DISTRIBUTION OF ^{220}RN AND ITS PROGENY IN A DWELLING OF BANGALORE, INDIA

L.A. Sathish[1], Samvit G. Menon[1], K. Nagaraja[2] and T.V. Ramachandran[3]

[1]Post Graduate Department of Physics, Government Science College, Banglaore-560 001, India
lasgayit@yahoo.com (Sathish L. A.)
[2]Department of Physics, Bangalore University, Bangalore–560 056, India
[3]Ex-Environmental Assessment Division, Bhabha Atomic Research Center, Mumbai–450 085, India

Abstract

The effective dose due to the inhalation of indoor radon (^{222}Rn) and its progeny account, on average, for about one-half of all natural sources of radiation. However, recently the indoor surveys in Asia revealed that the dose contribution from ^{220}Rn and its progeny can be equal to or even exceed that of ^{222}Rn and its progeny. In view of this, an attempt has been made to observe the distribution of ^{220}Rn levels for Bangalore, India. Dosimeters were installed at a constant distance from the wall, ceiling and flooring of the room. All the windows and doors were closed for 90 days to study the variations with respect to the distance. Dosimeters were also deployed in upper and lower parabolic fashion. Higher concentrations were observed at the wall, ceiling and flooring of the room lowering as the detector is moved away from them. Results are discussed in detail.

Key words

^{220}Rn, ^{220}Rn progeny, wall, ceiling, flooring and distance

Introduction

^{220}Rn (thoron) has a short half-life, 55.6 s, as compared to ^{222}Rn with a half-life of 3.82 days. This means that the distance ^{220}Rn gas atoms can migrate in ground, inside building materials, buildings etc. before they decay is much shorter than that traveled by ^{222}Rn gas. Thoron can be easily stopped by wall paper and other surface sealants. Therefore, the risk for high ^{220}Rn levels in the indoor environment can be expected to be low, at least much lower than the risk for high levels of ^{222}Rn. However, in buildings with an ineffective barrier between soil and indoor air the entry of ^{220}Rn could be significant. This is prominent if the gravel or sand filler or the soil itself immediately under the building has ^{232}Th. Li (Li et al., 1992) has demonstrated that the soil is a significant source of indoor ^{220}Rn.

The release of ^{220}Rn from building materials is also to be considered, especially for unsealed surfaces such as bare walls, floorings and ceilings. Under certain circumstances, outdoor air probably is the source of high indoor ^{220}Rn levels. Increased concentrations of ^{220}Rn were also measured in traditional residential dwellings in China (Tschiersch and Müsch, 2005; Shang et al., 2005) and India (Sreenath Reddy et al., 2004). Because of the short half-life of thoron gas, the main source of indoor concentration is the surrounding building materials. In traditional dwellings, this is the bare soil flooring, either soil in cave dwellings or unburned adobe bricks and uncovered stone and walls in above ground dwellings. Measurements were performed in order to form a basis for assessing the risk for high indoor ^{220}Rn levels in Bangalore city, India. The ^{220}Rn concentration in a controlled room of volume 30 m^3 is studied. The resulting indoor ^{220}Rn concentration is not only determined by the exhalation but also by the detector distance from the wall, ceiling and the flooring of the room. Because of its short half life, the indoor concentration is not homogeneous but decreases from the walls UNSCEAR (1993). It is reported that the annual effective dose from ^{220}Rn and its progeny is 75 µSv, and is only about 6% of that of ^{222}Rn and its progeny (UNSCEAR, 1993; 2000).

Literature Review on ^{232}Th content and ^{220}Rn levels

^{220}Rn, a decay product of ^{232}Th, series exist in soil and rocks. Differing from ^{222}Rn sources in dwellings, soil itself is not the main criterion as a source of ^{220}Rn in indoors, because the migration range of ^{220}Rn is very limited due to its short half life. The estimated concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the soils of Bangalore region vary in a wide range (Shiva Prasad et al., 2008). The ^{226}Ra is in the range of 7.7 –111.6 $Bqkg^{-1}$ with a mean value of 26.2 $Bqkg^{-1}$, the ^{232}Th has 16.7–98.7 $Bqkg^{-1}$ with a mean value of 53.1 $Bqkg^{-1}$ and ^{40}K varies between 151.8 to 1424.2 $Bqkg^{-1}$ with a mean of 635.1 $Bqkg^{-1}$. It is also reported that in about 67% of the samples in the region, the ^{232}Th concentrations were more than the world average of 40 $Bqkg^{-1}$. In our studied samples the concentrations were more than two-fold of that of the world average and the concentration was around 90 $Bqkg^{-1}$. However, the mean concentration of ^{232}Th was (53.1 $Bqkg^{-1}$) comparable to that of India and world average values (Shiva Prasad et al 2008). In other studies (Ningappa et al., 2008a) it is reported that the ^{220}Rn concentration in granite quarries varies from 30 to 160 Bqm^{-3} with a median of 84.5 Bqm^{-3} and its progenies range from 0.1 to 4.0 mWL with a median value of 1.2 mWL respectively.

