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Elevated radon levels–volumetric variations

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ABSTRACT

Different dwellings each of volume ranged from 30 to 310 cubic meters were selected in different locations on the basis of quality of construction, age, similar nature of walls and floorings. Twin cup dosimeters consisting of LR-115 plastic track detectors were installed in 42 houses to study the variation in indoor radon and thoron concentrations to record the significance of volume of the room that are similar type of constructions. After an exposure period of 90 days the films were removed and etched chemically in 10% NaOH solution at 60 ºC for an hour with mild agitation throughout, the etched films were alpha counted using spark counter. The measurement is continued for one complete calendar year to observe the seasonal variations. The large variations in the concentrations were observed during winter and summer seasons than in rainy and autumn seasons of the calendar year. The higher concentrations of radon, thoron and their progeny, and dose rates were observed in a room of lower volume than in higher volume. The ^{222}Rn and ^{220}Rn concentrations in dwellings of volume 30 to 310 cubic meters ranged between 4–93 Bq m^{-3} whereas their progeny concentrations ranged between 0.012–2.45 mWL, respectively. It is observed that the enhancement of volume by almost ten-fold reduces the concentration of ^{222}Rn to 23% and that of ^{220}Rn to 13% of the studied locations provided all conditions remain unaltered. Further it is observed, if the volume of room varies as geometric progression, there is no dependence on the concentrations in the same ratio. The annual effective dose due to radon, thoron and their progenies ranged between 0.105 and 0.457 mSvy^{-1} for the volume specified above.

KEYWORDS

Volumetric variation;
Indoor;
Radon;
Thoron;
Plastic track detectors;
Dose rate.

INTRODUCTION

Measurement of radon in indoor is of great importance since the radiation dose to human population due to inhalation of radon and its progeny alone contributes more than 50% of the total dose from natural sources[1]. The primordial radon isotopes such as radon - ^{222}Rn, thoron - ^{220}Rn and actinon – ^{219}Rn are gaseous in nature and may be released from the earth, rocks and also from building materials. The gases formed accumulate with their short-lived progeny in closed spaces, particularly in dwellings. ^{220}Rn and ^{219}Rn are not as important as ^{222}Rn because of their short half-life, which may reach levels of concentration in the air which are significant in terms of radiological protection. The dose deriving from the presence of ^{222}Rn in the air is linked to the inhalation of its short-lived daughters, which are deposited in the respiratory organs, if deeply inhaled; emit alpha-particles that are in contact with bronchial and pulmonary epithelium. For these reasons, the dose deriving from the exposure to ^{222}Rn in closed spaces has been placed in direct relation to the risk of lung cancer[2]. The main sources of indoor radon levels are the soil-gas, building materials, tap water and natural gas used for cooking. The topography, types of house construction, soil characteristics, ventilation rate, wind direction, atmospheric pressure and even the life style of the people, also influence significantly[3-5]. These features demand the importance of continuous long-term integrated data through experimental studies to make ideal models. Data on the volumetric variations of radon and thoron in the dwelling are limited and this work seems to be first of its kind in India.

The present study aims at the measurement of volumetric variations of indoor concentrations of radon, thoron, their progeny levels and dose rates using Solid State Nuclear Track Detectors (SSNTD) in the dwellings of Bangalore city.

STUDY AREA

The location selected for the present study is Bangalore city, situated in the south-eastern part of Karnataka State. It has an aerial extent of about 2200 square kilometers and population of around six millions. The district lies between the latitudes 12°39' to 13°13' N and longitudes 77°22' to77°52' E. The climate is having four distinct seasons. April is usually the hottest month with mean daily maximum temperature of 30-35°C and mean daily minimum 20-24°C. Relative humidity is high during rainy season for the South-West monsoon months and decreases thereafter. During the months May through September, the winds are from West to South-West to West, while for the period November to March, it is from East to North-East and East to South-East. The year is divided into four season's viz.:

1. Summer season [March to May]
2. Rainy season [June to August]
3. Autumn season [September to November] and
4. Winter season [December to February]

METHODOLOGY

The radon–thoron mixed field dosimeter employed for the measurement which are made up of a twin chamber cylindrical system using 12µm thick, LR-115 cellulose nitrate based SSNTDs. The dosimeters have been developed at the Bhabha Atomic Research Centre (BARC), Mumbai, INDIA and are schematically shown in Figure 1. Each chamber has a length of 4.1 cm and a radius of 3.1 cm.

