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Seasonal Variation of Indoor Radon and Thoron Concentration in Dwellings of Gurugram District, Haryana

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This study presents the seasonal variation of indoor radon/thoron and their progeny concentrations measured in 50 dwellings in the Gurugram district of Haryana state, India. Single-entry pinhole dosimeters were used for the measurement of radon and thoron concentration, and for the measurement of attached and unattached progenies of these gases, direct radon and thoron progeny sensor with and without wire-mesh were employed. The absorbed inhalation dose to people in the area was calculated for different seasons, and the total average inhalation dose from all seasons was also calculated. The average indoor radon and thoron concentration values were below the ICRP action level of 200-300 Bq/m^3 for all seasons. Also, the average absorbed inhalation dose for all seasons is below the action limit in the study area. It was also discovered that the highest concentration of radon and thoron gas is reported in the winter season and the lowest in the summer season.

Keywords: Radon; Thoron; Seasonal variation; Progenies; Dose

1 Introduction

Advancements in human knowledge about radiation exposure and health effects have led many researchers to estimate the concentration of various radionuclides present in naturally occurring and man-made materials[1-4]. Studies on radioactivity measurement in surface soil, water, air, building materials, minerals etc., have been reported worldwide[5-7]. In a report by UNSCEAR, the radiation dose to the human population from different sources, such as cosmic, terrestrial, occupational exposure, medicine testing *etc*., were compared, and an annual effective dose of 2.4 mSv per year was relayed for the natural causes along with 0.6 mSv per year from man-made causes[8].The annual effective dose for the natural causes was relayed at 2.4 mSv, while the annual effective dose from man-made causes was relayed at 0.6 mSv in a report by UNSCEAR, which compared the radiation dose to the human population from various sources such as cosmic, terrestrial, occupational exposure, medicine testing, etc. Inhalation of radon and thoron gases account for 52.5% of the natural radiation exposure, or 1.26 mSv per year. With a half-life of 3.82 days, radon gas (Rn-222) is a radioactive gas that forms during the decay of Uranium-238. With similar physical properties, thoron gas (Rn-220) is part of the decay chain of Thorium-232 and has a half-life of 55.6 seconds. Due to a relatively lower half-life than radon, thoron gas does not pose significant threats at lower concentrations[9]. However large thoron concentrations were reported in different countries[10,11], which may lead to severe health hazards. So, it is important to keep in check the concentration of these radioactive gases in indoor environmens[12]. Initially, various health hazards, such as leukemia, lung cancer *etc*., from inhalation of these gases had been studied for the laborers working in the uranium mines. A higher probability of these health hazards was discovered for the workers working in environments having higher radon concentrations. After this discovery concentration of indoor radon was also assessed in houses or dwellings. Some of the key sources of indoor radon are soil gas infiltration, emanation from building material, water, etc.[13]. From all of these sources, soil gas infiltration was recognized as the highest contributor to radon in the indoor environment[14].

The existence of these gases in our indoor environment can be critical, as these radioactive gases decay into their corresponding progenies by emission of high-energy alpha particles. Progenies of these

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gases are solids and can attach to the air molecules to form radioactive aerosols[15]. Some of these particles are inhaled by us during breathing and may enter the bronchial tissue in our lungs, where they disintegrate by releasing high-energy alpha particles[16]. These high-energy alpha particles can damage our lungs' pulmonary epithelium, resulting in lung cancer. This is why radon gas is2^{nd} major cause of lung cancer in the world[12]. Also, in dwellings with a concentration of more than 50 Bq/m^3, the ratio of radon contribution in causing leukemia to adults and children is 1:4.

One of the latest studies in upper north Thailand estimated that indoor radon could be solely responsible for 553 deaths per year[17]. In one of the reports from the International Commission on Radiological Protection (ICRP), an action level of 200 Bq/m^3 to 300 Bq/m^3 was set for the concentration of indoor radon worldwide[18]. However, WHO (2009) sets permissible limit of 100 Bq/m^3 for indoor radon concentration[12].