Data available in the literature on indoor ^{220}Rn are limited. Surveys from different countries have shown that the ^{220}Rn and its progeny value varies from 0.3 to 3.5 Bqm^{-3} and 1.1 to 12.7 mWL respectively, with a mean below 1.0 Bqm^{-3} (Mjones, 1986; Steinhäusler et al., 1994). In the UK, (Wrixon et al., 1988) measurements have been made in 390 dwellings and the mean was 0.6 Bqm^{-3}. It is also reported that the results from measurements in 150 dwellings in the Pennines, with a mean of 0.3 Bqm^{-3}, are more likely to be typical of the concentrations in dwellings. This has been confirmed by measurements in 50 dwellings in five major cities in the UK (Cliff et al., 1992). For Germany, Keller et al., (1982) have reported the results from measurements in 148 homes with a median of 0.3 Bqm^{-3}. From two departments in a granitic area in Brittany in western France medians of 0.7 and 0.8 Bqm^{-3} have been reported (Rannou et al., 1988). Schery (1985) has measured ^{212}Pb at 68 indoor locations in 18 states in US and found a mean of 0.28 Bqm^{-3}. In Elliot Lake, Canada about 95 dwellings have shown a mean concentration of ^{220}Rn as 1.5 Bqm^{-3} (Gunning and Scott, 1982).

In recent years, there are extensive studies on ^{220}Rn by Japanese research groups. They have found relatively high levels of ^{220}Rn and its progeny in traditional Japanese buildings with one or more walls covered with a widely used soil-based plaster. Guo et al., (1992) have found a mean ^{220}Rn concentration as 3.5 Bqm^{-3} in 4 houses with plaster walls in Nagoya area. A mean ^{220}Rn gas concentration of 394 Bqm^{-3} was found from measurements in 9 such houses (Guo et al., 1993). Doi and Kobayashi (1994b) have measured ^{220}Rn gas in 21 houses in the Hiroshima prefecture with a mean of 85 Bqm^{-3} and a maximum of 550 Bqm^{-3}. The measurements were made 20 cm from the wall. Several investigations have also reported that concentration decreases with the distance from a wall (Doi et al., 1994a).

Ningappa et al., (2008) have reported that the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in rocks of granitic regions of Bangalore area were found to vary from 32.2 to 163.6, 128.3 to 548.6 and 757.4 to 1418.4 Bqkg^{-1}, respectively, with corresponding arithmetic mean values of 93.2, 306.2 and 1074.4 Bqkg^{-1}. However, the activity concentrations in soil samples were found to vary from 32.4 to 55.2, 39.9 to 214.3 and 485.4 to 1150.2 Bqkg^{-1}, respectively, with corresponding arithmetic mean values of 40.7, 93.1 and 750.4 Bqkg^{-1}. The average activity levels of all these radio nuclides in Bangalore regions are above the global average.

Construction materials and the design of the house determine the total exposure. Wide variation in activity content of ^{232}Th in building material used for construction in India (Menon et al., 1987) is shown in Table 1.

Table 1: ^{232}Th levels in building materials used in India for construction (Menon et al., 1987)

Material	^{232}Th (Bqkg^{-1})
Cement	16 – 377
Brick	21 - 48
Stone	6 - 155
Sand	1 - 5074
Granite	4 - 98
Clay	7 - 1621
Fly ash	7 - 670
Lime stone	1 - 26
Gypsum	7 - 807