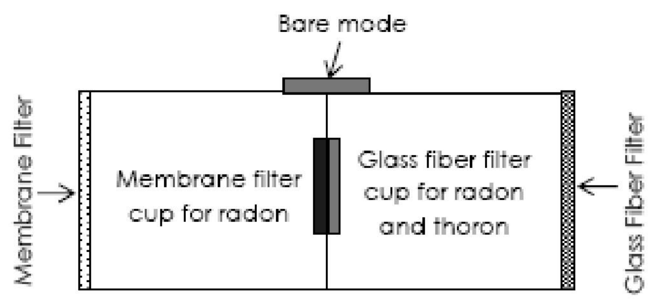

Figure 1 : The double chamber dosimeter cup

The SSNTD placed in the compartment which has membrane filter measures ^{222}Rn alone which diffuses into it from the ambient air through a semi-permeable membrane of 25µm thickness having diffusion coefficient in the range of 10^{-10}–10^{-9} m^2s^{-1}[6-8]. It allows the buildup of about 90% of the radon gas in the compartment and suppresses thoron gas concentration by more than 99%[9]. On the other hand, the compartment that has glass fiber filter paper of thickness 560 micron, allows both radon and thoron gases to diffuse in and hence the tracks on SSNTD placed in this chamber are related to the concentrations of both the gases. The SSNTD exposed in the bare mode registers alpha tracks attributable to both the gases and their alpha-emitting progeny, namely ^{218}Po, ^{214}Po, ^{216}Po and ^{212}Po. The choice of the detector LR-115 is made in view of the fact that LR-115 detectors do not develop tracks originating from the progeny alphas deposited on them[10,11] and therefore is ideally suited for air concentration measurements. Following the environmental exposure for a period of 90 days, the SSNTDs are etched with 2.5N NaOH solution in an etching bath at a temperature of 60 ºC for developing the registered tracks. The etching process removes a bulk thickness of 4 μm leaving a residual detector thickness of 8 μm. The detector is pre-sparked using a spark counter at a potential of 900 V to develop completely the partially etched track holes. The tracks are then counted at the voltage approximately 450 V corresponding to the plateau region of the counter and its design characteristics are similar to the one discussed by Garakani[12]. The paper deals with the studies on volumetric variations of radon, thoron and their progeny levels in dwellings. The detailed descriptions of methods of measurements and the calibrations are described by Sathish et al[13].

RESULTS AND DISCUSSION

About seven rooms in various locations were selected of different volume ranging from 30 to 310 cubic meters. Radon, thoron, their progeny levels and dose rates were measured using plastic track detectors. The details of volumetric variation of radon, thoron and their progeny levels in dwellings of various locations are listed in TABLE 1. The higher concentrations of radon and thoron were observed in lower volume room than in higher volume room in all the locations. The ^{222}Rn and ^{220}Rn concentrations in a dwelling of volume 30 to 310 cubic meters ranged between 4 – 93 Bq m^{-3}, whereas their progeny concentrations ranged between 0.012 – 2.45 mWL, respectively, for the similar dimension of rooms.

TABLE 1 : Variation of Concentration of ^{222}Rn, ^{220}Rn and their progeny levels in rooms of different volume

Volume of room m^3	Concentration range			
	^{222}Rn	^{220}Rn	^{222}Rn progeny	^{220}Rn progeny
	Bqm^{-3}		mWL	
200 – 310	10.53 - 4.05	12.50 -5.56	0.207 - 0.015	0.249 - 0.015
110 – 120	20.47 - 12.87	17.36 - 5.56	1.090 - 0.046	0.494 - 0.012
80 – 100	36.26 - 25.15	27.85 - 12.50	0.732 - 0.090	0.580 - 0.027
65 – 75	47.37 - 38.60	69.44 - 11.81	1.065 - 0.139	0.351 - 0.033
45 – 60	61.99 - 48.54	66.67 - 15.80	1.228 - 0.174	0.506 - 0.056
30 – 40	92.98 - 67.25	61.11 - 10.99	2.453 - 0.241	0.834 - 0.031

