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Environmental radon/thoron and their progenies

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ABSTRACT

Radon is the most important source of natural radiation and is responsible for approximately half of the dose received totally from the rest of the sources. Most of it comes from the inhalation of the progeny of ^{222}Rn and is prominent in closed atmosphere. The continuous measure of the levels of ^{222}Rn concentration in the different geographical areas is of great importance particularly in living places. The radon and thoron concentrations have been measured in houses of covering about 15 locations in different parts of Bangalore city, India. Solid state nuclear track detectors were used for measuring the concentrations. The data is continuously obtained for a period of two years since 2007, covering more than 150 houses. The construction materials used for building the houses are predominantly of cement, concrete and brick that is made up of local soil. The total average of radon in this area is found to be 33.38 Bqm^{-3}. The values above 100 Bqm^{-3} are very few and none of them have more than 150 Bqm^{-3}. The average value for radon in India is 57 Bq m^{-3} with a geometric mean of 42 Bqm^{-3}, being the effective annual dose of 0.97 mSvy^{-1}. The result shows no significant radiological risk for the inhabitants of Bangalore city and is well within the recommendations of International Commission on Radiological Protection.

KEYWORDS

Radon;
Dosimeter;
SSNTD.

INTRODUCTION

Now a days the public and Government is showing much concern on the study of natural radiation, environment, and particularly the radiation level in dwellings. Due to the high doses found as a consequence of the elevated radon concentrations, some countries are now subject to legislations. This is true particularly in cold climate countries where the energy crisis has a vital role. This is evident that the houses were built more hermetically so as to minimize ventilation conditions. Radon is the important natural source and contributes most to the effective dose received by population from natural sources. It has been estimated that radon and its progeny contribute a lot with 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 the total sources[1].

Radon emanates to a certain degree from all types of soil and rocks. Presence of radon in the biosphere is due to its semi-disintegration period nearly 4 days, which allow it to diffuse from the earth's crust into the atmospheric air. The radiological importance of radon does not lie on the concentration of radon gas itself, but on its short lived decay progenies such as polonium, bismuth and lead. During breathing radon comes out during exhale but the progenies, being a material particles may deposit on to the lungs, tracks of breathing etc. The mean concentration levels of ^{222}Rn in air over continents are in the range of 1-10 Bqm^{-3}[1]. Some of the factors that influences the diffusion of radon from the soil into the air are the uranium and radium concentration 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[2]. The concentration of indoor radon also depends on the emanation rate of the gas from the soil, the content of precursor nuclide ^{226}Ra, and ventilation rate of the dwelling. It is important to note that even though reduced ventilation rate aids to enhance the radon concentration and that of its daughters in air. It may be due to the presence ^{226}Ra rich soil or its component in construction material. The track etch technique is recognized as the most reliable technique for integrated and long term measurement of indoor radon concentrations[3-6]. The radon and thoron concentrations were carried out by using plastic track detectors and the results obtained are discussed in detail.

MEASUREMENT PROCEDURE

Solid state nuclear track detectors

About 150 houses of different types of construction have been surveyed simultaneously on a time integrated quarterly cycle of 90 days. Solid State Nuclear Track Detector (SSNTD) based dosimeters were used for the investigations[7-10]. The mode of sampling is passive and integrated for long duration taking into account the diurnal, monthly and seasonal variations of radon and thoron concentrations. Such long-term measurements were usually carried out using SSNTD technique[11]. These are simple to use and less expensive as compared to some continuous measurement systems like Alpha Guard, which is useful for comparison of SSNTD based dosimeters. In view of this, SSNTD based dosimeters were developed and calibrated at Bhabha Atomic Research Centre (BARC), Mumbai, India for the survey. The dosimeter is a cylindrical plastic chamber divided into two compartments of equal dimensions[12]. Each cup of the dosimeter has an inner volume of 135 cubic centimeter and internal height of 4.5 cm. Dimensions of the dosimeter are chosen based on the ratio of the effective volume of cup and its total volume, to achieve maximum track registration for the cylindrical cup[13,14]. The dosimeter is well designed to discriminate radon and thoron in mixed field situations, where both the gases are present even at monazite rich areas. A cellulose nitrate film of LR-115 TYPE II is used as the detector. The 12 μm thick film having a dimension of 2.5×2.5 cm^2 and is affixed at the bottom of each cup as well as on the outer surface of the dosimeter. The exposure of the detector inside the cup is termed as 'cup mode' and other one exposed openly is termed as 'bare mode'.

