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Distribution pattern of indoor thoron concentrations in a dwelling

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ABSTRACT

A test room of volume 31m^3 was selected and walls are classified as W, N, S, E, C and F for west, north, south, east, ceiling and flooring respectively. Nine dosimeters consisted of LR 115 type II plastic track detectors were installed at a constant distance from the west (74cm), east (533cm), ceiling (105cm) and floorings (191cm) with all the four windows and one door closed for 90 days to observe the explicit variations of ^{220}Rn and their progeny levels with respect to the distance from the north to south wall, south to north wall, ceiling to floorings and flooring to ceiling of the room. This process is repeated for one year to see the seasonal variations also. After the exposure period of 90 days the films were removed and chemically etched in 2.5N Na OH solution at 60 ºC for one hour and counted for alpha track densities using spark counter. A specific trend of indoor ^{220}Rn concentrations for bare, filter and membrane films were observed. It is viewed that as the dosimeter is moved away from the north to south wall or south to north wall the concentrations were found to decrease exponentially and becomes minimum at the central dosimeter, which gives the structure of parabola. Higher concentrations were observed at the ceiling and flooring of the room and it reduces as the detector is moved away from them. ^{220}Rn progeny concentrations did not show any typical variations with the distance from the wall. The ^{220}Rn concentration in the studied area is found to vary from 1.37 to 69.44 Bq m^{-3} where as their progeny concentrations ranges between 0.012 to 12.93 mWL respectively. The arithmetic mean concentration of ^{220}Rn and their progeny with standard error are 23.57 ± 0.67 and 0.43 ± 0.07 respectively. About 85 % of the dwellings have shown the concentrations below 30 Bq m^{-3} and 15 % of the dwellings show the concentrations above 50 Bq m^{-3}. The geometrical mean concentration of ^{220}Rn and their progeny of all the seasons in all the locations are 14.02 Bq m^{-3} and 0.12 mWL respectively.

KEYWORDS

Thoron;
Thoron progeny;
Wall;
Distance.

INTRODUCTION

Thoron has a short half-life, 55.6 seconds, compared to radon with a half-life of 3.8 days. This means that the distance that the thoron gas atoms can migrate in the ground and inside building materials and buildings before it decays is much shorter than for radon gas and also that it is comparatively easily stopped by wall paper and other surface sealants. Therefore the risk for high thoron levels indoors can be expected to be low, at least much lower than the risk for high levels of radon. However, in buildings with an ineffective barrier between soil and indoor air the entry of thoron could be significant, especially if the gravel or sand filler or the soil itself immediately under the building has a high concentration of ^{232}Th. Soil as a significant source of indoor thoron has been demonstrated by Li and coworkers[1]. The release of thoron from building materials has also to be considered, especially where unsealed surfaces are present, such as bare walls, floors or ceilings. Under certain circumstances outdoor air can probably also be a source of high thoron levels indoors. The concentration of thoron outdoors has been measured as high as 200 Bq.m^{-3} at 1 m above ground[2] and is strongly dependent on height. A few cm above ground the thoron concentration can be an order of magnitude higher. In Sweden, the thoron gas concentration outdoors at a site near one of the office buildings of the institute was measured for about two months beginning September 1991 and the thoron concentration was measured at 10 cm above ground and was found to vary between 20 Bq.m^{-3} and 330 Bq.m^{-3} with an approximate mean of 90 Bq.m^{-3}. Increased concentrations of ^{220}Rn were recently measured in residential traditional dwellings in China[3,4] and India[5]. Because of the short half-life (56 s) of the radioactive rare gas, the main source of the indoor concentration is the surrounding building material. In the traditional dwellings, this is the bare soil floor, either soil in cave dwellings or unburned adobe bricks and un plastered stone, wall in above ground dwellings. The measurements were performed in order to form a basis for assessing the risk for high thoron levels indoors in Bangalore city. The thoron concentration in the controlled room of volume 31m^3 is studied in dependence of the parameters soil thorium content and humidity. The resulting thoron indoor concentration is not only determined by the exhalation but also by the detector distance from the wall of the room. Because of the short half life of thoron, the indoor concentration is not homogeneous but increases towards the walls[3]. In the report of UNSCEAR[6], the annual effective dose from thoron and its progeny was evaluated to be 75 μSv, only about 6% of that of radon and its progeny.

