# RADIATION DOSE DUE TO INDOOR $^{222}$Rn AND $^{220}$Rn LEVELS IN BANGALORE CITY, INDIA

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

[1]Post Graduate Department of Physics, Government Science College, Banglaore-560 001, India
[2]Department of Physics, Bangalore University, Bangalore–560 056, India
[3]Ex-Environmental Assessment Division, Bhabha Atomic Research Center, Mumbai–450 085, India

Corresponding Author: Sathish.L.A (lasgayit@yahoo.com)

## Abstract

The $^{222}$Rn and $^{220}$Rn levels have been measured using solid state nuclear track detectors in various types of houses at 10 different locations around Bangalore city, India. The average values of more than 100 samples of $^{222}$Rn and $^{220}$Rn concentrations were found to be 33.4 ± 6.1 and 21.6 ± 2.5 Bqm$^{-3}$, respectively. The dose rate received by the population of Bangalore ranged between 0.6 and 2.6 mSvy$^{-1}$ with the arithmetic and geometric mean of 1.01 ± 0.05 and 1.03 mSvy$^{-1}$ respectively. Overall, the result does not show much significant radiological risk for the inhabitants and the $^{222}$Rn levels are well within the limits of global average concentration of 40 Bqm$^{-3}$. However, the $^{220}$Rn levels observed were higher than the global average of 10 Bqm$^{-3}$. The details of results were discussed in detail regarding the types of houses and the variation of concentration.

## Keywords

Dose, indoor, radiation, $^{222}$Rn, $^{220}$Rn.

# Introduction

Radon is an important natural source and is the largest contributor to the effective dose received by the population from natural sources. It has been estimated that radon and its progeny contribute three quarters of the annual effective dose received by human beings from natural terrestrial sources and are responsible for about half of the dose from all the sources. According to UNSCEAR (UNSCEAR, 2000) estimates, indoor inhalation dose due to $^{222}$Rn, $^{220}$Rn and their progeny is to be about 1.2 mSvy$^{-1}$ of the total 2.4 mSvy$^{-1}$ background dose.

Radon emanates to a certain degree from all types of soil and rocks. The radiological importance of radon does not rest on the concentration of radon gas itself, but on its short lived decay progenies such as polonium, bismuth and lead. During breathing, radon is exhaled but the short lived progenies, being material particles, gets deposited onto the lungs (UNSCEAR, 1993).

Some factors that influences the diffusion of radon from soil into the air are the existence of uranium and radium in soil and rock, emanation capacity of the ground, porosity of the soil and/or rock, pressure gradient between the interfaces, soil moisture and water saturation grade of the medium (Schery and Gaeddert, 1984).

The concentration of indoor radon also depends on the ventilation rates of the dwellings where reduced ventilation rates enhance the concentration of radon and its daughters in air. In an earlier survey (Subba Ramu et al., 1990) have carried out extensive studies on indoor levels of radon daughters in some higher background areas in India by using SSNTD technique and the reported values of the $^{222}$Rn (GM) concentration vary between 35.3 – 86.0 Bqm$^{-3}$ with a geometric mean of 9.4 mWL of potential alpha energy exposure level from radon daughters with annual effective dose equivalent value of 3.1 mSv. The authors have also cited that the dose equivalent estimated for all the studied locations is found to be 2.4 times higher than the annual background value of 1.3mSvy$^{-1}$ given by EPA for the United States.

The track etch technique is being recognized as the most reliable one for integrated and long term measurement of indoor radon concentrations (Abu Jarad and Fremlin, 1981). As a part of the measurements initiated in this country for a nationwide mapping the measurement for $^{222}$Rn and $^{220}$Rn concentrations were instigated by using plastic track detectors in and around Bangalore Metropolitan, India and the results obtained are discussed in detail. The data was continuously obtained for a period of three years starting in 2007, covering more than 150 dwellings and all the four seasons of the calendar year. The work presented is the first of its kind for the Bangalore environment and shows interesting results. The area of the present study is given by Sathish et al., (Sathish et al, 2010) and the detailed experimental methodology is discussed by Ramachandran and Sathish (Ramachandran and Sathish, 2010).