The study of indoor radon and thoron concentrations in various parts of India has been extensively conducted, with researchers reporting different ranges of radon concentration in dwellings of Punjab, Himachal Pradesh, Chandigarh, and Delhi [19-21]. However, it is crucial to note that indoor radon concentration is heavily dependent on various factors, including the type of dwelling, building material, and ventilation. Despite some studies being conducted in Gurugram city, studies on the seasonal variation of indoor radon and thoron concentration in Gurugram district are yet to be reported. Therefore, this report is of significant importance, as it sheds light on the seasonal variation of these radioactive gases in the study area and estimates the average inhalation dose received by the district's people.

2 Study Area

Gurugram district is located in the southeastern part of Haryana state of India shown in Fig. 1. It is around 30 km from Delhi, the national capital. With a population of approximately 1,514,085, this area is an industrial center. The overall area of Gurugram city is 1254 square kilometers, and there are 1207 people per square kilometer. A total of 596 millimeters of rainfall in the district each year. The area's climate can be categorized as savannah, semi-arid, and hot, with dry air dominating, except the monsoon season, scorching summers, and chilly winters[22]. Southwest monsoon months, which run from the final week of June to September, are three rainy months. High humidity, cloud cover, and monsoon rain are all caused by air from marine sources entering the area. The post-monsoon season develops in the months of October through December. The end of the cold season occurs between late January and early March, and the beginning of the hot season, which lasts until the last week of June. The terrain is noticeably flat, however, in the northeastern half, there are a few little hillocks made of Precambrian rocks. The Sahibi River, a tributary of the Yamuna river, creates the alluvial plain. The extreme northwestern, northern, and northeastern portions of the Gurugram district have tropical and brown soils, whereas the southern portion of the district has waterlogged and salt-affected soils.

3 Methodology

3.1 For radon and thoron concentration measurement

In order to examine the impact of seasonality on indoor radon and thoron concentration, a total of 50 dwellings were selected for measurement. The measurement was performed using single-entry pinhole dosimeters, which consisted of radon and thoron chambers separated by a wall containing pinholes as shown in Fig. 2. The dimensions of the chambers were precisely controlled, with a height of 4.1 cm and a radius of 3.1 cm[23]. In addition, the central disc of the dosimeter had holes with a diameter of 1 mm to block the transmission of thoron and allow only radon diffusion into the second

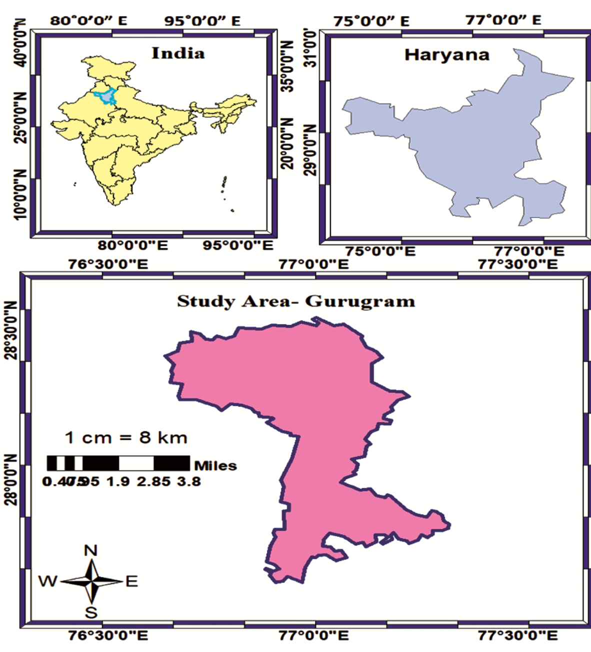

Fig. 1 — Map of the study area.