STUDY AREA

Bangalore is one of the 30 most populous cities in the world, the district extends between 12°15′ and 13°13′ N latitude and 77°3′ and 77°56′ E longitude with an average elevation of 900 m from the sea level. The study area has population density of 322.86 person's km^{-2} and 2978.59 person's km^{-2} respectively[7]. Geologically, the area belongs to peninsular gneisses, younger and older granites, dolerite and amphibolites dykes, laterite, charnockite, and amphibolites and pelitic schist. The soils of the study area are highly porous and sandy in nature. Red loams, red gravelly loams, and red sandy loams are the predominant types of soils. The rocks around the study area are called Closepet granites. These rocks are younger than the peninsular gneiss. The rocks are made up of several types of potassium granites with variable colour, texture and multiple intrusion relationships. The common rocks are pink, grey and porphyrite gneisses with large feldspars, dolerite (black). These rocks form an N–S band with a width of about 15–25 km[8,9]. The correlation between pegmatite and Closepet granite is ambiguous. The age of Closepet granite is 2380 million years. Uranium is concentrated in certain silicon and silica–alkaline igneous rocks. The climate is very agreeable and free from temperature extremes. It is classified as the seasonally dry savannah climate. City has are two rainy seasons; one the southwest monsoon (June–September) and the other northwest monsoon (October–November). The average rainfall is 793.6 mm per year. The season from December to February is the winter season of fine cool weather with little or no rainfall and from March to May is the summer season with low humidity.

THORIUM CONTENT IN BANGALORE/INDIA REGION

Thoron a decay product of thorium series, exist in soil and rocks. Differing from radon source in dwellings, soil itself is not the main source of thoron in indoor, because of the migrating range of thoron is very limited due to its short half life. On the other hand the studies of the concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the soils of Bangalore region, INDIA[10] reveals that the concentration of ^{226}Ra varied in the range of 7.7 –

111.6 Bq kg^{-1} with a mean value of 26.2 Bq kg^{-1}. The ^{232}Th concentration varied in the range 16.7–98.7 Bq kg^{-1} with a mean value of 53.1 Bq kg^{-1} and that of ^{40}K in the range 151.8 –1,424.2 Bq kg^{-1} with a mean value of 635.1 Bq kg^{-1}. It is also reported that about 67% of the samples of the region the ^{232}Th concentrations were more than the world average of 40 Bq kg^{-1}. In five samples the concentrations were more than two-fold of that of the world average and the concentration was around 90 Bq kg^{-1}. However, the mean concentration of ^{232}Th (53.1 Bq kg^{-1}) was comparable to that of the All India and the world average values. TABLE 1 give the estimated natural radioactivity content in the building materials used for construction in India. In the studies[11] it is reported that The thoron concentration in granite quarries varies from 30 to 160 Bq.m^{-3}with a median of 84.5 Bq.m^{-3} and its progenies varies from 0.1 to 4.0mWLwith a median of 1.2mWLrespectively.

TABLE 1 : Natural radioactivity content in Indian building materials[12]

Building Material	^{40}K	^{226}Ra Bq kg^{-1}	^{232}Th	Radium equivalent
Cement	5-385	16-377	8-78	40-440
Brick	130-1390	21-48	26-126	88-311
Stone	48-1479	6-155	5-412	24-311
Sand	5-1074	1-5047	4-2971	22-7759
Granite	76-1380	4-98	103-240	25-525
Clay	6-477	7-1621	4-311	11-1865
Fly ash	6-522	7-670	30-159	56-773
Lime stone	6-518	1-26	1-33	5-148
Gypsum	70-807	7-807	1-152	59-881