# Results and Discussion

About 150 dwellings in ten different locations of Bangalore city, India, were selected on the basis of construction, age of the building, nature of walls, floorings, rooms and different volumes of the houses to see the effective dose rates due to indoor $^{222}$Rn, $^{220}$Rn and their progeny levels in dwellings during different seasons of the year. The houses were categorized on the basis of ventilation that depended on the number of windows, doors and usage pattern (such as closed, open, partially open/close) to identify them as poor (no or 1-window), moderate (2-windows) and good (3 and above windows) ventilated houses.

**Geographical variations**

The concentration of $^{222}$Rn, $^{220}$Rn and their short lived progeny levels were observed simultaneously for a period of three years over a large area of Bangalore city. Figure 1 summarizes the average values of $^{222}$Rn and $^{220}$Rn found in the different locations during 2007 to 2010.

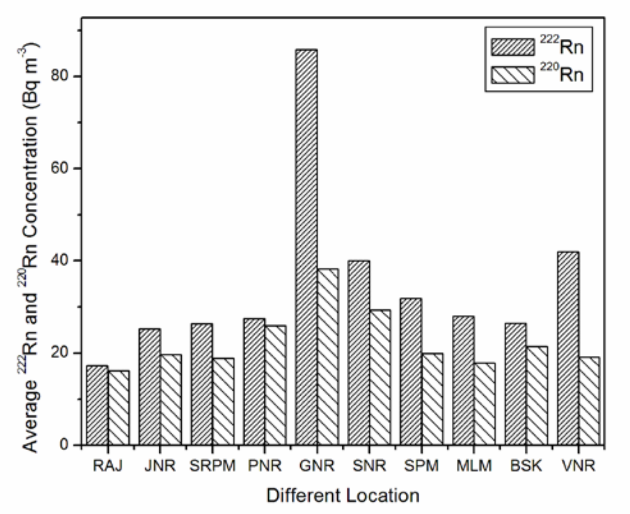


Fig. 1: Mean values of $^{222}$Rn and $^{220}$Rn

The lower $^{222}$Rn concentrations were observed in Rajajinagar and the higher were found in Government Science College of Gandhinagara; the lower and higher concentrations of $^{220}$Rn were seen in Vijayanagar and Government Science College of Gandhinagara respectively, this may be due to the activity concentrations of $^{226}$Ra, $^{232}$Th and $^{40}$K in the respective areas (Shiva Prasad et al 2008). The observations made for Bangalore region lie in the same range as reported elsewhere (Mishra and Sadasivan, 1971). The estimated $^{222}$Rn concentration levels at different locations of India varied from 6.4 to 95.4 Bqm$^{-3}$ with a geometric mean (GM) of 25.5 Bqm$^{-3}$ (GSD 2.1), whereas for $^{220}$Rn they ranged between 3.5 and 42.8 Bqm$^{-3}$ with a GM of 12.2 Bqm$^{-3}$ (GSD 3.22) (Mishra and Sadasivan, 1971).

The arithmetic mean values of $^{222}$Rn and $^{220}$Rn with different ventilation condition are given in Table 1. The results shows the concentration levels are higher in poor ventilated houses than in well ventilated houses. Comparisons of indoor $^{222}$Rn concentration for different seasons are made. The winter to summer ratio was observed maximum while the winter to autumn ratio was found minimum. The high values in winter are mainly because of ventilation factor.

Table 1 Arithmetic mean values of $^{222}$Rn and $^{220}$Rn with different ventilation condition

| Number of windows | Nature of Ventilation | AM ± SE $^{222}$Rn Concentration (Bqm$^{-3}$) | AM ± SE $^{220}$Rn Concentration (Bqm$^{-3}$) |
|---|---|---|---|
| 5 | Excellent | 7.3 ± 0.8 | 9.4 ± 0.9 |
| 4 | Very Good | 16.6 ± 0.9 | 10.6 ± 1.7 |
| 3 | Good | 31.3 ± 1.4 | 19.7 ± 2.0 |
| 2 | Moderate | 42.7 ± 1.1 | 29.5 ± 6.4 |
| 1 | Partial | 54.0 ± 1.5 | 33.9 ± 7.5 |
| 0 | Poor | 81.0 ± 3.5 | 38.6 ± 6.1 |

The indoor radon is influenced mainly by the ventilation condition of the dwellings. In most of the class rooms of the Government Science College, high $^{222}$Rn concentration in summer seasons were recorded than in winter season. This anomaly observed may be due to the fact that the class rooms are closed for a longer duration in summer (April to June) holidays. Further, the higher concentrations in Gandhinagar (GNR) may be due to the higher activity concentrations (Shiva Prasad et al., 2008) of $^{226}$Ra and $^{232}$Th and higher concentrations of radon gas in ground water in the surrounding area (Hunse et al., 2010). The winter to summer ratio in different locations are found to vary between 1.9 and 3.7 and this ratio is high compared to the ratio of winter to rainy and winter to autumn. This again depends on ventilation conditions of the dwellings. The concentrations of $^{222}$Rn and its progeny also follow the same trend, i.e., a maximum in summer and minimum during winter (Ramachandran et al., 1989).

