I J C R M
International Journal of Contemporary Research In Multidisciplinary

Research Article

Estimation of Indoor Radon, Thoron and Progeny Concentration in District Bijnor, Uttar Pradesh, India

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DOI: https://doi.org/10.5281/zenodo.21205241

Abstract

Indoor exposure to Radon (^{222}Rn), Thoron (^{220}Rn), and their progeny is one of the main contributors to natural radiation dose received by humans. In this work, indoor levels of these radionuclides were investigated in residential houses of Bijnor district, Uttar Pradesh, India. The study mainly focused on understanding how concentrations change with seasons, how they are distributed across dwellings, and how different types of houses influence their levels. For measurements, passive twin-chamber single-entry pinhole dosimeters coupled with LR-115 type II solid-state nuclear track detectors (SSNTDs) were used. Monitoring was carried out over a period of one year, divided into four seasons of nearly 90 days each. The track densities obtained after exposure were converted into concentrations of 222Rn, 220Rn, and their progeny using standard calibration relations. A clear seasonal variation was observed in both 222Rn and 220Rn concentrations (Table 1). 222Rn values ranged from 16.20 ± 1.17 to 44.31 ± 1.93 Bq/m³. whereas 220Rn varied between 6.44 ± 0.74 and 16.38 ± 1.17 Bq/m³. The highest concentrations were recorded during Season 2, while the lowest appeared in Season 4. This pattern is likely linked to differences in ventilation and prevailing atmospheric conditions during these periods. Similar behavior was noted for the equilibrium equivalent concentrations of radon (EERC) and thoron (EETC). The distribution pattern of measured concentrations (Fig. 4 and Fig. 5) does not follow a symmetric trend. Instead, the majority of dwellings fall within lower concentration ranges, while relatively fewer exhibit higher values. This positively skewed distribution reflects the influence of indoor environmental conditions, particularly variations in ventilation practices, occupancy behavior, and structural characteristics of the dwellings. Since the monitoring was conducted in well-defined seasonal intervals of 90 days (September–November, December–February, March–May, and June–August), the observed variability can be reasonably associated with seasonal changes in air exchange rates and indoor confinement conditions.When results were compared across different dwelling types (Fig. 6 and Fig. 7; Table 2),
noticeable differences emerged. Houses with mud flooring showed higher average concentrations, 57.55 Bq/m³ for 222Rn and 19.01 Bq/m³ for 220Rn than those constructed with brick and cement. This suggests that direct contact with soil and the nature of building materials play an important role in determining indoor levels. The annual mean concentrations were estimated to be 28.56 Bq/m³ for 222 Rn and 10.45 Bq/m³ for 220Rn. These values remain well within the limits recommended by international radiation protection guidelines. Based on these observations, indoor radiation levels in the study area can be considered safe, with variations primarily controlled by seasonal changes and housing characteristics.

Manuscript Information

- **ISSN No:** 2583-7397
- **Received:** 11-06-2026
- **Accepted:** 30-06-2026
- **Published:** 05-07-2026
- **IJCRM:**5(SP1); 2026: 71-78

- **Plagiarism Checked:** Yes
- **Peer Review Process:** Yes

How to Cite this Article

Rajpoot L, Kumar T, Kumar P, Rawat R. B. S. Estimation of Indoor Radon, Thoron and Progeny Concentration in District Bijnor Uttar Pradesh, India. Int J Contemp Res Multidiscip. 2026;5(SP1):71-78.

Access this Article Online

www.multiarticlesjournal.com

KEYWORDS: Radon, Thoron, DRPS and DTPS, SSNTDs, Ionising Radiation.

