

Estimation of indoor radon levels and absorbed dose rates in air for Chennai city, Tamilnadu, India

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Abstract Indoor radon concentrations were measured inside different types of dwellings in Chennai city on a quarterly basis using a solid state nuclear track detector (LR-115, Type II) for 1 year. Significant seasonal variations were observed. The average highest radon concentration was observed during winter (86.08 Bq m^{-3}) and the lowest in summer (42.50 Bq m^{-3}). The radon concentrations were also varying on the basis of different floor-covering materials. For a given season, the average maximum radon concentration was observed with cement flooring (118.96 Bq m^{-3}) followed by tiles (75.25 Bq m^{-3}) and marbles (74.04 Bq m^{-3}). Also, outdoor soil samples were collected in and around the same dwellings and determined the radioactivity content of three primordial radionuclides (^{238}U , ^{232}Th and ^{40}K) in these soil samples using NaI(Tl) scintillation detector based gamma-ray spectrometer.

Keywords Radon · Environmental radioactivity · Absorbed dose rate · Flooring materials

Introduction

Radon and its daughters are present in the atmosphere, especially at places where the ventilation is the lowest such as mines. Quantification of radon and their progeny, especially inside the dwellings, is necessary when determining the background radiation level to the population [11]. Internal exposures due to the intake of naturally occurring short-lived daughter products of ^{222}Rn (^{218}Po , ^{214}Pb , ^{214}Bi and ^{214}Po) in the indoor environment can pose a significant risk to human health [3]. The radon concentration inside a room is dependent on the concentration of radium isotopes in the building materials and the porosity of the building materials. The emanation of gaseous radon from the ground is also of importance [11]. The ventilation pattern, type of building materials, topography and meteorological parameters play a very important role in resultant concentration of radon in the dwellings. Subba Ramu et al. [12] also reported that ventilation and atmospheric pressure have definite influence on the levels of radon concentration. Higher radon levels are associated with igneous rocks, such as granite, and lower radon levels with sedimentary rocks with some exceptions in case of shale and phosphate rocks [5].

Human beings are exposed outdoors to the natural terrestrial radiation that originates predominantly from the upper 30 cm of the soil [7]. The dose rates vary from one place to another depending upon the concentration of the primordial radionuclides present in soil. The presence of primordial radionuclides and their daughter products in earth's crust, besides cosmic rays, pose exposure risks

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externally due to their higher energy gamma-ray emissions and internally due to radon and its progeny that emit alpha particles [1, 13].

As part of a comprehensive country-wide radon mapping study, the present study of estimation of radon concentration in Chennai city dwellings, one of the four major metropolitan cities of India, was undertaken. Towards this, different types of dwellings were selected. The variation in indoor radon concentration was investigated on the basis of seasonal variation as well as the type of building materials (marble, tiles and cement floorings). Also, outdoor soil samples were collected in and around the same dwellings and determined the radioactivity content of three primordial radionuclides in these soil samples (^{238}U , ^{232}Th and ^{40}K) using NaI(Tl) scintillation detector based gamma-ray spectrometer. A preliminary study of radon and thoron measurements in the dwellings of Madras city was reported by Lakshmi et al. [6]. In this study, grab sampling technique was employed which is qualitative.

Materials and method

Description of study area

Chennai city is on the southeast coast of India in the northeast of Tamilnadu State on a flat coastal plain known as Eastern Coastal Plains. The Chennai city can be said as gateway to south India. Forty-two sample locations (dwellings) were selected along the length and breadth of the city suburbs and the same are listed in Table 1 and numbered as S1–S42. These locations are shown in Fig. 1.

Measurement of radon concentration using solid state nuclear track detectors (SSNTDs)

Four LR-115 type II track detectors (size 2.5×2.5 cm), a widely used SSNTD for estimation of radon, were affixed on a thick plastic card board. These boards are suspended inside the dwellings at a minimum height of 1 m from the ceiling in the dwellings to take care of the plate-out effect which is to avoid the depletion of radon daughter's concentration in the air. After exposure for about 3 months, the detectors were collected and replaced by fresh ones at end of each quarter, thus covering all the four seasons in 1 year. The exposed SSNTDs (LR-115 type II films) were retrieved and etched in 2.5 N NaOH at 60 °C for 110 min in a constant temperature bath. After etching, the detectors were peeled off from the plastic base and recorded tracks were counted using a spark counter.