It is observed that the enhancement of volume by almost ten-fold reduces the concentration of ^{222}Rn to 23% and that of ^{220}Rn to 13% of the studied locations provided all conditions remain unaltered. Further it is observed, if the volume of room varies as geometric progression, there is no dependence on the concentrations in the same ratio. The geometric mean of radon and thoron concentration with the volume of the rooms is shown in Figure 2. Higher concentrations of radon and thoron were observed in the dwellings of volume ranged between 30-40 cubic meter and the lower concentrations were observed for dwellings of 200-310 cubic meters. Figure 3 shows the frequency distribution of radon, thoron concentration in dwellings of different volume ranged between 30-310 cubic meters. About 67% of monitored houses have the volume in the range 30-100 cubic meters and showed the concentrations 30 Bq m^{-3} leading to 60% and above and 32% of the dwellings had the volume between 110-310 cubic meter have shown the concentrations less than 20 Bq m^{-3}. This clearly indicates that though the observations have been made almost for similar type of constructions, ventilation and age, but as the volume of the room increases the concentrations reduces exponentially and it becomes almost constant above the volume of 150 cubic meters.

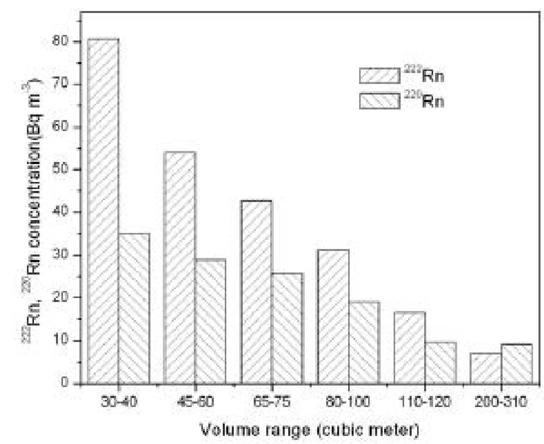

Figure 2 : Variation of ^{222}Rn, ^{220}Rn with volume of the room

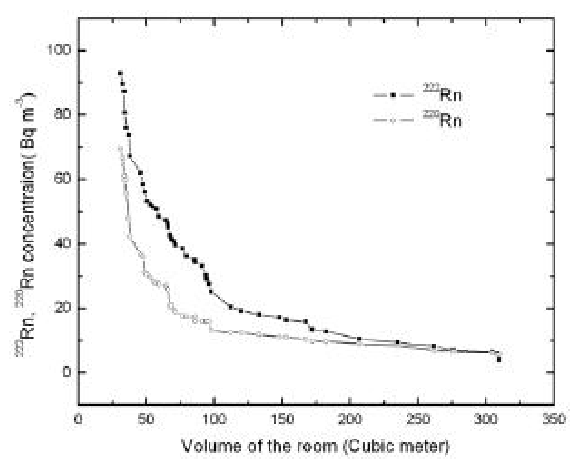

Figure 3 : Frequency distribution of radon and thoron

About 39% dwellings of volume in the range between 94–310 m^3 have shown the radon concentrations below 29 Bq m^{-3} and 60% of the dwellings whose volumes were in the range of 30–93 m^3 have shown the concentrations above 30 Bq m^{-3} with a maximum concentration of 93 Bq m^{-3} where as 76% dwellings of volume ranged between 50–310 m^3 have shown the thoron concentrations below 29 Bq m^{-3} and 24% dwellings of volume ranged between 30–49 m^3 with a maximum concentration of 69.44 Bq m^{-3}. It emphasis that normal rooms of dimensions with average height around 4m may have the dimensions 5x6 m or 5x5 m may pose higher risk compared to the rooms of larger volume. The correlation coefficient for exponential decay is more than 90% in all cases and envisages that there is a direct dependence with volume and concentration. Normally halls, big rooms, class rooms, conferences halls etc. are of higher dimensions with good ventilation too and will have less risk. This factor can be clearly seen from Figure 3, where frequency is less for higher dimensions beyond 100 cubic meters.