1. INTRODUCTION

Natural radiation is an unavoidable component of the environment and contributes significantly to the radiation dose received by humans. Among the various sources of natural radiation, ^{222}Rn (Radon) and ^{220}Rn (Thoron) gases are considered particularly important due to their ability to accumulate in indoor environments and deliver radiation dose through inhalation[1]. ^{222}Rn is a radioactive noble gas produced during the decay of ^{238}U present in rocks and soil. ^{220}Rn, on the other hand, originates from the ^{232}Th decay series[2], [3]. Both gases are colourless, odourless, and chemically inert, allowing them to migrate through soil pores and building materials into indoor spaces[4]. Once inside a dwelling, they decay into a series of short-lived progeny which attach to aerosols and dust particles in the air. These radioactive particles can be inhaled and deposited in the respiratory tract, delivering radiation dose to lung tissues[5], [6]. Due to this mechanism, ^{222}Rn and its progeny are recognized as one of the major contributors to the natural radiation exposure of the population and have been identified as the second leading cause of lung cancer after smoking by the World Health Organization[2].

The concentration of indoor ^{222}Rn and ^{220}Rn varies widely depending on several factors including geological characteristics, soil permeability, building materials, house construction style, ventilation rate, and climatic conditions. Seasonal changes may also influence indoor concentrations due to variations in atmospheric pressure, temperature gradients, and air exchange rates[7], [8]. In India, several studies have been conducted in different regions to evaluate indoor ^{222}Rn levels; however, data from many districts are still limited. Bijnor district, located in the western part of Uttar Pradesh, lies in the fertile Indo-Gangetic plains where geological and environmental conditions may influence the migration of naturally occurring radionuclides. The present investigation was therefore undertaken to measure indoor ^{222}Rn and ^{220}Rn concentrations in residential dwellings of Bijnor District, evaluate their seasonal variation, determine equilibrium equivalent concentrations of their progeny, and compare the results with internationally recommended safety limits[9], [10].

Study Area

Bijnor district is situated in the north-western part of Uttar Pradesh, India, and forms a part of the Indo-Gangetic alluvial plains. The region lies approximately between latitudes 29°N to 30°N and longitudes 78°E to 79°E. The district is characterized by fertile alluvial soil deposits formed by riverine systems of the Ganga basin. The climate of the region is typically subtropical, with distinct seasonal variations including 4 seasons. Residential buildings in the district are generally constructed using bricks, cement, sand, and concrete materials. Some houses may also contain mud-based construction elements, especially in rural areas. Differences in building design, floor structure, ventilation openings, and room occupancy patterns may lead to variations in indoor ^{222}Rn and ^{220}Rn concentrations[11], [12].