Table 1 Seasonal variation of radon concentration (Bq m^{-3}) at different locations of Chennai city

Site	Location	Radon concentration (Bq m^{-3})			
		Summer	Rainy	Autumn	Winter
S1	Adayar ^b	30.18	67.94	64.91	119.29
S2	Ambattur ^b	30.62	73.55	58.52	110.28
S3	Anna nagar ^b	52.43	94.24	68.16	98.53
S4	Chrompet ^d	51.09	61.32	57.89	65.60
S5	Egmore ^d	NA ^a	37.02	21.68	77.97
S6	Jamalia ^b	NA ^a	39.07	34.09	44.76
S7	Kaniampakkam ^d	24.99	75.19	64.61	128.40
S8	Kannathur	NA ^a	NA ^a	NA ^a	NA ^a
S9	Kilpauk ^b	48.19	65.29	62.25	70.80
S10	Kodampakkam ^d	117.18	166.32	157.39	216.11
S11	Kottur ^d	37.93	59.67	51.40	120.76
S12	Koyambedu ^c	NA ^a	20.84	21.01	35.87
S13	Manali ^d	38.50	71.47	68.39	72.05
S14	Mehta nagar	NA ^a	NA ^a	NA ^a	NA ^a
S15	Minjur ^c	NA ^a	32.18	NA ^a	40.02
S16	Mogaper west ^c	NA ^a	56.06	34.71	78.50
S17	Mylapore ^b	NA ^a	51.04	40.19	65.82
S18	Nanganallur ^b	43.78	68.65	68.71	89.44
S19	Neelangari ^b	NA ^a	37.01	28.52	42.81
S20	Pammal ^b	28.78	60.15	56.55	79.55
S21	Pattabiram ^d	32.09	50.24	46.58	75.50
S22	Peravallur ^b	44.36	96.32	49.71	93.72
S23	Perungudi ^b	34.25	39.85	40.02	45.43
S24	Poonamalle ^b	28.29	31.19	36.06	54.33
S25	Puzhal ^c	31.34	83.09	61.49	116.11
S26	Ramavaram ^c	23.62	45.12	26.71	NA ^a
S27	Redhills ^d	90.27	NA ^a	177.06	195.28
S28	Saidapet ^b	NA ^a	29.96	26.11	35.97
S29	T. Nagar ^b	34.53	46.59	35.91	53.74
S30	Tambaram	NA ^a	NA ^a	NA ^a	NA ^a
S31	Teachers colony ^b	36.27	65.40	42.27	95.28
S32	Thirunindravur	66.30	143.73	61.68	133.54
S33	Thiruvanniyur ^c	36.47	53.43	39.32	NA ^a
S34	Thoraipakkam ^b	42.69	50.15	44.11	61.99
S35	Triplicane ^b	30.38	38.85	27.12	48.26
S36	Valsaravakkam ^b	25.81	76.42	38.58	81.92
S37	Vandalur ^c	43.02	69.82	55.42	93.82
S38	Velachery ^b	NA ^a	36.29	25.45	40.31
S39	Veperry ^b	31.87	50.03	34.87	66.00
S40	Villivakam ^c	37.94	51.97	47.45	79.90
S41	Vyasarpadi ^b	53.75	70.92	64.04	120.42
S42	West mambalam ^b	48.12	97.99	69.81	136.76
	Minimum	23.62	20.84	21.01	35.87
	Maximum	117.18	166.32	177.06	216.11
	Average	42.50	62.22	52.86	86.08

^a NA not available (Due to damage of films during chemical etching), ^b tiles flooring houses ^c marble flooring houses, ^d cement flooring houses