Methods and Measurements

Solid State Nuclear Track Detectors

The inhalation pathway is reported to be the major contributor to the radiation dose received by man from natural sources (UNSCEAR 2000). This pathway dose is mainly contributed to by radon and progeny nuclides. Measurements of radon in the indoor air thus becomes pertinent while assessing dose from the natural environment. Since radon gas concentrations in the environment vary diurnally and seasonally, it is essential that long-term integrated measurements are carried out for a meaningful estimate of the gas concentration. Solid State Nuclear Track Detector (SSNTD) based dosimeters are used for long term measurement of radon in atmosphere (Fleischer, 1988). In the present method, the mode of sampling is passive and time integrated for long duration sampling. Since they are less expensive compared to commercially available continuous monitoring equipments like Alpha Guard, Radon scout etc., SSNTD dosimeters can be used in large numbers covering more numbers of sampling locations for integrated long-term measurements (Ilic and Sutej, 1977). For this study the twin cup dosimeter developed in Bhabha Atomic Research Centre (BARC), Mumbai, India was used. A description of these dosimeters can be found elsewhere (Ramachandran and Sathish, 2011a).

The dosimeters were kept at a height of about 1.5 m from the ground, considered to be the least disturbing to the occupants, and the sensitive area of the bare card at least 10 cm away from any surface to avoid tracks due to attenuated alphas reaching from other surfaces. After the exposure of the dosimeters for 3 months, the SSNTD films were retrieved and etched in 10% NaOH solution at 60 ºC for 60 minutes with mild agitation throughout (Miles, 1997). The exposure period was continued for all the seasons of a calendar year. The tracks recorded on LR-115 films were counted using a spark counter. A methodology developed using track densities to obtain individual equilibrium factors for ^{222}Rn and ^{220}Rn by way of ventilation parameters (Mayya et al., 1998) is employed in this study:

$$C_R(Bqm^{-3}) = \frac{T_m}{d \times S_m} \qquad (1)$$

$$C_T(Bqm^{-3}) = \frac{T_f - d \times C_R \times S_{rf}}{d \times S_{tf}} \qquad (2)$$

where T_m is the track density of the film in membrane compartment (Trcm^{-2}), d is the period of exposure in days (d), S_m refers to the sensitivity factor of membrane compartment (Trcm^{-2})/(Bqdm^{-3}), T_f is the track density of the film in filter compartment (Trcm^{-2}), S_{rf} is the sensitivity of ^{222}Rn in filter compartment(Trcm^{-2})/(Bqdm^{-3}), and, C_R and C_T are the concentrations (Bqm^{-3}) of ^{222}Rn and ^{220}Rn, respectively.

$$R_n(mWL) = \frac{C_R \times F_R}{3.7} \qquad (3)$$

$$R_T(mWL) = \frac{C_T \times F_T}{0.275} \qquad (4)$$

where R_n and R_T refers to the progeny concentrations of ^{222}Rn and ^{220}Rn, respectively.

$$F_R = 0.104F_{RA} + 0.514F_{RB} + 0.37F_{RC} \qquad (5)$$

$$F_T = 0.91F_{TB} + 0.09F_{TC} \qquad (6)$$

where F_{RA}, F_{RB} and F_{RC} are the activity fractions with respect to parent gas. But F_R and F_T represents the equilibrium factors for ^{222}Rn and ^{220}Rn progeny corresponding to the extracted ventilation rate (Mayya et al., 1998). Equilibrium factor is determined using the working level concentrations, and the inhalation dose rates ($mSvy^{-1}$) are estimated by using UNSCEAR (2000):

$$D\left(mSv\,y^{-1}\right) = 0.8 \times 24 \times 365 \times \left[\left(0.17 + 9F_R\right)C_R + \left(0.11 + 40F_T\right)C_T\right] \times 10^{-6} \qquad (7)$$

The detailed description of calibration facility, standardization of dosimeter and dosimetric methodology are discussed elsewhere by Ramachandran and Sathish (2011b)

Results and discussion

The main aim of the study is to find an approximate mean concentration and the range of ^{220}Rn and its progeny in buildings in order to assess the possible health hazards from indoor ^{220}Rn levels in Bangalore Metropolitan, India. The measured values of ^{220}Rn in a test room for a period of three years are presented. All the measurements were made on the ground floor.