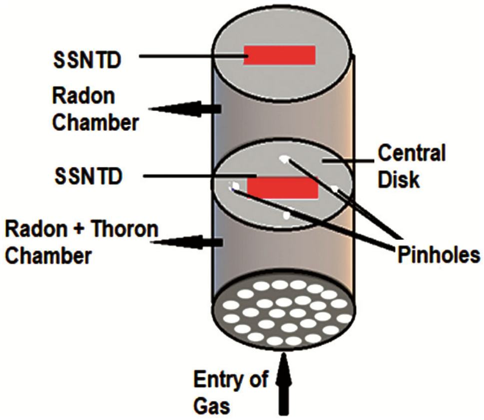

Fig. 2 — Block diagram of Pinhole dosimeters.

chamber due to its longer half-life. The use of LR-115 type-2 plastic solid state nuclear track detectors ensured accurate measurement of indoor radon and thoron concentrations. These dosimeters were hung at a height of 7-9 feet above the ground in selected dwellings, and at least 30-50 cm away from the walls to avoid exposure to high concentrations of radiation from building materials. These strict measures were taken to ensure the reliability and validity of the data collected, and to protect the health and safety of the occupants of the dwellings. Four seasons were considered for the seasonal study of indoor radon, *i.e.*, summer (May- July), rainy (August to October), winter (November to January) and autumn (February to April).

The LR-115 was removed after the completion of each season, and fresh films were used to measure indoor radon for the next season.

These films were then etched in 2.5 N of sodium hydroxide solution for 90 minutes at a constant temperature of 60 ºC[24]. After etching and washing with distilled water, the active layer of cellulose nitrate is peeled off from the polyester base and dried in the air for some time. The track density of alpha particles was detected using a spark counter.

3.2 Measurement of progeny concentration

Equivalent equilibrium radon and thoron concentrations were measured using direct radon and thoron progeny sensors (DRPS/DTPS). The DRPS used LR-115 films covered with an aluminum mylar of 25 microns and peeled cellulose nitrate of 12 µm, to register tracks only due to alpha particles of Po-214 with an energy of 7.67 MeV. Similarly, the DTPS used an aluminum mylar of 50 microns to cover LR-115 and register tracks only due to alpha particles of Po-212 with an energy of 8.78 MeV[25]. Wire-mesh DRPS/DTPS were also deployed to detect the concentration of attached and unattached progeny.

Radon and thoron concentrations were measured from the track density of LR-115 films collected from pinhole dosimeters by using the following equations[26]

$$C_R = \frac{T_1}{d \cdot K_R} \quad \ldots (1)$$

$$C_T = \frac{T_2 - d \cdot C_R \cdot K_R'}{d \cdot K_T} \quad \ldots (2)$$

For the measurement of EERC and EETC, the track density of LR-115 films used in direct radon and thoron progeny sensors was calculated, and the following equations were used to calculate progeny concentrations [27]

$$EERC(Bq/m^3) = \frac{T_R}{t \cdot S_R} \quad \ldots (3)$$

$$EETC(Bq/m^3) = \frac{T_T}{t \cdot S_T} \quad \ldots (4)$$

Where T_R is calculated using following equation

$$T_{Rn} = T_{DRPS} - \frac{\eta_{RT}}{\eta_{TT}} T_{DTPS} \quad \ldots (5)$$

T_{DRPS}, T_{DTPS} are the tracks of Lr-115 in DRPS and DTPS, η_{RT} and η_{TT} are the track registration efficiency for DRPS and DTPS, S_T (0.94 tracks $cm^{-2}\, d^{-1}/(Bq/m^3)$) and S_R (0.09 tracks $cm^{-2}\, d^{-1}/(Bq/m^3)$) are the sensitivity factors for radon and thoron progenies[28]. This value of effective equivalent radon/thoron concentration corresponds to total progeny concentration, *i.e.*, the concentration of attached and unattached progenies. For measurement of attached progeny concentration wire-mesh, DRPS/DTPS were used. The basic measurement principle is the same as DTPS/DRPS, with the only difference being the inclusion of wire mesh, which only detects the course fraction activity by reducing the fine fraction. The equation used for calculating attached progeny is the same as equations 3 and 4 but with different values of sensitivity factors given elsewhere[29].