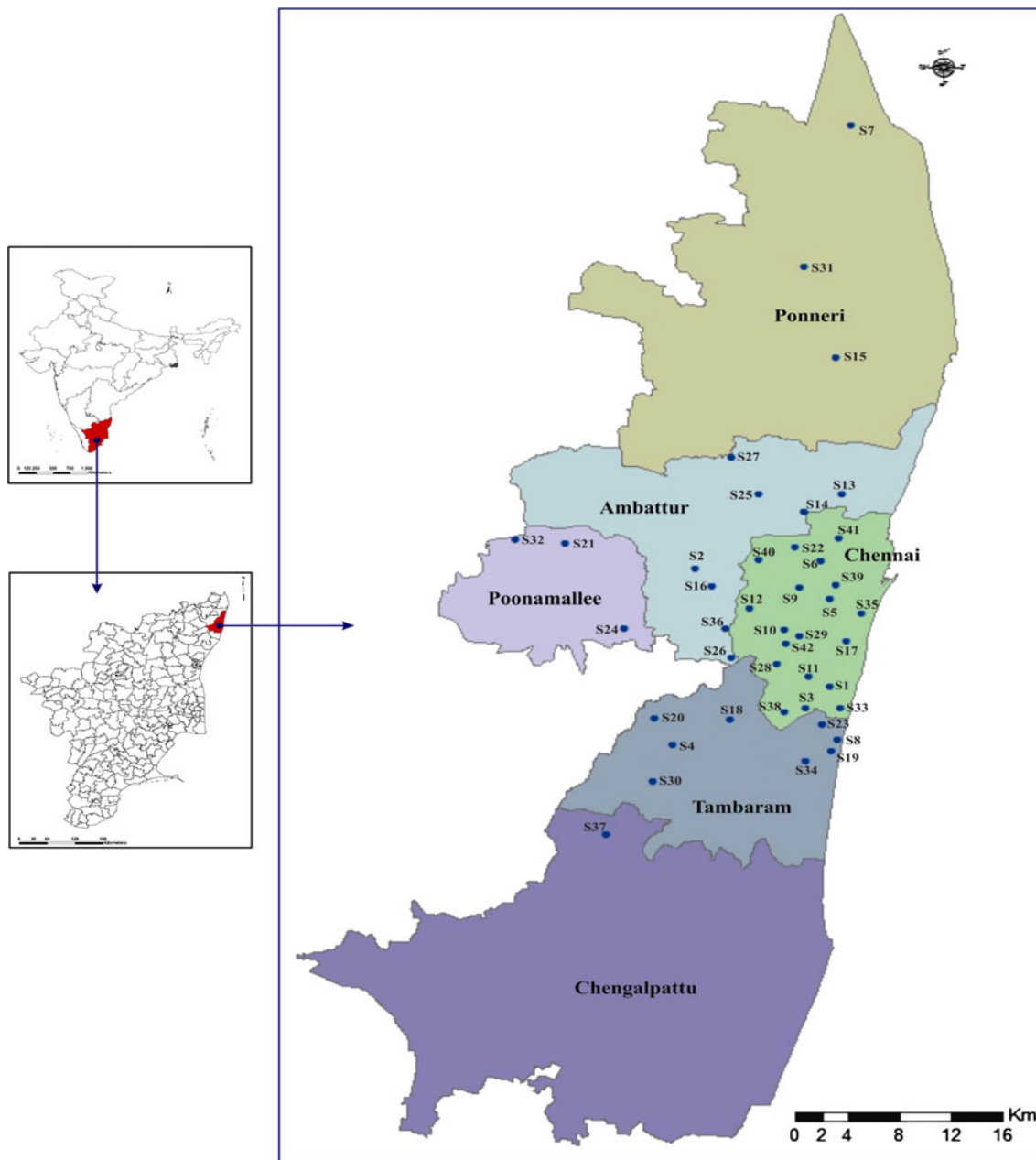


Fig. 1 The map of study area in Chennai city

Spark counter

The LR-115 type II films (detectors) were placed on the electrode which has an area of 1 cm², and then the aluminised foil (Mylar film) was kept to establish contact with the two electrodes and a pre-sparking high voltage is applied. The aluminised side of the plastic foil is in contact with the thin film detector. A relatively heavy weight disc is kept on top of the aluminised plastic foil to have an intimate contact between the thin film (LR-115 type II) and the electrodes. The purpose of pre-sparking the detector prior to the counting is to convert any latent

tracks (partially developed holes) into full ones if any residual thickness is remaining after etching, which is expected due to the difference in energies of the incident alpha particles. Then, without disturbing the thin film detector, the Mylar film is replaced by a fresh one and the operating voltage between the electrodes is set and the counts noted. Three measurements for each detector film were taken and their average count was used to find the track density (Tracks/cm²). From the measured track density, the concentration of radon was estimated using a well-established calibration factor (0.02 tracks/cm²/day per Bq m⁻³) [2, 15].