ENVIRONMENTAL THORON LEVELS ACROSS THE GLOBE

Data on indoor thoron are limited. Surveys from different countries show mean thoron progeny values (Equilibrium Equivalent concentration of Thoron, EET) from 0.3 Bq.m^{-3} to 3.5 Bq.m^{-3} (23 nJ Bq.m^{-3} to 2 65 nJ Bq.m^{-3}), 1.1 mWL to 12.7 mWL, Potential Alpha Energy concentration, PAEC and Working Level for thoron progeny), with most means below 1.0 Bq.m^{-3} (76 nJ Bq.m^{-3}, 3.6mWL)[13,14]. The most extensive surveys have been performed in the UK, Germany and France. In the UK, measurements have been made in 390 dwellings. The mean of these measurements was 0.6 Bq.m^{-3} (46 nJ Bq.m^{-3}, 2.2 mWL). According to the authors, results from measurements in 150 dwellings in the Pennines, with a mean of 0.3 Bq.m^{-3} (nJ Bq.m^{-3}, 1.1 mWL), are more likely to be typical of the concentrations in UK dwellings[15]. This has been confirmed by measurements in 50 dwellings in five major cities in the UK[16]. In Germany Keller and coworkers[17] have published results from measurements in 148 homes with a median of 0.3 Bq.m^{-3} (23 nJ Bq.m^{-3}, 1.1 mWL). From two departments in a granitic area in Brittany in western France medians of 0.7 and 0.8 Bq.m^{-3} (53 and 61 nJ.m^{-3}, 2.5 and 2.9 mWL) have been reported[18]. Schery[19] has measured ^{212}Pb at 68 indoor locations in 18 states in the United States and found a mean of 0.28 Bq.m^{-3} (21 nJ Bq.m^{-3}, 1.0 mWL). In Elliot Lake in Canada 95 dwellings have been investigated with a mean of 1.5 Bq.m^{-3} (1 14 nJ Bq.m^{-3}, 5.5 mWL)[20]. Thoron progeny investigations have also been reported from, for example, Norway and Hong Kong[21,22].

In recent years several investigations concerning thoron have been performed by Japanese research groups. They have found relatively high levels of thoron progeny and thoron gas in traditional Japanese buildings with one or more walls covered with a widely used soil-based plaster. Guo and coworkers[23] have found a mean thoron progeny concentration of 3.5 Bq.m^{-3} (265 nJ Bq.m^{-3}, 12.7 mWL) in 4 houses with plaster walls in the Nagoya area. A mean thoron gas concentration of 394 Bq.m^{-3} was found from measurements in 9 such houses[24].

Doi and coworkers have measured activity concentrations of thoron gas in 21 houses in the Hiroshima prefecture with a mean of 85 Bq.m^{-3} and a maximum of 550 Bq.m^{-3}. The measurements were made 20 cm from a wall[25]. Several investigations show that the thoron concentration decreases exponentially with the distance from a soil-plastered wall[26,24]. Measurements of the concentration of ^{232}Th in the soil have shown values of about 90 Bq.kg^{-1} in the Hiroshima area[25] and about 35 Bq.kg^{-1} in the Nagoya area[23].

The Swedish preliminary study included thoron progeny measurements in nine dwellings, eight basements and four workplaces in 12 different buildings. In this study the mean thoron progeny concentration in the measured dwellings was 0.3 Bq.m^{-3} (EET) (23 nJ Bq.m^{-3}, 1.1 mWL) and in the basements 1.5 Bq.m^{-3} (114 nJ Bq.m^{-3}, 5.5 mWL) measured with a gamma meter and a portable gamma spectrometer.

TABLE 2 : Ratio of exposure from thoron and its progeny to that from radon, thoron and their progeny

Area	Ratio (%)
Norway[28]	12
Czechoslovakia[29]	16
USA[30]	17
Hong Kong, China[31]	18
Fujian, China[32]	20.3
Guangdong, China[33]	30.5
Italy[34]	32
Japan[35]	36

Ningappa et al[27] have shown that the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in rocks of granitic regions of Bangalore are found to be vary from 32.2 to 163.6, 128.3 to 548.6 and 757.4 to 1418.4 Bq kg^{-1}, respectively, with corresponding arithmetic mean values of 93.2, 306.2 and 1074.4 Bq kg^{-1}. Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil samples were found to vary from 32.4 to 55.2, 39.9 to 214.3 and 485.4 to 1150.2 Bq kg^{-1}, respectively, with corresponding arithmetic mean values of 40.7, 93.1 and 750.4 Bq kg^{-1}. The average activity levels of all these radionuclides in Bangalore regions are above the global average. High contributions of thoron and its progeny to the total exposure of radon, thoron and their progeny have been reported in some areas in the world are shown in TABLE 2.

In view of these it was felt that it is important to evaluate the annual effective dose equivalent dose due to ^{220}Rn and its progeny. The present paper describes the dependence of the indoor thoron concentration with distance of wall, ceiling and floorings in a controlled room.

METHODS AND MEASUREMENTS

The concentrations of thoron and its progeny are measured in the controlled room of the Bangalore city using Solid State Nuclear Track Detectors (SSNTD), which are thin sheets of dielectric materials such as cellulose nitrate (CN) and polycarbonates. They are sensitive to alpha but not to beta and gamma radiations. They are unaffected by moderate humidity, heat and light. For indoor measurements normally LR-115 type II plastic track detector is preferred. For the detailed description of the methodology and the calibration experiments has been given by Sathish et al[36].