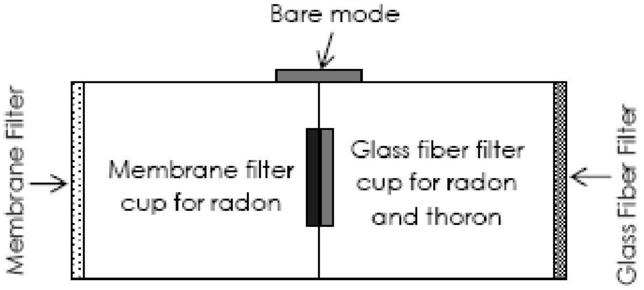

Figure 1 : The double chamber dosimeter cup

One of the cups has its entry covered with a glass fiber filter paper that permeates both radon and thoron gases into the cup and is called 'glass fiber filter cup'. The other cup is covered with a semi permeable membrane sandwiched between two glass fiber filter papers called 'membrane filter cup'[15]. These types of membranes have permeability constant in the range of 10^{-10} -10^{-9} m^{2}s^{-1} and allow more than 95% of the radon gas to diffuse while it suppress the entry of thoron gas to less than a percent[16-18]. Thus, the SSNTD films inside the membrane cup register tracks attributes to radon alone, while the 'filter film' records tracks due to both radon and thoron. The third film exposed in the bare mode registers alpha tracks produced by the presence of both gases and their alpha emitting progeny. Eappen et al. (1998)[19] have reported that the LR-115 of 12 μm film does not register tracks from deposited activity. This is because the maximum energy for LR-115 film is 4 MeV and all the progeny isotopes of radon/thoron emit alphas with energies 5 MeV. Thus the uncertainty from the deposited activity is removed; otherwise it is difficult to evaluate the track densities due to alpha emissions using LR-115 film. The dosimeter is kept at a height of 1.5 m from the ground and care is taken to keep the bare card at least 10 cm away from any surface. Since the range of alpha particles from radon/thoron progeny falls within 10 cm distance, thereby minimizing the contribution of errors due to tracks from deposited activity from nearby solid surfaces. After the exposure period of 90 days, the SSNTD films were retrieved and chemically etched in normality of 2.5 NaOH solution at 60 °C for 60 minutes with mild agitation throughout[20]. The exposure period is continued for all the seasons of a calendar year. The tracks recorded on all the three SSNTD films were counted using spark counter. A methodology developed using track densities to obtain individual equilibrium factors for radon and thoron by way of ventilation parameters[21] is employed in this study.

$$\mathbf{C_R\ (Bq\ m^{-3}) = T_m / (d\ S_m)}$$

$$\mathbf{C_T\ (Bqm^{-3}) = (T_f - d\ C_R\ S_{rf}) / (d\ S_{rf})}$$

where T_m is the track density of the film in membrane compartment, d is the period of exposure in days, S_m refers to the sensitivity factor of membrane compartment, T_f is the track density of the film in filter compartment, S_{rf} is the Sensitivity of ^{222}Rn in filter compartment, and, C_R and C_T is the concentration of ^{222}Rn and ^{220}Rn, respectively.

$$\mathbf{R_n\ (m\ WL) = (C_R\ F_R) / 3.7}$$

$$\mathbf{R_T\ (m\ WL) = (C_T\ F_T) / 0.275}$$

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

$$\mathbf{F_R = 0.104\ f_{RA} + 0.518\ f_{RB} + 0.37\ f_{RC}}$$

$$\mathbf{F_T = 0.91\ f_{TB} + 0.09\ f_{TC}}$$

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[21]. Equilibrium factor is determined using the working level concentrations, and the inhalation dose rates (*mSvy*$^{-1}$) is estimated by using UNSCEAR (2000)[22]:

$$\mathbf{D = 7\times[(0.17 + 9F_R)\ C_R + (0.11 + 32F_T)\ C_T] \times 10^{-3}}$$