Also, the equilibrium factor was calculated using the equation

$$E_{Rn} = \frac{EERC}{C_{Rn}} \quad \ldots (6)$$

$$E_T = \frac{EETC}{C_T} \quad \ldots (7)$$

The dose received per year due to inhalation of radon and thoron gas was estimated using the following equations[30]

$$AID_{Rn} = [(C_R \times 0.17) + (EERC \times 9)] \times 8760 \times 0.8 \times 10^{-6} \text{ mSv} \quad \ldots (8)$$

$$AID_{Th} = [(C_T \times 0.11) + (EETC \times 40)] \times 8760 \times 0.8 \times 10^{-6} \text{ mSv} \quad \ldots (9)$$

4 Results and discussions

In a comprehensive study conducted in the Gurugram district of Haryana, the indoor radon, thoron, and their progeny concentrations were meticulously measured across 50 dwellings, spanning various areas. The study meticulously documented the concentration of these radioactive elements during all four seasons of the year, namely summer, rainy, winter, and autumn. Radon levels indoors range from 13.14 - 126.5 Bq/m^3 with an average of 51.07 for the summer, 29.41 - 196.08 Bq/m^3 with an average of 79.81 the rainy, 45.36 - 205.49 Bq/m^3 with an average of 99.81 for the winter and 29.41 - 175.82 Bq/m^3 with an average of 65.88 for the autumn seasons. Thoron levels indoors range from 5.13 - 174.44 Bq/m^3 with an average of 42.23 for the summer, 11.11 - 228.89 Bq/m^3 with an average of 70.54 for the rainy, 30.0 - 246.67 Bq/m^3 with an average of 91.75 for the winter, 10.0 - 191.41 Bq/m^3 with an average of 58.06Bq/m^3 for the autumn seasons. The seasonal variation of indoor radon and thoron concentration is given in Table 1. Also, the seasonal variation of equivalent equilibrium radon and thoron concentration is reported and is shown in Table 2. The frequency distribution of radon and its progeny concentration is shown in Fig. 3, in which a box whisker graph of the concentration is plotted. A similar graph for thoron and its progeny concentration is plotted in Fig. 4.

Wire-mesh DRPD/DTPS was also used in conjunction with PRTM to measure both the attached and unattached progeny concentration. The frequency

Table 1 —- Seasonal variation of indoor radon and thoron concentration in 50 dwellings of Gurugram district.

	Radon concentration (Bq/m^3)				Thoron concentration (Bq/m^3)			
	Summer	Rainy	Winter	Autumn	Summer	Rainy	Winter	Autumn
Average	51.07	79.14	99.81	65.88	42.23	70.54	91.75	58.06
Max	126.5	196.08	205.49	175.82	174.44	228.89	246.67	191.41
Min	13.14	29.41	45.36	29.41	5.13	11.11	30	10
Median	39.33	76.8	96.08	65.36	29.67	57.22	81.66	45.29
Kurt	8.53	2	4.56	6.84	5	4.09	1.96	3.93
St. Dev.	18.23	27.77	30.31	28.79	33.27	44.64	44.64	39.34

Table 2 — Seasonal variation of effective equivalent radon and thoron concentration in 50 dwellings of Gurugram district.