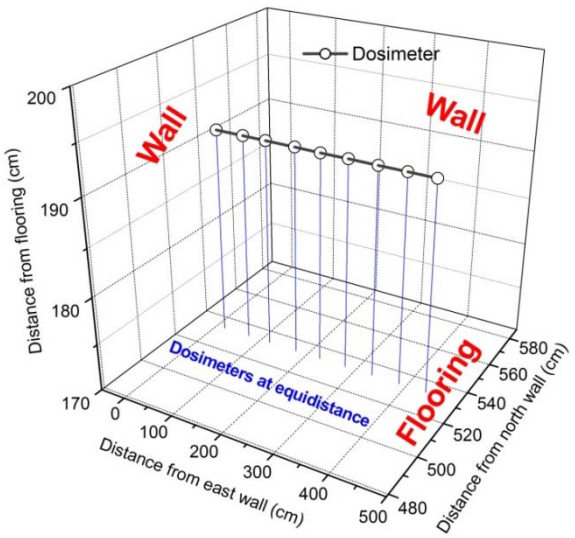


Fig.2: Deployment of dosimeter in equidistant fashion

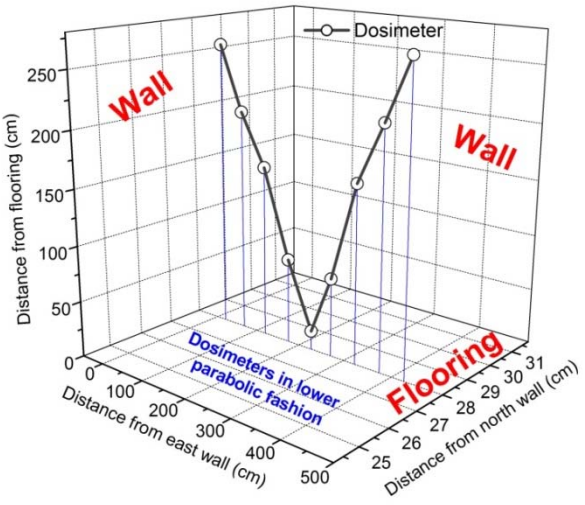


Fig.3: Deployment in lower parabolic fashion

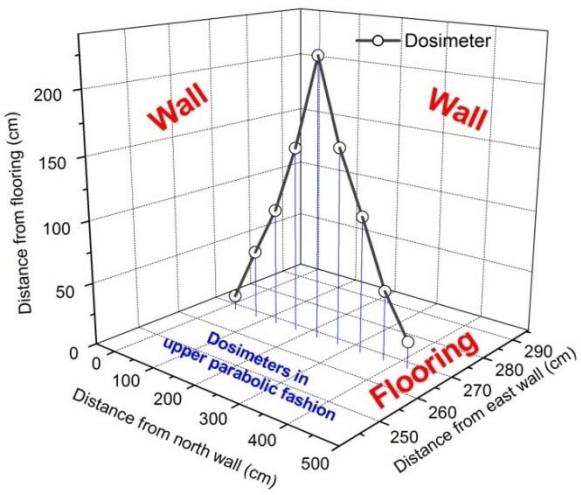
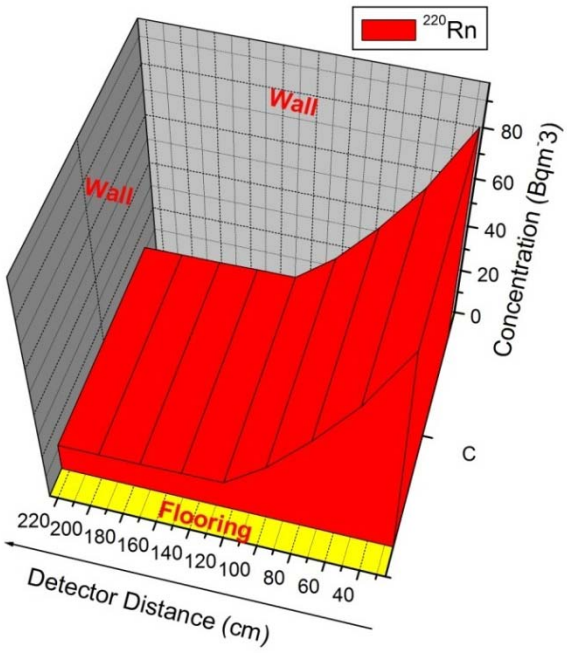


Fig.4: Deployment of dosimeter in upper parabolic fashion

Dosimeters were suspended equidistant from the floor and ceiling of the room and were at a distance of 50 cm each up to 400 cm from north to south wall as well as from south to north wall of the test room of volume 31m^3 and also in a lower and upper parabolic fashion shown in Figs. 2-4.