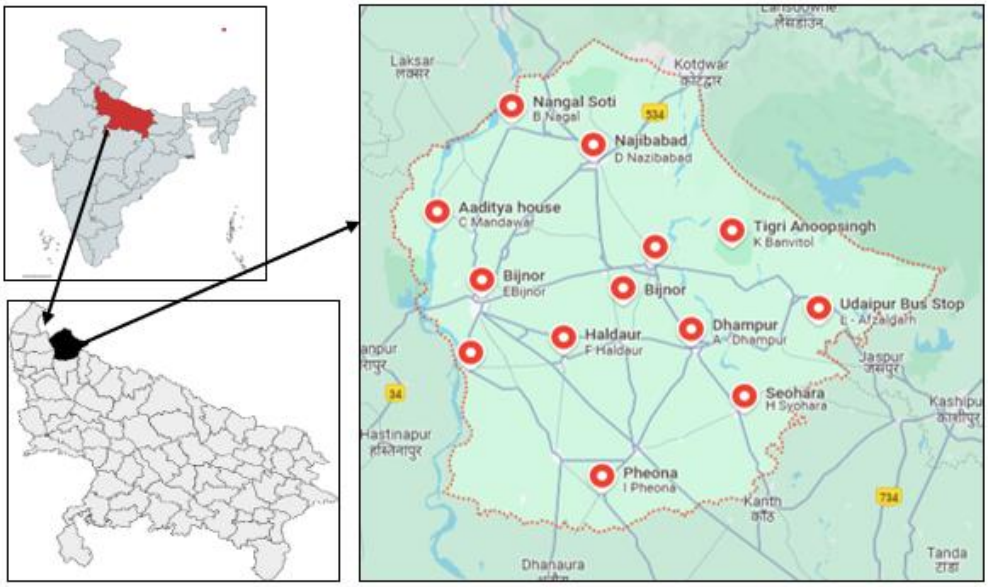

Fig. 1: Map of the Study Area: Bijnor District, Uttar Pradesh

2 .MATERIALS AND METHODS

This study investigates indoor concentrations of ^{222}Rn and ^{220}Rn, along with their radioactive decay products, in dwellings of the Bijnor district. To ensure accurate assessment, two complementary passive techniques are used. The twin chamber pinhole dosimeter, equipped with Type II LR-115 solid-state nuclear track detectors[13], measures ^{222}Rn and ^{220}Rn while Direct Radon Progeny Sensors (DRPS) and Direct Thoron Progeny Sensors (DTPS) measure the concentrations of their respective progeny perorally using selective detection of alpha particles[14].

3.1 Dosemeter

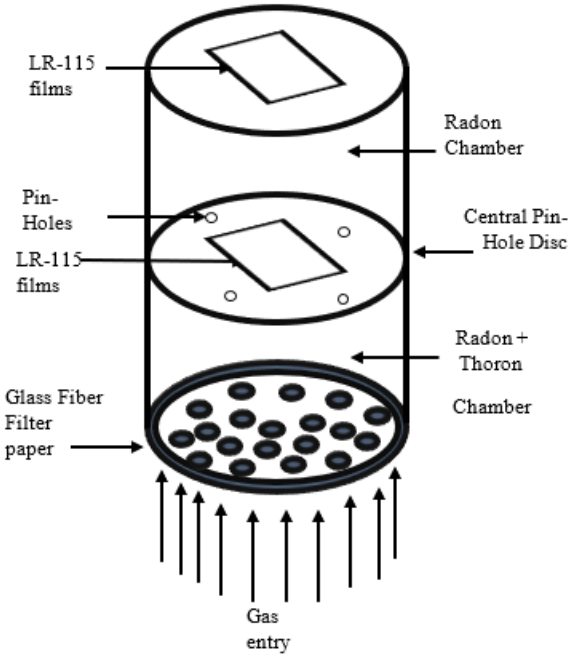

Fig. 2: Schematic Diagram of the LR-115 Dosimeter

^{222}Rn and ^{220}Rn measurements were carried out using passive twin-chamber single-entry pinhole dosimeters (Fig. 2) equipped with LR-115 type II solid-state nuclear track detectors (SSNTDs). This technique is widely used for long-term environmental monitoring because of its reliability, simplicity, and ability to provide integrated measurements over extended exposure periods. The dosimeter consists of two chambers separated by a partition. One chamber allows entry of both ^{222}Rn and ^{220}Rn gases, while the other chamber is designed to allow only ^{222}Rn diffusion due to the presence of a pinhole entry system. This configuration enables the simultaneous estimation of ^{222}Rn and ^{220}Rn concentrations from the track densities recorded in the detectors[15]. For the present study, dosimeters were installed in selected residential dwellings across different locations within Bijnor district. Care was taken to place the detectors at a height of approximately two meters from the floor level, representing the typical breathing zone for occupants. The dosimeters were positioned away from doors, windows, kitchens, or direct air drafts to minimize the influence of localized ventilation effects[16], [17], [18]. The monitoring program was conducted over a period of one year separated into four seasons of equal 90 days named as season 1, season 2 , season 3 and season 4 dated as 1 September 2023 to 29 November 2023 , 30 November 2023 to 27 Feb 2024, 28 Feb 2024 to 27 may 2024 and from 28 May 2024 to 25 august 2024 ,respectively, in order to capture seasonal variations in indoor radionuclide concentrations.

3.2 DTPS and DRPS

Progeny of ^{222}Rn and ^{220}Rn is measured by Direct Radon Progeny Sensors (DRPS) and Direct Thoron Progeny Sensors (DTPS) also equipped by LR 115 type II SSNTDs. In the figure 3(a) it is shown that in DTPS, the detector LR 115 film is capped with an absorber aluminium mylar of thickness 50 µm while in DRPS, the detector film is capped by a 37 µm thick cap of a combination of aluminium mylar and LR115 film[14], [19], [20].