In order to get a clear idea of the spatial variations, the observed values are compared with surveys made in different areas. The range (minimum to maximum) values of $^{222}$Rn and $^{220}$Rn are plotted in Figure 2. The elevated radon levels are seen in poor ventilated houses in all locations where most of the houses were built with local soil and sedimentary gravel. Some buildings with higher radon levels were found on gravel but all the lower values were observed in Rajajinagar area. This may be due to the lower radon concentration in the ground

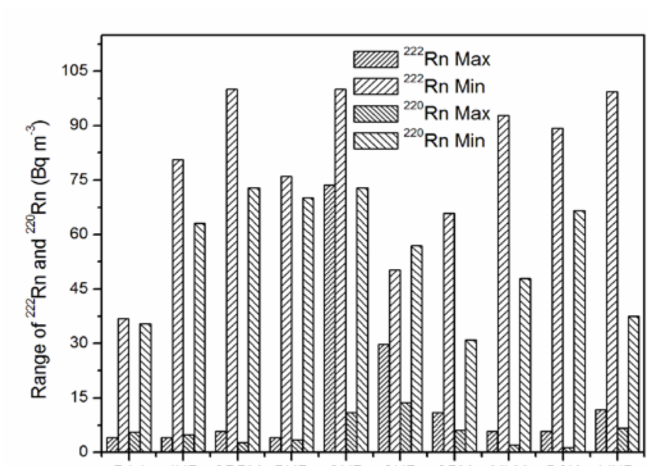


Fig. 2: Location versus range of $^{222}$Rn and $^{220}$Rn

water in the surrounding area (Hunse et al., 2010). Whereas the higher concentration may be due to the higher activity concentrations of $^{226}$Ra and higher concentrations of radon in water in those monitored locations.

The authors (Shiva Prasad et al., 2008; Hunse et al., 2010) have also reported that the activity concentrations of $^{226}$Ra in the surrounding area of Rajajinagar (Mallathalli) and Gandhinagar (Lalbagh) are 23.7 ± 0.7 and 111.6 ± 1.2 Bqkg$^{-1}$, whereas the activity concentrations of $^{232}$Th in the surrounding areas of Vijayanagar (Mallasandra) and Gandhinagar (Lalbagh) are 29.5±0.9 and 95.4±1.5 Bqkg$^{-1}$. The concentrations of $^{222}$Rn in water of Nagarbhavai (Vijayanagar), Rajajinagar and Lalbagh area were found to be 97.17 ± 5.74, 166.62 ± 8.08 and 887.67 ± 34.1 BqL$^{-1}$ respectively.

The frequency distribution of $^{222}$Rn and $^{220}$Rn are plotted in Figure 3. About 60% of indoor radon levels are found to vary between 20 and 39 Bqm$^{-3.}$