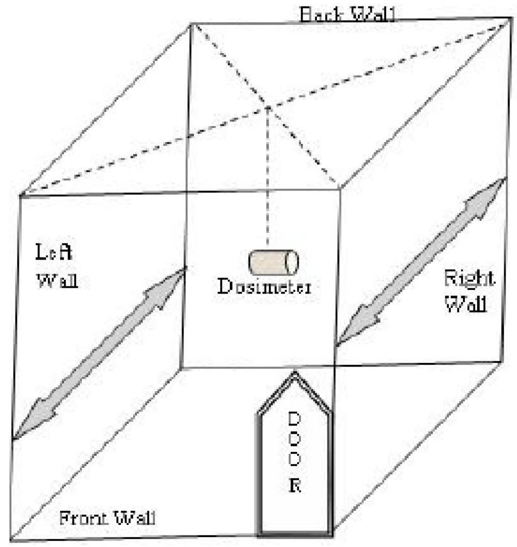

Figure 1 : Outline of the controlled room

RESULTS AND DISCUSSION

The aim of the studies has been to find an approximate mean and range of thoron and its progeny in buildings in order to assess the possible health hazards from thoron in indoors in Bangalore city. Buildings were chosen regardless the natural ^{232}Th concentrations. All the measurements were made on the ground floor. Nine dosimeters were suspended at equidistant from the flooring and ceiling of the room and at a distance of 25, 50, 75, 100,125,150, 175,200 and 225cm from north to south as well as south to north wall of test room of volume 31m^3 and in a lower and upper parabolic fashion shown in Figure 1. Due to the short half-life of ^{220}Rn, it is assumed that the distribution of ^{220}Rn may be quite different to that of ^{222}Rn[37]. We have investigated the dependence of ^{220}Rn concentration on the distance from the wall and on the flooring in a controlled room with brick wall coated with cement plaster and mud flooring. Keeping the dosemeters for 90 days and the procedure is continued for one year to see the seasonal variation. The result of the measurements of variations of ^{220}Rn concentrations with wall distance for the period of April 2008 to March 2009 are shown in Figure 2a and 2b. These figure illustrates that the ^{220}Rn concentration decrease exponentially with as a function of the distance from the wall and it may be due to its short half life[37,38]. This suggests that it is necessary to keep the distance from the wall when we measure indoor ^{220}Rn concentration. During the measurement period with twin cup dosimeters, the distribution of ^{220}Rn progeny and ^{222}Rn concentration were also measured at the different distance from wall and floorings.

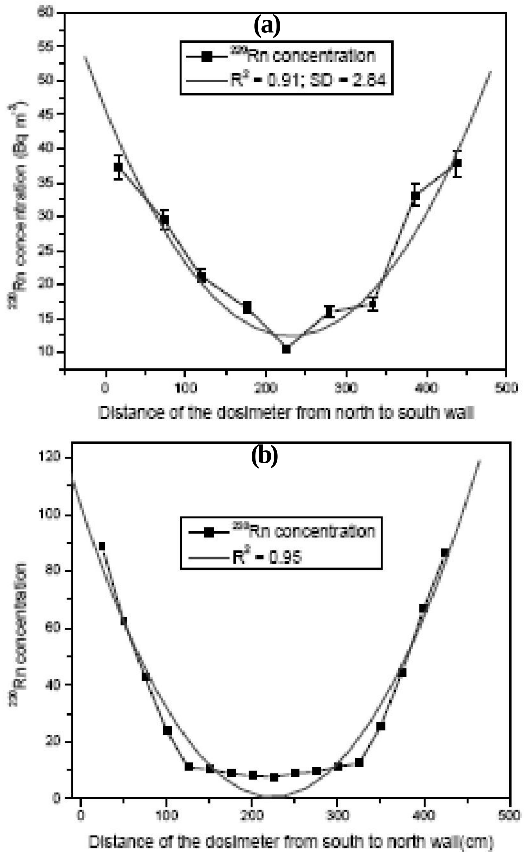

Figure 2 : (a) & (b) Distribution of ^{220}Rn concentration with distance of wall