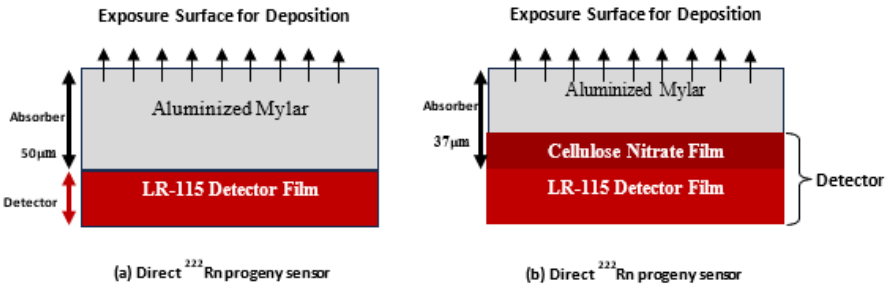

Fig. 3: DRPS and DTPS diagram

At the end of each exposure cycle, the detectors were carefully retrieved and replaced with new ones for the subsequent season. After completion of the exposure period, the LR-115 detectors were chemically etched in a 2.5 N sodium hydroxide (NaOH) solution maintained at a temperature of 60 °C for 90 minutes[16], [21]. This etching process enlarges the latent alpha particle tracks produced during exposure, making them visible for counting. The etched detectors were then washed thoroughly with distilled water and allowed to dry under controlled conditions. The developed alpha tracks were subsequently counted using a spark counter, which provides accurate measurement of track density[16], [22]. ^{222}Rn and ^{220}Rn concentrations were calculated using calibration factors discussed in "Standard formula used" section, formula to calculate the ^{222}Rn and ^{220}Rn concentrations (C_R) and (C_T) respectively is given in equation 1 and 2. EERC and EETC were also estimated using standard equilibrium factors which is again discussed in section "Standard formula used" and equations 3 and 4 are used as formula to calculate EERC and EETC[23], [24]. Statistical uncertainties in the measurements were evaluated using Poisson counting statistics and the corresponding errors were reported along with the calculated concentration values.

3.3 Standard Formula Used

The track densities obtained from the LR-115 detectors of pin hole dosimeters were analysed using following equations (1) and (2)[23], [24].

$$C_R = \frac{T_1 - B}{dK_R} \qquad (1)$$

$$C_T = \frac{T_2 - dC_R K'_R - B}{K_T} \qquad (2)$$

Here,

T_1= Track density in Radon chamber

T_2 = Track density in 'Radon + Thoron' chamber

K_R = Calibration factor for Radon in the 'Radon ' chamber (0.017 tr.cm^{-2}.d^{-1}/Bq.m^{-3})

d = Number of days for the dosimeter installed

K'_R= Calibration factor for Radon in (Radon plus Thoron) chamber (0.0172 tr.cm^{-2}. d^{-1}/Bq.m^{-3})

K_T = Calibration factor for Thoron in (Radon plus Thoron) chamber (0.010 tr.cm^{-2}. d^{-1}/Bq.m^{-3})

B = Number of background tracks

For the DRPS and DTPS sensors, the concentration of radon and thoron progeny was determined using the following equations (3) and (4)[12], [23], [24] .

$$EERC\left(\frac{Bq}{M^3}\right)\frac{T_3}{d.K_R}$$

$$EETC\left(\frac{Bq}{m^3}\right)\quad\frac{T_4}{d.K_T}$$

T_3= Track density in DRPS caused by progeny of Radon

T_4= track density in DTPS due to the progeny of Thoron.

K_R (Radon progeny calibration factor) = 0.09 tracks cm^{-2}. d^{-1} per EERC (Bq / m^3)

K_T (Thoron progeny calibration factor) = 0.94 tracks cm^{-2}. d^{-1} per EETC (Bq / m^3).

Statistical calculations are performed using Microsoft Excel while various graphs are plotted using Origin 8.5 to examine the spatial variations in ^{222}Rn, ^{220}Rn and their progeny concentrations.