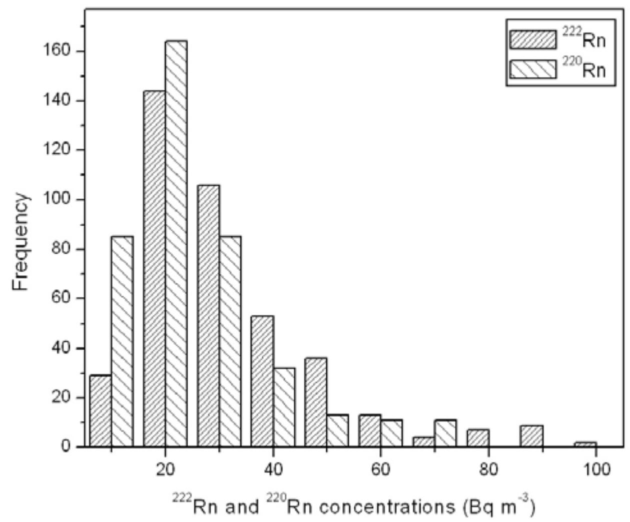


Fig. 3: Frequency Distributions of $^{222}$Rn and $^{220}$Rn

The higher concentrations of values more than 80 Bqm$^{-3}$ were observed in 6% of the studied houses. Nearly 23% of buildings show concentrations of 50–80 Bqm$^{-3}$ and they were 40-year old dwellings, poorly constructed with several cracks in foundation, walls and basic slabs, thorough which radon can easily enter the rooms. About 85% of the dwellings have shown $^{220}$Rn concentrations below 30 Bqm$^{-3}$; 15% of them had the concentrations above 50 Bqm$^{-3}$. The estimated (Mishra and Sadasivan, 1971) $^{222}$Rn concentration levels at different locations of India varied from 6.4 to 95.4 Bqm$^{-3}$ with a GM of 25.5 Bqm$^{-3}$ (GSD 2.1), whereas for $^{220}$Rn they were ranged between 3.5 and 42.8 Bqm$^{-3}$ with a GM of 12.2 Bqm$^{-3}$ (GSD 3.22) with the effective annual dose of 0.94 mSvy$^{-1}$.

The observed values of $^{222}$Rn (17.2 to 85.8 Bqm$^{-3}$) and $^{220}$Rn (8.3 to 38.3 Bqm$^{-3}$) concentrations for the environment of Bangalore are found to be comparable with the observations made elsewhere in India (Mishra and Sadasivan, 1971). In general the radon concentration was found higher in mud houses than in cemented houses (Ramola et al., 1995). Such houses on the ground floor are directly constructed on the top of soil with a coating of mud. This being the case, the ground floor allows more radon to diffuse inside the houses because of the higher porosity of materials used (Sathish et al., 2006).

**Seasonal variations and dose rates**

The mean values of the $^{222}Rn$ and $^{220}Rn$ concentrations of all the studied locations during different seasons are shown in Figure 4(a) and the annual effective dose rates in Figure 4(b). The concentration shows clear trends of seasonal variations. The concentration is found to be maximum during the winter and minimum in summer months as observed elsewhere (Virk and Sharma, 2000).

The majority of the houses are well ventilated in the summer season and the indoor radon concentrations might be expected to be lower for summer than in winter season (Ramachandran et al., 1989).

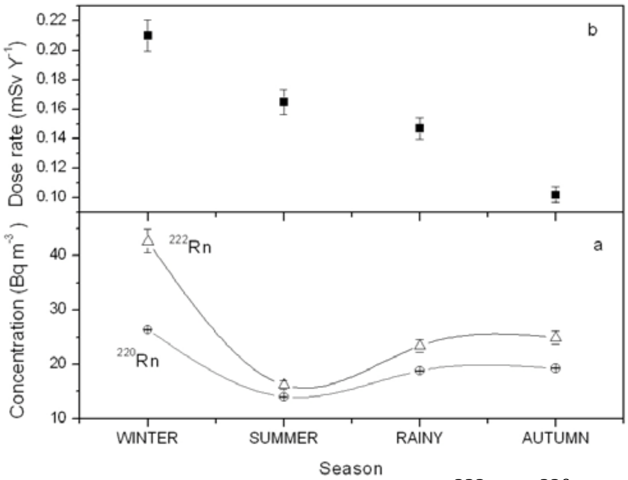


Fig.4: Seasons and dose rates of $^{222}Rn$, $^{220}Rn$

The higher concentrations observed during the winter season may be due to the radioactive gases that are trapped near the surface because of temperature inversions. In summer, the higher rate of vertical mixing and dispersions lifts the aerosols to higher altitudes resulting in a decrease in the concentration near the ground level air (Sesana et al., 2003). Magalhaes (Magalhaes et al, 2003) has observed two-orders of magnitude variability, with a maximum of 50 $Bqm^{-3}$ in winter and a minimum of 0.5 $Bqm^{-3}$ in summer months. In addition, radon exhalation rates also decrease during the monsoon as soil pores get filled by water, resulting in lower concentration of $^{222}Rn$ and $^{220}Rn$ (Nagaraja et al., 2003).

**Association between wall variations and dose rates**

The mean concentration of $^{222}Rn$ and $^{220}Rn$ levels within houses constructed using different walls is shown in Figure 5(a) and the respective dose rates in Figure 5(b). Higher concentrations and dose rates were observed in mud wall houses and lower in concrete walls. The concentrations were found to vary from wall to wall. The variation may be due to the random distribution of radioactive rock species used indiscriminately in the construction of houses (Kumar et al., 1994).

