conclusions

To conclude, a pilot study was conducted in the selected workplaces of Muzaffarabad Azad Jammu and Kashmir to simultaneously measure indoor ^{222}Rn and ^{220}Rn concentration at the workplaces using alpha track passive detectors. The study showed that significant ^{220}Rn concentrations are present in the selected locations of Muzaffarabad in workplaces. The results showed that while calculating the dose due to ^{222}Rn, ^{220}Rn concentration in the indoor environment should not be ignored as in some case its concentration is higher than ^{222}Rn concentration. Passive technique is suitable and inexpensive to measure indoor ^{222}Rn and ^{220}Rn concentration in workplaces.

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REFERENCES

Ali N, Khan E U, Akhter P, Khan F, Waheed A (2010). Estimation of Mean Annual Effective Dose through Radon Concentration in the Water and Indoor Air of Islamabad and Murree. Radiat. Prot. Dosim. 141(2):183-191.

Guo Q, Cheng J, Shang B, Sun J (2001). The levels of indoor thoron and its progeny in four areas in China. J. Nucl. Sci. Technol. 38(9):799-803.

Guo Q, Shimot M, Ucebet Y, Minatof S (1992). The study of thoron and radon concentrations in dwellings in progeny Japan Radiat. Prot. Dosim. 45:357-359.

Harley NH, Chittaporn P, Medora R, Merrill R, Wanitsooksumbut W (2005). Thoron versus radon: measurement and dosimetry. Int. Cong. Series 1276:72-75.

International Commission on Radiological Protection (ICRP) (1987). Lung cancer risk from indoor exposures to Radon daughters. ICRP Publication 50. Annals of the ICRP 17(1) Pergamon Press, Oxford.

Matiullah, Ahad A, Rehman S, Mirza ML (2003). Indoor radon levels and lung cancer risk estimates in seven cities of the Bahawalpur division, Pakistan Radiat. Prot. Dosim. 107(4):269-276.

McLaughlin J (2010). An overview of thoron and its progeny in the indoor environment. Radiat. Prot. Dosim. 141(4):316-321.

Nuccetelli C, Bochicchio F (1998). The Thoron Issue: Monitoring Activities, Measuring Techniques and Dose Conversion. Radiat. Prot. Dosim. 78:59-64.

Pressyanov DS (2012). Retrospective measurements of thoron and radon by CDs/DVDs: a model approach. Radiat. Protect. Dosim. 149(4):464-468.

Rafique M, Rahman SU, Rahman S, Matiullah, Shahzad MI, Ahmed N, Iqbal J, Ahmed B, Ahmed T, Akhtar N (2010). Assessment of indoor radon doses received by the students in the Azad Kashmir schools, Pakistan. Radiat. Prot. Dosim. 142(2-4):339-346.

Rafique M, Rahman SU, Rahman S, Nasir T, Matiullah (2011). Radiation doses due to indoor radon exposure, before and after the 2005 earthquake, in the dwellings of Muzaffarabad and the Jhelum Valley, Azad Kashmir, Pakistan, Indoor Built Environ. 20(2):259-264.

Rafique M, Matiullah, Masood M, Muzahir H (2012). Estimation of the indoor radon concentration in dwellings of the District Kotli, Azad Kashmir-Pakistan. Carpathian J. Earth Environ. Sci. 7(2):49-56.

Rahman SU, Rafique M, Matiullah, Anwar J (2010a). Radon measurement studies in workplace buildings of the Rawalpindi region and Islamabad Capital area, Pakistan, Building Environ. 45:421-426

Rahman SU, Matiullah, Anwar J, Jabbar A and Rafique M (2010b). Indoor Radon Survey in 120 Schools Situated in Four Districts of the Punjab Province - Pakistan Indoor and Built Environment. 19(2): 214-220.

Ramachandran TV, Sathish LA (2011). Nationwide indoor ^{222}Rn and ^{220}Rn map for India: A review. J. Environ. Radioact. 102(11):975-986.

Ramola RC, Negi MS, Choubey VM (2005). ^{222}Rn and ^{220}Rn monitoring in the environment of Kumaun Himalayas: survey and outcomes. J. Environ. Radioact. 79(1):85-92.

Ramola RC, Ramachandran TV (2000). Variation of Radon and Thoron Levels in Garhwal Homes. http://www.irpa.net/ IRPA 10-HIROSHIMA - May 2000.

Steck DJ (2006). A Preliminary Thoron Survey in the upper Mid West. Proceeding of the 2006 International Radon Symposium.

Steck DJ, Field RW, Lynch FF (1999). Exposure to Atmospheric radon. Env. Health Perspect. 107:123-127.

Tokonami S, Sun Q, Yonehara H and Yamada Y (2002). A simple measurement technique of the equilibrium equivalent thoron

concentration with a CR-39 detector. Japan Health Physics Society pp. 59-63.
Tokonami S (2005). Summary of dosimetry (Radon and Thoron) studies. Int. Congress Series 1276:151-154.
Tokonami S, Zhuo W, Ryuo H, Yonehara H, Yamada Y and Shimo M (2003). Instrument performance of a radon measuring system with the alpha-track detection technique Radiat. Prot. Dosim. 103:69-72.
Tufail M, Khan MA, Ahmad N, Khan HA, Zafar MS (1992). Measurement of Radon Concentration in some cities of Pakistan. Radiat. Prot. Dosim. 40(1):39-44.
Tufail M, Matiullah, Aziz S, Ansari F, Qureshi AA, Khan HA (1988). Preliminary Radon Concentration Survey in some Houses of Islamabad Nucl. Tracks Radiat. Measur. 15:659-662.
United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (2000). Report to the general assembly. Annex B: exposures from natural radiation sources. (NY: UNSCEAR), ISBN-10:9211422388.
United Nations. Sources and Effects of Ionizing Radiation (1993). United Nations Scientific Committee on the Effects of Atomic Radiation, 1993 Report to the General Assembly, with scientific annexes. United Nations sales publication E.94.IX.2. United Nations, New York.
UNSCEAR 1988 Report, Sources, effects and risks of ionizing radiation United Nations Scientific Committee on the Effects of Atomic Radiation 1988 Report to the General Assembly.
Yamasaki T, Guo Q, Iida T (1995). Distributions of thoron progeny concentrations in dwellings Radiat. Prot. Dosim. 59:135-140.
Yamada Y, Sun Q, Tokonami S, Akiba S, Zhuo W, Hou C, Zhang S, Ishikawa T, Furukawa M, Fukutsu F, Yonehara H (2006). Radon-thoron discriminative measurements in Gansu Province, China, and their implication for dose estimates. J. Toxicol. Environ. Health Part A: 69(7-8):723-734.