Calibration procedure

The calibration were carried out at the BARC, Mumbai for the estimation of calibration factors[23-25]. The experiments were carried out separately for radon and thoron, in a setup of stainless steel chamber of 0.5 cubic meter volume. The calibration chamber has facility for imputing aerosols from an aerosol generator. The chamber has also got provisions for an online Lucas cell system in conjunction with an Alpha Guard for continuous measurement of radon gas concentration. The radon concentration inside the chamber was varied for different experimental conditions and compared with the Alpha Guard readings, radon or thoron, as the case may be, was introduced into the chamber from separate sources of Pylon, Canada. A laminar flow of monodispersed aerosol of di-2-ethylhexyl sebcate condensed on NaCl nuclei is used to generate aerosols to produce a laminar flow. The temperature of the system is maintained to obtain mono-dispersed aerosol of size 0.l25 μm diameter. Aerosol concentrations of the order of 10^4 to 10^5 particles per cubic centimeter of air were generated to stimulate the indoor environmental conditions. The activity median aero dynamic diameter for indoor aerosol is estimated to be 0.2 μm[26]. Aerosol was introduced for maintaining the equilibrium factors at the desired levels[27]. Decay pattern of the aerosol inside the chamber was studied and accordingly aerosols were fed into the chamber to maintain the desired number concentrations. Alpha Guard kept inside the chamber records the hourly average radon concentration. The online Lucas cell system was coupled to an alpha counting setup and counts were taken synchronizing with the timing of the Alpha Guard. The comparison of radon measured by the two systems for a wide range of concentrations, showed very good correlation with a slope equal to unity[25].

Calibration factor

Calibration factors are required to translate the recorded tracks in the expected SSNTD films into radon and thoron concentrations. The estimation of calibration factors for all the modes of exposures are described in detail[25] for the sake of continuity of the work presented.

Cup mode

Calibration factors (CFs) for radon and thoron gases in the cup mode were determined through a series of experiments. The CFs for radon (K_R) and for thoron (K_T) in terms of tr cm^{-2} per Bqdm^3 can be equated as

$$\mathbf{K_R = (24 \times T)/ (^{222}Rn \times H)}$$

$$\mathbf{K_T = (24 \times T)/ (^{220}Rn \times H)}$$

where, T is the tracks per unit area (tr cm^{-2}), ^{222}Rn is concentration of the radon gas (Bqm^{-3}) ^{220}Rn is the concentration of thoron gas (Bqm^{-3}) and H is the exposure time in hours.

Estimated calibration factors for radon in the membrane compartment is found to be slightly lower than that in the filter paper compartment. This may be due to the attenuation effect in the membrane. CF for thoron in the membrane cup is essentially zero and that in the filter paper cup is 0.017 tr cm^{-2}/Bq d m^3.

Bare mode

The definition of the CF for the bare mode has certain ambiguities. In the earlier approach, the CF for the bare detector was defined as the track density rate obtained per unit working level (WL)[28-31]. In reality, track formation rate in the bare mode is not a unique function of working level, but will depend on the equilibrium factor (F). If bare detector calibration factor is taken as k_B (tr cm^{-2}/Bqdm^3) of each species, it may be easy to show that this quantity is independent of the equilibrium factor as well as the incident energy of the alpha particles. For a given track density rate T (tr cm^{-2}d^{-1}) and working level (W_R for radon and W_T for thoron in mWL units) and the corresponding equilibrium factors, F_R and F_T, the calibration factors as defined above can be obtained for radon (k_{BR}) and for thoron (k_{BT}) respectively in terms of tr cm^{-2}/Bqdm^3 using the following expressions:

$$\mathbf{K_{BR} = (T/3.7\ W_R)\ (F_R/1+2F_R)}$$

$$\mathbf{K_{BT} = (T/0.275\ W_T)\ (F_T/2+ F_T)}$$

On the afore-mentioned concepts, CF was obtained for the species matrix for radon, thoron and their progeny concentrations. They were found to be nearly constant for a wide range (0.1-0.72) of equilibrium factors supporting the basic assumption of the approach. The results of the CFs for the cup mode and bare mode exposure for radon and thoron[25] are shown in Figure 2. The CF for radon and thoron are estimated as 0.020 and 0.019 trcm^{-2}/Bqdm^3, respectively and are of the same range. This confirms the assumption that the bare mode calibration factors are the same for the alpha emitters since they are functions of only the difference in the ranges and the lower and upper cut off energies of the detector. Hence for practical use, an average value of 0.020 tr cm^{-2}/Bqdm^3 may be used as the CF for radon and thoron in the bare mode exposure.