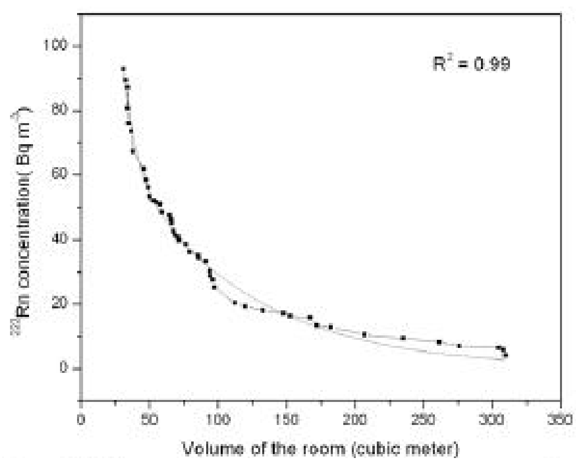

Figure 4 : Volumetric variations of ^{222}Rn concentrations

The variation of the radon, thoron and their progeny concentration with volume of the room are shown in Figures 4-7, the variation in the concentration follows the exponential law with the regression coefficients for radon, thoron are 0.99, 0.96 and for their progenies it is 0.91 and 0.91, respectively. The exponential decay in concentration with volume of the room is observed only in poor ventilation rooms of all the locations and the same exponential law is not observed with good ventilation houses. For the volume greater than 100 cubic metes the concentrations remains almost constant.

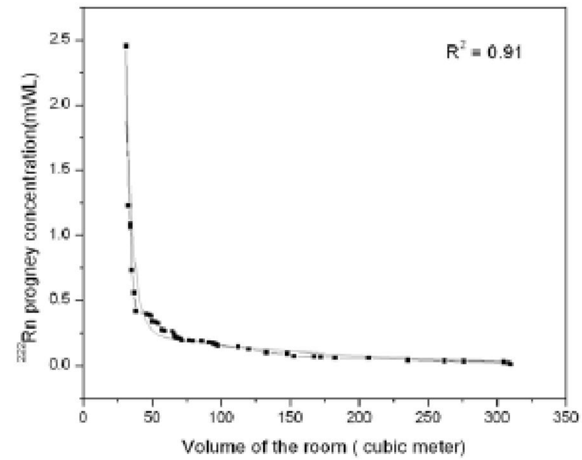

Figure 5 : Volumetric variations of ^{222}Rn progeny concentrations

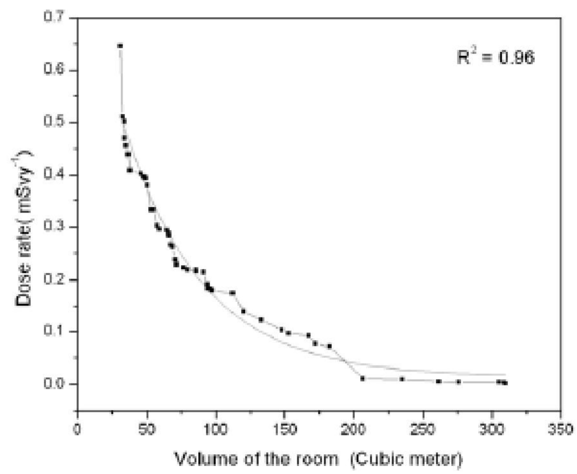

Figure 6 : Volumetric variations of ^{220}Rn concentrations

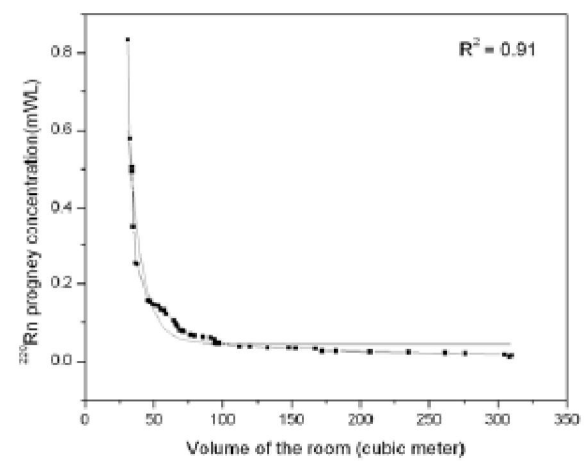

Figure 7 : Volumetric variations of ^{220}Rn progeny concentrations

It may also be seen that the possibility of radon concentration mitigates and follows quicker diffusion rate as the volume of the room increases, assuming the radon source and ventilation conditions are constant. It is also observed that if the volumes of the rooms are in the ratio of geometric progression as 1, 2, 4 and 8, then the concentrations of ^{222}Rn and ^{220}Rn vary in the ratio of 1.96, 2.45, 2.06 and 2.31, respectively. The values are tabulated in TABLE 2 for understanding the phenomena clearly.