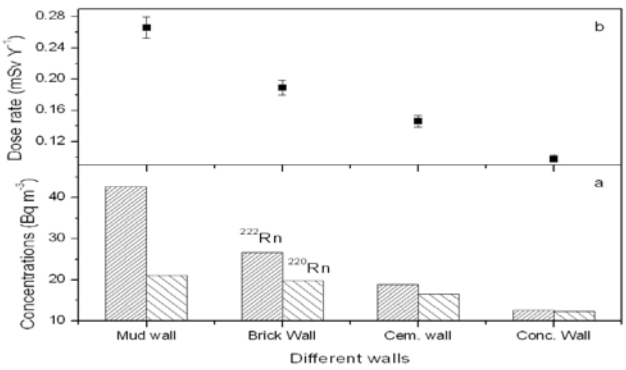


Fig. 5: Wall materials versus $^{222}$Rn and $^{220}$Rn dose rates

**Association between floor variations and dose rates**

The higher concentrations of $^{222}$Rn and $^{220}$Rn were observed in granite flooring houses and lower in mosaic flooring and are shown in Figure 6(a). Granite is rich in radium and it may be the reason for the higher concentration of radon in granite flooring houses. The materials used for construction of buildings are sufficiently porous and allow radon to enter into the indoor atmosphere (Gaso, 2005). Granite samples show higher radon exhalation rate than mosaic. There is a positive correlation between radium content of granite with radon exhalation and its concentration (Al-Jarallah., 2001). The variations of dose rates in different floorings are shown in Figure 6(b). The elevated levels were observed in the granite floorings and the lower in mosaic floorings.

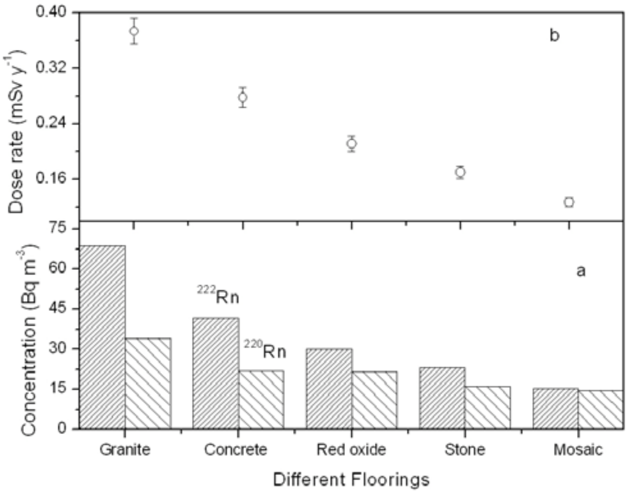


Fig.6: Floor materials versus $^{222}$Rn and $^{220}$Rn dose rates

**Association between room variations and dose rates:**

Variations of indoor $^{222}$Rn and $^{220}$Rn concentrations in different rooms of houses are shown in Figure 7(a). The high concentrations were observed in the bath room, bed room and the lower concentrations in living rooms.

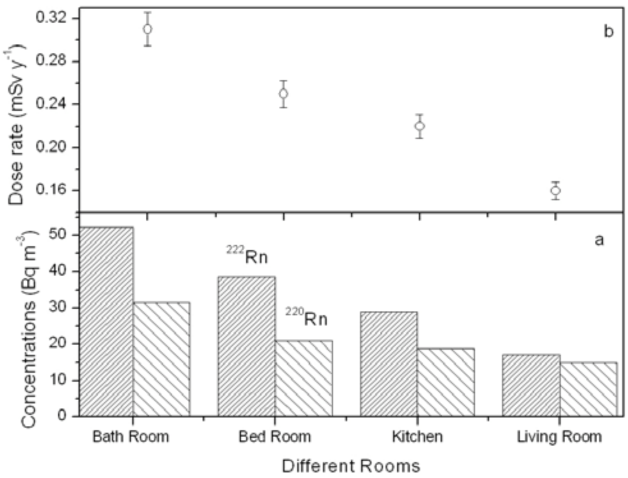


Fig.7: Variations of $^{222}$Rn and $^{220}$Rn dose rates in different rooms

One can clearly see in the figure that there is a larger concentration in the bathroom compared to the other rooms of the houses. Bed rooms might be expected to be least ventilated, on the average, based upon limited use patterns and bath rooms may receive some additional $^{222}$Rn due to $^{222}$Rn dissolved in water (Sathish et al., 2006). $^{222}$Rn is shown to be released in spray from faucets or shower fixtures(Gessel, 1980). Air in living rooms, on the other hand, is most readily diluted due to outdoor air ventilation.