The results of the measurement of ^{220}Rn concentrations with wall distance placed in an equidistant manner are depicted in Fig.5. The figure illustrates that the concentration drops exponentially as a function of distance and it may be due to its short half life (Tso and Li, 1987; Yamasaki et al., 1995). This suggests that it is necessary to hold the distance from the wall constant while measuring indoor ^{220}Rn.



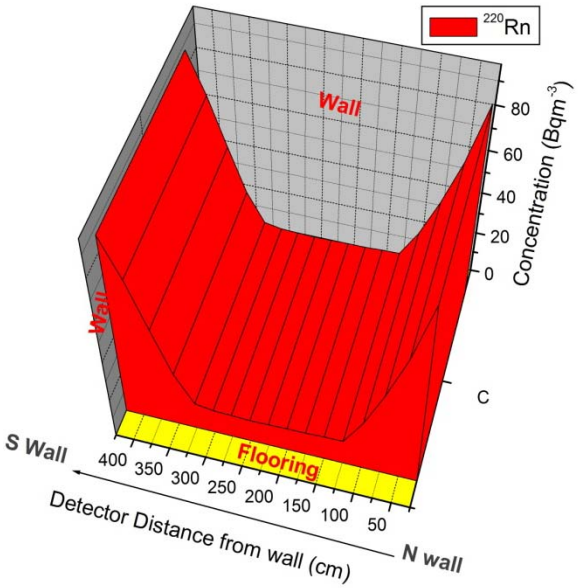


Fig.5: Horizontal distribution of ^{220}Rn in a dwelling Fig. 6: Distribution of ^{220}Rn concentration from the wall

But as the detector is moved from one wall (say, north wall) to the other wall, (say, south wall) the effect of distance on the concentrations are different as is shown in Fig.6. The measurements were also made by twin cup dosimeters to observe the distribution of ^{220}Rn and ^{222}Rn concentration simultaneously at different distance from walls, ceilings and floors.

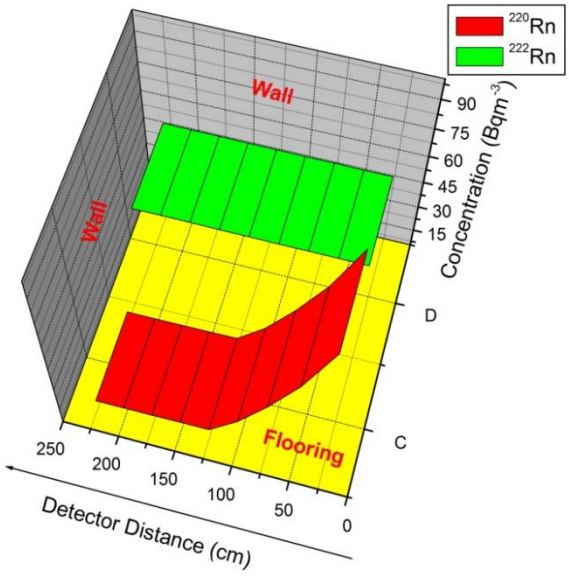


Fig. 7: Distribution of ^{220}Rn and ^{222}Rn concentrations

Figure 7 represents the distribution of ^{222}Rn and ^{220}Rn concentrations in a dwelling. It is believed that the walls were constructed using bricks which are of local origin and flooring was of local soil materials which are the source of ^{222}Rn and ^{220}Rn. Because of the short half-life of ^{220}Rn and the time necessary for its transport, the concentration decreases towards the room center as evident in Fig. 6, above. In contrast, the ^{222}Rn concentration is homogeneous within the dwelling due to its much longer half-life of 3.82 days. Close to the walls the ^{220}Rn concentration is significantly higher than ^{222}Rn concentration as shown in Fig. 7. At increasing wall distances, the concentration become more similar, and at wall distances larger than about 15 cm, the ^{220}Rn concentration may decrease below the ^{222}Rn concentration and remains steady and is plotted in Fig. 7. Similar type of observation was also made in several dwellings of Gansu area (Shang et al., 2005), so that it appears to represent a general feature of ^{222}Rn indoor concentration. The turbulent transport from the wall into the room center decreases the relative contribution of ^{220}Rn close to the wall. This is important for dose assessment of the dwellers only for ventilation rates above the exhalation saturation of the total activity (Tschiersch et al., 2007).