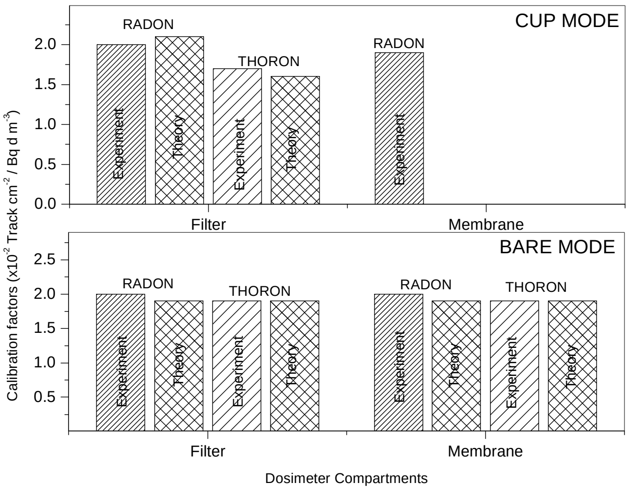

Figure 2 : Estimated calibration factors for bare mode and cup mode exposure

Comparisons of the theoretical and experimental values show close agreement with each other. The progeny working levels were estimated using the relations:

$$\mathbf{WL_R = C_R F_R / 3700}$$
$$\mathbf{= C_R (0.104F_{R-A} + 0.518\ F_{R-B} + 0.37\ F_{R-C})/3700}$$
$$\mathbf{WL_T = C_T F_T / 275}$$
$$\mathbf{= C_T (0.908F_{T-B} + 0.092\ F_{T-C} /275}$$

where F_R and F_T are the equilibrium factors for radon and thoron progeny, respectively, which are related to the ventilation rate.

Information obtained from the bare mode SSNTD is being used in conjunction with RFM for building a database on the equilibrium factors. The purpose is to obtain a representative equilibrium factor for the region under study. Thus, at present, the effective dose due to inhalation was estimated from the gas and progeny concentrations using the UNSCEAR equilibrium factors.

Spark counter

Analysis of etched tracks in SSNTDs by an optical microscope is difficult, time consuming and expensive task. The attempts for automatic track counting have led to the use of image analyzer instruments and spark counter systems. Spark counter technique, which is applicable to plastic detectors, provides a convenient, economical and fast method for track counting. The spark counting technique was developed by Cross-and Tommasino (1970)[32] and is discussed by several researchers[33-36]. The spark counter is a very simple and reliable instrument to measure the number of tracks which are nothing but – holes in LR – 115 films formed after etching. This is a compact unit designed primarily to count the number of tracks formed. It is found that counting of the tracks by spark method is the most convenient and efficient method. It essentially consists of a spark head, continuously adjustable high voltage and four digit LCD/LED display for counts. The spark head assembly of the spark counter has two electrodes fitted into a circular cylindrical base, made of acrylic material. One of the electrodes referred as 'spark head' has an area of exactly 1 cm^2 and the other electrode has a spring loaded contact that is electrically grounded. High voltage is applied across the spark head and the ground, then the etched film is placed on the electrode and an aluminized Mylar film is placed covering both the electrodes such that conducting side is facing the film and also makes contact with the grounded electrode. A cylindrical weight with transparent window is placed for viewing the spark.