3. RESULTS AND DISCUSSION

The measured indoor concentrations of ^{222} Rn and ^{220}Rn show a clear seasonal variation, as summarized in Table 1.^{222} Rn concentration (C_R) varied from 16.20 ± 1.17 Bq/m³ to 44.31 ± 1.93 Bq/m³, while that of ^{220}Rn (C_T) ranged between 6.44 ± 0.74 Bq/m³ and 16.38 ± 1.17 Bq/m³. In all seasons, value of C_R levels was consistently higher than that of C_T, which is expected due to the much longer half-life of ^{222}Rn compared to ^{220}Rn[25]. Both radionuclides exhibited maximum concentrations during Season 2 and minimum values during Season 4.

Parameter	Season 1	Season 2	Season 3	Season 4
CR (Bq/m³)	28.76 ± 0.78	44.31 ± 0.97	24.96 ± 0.73	16.20 ± 0.59
EERC (Bq/m³)	6.81 ± 0.76	15.84 ± 1.15	10.95 ± 0.96	9.16 ± 0.88
CT (Bq/m³)	9.13 ± 0.44	16.38 ± 0.59	9.83 ± 0.46	6.44 ± 0.37
EETC (Bq/m³)	0.39 ± 0.19	1.35 ± 0.34	0.86 ± 0.27	0.67 ± 0.24

Table 1- Average seasonal values of (C_R and C_T)) and EERC, EETC (Bq/m3

Since the monitoring was carried out in well-defined seasonal intervals of 90 days (September–November, December–February, March–May, and June–August), this variation can be linked to changes in indoor ventilation and atmospheric conditions. During Season 2, relatively stable indoor environments and reduced air exchange may have allowed the accumulation of radioactive gases, whereas increased ventilation and air movement during Season 4 likely contributed to their dilution[14], [26], [27]. The overall average value of distribution of C_R and C_T across all dwellings is shown in Fig. 4 and Fig.5, respectively

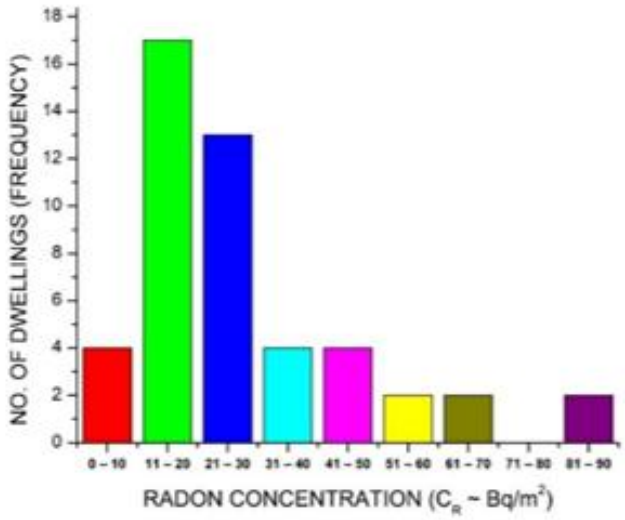

Fig. 4: Frequency distribution of ^{220}Rn concentration (C_R) (Bq/m^3) throughout the year in Bijnor

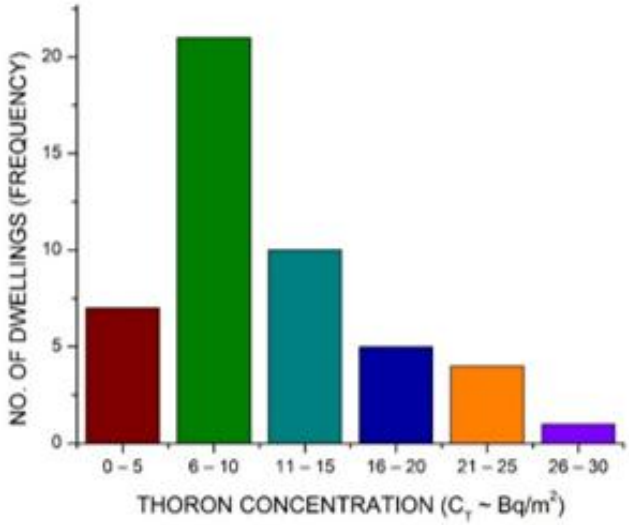

Fig. 5: Frequency distribution of ^{220}Rn concentration (C_T) (Bq/m^3) throughout the year in Bijnor