Fig. 8 represent the vertical distributions of ^{220}Rn and its progeny concentration. As distance increases from the floor, the ^{220}Rn concentration drops exponentially, whereas the progeny concentration was nearly independent of the distance from wall. The uniformity of ^{220}Rn progeny concentrations in a dwelling may be due to their long half life (10.64 h) and this was confirmed through model calculations (Tso and Li., 1987).

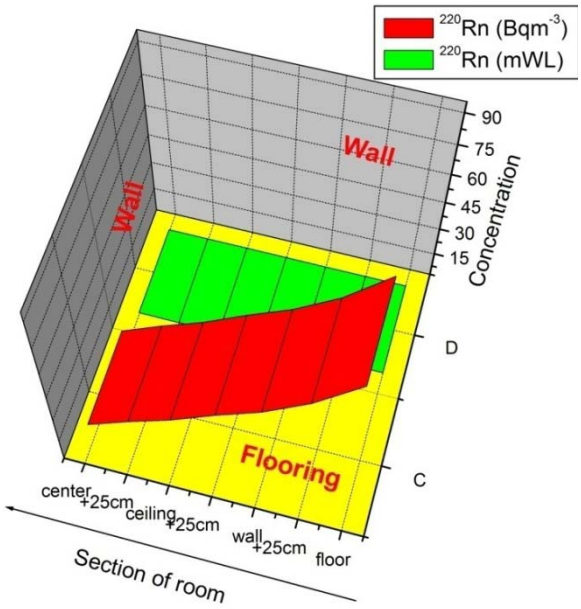


Fig. 8: Vertical distributions of ^{220}Rn and its progeny concentration

The measurements were also made by deploying the dosimeters in upper and lower parabolic fashions and the variations are shown in Figs 9 and 10.

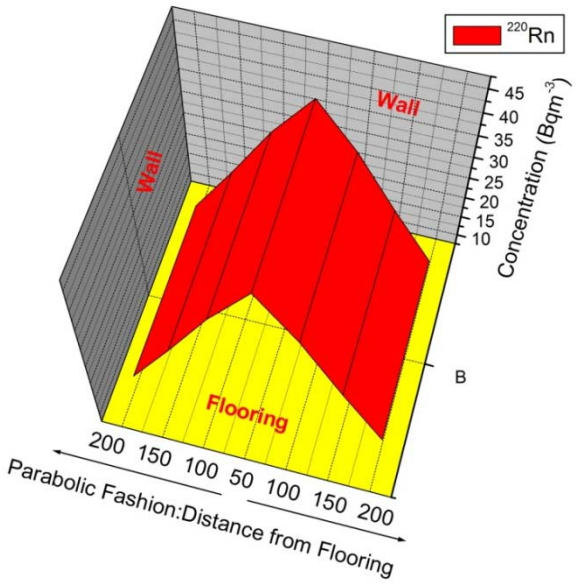


Fig. 9: ^{220}Rn level when the dosimeters placed in lower parabolic fashion: Distance from flooring

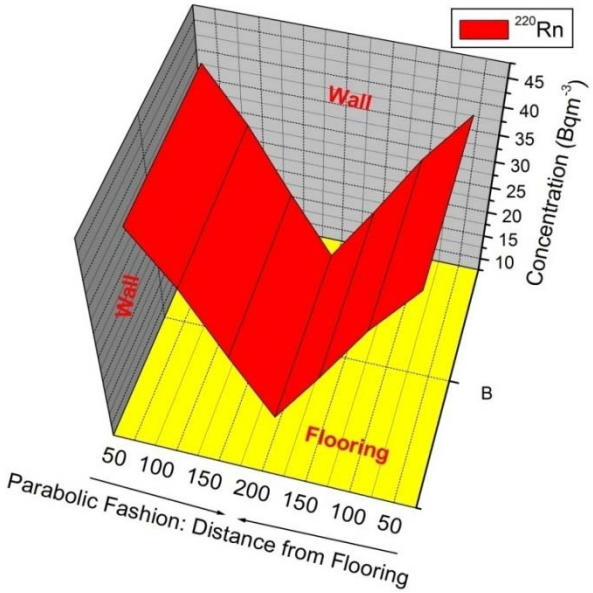


Fig. 10: ^{220}Rn level when the dosimeters placed in upper parabolic fashion: Distance from flooring

It is very interesting to see the reverse order of concentrations with respect to the position of the dosimeters and it may due to the short half of ^{220}Rn, as the detector is moved away from the flooring of the room the concentration drops and yielded the overturn in concentrations.