Operation and working

The spark counter has to be stabilized for 30 to 45 min, before it is used to measure the counts. The chemically etched film was placed on the round electrode on spark head. As the potential increases there were no counts till potential reaches 250 V. The aluminized Mylar foil was placed on the etched film such that the counting surface was in contact with the etched face of the film and the grounded electrode. The heavy weight was placed on Mylar gently, without disturbing the film to maintain proper position and contact. At this stage an internal relay gets actuated and high voltage will be applied across the film. At each hole there will be a discharge and leads to one count and it will not be counted again because of evaporation of the aluminum at that spot. The cumulative count will be recorded on digital display. After some time when the duration between two consecutive pulses exceeds a preset time interval, the counting will stop. Then, the potential is increased by 10 volt. The counter weight and the Mylar foil were carefully removed without disturbing the etched film and that is cleaned with soft tissue paper without disturbing the sparked area. A fresh Mylar foil was kept along with the counter weight and the procedure is repeated. Thus by taking counts in steps of 10 volts, the optimum counting voltage of the spark counter was determined from the plateau obtained from a plot of track count against sparking voltage. The midpoint of the plateau region (~ 425 V) was chosen as the optimum voltage as shown in Figure 3.

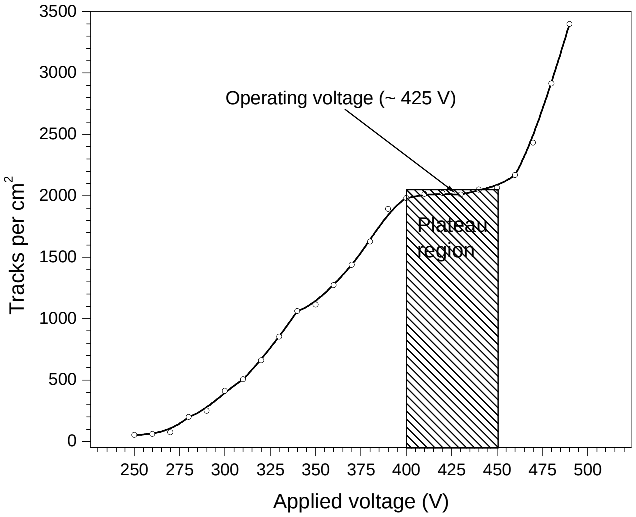

Figure 3 : Plateau of spark counter

RESULTS AND DISCUSSION

The TABLE 1 summarizes the values of radon concentration found in the different locations of Bangalore city and also the number of houses monitored in each area during 2007-2009. The arithmetic mean of radon concentration in monitored area varies from 17.24±1.29 to 85.89 ± 2.30 Bqm^{-3} with a mean of 33.38 ± 6.10Bqm^{-3}. The radon concentrations observed is low in Rajajinagar and higher concentrations are observed in Government Science College of Gandhinagara. The average indoor radon concentration reported for dwellings of different cities across the world varies between 8.7 Bqm^{-3} for Australia and 190 Bqm^{-3} for Saxony and Turingia of Germany, with a weighted arithmetic mean for all the cities considered of 40 Bq m^{-3}[1]. The observations made for Bangalore region also having the same range reported elsewhere.

TABLE 1 : Average radon concentration in each monitored locations of the city

Name of the Location	Radon concentration (Bq m^{-3})	Number of dwellings
Rajajinagar	17.24 ±1.29	11
Srinivasanagar	40.03 ± 1.91	10
Sheshadripuram	31.80 ± 3.15	10
Srirampuram	26.32 ± 3.21	15
Padhmanabhanagar	27.45 ± 1.72	15
Jayanagar	25.25 ± 1.66	15
Banashankari	26.45 ± 2.02	12
Malleshwaram	27.96 ± 2.92	12
Vijayanagar	25.46 ± 3.88	10
Gandhinagara	85.89 ± 2.30	10
Arithmetic Mean	33.38 ± 6.10	120

The average radon concentration for the different seasons and temperature of Bangalore city using SSNTD are tabulated in TABLE 2. The obtained concentration shows a clear seasonal variation for radon.

TABLE 2 : Variation of radon concentration and temperature in 20 dwellings of Jayanagar area, Bangalore city

Season	Period	Mean Temperature (?C)	Radon Concentration (Bq m^{-3})
Winter	December - February	20	22.56
Autumn	September - November	24	16.96
Rainy	June - August	30	11.44
Summer	March - May	35	10.99

The temperature profile shows the variations and is affecting the ventilation rate, showing maximum radon concentrations in winter and lower in summer. This may be due to the increased in radon exhalation and reduced ventilation as observed elsewhere[37-39].

