Indian Journal of Pure & Applied Physics
Vol. 61, June 2023, pp. 443-449
DOI: 10.56042/ijpap.v61i6.2415

Mapping the Variation in Indoor Radon, Thoron and Their Progeny Concentration for Different Seasons

Vimal Mehta[a], Chandan Kapil[a, b], Deep Shikha[a]* & Sandeep Kanse[c]
[a]Department of Physics, Sri Guru Teg Bahadur Khalsa College, Sri Anandpur Sahib 140 118, India
[b]Department of Physics, Punjabi University, Patiala 147 002, India
[c]Scientific Officer RP & AD, Bhabha Atomic Research Centre, Mumbai 400 085, India

Received 20 February 2023; accepted 23 May 2023

An investigation on passive measurement of indoor radon and thoron concentration was carried out in 50 dwellings of the Patiala district of Punjab, India. A one-year study was conducted to cover all the seasons, and seasonal variation of these radioactive gases was reported. All the measurements were performed using pin-hole dosimeters for passive measurement of radon and thoron gases and their progeny for different seasons. To quantify attached and unattached progeny concentration, DRPS/DTPS and wire-mesh DRPS/DTPS were deployed with dosimeters. The average radon and thoron concentration in all the seasons was below the ICRP action level limit of 200-300 Bq/m^3. Out of all season's data, the maximum value of radon and thoron was observed during the winter and the minimum for summer. The ratio of radon and thoron concentration for different seasons was also calculated in this report. Average annual indoor concentrations are compared with the average concentration of different seasons. It was concluded that the average concentration value is very near to monsoon season values, suggesting that the monsoon season is ideal for radon and thoron measurements.

Keywords: Radon; Thoron; Concentration; Seasonal; Progenies

1 Introduction

Humans are continuously exposed to radiation to different extents in the environment due to either cosmological or terrestrial causes. Although exposure to low radiation content does not impose a harmful or deadly impact on our bodies, it is crucial to keep a check on the radiation exposure to the human body as radon and thoron are the radioactive gases present in our atmosphere, inhalation of these gases while breathing contributes majorly to our radiation exposure. Radon and thoron are the only radioactive elements in a gaseous state in the decay series of Uranium-238 and Thorium-232. Due to their gaseous nature, they diffuse from their emanation sites through the pores between soil and stone into the atmosphere. The progenies of these gases emit alpha particles of high energies that can cause damage to cell tissues and, in the worst case, lead to cancer[1,2]. It has been reported that the concentration of these gases in the indoor environment varies with factors like ventilation of the dwellings, building materials used, radon exhalation from surrounding areas' soils, and geographical factors[3-6]. Most of the time spent by people is mostly indoors, so the majority of intake of airborne pollutants and radioactive materials is through inhalation in indoor environments. These radioactive gases, when inhaled, get trapped inside cell tissues. When these gases decay into their corresponding progenies, which are solid and have a short half-life, they decay into their decay product emitting high-energy alpha particles. If these alpha particles cause any changes in deoxyribonucleic acid (DNA), they can cause cancer.

In some cases, these progenies enter the bloodstream through the lungs and are pumped to the whole body by the heart[7]. Also, long-term radiation exposure can be fatal to human health. So, estimating indoor radon and the factor affecting its concentration is critical as we spend most of our time indoors.

As we know, radon gas accumulates in rooms, and its concentration depends upon many factors, but if it remains there for more than its half-life, it decays into its progenies Polonium-218, Polonium-214, and Bismuth-214 etc[8]. Due to their positive charge, these progenies easily get attached to air particles and can deposit to surfaces; such progenies are known as attached progenies. These progeny concentrations are directly measured using deposition based DRPS/DTPS[9].

*Corresponding author: (E-mail: deep_shikha79@yahoo.co.in)

The rate of flow of radon into our surroundings is nearly equal, so accumulating these attached progenies can increase continuous activity size distribution. These attached progenies are also known as coarse fractions, with a size of about 100nm[10]. The size of unattached progenies is near 2nm and has a higher probability of coalescing with blood vessels after inhalation. So, measurement of the concentration of these radioactive progenies in human residents is crucial.

According to the ICRP recommendations[11], dwellings containing more than 200-300 Bq/m^3 of indoor radon levels impose radiation health hazard to the human body[12]. So, it becomes imperative to evaluate the indoor radon and thoron concentrations and then calculate absorbed doses from inhaling these gases. Many researchers used pin-hole dosimeters developed by BARC for long-term evaluation of indoor radon and thoron concentration. Also, direct radon and thoron progeny sensors were used to measure effective equivalent radon and thoron concentration in dwellings. Knowing effective equivalent radon and thoron activities help us accurately calculate absorbed equivalent inhalation doses for the residents. The seasonal variation of indoor radon and thoron concentration is one of the significant parameters to study. The primary factor contributing to the seasonal variation of these gases in human surroundings is ventilation conditions for different seasons[13]. In this report, the study of seasonal variation of indoor radon, thoron and their progenies concentration in dwellings of Patiala district is reported.