**Association between room volume variations and dose rates**

Rooms were also classified broadly into '6-groups' on the basis of their volume, which ranged between 30 to 310 m$^3$ (30–40, 45–60, 65–75, 80–100, 110–120 and 200–310). At least 7 rooms were selected for each dimension and this covered ten different locations. Hence, the total number of rooms covered in each volume is 42 rooms of different dwellings. However, the total number of rooms monitored is 42×10 locations = 420 rooms. These 420 rooms have been analyzed for four seasons and lead to 1680 measurements. The total number of films (LR-115 detectors) exposed during this period of measurement is more than 5000. The volumetric variations of $^{222}$Rn and $^{220}$Rn are shown in Figure 8(a).

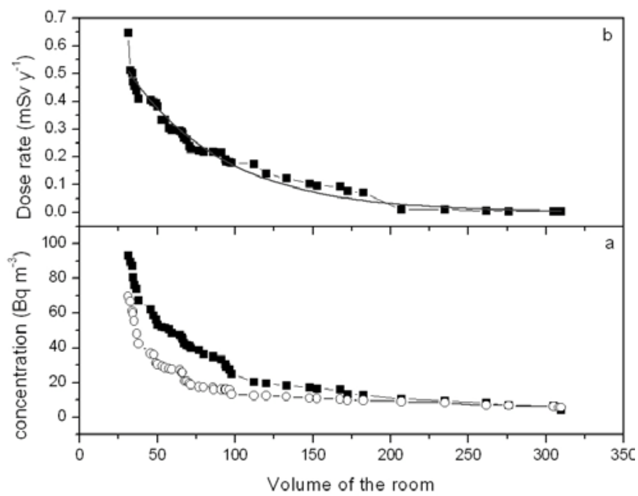


Fig. 8: $^{222}$Rn and $^{220}$Rn versus room volume

Higher concentrations were observed in lower volume rooms than in the higher volume rooms. The concentrations in a dwelling of volume 30-310 $m^3$ ranged from 4 to 93 $Bqm^{-3}$. It is interesting to note that as the volume of room varies in geometric progression; there is no linear dependence on the concentrations. This clearly indicates that though the observations have been made almost for similar type of constructions, ventilation and lifetime of the houses, but as the volume of the room increases the concentrations reduces exponentially and it becomes almost constant above the house volume 150 $m^3$. The regression coefficients for the exponential drops for $^{222}Rn$ and $^{220}Rn$ are 0.99 and 0.98 respectively. The variations of dose rates are shown in Figure 8(b). The present work reveals that the dwellers of lower volume houses will expose themselves to the higher dose rates 4.4 times the dose received in higher volume rooms.

## Conclusions

The estimated concentration of $^{222}Rn$ and $^{220}Rn$ for the environment of Bangalore, India varies from 17.2 ± 1.2 to 85.8 ± 2.3 $Bqm^{-3}$ and 8.3 ± 1.2 to 38.3 ± 5.4 $Bqm^{-3}$ with a mean of 35.0 ± 0.9 and 22.6 ± 0.7 $Bqm^{-3}$, respectively. The dose rate received by the population of Bangalore ranged between 0.6 and 2.6 $mSvy^{-1}$ with the arithmetic and geometric mean of 1.01 ± 0.05 and 1.03 $mSvy^{-1}$ respectively. The lower concentration of $^{222}Rn$ is observed in Rajajinagar and higher in Government Science College of Gandhinagara. $^{220}Rn$ is lower in Vijayanagar and higher in Government Science College. The investigation shows no significant radiological risks for the inhabitants and is well within the limits prescribed by UNSCEAR. The study on estimations of dose rates in dwellings of different features reveals the higher values for “lower volume” house, granite flooring house, bath room, mud wall houses and during winter season. Among these, the lower volume and granite flooring house inhabitants are exposed to higher dose. Hence, it is recommended that the “lower volume” houses should have good ventilation to reduce the effective dose rate.