Conclusions

Twin cup passive detectors were used for measuring the ^{220}Rn and its progeny concentrations in a controlled room of Bangalore Metropolitan, India. The concentrations were high near the wall, ceiling and flooring of the room and drops 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. Continuous and long-term studies such as diffusion of ^{220}Rn from each wall of the building materials used and factors that influences the ^{220}Rn progeny levels in dwellings are necessary to assess the dose due to ^{220}Rn and its progeny. More detailed studies on the evaluation of public exposure from the natural radiation; particularly the exposure from ^{220}Rn and its progeny should be planned and performed in the country.

Acknowledgements

The research work is supported by the University Grants Commission, UGC, New Delhi, India in the form of grants under the Research Funding Council for major research project. The cooperation extended by all the principals of government science college, Bangalore for allowing us to carry out the research work in the test room is highly acknowledged.

References

Cliff KD, Green BMR, Mawle A and Miles JCH (1992) Thoron daughter concentrations in UK homes, Rad Prot Dosim, 45(1/4), 361-366.

Doi M and Kobayashi S (1994b) Characterization of Japanese wooden houses with enhanced radon and thoron concentrations, Health Phys, 66, 274-282.

Doi M, Fugimoto K, Koyabshi S and Yenhara H (1994a) Spatial distribution of thoron and radon concentrations in the indoor air of a traditional Japanese wooden house, Health Phys, 66, 43-49.

Eappen KP and Mayya YS (2004) Calibration factors for LR-115 (type-II) based radon thoron discriminating dosimeter, Rad Meas, 38, 5-17.

Fleischer, RL (1988) Radon in the environment-Opportunities and hazard, Nucl Trac Rad Meas, 14, 421-435.

Gunning C and Scott AG (1982) Radon and thoron daughters in housing, Health Phys, 42(4), 527-528.

Guo Q, Shimo M, IkebeY and Minato S (1992) The study of thoron and radon progeny concentrations in dwellings in Japan, Rad Prot Dosim, 45(114), 357-359.

Guo Q, Iida T and IkebeY (1993) Indoor thoron and radon concentration measurements with passive cup monitor. Indoor Airs 93. Proceedings of the 6th International Conference on Indoor Air Quality and Climate, Helsinki, Finland, July 4-8, 4, 517-522.

Guo Q, Iida T, Okamoto K (1995), Measurements of Thoron Concentration by Passive Cup Method and Its Application to Dose Assessment, Journal of Nuclear Science and Technology, 32(8), 794-803.

Illic R and Sutej T(1977) Radon Monitoring devices based on Etched Track Detectors, In: ^{222}Rn Measurements by Etched Track Detectors, Applications in Radiation Protection, Earth Sciences and the Environment, (Eds., S.A. Durrani. and R. Ilic), World Scientific, (Singapore), 103-128.

Eappen KP and Mayya YS (2004) Calibration factors for LR-115 (type II) based radon thoron discriminating dosimeter, Radiation Measurements, 38, 5–17.

Keller G, Folkerts KH and Muth H (1982) Activity concentrations of ^{222}Rn, ^{220}Rn and their decay products in German dwellings, dose calculations and estimate of risk, Rad Environ Biophys, 20, 263-274.

Li Y, Schery SD and Turk B (1992) Soil as a source of indoor ^{220}Rn, Health Phys, 62(5), 453–457.

Martinez T, Navarrete M, Gonzalez P and Ramirez A (2004) Variation in indoor thoron levels in Mexico City Dwellings, Rad Prot Dosim, 111, 111–113.

Mayya YS, Eappen KP and Nambi KSV (1998) Methodology for mixed field inhalation dosimetry in monazite areas using a twin cup dosimeter with three track detectors. Rad Prot Dosim, 77, 177-184.

Menon MR, Lalith BY and Shukla VK (1987) Natural Radioactivity content in building construction materials in India, Bull Rad Prot, 14, 45-48.

Miles JCH (1997) Calibration and standardization of etched track detectors in Radon measurements by etched track detectors, applications in radiation protection, Earth Sciences and the Environment (Eds, Durrani, S.A., and Ilic, R) World Scientific, (Singapore), 43-176.