Radon levels in closed environment are affected both by the degree of exchange with outdoor air as measured by the ventilation rate and by changes in the entry rate of radon rich air from the underlying soil and rocks. Since majority of the houses are well ventilated in summer season, indoor radon concentrations might be expected to be lower for summer than in winter season[40].

To get a clear idea of the spatial variations, the observed values are compared with the surveys made in different areas. The range and arithmetic mean with standard error for each location were estimated and are given in TABLE 3. The elevated radon levels are seen in poor ventilation and lower volume of the houses in all locations where most of the houses were built by local soil and sedimentary gravel. Some buildings with higher radon levels were found on gravel but all the lower values observed in Rajajinagar area. The reason being the existence of the subsurface 5 to 15 m deep clay layer is good barrier against radon emanation from ground water, especially when it is wet or frozen[41].

TABLE 3 : Area wise annual statistics of radon, thoron and their progeny levels and total dose rates in dwellings of Bangalore city

Area	Range				AM ± SE		Dose
	Concentration of ^{222}Rn (Bq m^{-3})	Concentration of ^{220}Rn (Bq m^{-3})	^{222}Rn progeny (mWL)	^{220}Rn progeny (mWL)	Concentration of ^{222}Rn (Bq m^{-3})	Concentration of ^{220}Rn (Bq m^{-3})	µSv h^{-1}
Rajajinagar	4.05 – 36.84	5.56 – 35.42	0.015 – 0.951	0.018 – 0.502	17.24 ±1.29	16.14 ±1.44	0.131
Srinivasanagar	29.82 – 50.29	13.74 – 56.94	0.118 – 1.910	0.041 – 0.711	40.03 ± 1.91	29.29 ± 4.32	0.274
Sheshadripuram	5.85–100.00	2.78 – 72.92	0.021 – 1.600	0.015 – 0.869	31.80 ± 3.15	19.88 ± 2.08	0.202
Srirampuram	10.99 – 65.93	6.18 – 30.91	0.061 – 1.163	0.018 – 1.860	26.32 ± 3.21	18.85 ± 1.66	0.177
Padhmanabhanagar	4.09 – 76.02	3.47 – 70.14	0.015 – 1.569	0.018 – 3.480	27.45 ± 1.72	25.95 ± 2.04	0.242
Jayanagar	4.09 – 80.70	4.86 – 63.19	0.021 – 2.245	0.012 – 1.761	25.25 ± 1.66	19.70 ± 1.27	0.180
Banashankari	5.85 – 89.47	1.37 – 66.67	0.021 – 4.467	0.012 – 1.293	26.45 ± 2.02	21.40 ± 2.20	0.191
Malleshwaram	5.85 – 92.98	2.08 – 47.92	0.020 – 2.261	0.016 – 4.831	27.96 ± 2.92	17.88 ± 1.57	0.189
Vijayanagar	11.70 – 99.42	6.79 – 37.50	0.048 – 1.482	0.024 – 0.938	25.46 ± 3.88	8.34 ± 1.27	0.247
Gandhinagara	73.68–100.02	10.99 – 72.92	0.264 – 4.467	0.030 – 1.025	85.89 ± 2.30	38.26 ± 5.40	0.493

Figure 4 shows the frequency distribution of radon concentrations in about 150 houses of different locations of Bangalore city. About 60% of indoor radon levels are found to vary between 20 and 39 Bqm^{-3}. The higher concentrations were observed in 6% of the studied houses, this may be due to the buildings without the basic concrete slab or the slab that was not properly built or already damaged[41]. 23% of buildings show radon concentration between 50–80 Bqm^{-3} are 40 year old, poorly constructed with several cracks in foundation, walls, basic slabs thorough which radon can easily enter the rooms[41].