Figure 3 and 4 of winter season represent the horizontal and vertical distributions of ^{220}Rn concentrations, as the distance increases both from the wall and the floorings the ^{220}Rn concentration decrease exponentially. Variations of ^{220}Rn progeny with the distance from the wall are shown in Figure 5. ^{220}Rn progeny concentration was nearly independent of the distance from soil wall. The uniformity of ^{220}Rn progeny concentrations in a dwelling is may be because of their long half life (10.64 h)[23] and this was also confirmed by a model calculation by elsewhere[38]. Thoron exhalation from the building material provokes a certain indoor thoron activity concentration. Due to the short half-life, the concentration is not homogeneous in the room but higher towards the walls, floor and ceiling of the room built from the exhaling material. The steep increase close to the wall is shown in Figure 1. The turbulent transport from the wall into the room center decreases the relative contribution of the thoron close the wall. However, the portion in the room center increases. This is important for dose assessment of the dwellers. Only at ventilation rates above the exhalation saturation the total activity declines[39].

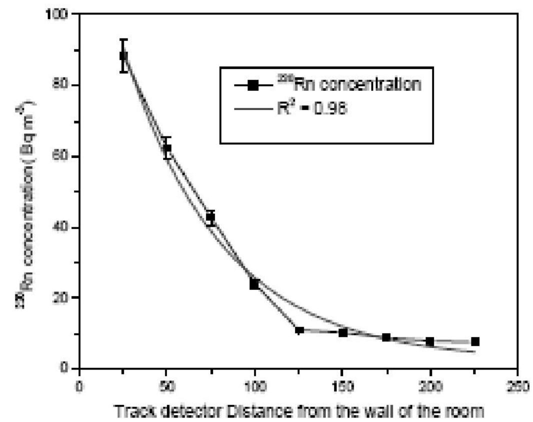

Figure 3 : Horizontal distribution of ^{220}Rn with distances from the wall

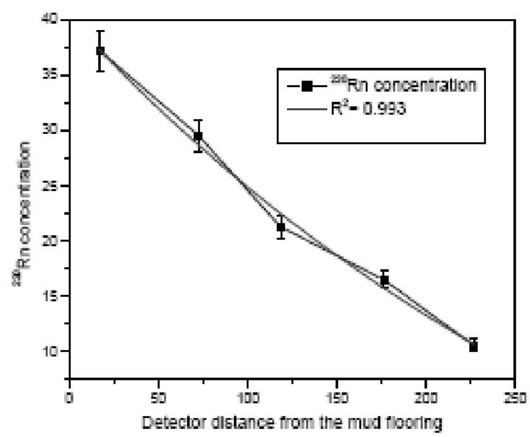

Figure 4 : Vertical distribution of ^{220}Rn with distance from the mud flooring

Figure 6 shows the frequency distribution of indoor ^{220}Rn concentration in dwellings of Bangalore city during 2007-2009. About 85 % of the dwellings have shown the concentrations below 30 Bq m^{-3} and 15 % of the dwellings showed the concentrations above 50 Bq m^{-3}. The ^{220}Rn concentrations during winter season is 1.74 ± 0.16 times that of summer season, where as its progeny during winter is 2.70 ± 0.70 times that of summer season and not much variations are observed between rain and autumn seasons. The winter to summer ratio of ^{220}Rn and its progeny of the studied locations vary between 1.11 – 2.45 Bq m^{-3} and 1.18 0 6.64 mWL respectively.

A survey carried out by Wu et al[31] in Guangdong province gives one of the limited data of thoron and its progeny in China. The concentrations of thoron and its progeny were measured by grab sampling both indoors and outdoors, the reported average concentrations of thoron were 48.1 ± 20.0 Bq m^{-3} and 22.1 ± 10.7 Bq m^{-3} for indoor and outdoor environment respectively. The average equilibrium-equivalent concentrations of thoron were 1.13 ± 0.80 Bq m^{-3} and 0.50 ± 0.29 Bq m^{-3} for indoor and outdoor environment respectively.