TABLE 2 : Variations of ^{222}Rn and ^{220}Rn in the room volume enhances geometrically

Volume m^3	^{222}Rn	^{220}Rn	^{222}Rn	^{220}Rn
	Bq m^{-3}		mWL	
30	92.98	69.44	2.453	0.834
60	47.37	27.08	0.264	0.105
120	19.31	12.5	0.124	0.038
240	9.36	8.33	0.046	0.023
400	4.05	5.56	0.015	0.012

The arithmetic mean with standard error for concentrations of radon and thoron are also listed in table for the better understanding of the variations with reference to the volume. TABLE 3 reveals that the concentrations and effective dose rate are low in higher volume rooms and good ventilated rooms, the higher concentrations and effective dose rate were observed in lower volume rooms and the poor ventilated rooms of all the location the arithmetic mean with standard error concentrations of ^{222}Rn and ^{220}Rn also decreases exponentially as the volume of the room increases with the regression coefficients 0.99 and 0.97, respectively.

The variations of dose rates due to the radon, thoron and their progeny levels with the volume of the monitored locations are shown in Figure 8. The dose rate reduces exponentially like radon and thoron with the regression coefficient 0.97. On the other hand the concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the soils of Bangalore region[14] reveals that the concentration of ^{226}Ra varied in the range of 7.7–111.6 Bq kg^{-1} with a mean value 26.2 Bq kg^{-1}. The concentration of ^{232}Th varied in the range 16.7–98.7 Bq kg^{-1} with a mean value 53.1 Bq kg^{-1} and that of ^{40}K in the range 151.8–1424.2 Bq kg^{-1} with a mean value of 635.1 Bq kg^{-1}. It is also reported that about 67% of the samples from Bangalore region the ^{232}Th concentrations were more than the world average of 40 Bq kg^{-1} and 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 India and the world average values. The early morning joggers are expected to pose to the annual effective dose of 0.085 mSvy^{-1} for Bangalore region[15]. The present work reveals that the dwellers of lower volume houses will expose themselves to the higher dose and it is 1: 4.4 for higher volume houses. It is suggested that the lower volume houses should have good ventilation to reduce the effective dose rate due radon and its daughters.

TABLE 3 : Arithmetic mean values of ^{222}Rn, ^{220}Rn and dose rate

Nature of Ventilation	Arithmetic Mean of volume of the room M^3	AM ± SE ^{222}Rn Concentration Bqm^{-3}	AM ± SE ^{220}Rn Concentration Bqm^{-3}	Total Dose µSv y^{-1}
Excellent	272	7.34 ± 0.82	9.41 ± 0.90	0.105
Very good	155	16.67 ± 0.94	10.64 ± 1.74	0.170
Good	92	31.37 ± 1.41	19.71 ± 2.01	0.204
Moderate	70	42.76 ± 1.11	29.51 ± 6.45	0.279
Partial	53	54.09 ± 1.56	33.91 ± 7.54	0.358
Poor	35	81.06 ± 3.52	38.66 ± 6.13	0.457

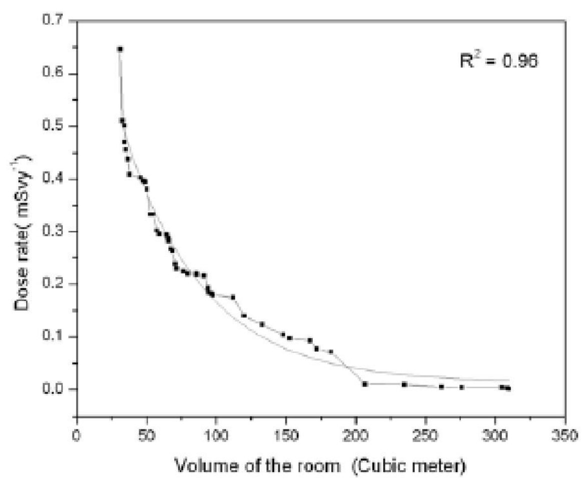

Figure 8 : Variation of dose rate with the volume of the room

CONCLUSIONS

With the objective of estimation of the concentrations in different volume of the room due to exposure to indoor radon gas, the concentrations are more in smaller volume rooms and low in larger volume rooms of the monitored dwellings. It is suggested that the lower volume rooms should be well ventilated to reduce the radiation exposure due to radon and its progeny. On the basis of the results obtained it may be conclude that the levels of indoor radon and thoron are well within the acceptable values for the population prescribed by UNSCEAR.

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