## Acknowledgements

One of the authors, Dr. Sathish, is thankful to the Research Funding Council, University Grants Commission, New Delhi, India for providing the financial assistance to carry out the research work. The cooperation extended by all the residents of Bangalore is highly appreciated.

# References


Abu Jarad F and Fremlin JH (1981) A working level monitor for radon measurements inside houses, Rad Prot Dosim, 1(3), 221-226.

Al-Jarallah (2001) $^{222}Rn$ exhalation from granites used in Saudi Arabia, J Env Radioact, 53, 91-98.

Gaso MI, Segovia N, Pulinets S, Leyva A, Ponciano G, Pena P (2005) Indoor radon and annual effective doses at a high altitude region in central Mexico, J Appl Sci, 5, 1356-1362.

Gessel TF and Prichard HM (1980) The concentration of $^{222}Rn$ in tap water to Indoor $^{222}Rn$ concentrations. In: Natural Radiation Environment-III, Eds. Gessel TF, Prichard HM, Springfield, 1347-1363.

Hunse TM, Mohamed Najeeb K, Rajarajan K and Muthukkannan M (2010) Presence of Radon in Groundwater in Parts of Bangalore, Journal of Geological Society of India. ***75:*** 704-708.

Kumar J, Malhotra R, Singh J, Singh S (1994) $^{222}Rn$ measurements in dwellings in radioactive areas in Himachal Pradesh, India, using LR-115 Plastic Track Detectors, Nucl Geophys, 6, 573-576.

Magalhaes MH, Amaral ECS, Sachett I and Rochedo (2003) Radon-222 in Brazil: an outline of indoor and outdoor measurements, J of Env Rad, ERR, 67, 131-143.

Mishra UC and Sadasivan S (1971) Natural radioactivity levels in Indian soil", Journal of Science and Industrial Research, ***30***: 59-62.

Nagaraja K, Prasad BSN, Madhava MS (2003) Chandrashekara MS, Paramesh L, Sannappa J, Pawar SD, Murugavelu P and Kamra AK, Radiat Meas, 36, 413-417.

Ramachandran TV, Muraleedharan TS, Shaikh AN and Subba Ramu MC (1989) Seasonal variation of indoor radon and its progeny concentration in dwellings, Atmos Environ, 24 A (3), 639-643.

Ramachandran TV and Sathish LA (2010) Nationwide $^{222}Rn$ and $^{220}Rn$ atlas for India, International Symposium on Radon (RADON -2010), pp.1-41, October 17 – 20, 2010, Hyatt Regency Columbus, Columbus, Ohio, USA.

Ramola RC, Rawat RBS and Kandari MS (1995) Estimation of Risk from Environmental Exposure to Radon in Tehri Garhwal, Nucl Geophys, 9, 383-386.

Sathish LA, Sannappa J, Paramesh L, Chandrashekara MS and Venkataramaiah P (2006) Studies on the concentrations of radon/thoron and their progeny in houses of different types of floorings in Mysore city, Environ Geochem, 9, 105-108.

Sathish LA, Nagaraja K, Ramanna HC, Nagesh V, Sundareshan S and Ramachandran TV (2010) The Spatial and Volumetric Variation of Radon in Bangalore City, India, , International Symposium on Radon (RADON -2010), pp.125-142, October 17 – 20, 2010, Hyatt Regency Columbus, Columbus, Ohio, USA.

Schery SD and Gaeddert DH (1984) Factors affecting exhalation of radon from a gravelly sandy loam, J of Geophys Res, 89, 7299-7309.

Sesana L, Caprioli E and Marcazzan GM (2003) Long period study of outdoor radon concentration in Milan and correlation between its temporal variations and dispersion properties of atmosphere, Journal of Environmental Radioactivity, 65, 147-160.

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 Physics, **94(3):** 264- 271.

Subba Ramu MC, Ramachandran TV, Muraleedharan TS and Sheik AN (1990) Indoor levels of radon daughters in some high background areas in India, Rad Prot Dosim, 30(1), 41-44.
United Nations Scientific Committee on the Effects of Atomic Radiations (UNSCEAR). Sources and Effects of Ionizing Radiation. UNSCEAR 1993 Report to the general assembly, with annexes. pp. 73-98. (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).
Virk HS and Sharma N (2000) Indoor $^{222}Rn/^{220}Rn$ survey report from Hamirpur and Uuna districts, Himachal Pradesh, India, Applied Radiation and Isotopes, 52, 137-141.