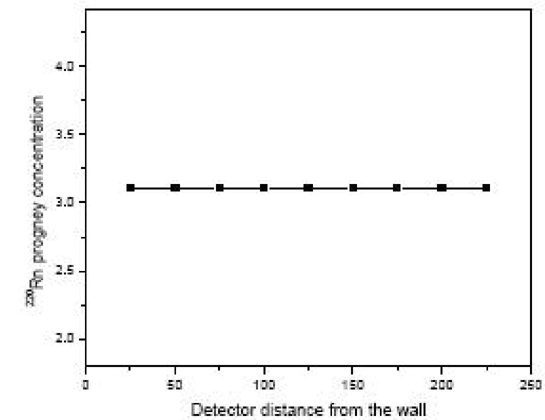

Figure 5 : Distribution of ^{220}Rn progeny with distance from the wall

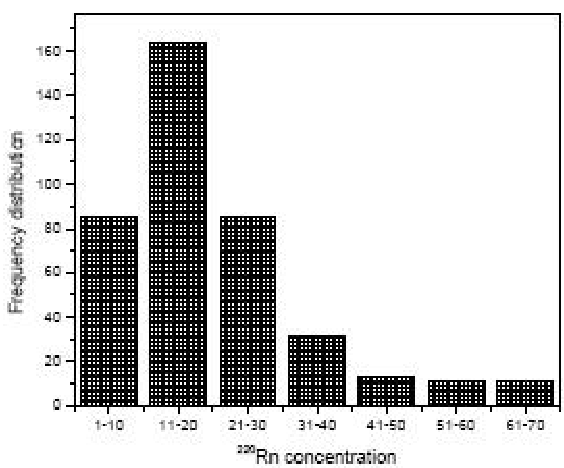

Figure 6 : Frequency distribution of ^{220}Rn concentrations

For different building materials of the walls, the house with soil/mud walls had the highest thoron concentration; the reported average value of this kind of house was 104.0 Bq m^{-3}. The ratio between the exposure from thoron and its progeny and that from radon and thoron as well as their progeny was reported to be 30.5 % in Guangdong province. Martinez et al[40] have done the variation in indoor thoron levels in Mexico City dwellings and showed the general log–normal distribution of integrated indoor thoron concentration with annual arithmetic and geometric means of 82 and 55 Bq m^{-3}, respectively, with ranges from 8 to 234 Bq m^{-3} higher than world average of 3 Bq m^{-3}. The seasonal variation shows the minimum mean values in the summer season that were 35% lower than in autumn.

The range of ^{220}Rn and its progeny in different locations of Bangalore city are shown in the TABLE 3. ^{220}Rn concentrations in the study area vary between 1.37 – 72.92 Bq m^{-3} where as its progeny ranged from 0.012 – 4.83 mWL respectively. The arithmetic mean concentrations of ^{220}Rn and its progeny are 20.53 ± 0.67 Bq m^{-3} and 0.432 ± 0.07. Higher ^{220}Rn concentrations are observed in Sheshadripuram, lower in Srirampura area, where as the higher progeny are observed in Malleshwaram, lower in Banashankari area.

TABLE 3 : Range of ^{220}Rn and its progeny levels in different locations of Bangalore city

Area	RANGE		AM ±SE of ^{220}Rn (Bq m^{-3})
	^{220}Rn Conc. (Bq m^{-3})	^{220}Rn progeny (mWL)	
Rajajinagar	5.56 – 35.42	0.018 – 0.502	16.14 ±1.44
Srinivasanagar	13.74 – 56.94	0.041 – 0.711	29.29 ± 4.32
Sheshadripuram	2.78 – 75.92	0.015 – 0.869	19.88 ± 2.08
Srirampuram	6.18 – 30.91	0.018 – 1.860	18.85 ± 1.66
Padhmanabhanagar	3.47 – 70.14	0.018 – 3.480	25.95 ± 2.04
Jayanagar	4.86 – 63.19	0.013 – 1.761	19.70 ± 1.27
Banashankari	1.37 – 66.67	0.012 – 1.293	21.40 ± 2.20
Malleshwaram	2.08 – 47.92	0.016 – 4.831	17.88 ± 1.57
Vijayanagar	6.79 – 37.50	0.024 – 0.938	8.34 ± 1.27
Gandhinagara	10.99 – 72.92	0.030 – 1.025	38.26 ± 5.40

CONCLUSION

Twin cup passive detectors were used for measuring the ^{220}Rn concentrations. The concentrations were high near the wall and flooring of the room and the concentration decreases exponentially with the distance from wall, ceiling and flooring of the room. Indoor ^{220}Rn progeny concentrations are uniform with the distance from the wall. Detailed studies such as the diffusion of thoron from each wall of the building materials used and influence factors of thoron progeny levels in dwellings are necessary to assess the dose due to thoron and its progeny. Further work and more detailed studies on the evaluation of the public exposure from natural radiation, especially the exposure from thoron and its progeny should be planned and performed in the country.

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