The` distributions are not symmetric; instead, most of the measured values are concentrated in the lower range, with only a few dwellings showing higher concentrations. This results in a positively skewed distribution, which is commonly observed in indoor ^{222}Rn studies [12], [20], [28], [29], [30], [31]. Such behavior indicates that while typical houses experience moderate levels, certain dwellings due to their structural or ventilation conditions can accumulate relatively higher concentrations 4.2 Equilibrium Equivalent Concentrations (EERC and EETC) The equilibrium equivalent concentrations of ^{222}Rn (EERC) and ^{220}Rn (EETC) are also presented in Table 1. The EERC values ranged from 6.81 ± 0.76 Bq/m³ to 15.84 ± 1.15 Bq/m³, whereas EETC values varied between 0.39 ± 0.19 Bq/m³ and 1.35 ± 0.34 Bq/m³. A seasonal trend similar to that of C_R and C_T is observed here as well. Higher values during Season 2 and lower values during Season 4 suggest that progeny concentrations are strongly influenced by the same environmental factors, particularly ventilation and indoor air stability[14], [32], [33]. Since equilibrium equivalent concentrations depend on both gas concentration and the fraction of progeny present in air, the relatively lower values of EETC compared to EERC can be attributed to the short half-life of ^{220} Rn and its limited ability to persist in indoor air. These results indicate that indoor exposure levels are not constant throughout the year but are governed by seasonal indoor conditions and air exchange processes.

4.3: Variation of C_R and C_T According to House Type

Statistic	Cemented House with Marble Floor		Brick House with Cemented Floor		Brick House with Mud Floor	
	CR (Bq/m³)	CT (Bq/m³)	CR (Bq/m³)	CT (Bq/m³)	CR (Bq/m³)	CT (Bq/m³)
Average	16.42	7.68	33.91	11.17	57.55	19.01
Maximum	29.16	17.17	62.06	24.96	86.87	25.66
Minimum	4.61	2.02	16.05	3.10	29.81	12.07
Standard Deviation	6.34	3.81	12.23	5.21	18.92	4.81