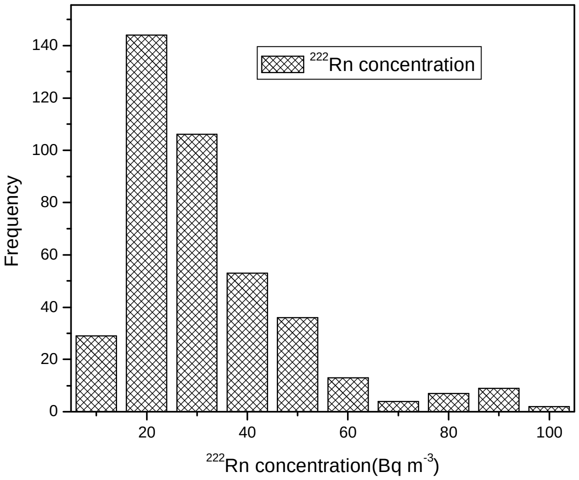

Figure 4 : Frequency distribution of activity range of radon concentration

The observed values of radon concentration are found comparable with variation observed in the country and ranges from 6.4 to 95.4 Bqm^{-3} with a Geometrical mean 25.5 Bq m^{-3}[42]. The houses selected in the present study are in the Bangalore city. The geology of this part forms predominantly a granite terrain with numerous varieties of granites, granitic gneiss, pegmatite, charnockites and so on. 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 color, texture and multiple intrusion relationships. The common rocks are pink, grey and porphyrite gneisses with large feldspars, black dolerite. These rocks forms geological band of a width 15-25 km[43,44]. Most of the studied houses in the city are constructed with cement and bricks and few were mud houses. These houses are constructed with local stone and rocks with thin plaster of cement as layer to the wall. In general the radon concentration was found higher in mud houses than in cement houses[45,46]. The ground floor of such houses is directly constructed on the top of soil with a coating of mud. The ground floor allows more radon to diffuse inside the houses because of higher porosity of materials used, which also justify our previous findings[47]. The emanation of radon may also contribute higher radon from rocks and local stones. In addition, the mud houses have small doors and a small window, which remain closed for most of the time to conserve the energy. Due to poor ventilation, the radon is accumulated inside the houses and thus results higher concentration.

The radon concentration was found highest in winter and lowest in summer. The winter/summer ratio was observed maximum while the winter/autumn ratio was found minimum. The high values in winter are mainly because of ventilation factor[40]. A comparison of indoor radon concentration for different seasons is shown in TABLE 4. The indoor radon is influenced mainly by the ventilation condition of the house. In most of the class rooms of the Government science college high radon concentration in summer is observed than in winter. This anomaly observed in the college is may be due the fact that the class rooms will be closed for longer duration in summer holidays (April to June). The winter /summer ratio in different locations are found to vary between 1.92 and 3.69 and this ratio is high compared to the ratios of winter/rainy and winter/autumn. This again depends on ventilation condition of the houses. The concentrations of radon and its progeny also follow the same trend as it was recorded maximum in summer

TABLE 4 : Relative indoor radon concentrations

Location	Number of Houses	W/S	W/R	W/A
Srirampura	20	2.10	1.89	1.36
Rajajinagar	11	2.99	1.40	1.40
Vijayanagar	10	3.03	1.45	1.41
Sheshadripuram	10	3.69	1.94	1.76
Malleshwaram	12	2.76	1.31	1.21
Jayanagar	15	3.38	1.99	1.83
Banashankari	12	2.03	1.21	1.08
Padmanbhanagar	15	2.83	1.30	1.24
Sinivasnagar	10	2.39	1.58	1.54
Gandhinagara	10	1.92	1.58	1.52
MAX		3.69	1.99	1.83
MIN		1.92	1.21	1.08
AM		2.71	1.56	1.43
GM		2.65	1.54	1.43

Winter / Summer - W/S, Winter / Rainy - W/R, Winter/ Autumn - W/A

and minimum during winter[37-39]. However the thoron and its progeny concentration was found maximum during winter and minimum during rainy.

This behavior is may be due to low emanation rate of thoron during rainy season and also it may be due to the possibility of brief half life, it cannot escape easily from the soil capillaries that are mostly occupied by water during the rainy season[48].

CONCLUSION

It is observed that the concentrations of indoor radon, thoron and their progeny levels are more in poor ventilated houses as well as smaller volume of the room than in well ventilated rooms and rooms of larger volume. The results observed for Bangalore are well within the limits of International Commission on Radiological Protection. The higher radon concentration observed may be due to the presence of radioactive contents in the building materials used for construction of the houses. It is suggested that the room should be well ventilated and building construction materials must by free from radioactive species to minimize the radon, thoron concentrations in the dwellings.

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