Soil sample preparation techniques

Soil samples were collected from a pit of $30 \times 30 \times 15$ cm length, width and depth, respectively. The dugout samples were uniformly mixed, sieved and air dried. The samples were further dried in an oven at temperature of 100–120 °C for 1 h to remove the moisture content and stored in an airtight 250 ml plastic container for 1 month before subjecting them to gamma ray spectral analysis. This is to ensure attaining secular equilibrium between radium and its short-lived daughter products. The net weight of the samples was determined before counting.

Gamma ray-spectroscopy

A $3'' \times 3''$ NaI(Tl) scintillation detector based gamma-ray spectrometer is used for spectral measurements to enable one to cover the entire energy range of the naturally occurring radionuclides up to 3 MeV (to cover 2.6 MeV energy emitted by ^{208}Tl , one of the daughter products of ^{232}Th). The detector is shielded by 15 cm thick lead on all sides including at the top to reduce background due to cosmic ray component by almost 98%. The inner sides of the lead shielding are lined by 2-mm thick cadmium and 1-mm thick copper to cut off lead X-rays and cadmium X-rays, respectively. These graded-lining shield materials further reduce the background especially in the low energy region. Standard sources of the primordial radionuclides obtained from IAEA in the similar geometry and having soil equivalent matrix, were used to determine the efficiency of the detector for various energies.

The soil samples were placed on the top of $3'' \times 3''$ NaI (Tl) detector and count spectra were obtained for each of the soil sample. The net activity content of the three primordial nuclides viz. ^{40}K , ^{232}Th and ^{238}U are deduced from the count spectra. The region under the peaks corresponding to 1.46 (^{40}K), 1.764 (^{214}Bi) and 2.614 MeV (^{208}Tl) energies are considered to arrive at the radioactivity levels of ^{40}K , ^{238}U and ^{232}Th , respectively. The below detectable limit (BDL) of each of the three primordial radionuclides is determined from the background radiation spectrum obtained for the same counting time as was done for the soil samples. The estimated BDL values are 2.22 Bq.kg^{-1} for ^{238}U , 2.15 Bq.kg^{-1} for ^{232}Th and 8.83 Bq.kg^{-1} for ^{40}K .

Results and discussion

The alpha tracks using the spark counter were counted thrice for each detector film and the average was calculated. The track densities were then converted into radon concentration by applying the calibration factor for LR-115, Type II film SSNTDs.

The track density was calculated using the equation,

$$T_d = \frac{\text{Number of Tracks (Counts)}}{\text{Area of the electrode (1cm}^2\text{)}} \quad (1)$$

Concentration of radon in Bq m^{-3} was calculated using the formula,

$$Rn(\text{Bq m}^{-3}) = T_d - T_b/k \times t \quad (2)$$

where T_d represents the track density per cm^2 , T_b is the background track density per cm^2 , t is the number of day's exposure, and k represents the calibration factor ($0.02 \text{ tracks/cm}^2/\text{day per Bq m}^{-3}$) of the LR-115 film (Type II). Table 1 presents the minimum, maximum and average concentration of radon for all the four seasons. The radon concentration varied from 23.62 to 117.18 Bq m^{-3} with an average of 42.50 Bq m^{-3} for summer season, $20.84\text{--}166.32 \text{ Bq m}^{-3}$ with an average of 62.22 Bq m^{-3} for rainy season, $21.01\text{--}177.06 \text{ Bq m}^{-3}$ with an average of 52.86 Bq m^{-3} for autumn seasons, $35.87\text{--}216.11 \text{ Bq m}^{-3}$ with an average of 86.08 Bq m^{-3} for winter seasons.