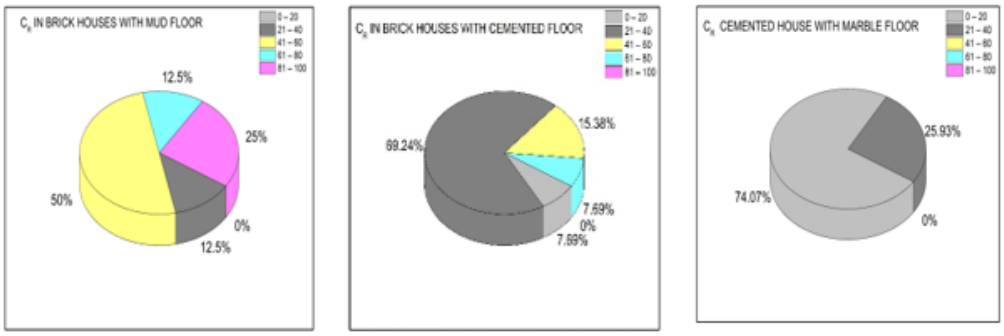

Fig. 6: Variation of ^{222}Rn-concentration (C_R) according to House Type

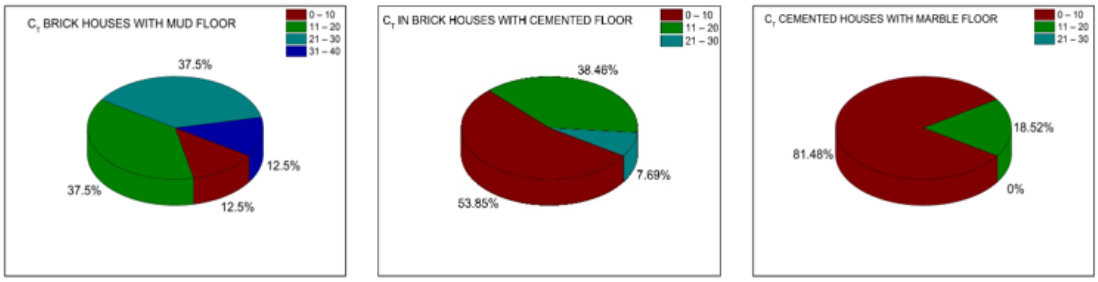

Fig. 7: Variation of ^{220}Rn-concentration (C_T) according to House Type

And the corresponding statistical parameters are summarized in Table 2. Houses with mud flooring show the highest average concentrations, with values of 57.55 Bq/m³ for ^{222} Rn and 19.01 Bq/m³ for ^{220} Rn. In comparison, brick houses with cemented floors exhibit moderate concentrations, while cemented houses with marble flooring show the lowest levels (16.42 Bq/m³ for ^{222} Rn and 7.68 Bq/m³ for ^{220} Rn). This trend suggests that building materials and the degree of contact with the ground surface play an important role in determining indoor radionuclide levels. Mud floors, being more permeable, allow easier entry of soil gases into indoor spaces, whereas cemented

and marble floors act as partial barriers, reducing gas infiltration[32], [34]. Additionally, differences in construction style and ventilation conditions across these dwelling types may further influence the accumulation of ^{222}Rn and ^{220}Rn indoors. The statistical spread shown in Table 2, including maximum, minimum, and standard deviation values, also indicates that variability is higher in mud-floor houses compared to more finished constructions. This suggests that less controlled structural conditions can lead to greater fluctuations in indoor concentrations[30].

4.5 Annual Assessment

The annual mean concentrations were found to be 28.56 Bq/m³ for ^{222}Rn and 10.45 Bq/m³ for ^{220}Rn. These values are well within the recommended limits prescribed by international radiation protection guidelines. Therefore, the indoor environments studied in Bijnor district can be considered radiologically safe for occupants[35], [36], [37]. At the same time, the observed seasonal variation and dependence on dwelling type highlight the importance of ventilation practices and construction features in controlling indoor exposure levels.

4. CONCLUSION

The present study provides a comprehensive assessment of indoor ^{222}Rn, ^{220}Rn and their progeny concentrations in residential dwellings of Bijnor district, Uttar Pradesh. The

results clearly indicate that both ^{222}Rn and ^{220}Rn exhibit noticeable seasonal variation with higher concentrations observed during Season 2 and lower levels during Season 4. This behaviour highlights the role of ventilation conditions and indoor air exchange processes in controlling the accumulation of these gases. EERC and EETC followed trends similar to those of the parent gases confirming that indoor exposure is influenced not only by radionuclide concentration but also by the prevailing indoor environmental conditions. The comparatively lower values of EETC further reflect the limited persistence of ^{220}Rn and its progeny in indoor air. A significant variation in radionuclide concentration was observed across different types of dwellings. Houses with mud flooring showed higher concentrations compared to brick and cemented constructions, indicating that building materials and the degree of contact with the ground surface play an important role in determining indoor ^{222}Rn and ^{220}Rn levels. This emphasizes the importance of construction practices in managing indoor radiation exposure. The frequency distribution of measured concentrations suggests that most dwellings fall within lower concentration ranges, with only a few cases showing elevated levels. This indicates that while the general indoor environment remains safe, localized conditions within certain houses can lead to relatively higher accumulation. The annual average concentrations of ^{222}Rn (28.56 Bq m^{-3}) and ^{220}Rn (10.45 Bq m^{-3}) were found to be well within internationally recommended limits. Therefore, the indoor radiation levels in the studied area do not pose any significant health risk to the occupants. The study provides a valuable regional dataset on indoor ^{222} Rn and ^{220} Rn levels. These findings may be helpful for future environmental radiation monitoring and for improving awareness regarding simple mitigation measures such as better ventilation and appropriate building practices.

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