	EERC (Bq/m^3)				EETC (Bq/m^3)			
	Summer	Rainy	Winter	Autumn	Summer	Rainy	Winter	Autumn
Average	8.38	15.5	19.58	14.9	1.82	1.87	0.94	2.2
Max	16.63	39.93	91.91	47.34	6.5	4.73	2.26	9.04
Min	3.04	6.35	10.63	7.57	0.84	0.72	0.34	1.03
Median	7.75	14.18	17.61	13.75	1.59	1.77	0.96	1.99
Kurt	3.2	4.42	32.52	9.7	11.1	3.99	2.64	18.75
St. Dev.	3.27	6.19	11.54	6.76	0.97	0.86	0.35	1.25

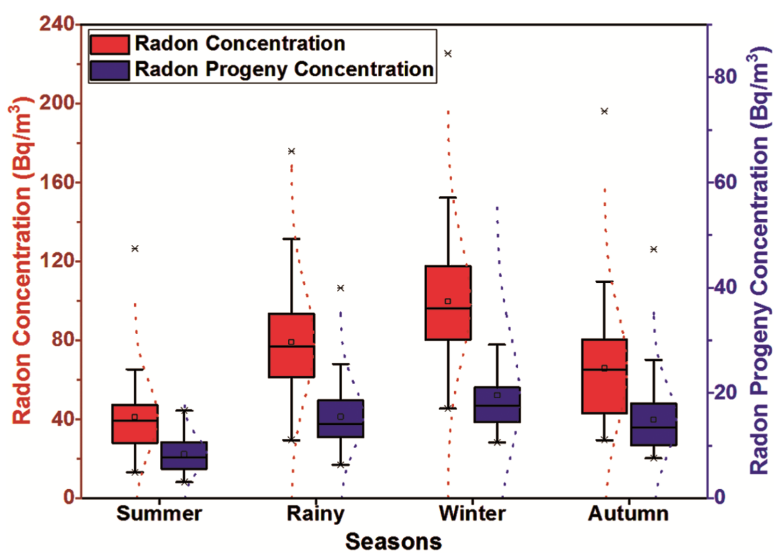

Fig. 3 — Box whisker plot of seasonal variation of indoor radon and its progeny concentration.

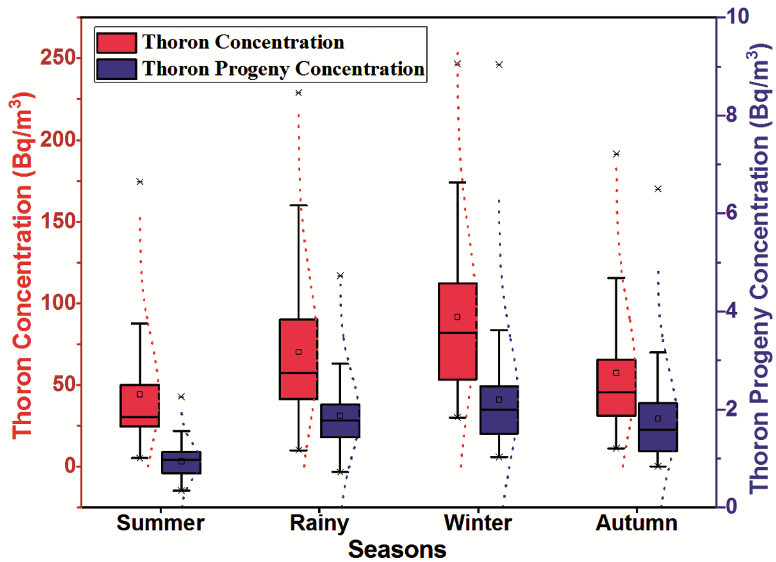

Fig. 4 — Box whisker plot of seasonal variation of indoor thoron and their progeny concentration.

distribution plots for seasonal variations of attached progeny concentration are illustrated in Fig. 5. From the plots, it is evident that the highest EETC/EERC is recorded for the winter season and the lowest for the summer season. Moreover, the EERC/EETC values for the rainy season are higher than those for autumn and summer but lower than those for the summer season. For the autumn season, the attached progeny concentration is lower than that in the winter and rainy seasons but higher than that in the summer season. Fig. 3 and 4 indicate that radon/thoron and their progeny concentrations are reported to be maximum during the winter season, followed by the rainy and autumn seasons, and least during the summer season. The comparatively higher ventilation in the summer season could be the reason for the lower indoor radon and thoron concentration levels. The doors and windows are typically left open during the summer months to alleviate the heat, which could be responsible for the low indoor radon and thoron concentrations[31].