Mjones L (1986) Gamma radiation in Swedish dwellings, Rad Prot Dosim, 15(2), 131-140.

Nambi KSV, Subba Ramu MC, Eappen KP, Ramachandran TV, Muraleedharan TS and Shaik AN (1994) A new SSNTD method for the measurement of Radon -Thoron mixed working levels in dwellings, Bull of Rad Prot, 17, 34-35.

Ningappa C, Sannappa J, Chandrashekara MS and Paramesh L (2008) Concentrations of radon and its daughter products in and around Bangalore city, Rad Prot Dosim, 130 (4), 459-465.

Ningappa C, Sannappa J, Chandrashekara MS, Paramesh L (2008a) Studies on thoron and its progenies levels around Bangalore rural district, J of Environ Sci, 3(1), 1-5.

Ramachandan TV and Sathish LA (2011a) 220-Rn in the indoor environment and work places: a review: Proceedings of the 2011 AARST International Symposium, Vol 1, 9-10. October, 2011

Ramachandan TV and Sathish LA (2011b) Nationwide indoor ^{222}Rn and ^{220}Rn map for India: a review, J of Environ Radioact, doi: 10.1016/ j.jenvrad.2011.06.009. Article in Press

Rannou, Mouden A, Renouard H, Kerlau G and Tymen G (1988) An assessment of natural radiation exposure in granitic areas in the west of France, Rad Prot Dosim, 24(1-4), 327-331.

Schery SD (1985). Measurements of airborne ^{212}Pb and ^{220}Rn at varied indoor locations within the United States, Health Phys, 49, 1061-1067.

Shang B, Chen B, GaoY, Cui H and Li Z (2005) Thoron levels in traditional Chinese residential dwellings, Rad Environ Biophys, 44, 193- 199.

Shiva Prasad NG, Nagaiah N, Ashok GV and Karunakara N (2008) Concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in the soil of Bangalore region, INDIA, Health Phys, 94(3), 264- 271.

Sreenath Reddy M, Yadagiri Reddy P, Rama Reddy K, Eappen KP, Ramachandran TV and Mayya YS (2004) Thoron levels in the dwellings of Hyderabad city, Andhra Pradesh, India, J of Environ Radioact, 73, 21-28.

Steinhäusler F, Hofinann W and Lettner H (1994) Thoron exposure of man: A negligible issue? Rad Prot Dosim, 56(1/4), 127-131.

Tschiersch J and Müsch M (2005) Radon exposures in homes: Is the contribution of ^{220}Rn (Thoron) to dose always negligible? In: U. Oeh, P. Roth, H.G. Paretzke (Eds.): 9th International Conference on Health Effects of Incorporated Radio nuclides (HEIR 2004), Neuherberg, Germany, GSF-Bericht 06/05, 214-220.

Tschiersch J, Li WB and Meisenberg O (2007) Increased ^{220}Rn indoor concentrations and implication to inhalation dosimetry. Rad Prot Dosim, 127(1-4), 73-78.

Tso MW and Li C (1987) Indoor and outdoor ^{222}Rn and ^{220}Rn daughters in Hong Kong, Health Phys. 53(2), 175–180.

UNSCEAR (1993) United Nations Scientific Committee on the Effects of Atomic Radiations. Sources and Effects of Ionizing Radiation, pp. 73. (New York: United Nations)

UNSCEAR (2000) United Nations Scientific Committee on the Effects of Atomic Radiation, Sources, Effects and Risks of Ionizing Radiation, Report to the General Assembly, (United Nations, New York).

Wafaa A (2002) Permeability of Radon-222 through some materials. Rad Meas, 35, 207-211.

Ward W, Fleischer RL and Morgo C (1977) Barrier technique for separate measurement of Radon isotopes, Revised Science Instruments, 48 (11), 1440-1441.

Wrixon AD, Green BMR, Lomas PR, Miles JCM, Cliff KD, Francis EA, Driscoll CMH, James AC and O'Riordan MC (1988) Natural radiation exposure in UK Dwellings. NRPB-R 190 (Chilton: NRB).

Yamasaki T, Guo Q and Iida T (1995) Distributions of thoron progeny concentrations in Dwellings, Rad Prot Dosim, 59(2), 135–140.

Zhuo W, Iida T and Yang X (2000) Environmental radon and thoron progeny concentrations in Fujan province of China, Rad Prot Dosim, 87, 137–140.