The maximum concentration of radon was observed for winter season, which is approximately twice as compared to summer. This variation must be due to closing of doors and windows of the houses during winter seasons for most of the times, which reduces the air ventilation inside the houses and resulting in accumulation of radon emanating from walls and floors [9]. Radon levels in closed environment are affected both by the degree of exchange with outdoor air as measured by ventilation rate and by changes in the entry rate of radon-rich-air from the underlying soil and rocks [16].

Type of flooring materials

The radon concentration in indoors for three different flooring materials is shown in Fig. 2. The most common types of flooring materials used in Chennai city are: (a) Tiles, (b) Marble and (c) Cement. Tiles are available in

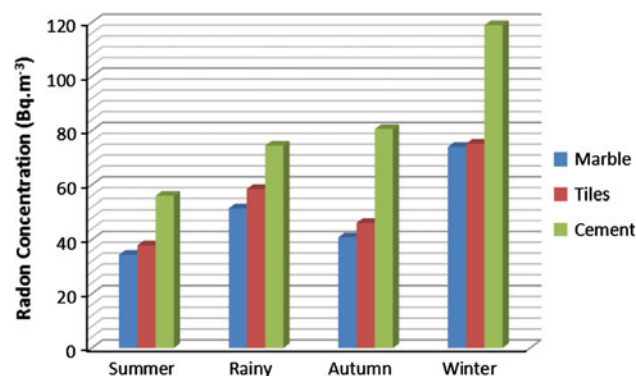


Fig. 2 Seasonal variation of different flooring materials in Chennai city dwellings

Table 2 Average radon concentration (Bq m⁻³) for different types of flooring materials

Seasons	Tiles	Marble	Cement
Summer	35.20	30.33	50.05
Rainy	58.50	51.56	74.46
Autumn	46.18	40.87	80.63
Winter	75.25	74.04	118.96

Table 3 Average radioactivity content of primordial radionuclides in the soil samples of Chennai city

	Activity concentration (Bq kg ⁻¹)		
	²³⁸ U	²³² Th	⁴⁰ K
Minimum	BDL ^a	19.65 ± 4.05	284.96 ± 22.90
Maximum	39.41 ± 8.23	135.14 ± 16.71	729.29 ± 51.86
Average	17.04 ± 6.06	55.29 ± 9.43	499.99 ± 37.31
World average	33	45	420

^a BDL (below detectable limit)

different patterns, designs and utility options. Tiles are normally costlier than the cement concrete flooring and its cost depends upon the type of tile being used. Various types of flooring tiles in India include ceramic tiles, vitrified tiles and mosaic tiles, etc.

In Table 1, the details of flooring materials used in different locations have been indicated. In Table 2 is given the average radon concentration levels for the three different flooring materials for all the four seasons. These results are given in the form of bar chart in Fig. 2. It may be seen from the Table 2 that the radon concentration levels inside the dwellings having tiles and marble as flooring materials, are almost same excepting for the seasonal variations. However, in the dwellings having cement as the flooring materials, the radon concentrations are comparatively higher in all the four seasons.

Yu et al. [17] have reported that plastic is the most effective material to inhibit radon exhalation from the floor (due to its non-porosity), while mud and concrete floor surfaces have the highest radon exhalation rates. This may be the reason for lower radon concentration of radon and

their progeny in the dwellings having flooring materials covered by tiles, marbles, etc.

It is reported by Sivakumar et al. [10] that another predominant source of indoor radon is due to the natural radioactivity content in the soil used for the construction purpose. Ramola et al. [8] also observed that the ground surface of the dwellings allows more gaseous radioactive ²²²Rn isotopes to diffuse inside the dwellings because of higher porosity of the kind of flooring materials such as cement, etc., used in construction of dwellings.

Towards establishing this fact in the present study, soil samples in and around the same dwellings (where radon concentrations was determined) were collected and the radioactivity content of the naturally occurring three primordial radionuclides (²³⁸U, ²³²Th and ⁴⁰K) was estimated by subjecting the soil samples to gamma ray spectral analysis. In Table 3 is given the measured specific activities of ²³⁸U, ²³²Th and ⁴⁰K in Bq kg⁻¹ in the soil samples. The average activity content of ²³⁸U, ²³²Th and ⁴⁰K isotopes are 17.04 ± 6.06 Bq kg⁻¹, 55.29 ± 9.43 Bq kg⁻¹ and 499.99 ± 37.31 Bq kg⁻¹, respectively. The absorbed dose rate in air (external exposure) at 1 m above the ground surface depends on the specific activity of ²³⁸U, ²³²Th and ⁴⁰K in the soil. The measured specific activity values of ²³⁸U, ²³²Th and ⁴⁰K are converted into absorbed dose rates using [14] conversion factors of 0.462, 0.604 and 0.0417, respectively. These factors are used to arrive at the total absorbed dose rate using the following equation:

$$D \text{ (nGy h}^{-1}\text{)} = (0.462A_U) + (0.604A_{Th}) + (0.0417A_K) \tag{3}$$

where A_U, A_{Th} and A_K are the activity concentrations of ²³⁸U, ²³²Th and ⁴⁰K in Bq kg⁻¹, respectively. The estimated absorbed dose rate due to all the three primordial radionuclides for Chennai city soil samples is 62.11 ± 10.05 nGy h⁻¹ (Table 4). This is comparable to the world average (Population-weighted value) value of 60 nGy h⁻¹. It is observed that the largest contribution to the absorbed dose in air is due to ²³²Th (53.75%), followed by ⁴⁰K (33.56%) and ²³⁸U (12.67%). The percentage values for the three radionuclides for the world as given by UNSCEAR [14] are 45, 30 and 25% for ²³²Th, ⁴⁰K and ²³⁸U, respectively.

The above results indicate that due to comparatively higher level of ²³²Th content in the soil samples of Chennai

Table 4 Estimation of absorbed dose rate (nGy h⁻¹) in air for Chennai city

Radionuclides	Absorbed dose rate in air (nGy h ⁻¹)			World average
	Minimum	Maximum	Average	
²³⁸ U	1.03 ± 1.03	18.21 ± 3.80	7.87 ± 2.80	15
²³² Th	11.87 ± 2.45	81.62 ± 10.09	33.39 ± 5.69	27
⁴⁰ K	11.80 ± 0.95	30.41 ± 2.16	20.85 ± 1.56	18
Total dose	29.81 ± 4.43	118.54 ± 15.9	62.11 ± 10.05	60

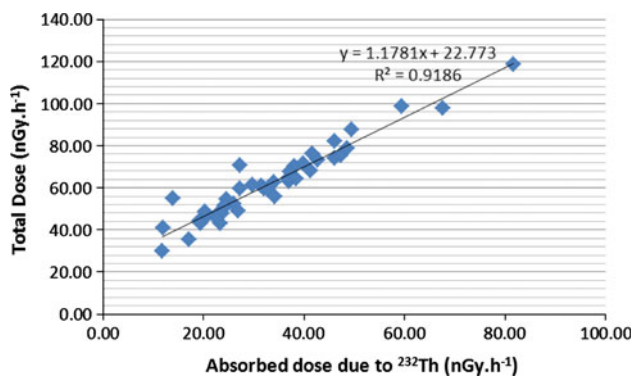


Fig. 3 Correlation between the absorbed dose due to ^{232}Th and total dose

city, the houses constructed with cement flooring and not further covered by external flooring materials (Tiles, Marbles, etc.), the radon concentration in such dwellings is found to be higher. However, the higher concentration of radon can also additionally be attributed to ventilation and flooring and other building materials. Since the contribution of absorbed dose rate due to ^{232}Th is more than 50%, an attempt was made to examine the existence of any correlation between the total absorbed dose due to all the three primordial radionuclides and ^{232}Th alone. This is given in Fig. 3. A reasonably acceptable correlation coefficient of 0.9186 could be obtained.

Conclusion

The establishment of radon levels in the dwellings of one of the four metropolitan cities of India viz., Chennai will be an useful data to the on-going country's radon mapping network. The study covered all the four seasons and, as expected, the radon levels are the highest in winter season though very much within the ICRP-103 [4] recommended limit of 300 Bq m^{-3} as applicable for the dwellings. The dwellings with cement as flooring materials indicate higher radon levels as compared to other flooring materials (Tiles, Marbles). The absorbed dose rate for the population residing at Chennai city is 62 nGy h^{-1} , estimated on the basis of gamma-ray spectral analysis of large number of soil samples.

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