As in winter, due to low temperatures and cold conditions, doors and windows are mostly closed, causing poor ventilation, which may result in higher concentrations of radon and thoron indoors[32]. The ratios of radon and thoron concentration for different seasons in different dwellings were also reported and shown in Fig. 5.

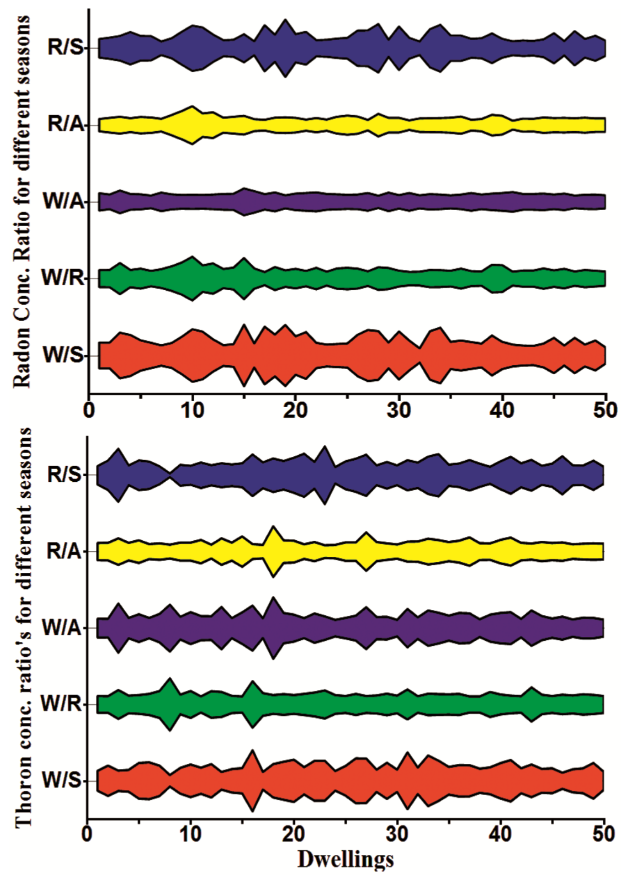

Fig. 5 — Graph showing the variation of the ratio of radon and thoron concentrations of different seasons in different dwellings.

The average ratio of indoor radon concentration for winter to summer is 2.17, winter to rainy is 1.3, winter to autumn is 1.64, rainy to autumn is 1.28, and rainy to summer is 1.73. Similarly, for thoron concentration, the ratio of winter to summer is 1.95, winter to rainy is 1.38, winter to autumn is 1.73, rainy to autumn is 1.28, and rainy to summer is 1.73. The value of the equilibrium factor for radon is approximately equal for all seasons with the value of 0.22, and for thoron, its value is approximately equal to 0.04. The total absorbed doses due to inhalation of radon gas are estimated for all seasons and have average values of 0.55 mSv/year, 0.88 mSv/year, 1.64 mSv/year and 2.04 mSv/year for summer, autumn, rainy and winter season. Total inhalation dose due to inhalation of indoor radon and thoron gas averaged over all the seasons was reported to have a value of 1.28 mSv/year which is lesser than the ICRP action level of 3-10 mSv/year[33].

5 Conclusions

The average values of indoor radon and thoron concentration in dwellings of the study area were lower than the action level limit of 200-300 Bq/m^3 recommended by ICRP. It was discovered that for winter season some of the locations have radon and thoron concentration values above the action level limit, which may be due to poor ventilation conditions and higher exhalation rates from building materials. For most of the dwellings, the average inhalation dose per year was found to have a value of 1.28 mSv/Year, which is also less than the action limit of 3-10 mSv/Year. It is feasible to conclude that winter season had the highest indoor radon concentration values, followed by the rainy and autumn seasons, while summer season had the lowest. The specific result could be the result of varying ventilation conditions in houses during different seasons.

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