2 Geology of Patiala district

Patiala district is situated at the southwest corner of Punjab state and covers 3218 sq.km of the total geographical area. It lies between 29° 49' and 30° 40' of north latitudes and 75° 58' to 76° 48' of east longitude as shown in Fig. 1. The district's total population is 1,892,282, with a population density of 588 people per square kilometre. Most of the areas of the district have tropical arid brown and arid brown soil. Most of the population depends upon the agriculture sector, as 80% of the total geographical area is used for agricultural purposes. The soils of this district have some deficiency of nitrogen and phosphorus. In this region, the four distinct seasons span the whole year. The weather is dry due to the hot summer and cold winter, except for the rainy season. The summer season starts in April and ends in June; the monsoon ends in the last week of September; winter ends in mid-January; and the autumn season ends in mid-April. The district receives 677mm of annual rainfall, and a significant drainage source is the Ghaggar river.

3 Study Plan

The present study is conducted in the Patiala district of Punjab. Indoor radon concentration was measured in 50 dwellings, including dwellings in

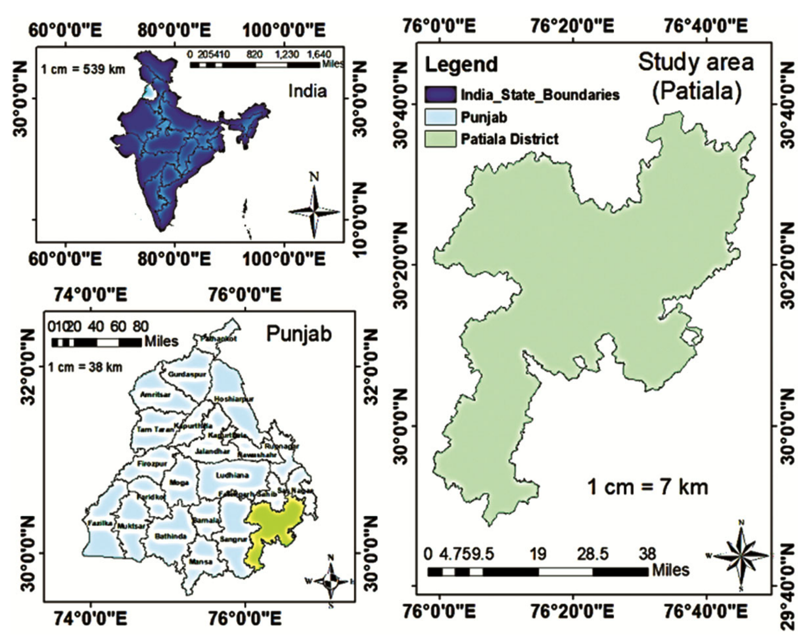

Fig. 1 — Study area map (Patiala).

farms, farmhouses and residential houses in villages. Pin-hole dosimeters were deployed from the ceilings of these dwellings. The dosimeter was deployed at least 20-30 centimetres from each dwelling wall to avoid any radon or thoron progenies emitted by building material[14]. The dosimeters were deployed for completeone year, covering all the seasons of 2021.

The films were removed after the completion of every season, and new films were placed on dosimeters and DRPS/DTPS for exposure for the next season. The removed films were then used to calculate the concentrations for that particular season. This procedure is repeated for all seasons.

4 Methodology

A time-integrated approach was used to detect indoor radon and thoron concentration. LR-115 solid-state nuclear track detectors (SSNTD) were placed inside the dosimeter's radon and thoron chambers and exposed to the indoor environment[15]. LR-115 contains an active layer of cellulose nitrate having 12 µm thickness and a polyester layer of 100 µm. After radiation exposure of three months, they were etched in a constant temperature bath using a 2.5 N solution of NaOH for 90 minutes to open up the tracks formed by alpha particles in SSNTD. Then films were stripped off the polyester base and placed in a spark counter developed by Polltech to measure track densities. Similarly, the measurement of progeny concentration is accomplished by using direct radon and thoron progeny sensors with and without wire mesh. The basic principle of these sensors is only to detect the alpha particles emitted either by Polonium-214 (α of energy 7.83 MeV) or Polonium-212 (α of energy 8.78 MeV) by using aluminium mylar of specific thickness that only allow these alpha particles to register tracks on SSNTD.

4.1 Measurement of indoor radon and thoron concentration and progeny concentration

Single entry twin cup dosimeters were used for radon and thoron concentration. Gas enters the thoron chamber first and passes through to the radon chamber from the four holes present in the thoron chamber. The following equations were used for the measurement[16]

$$C_R = \frac{T_1 - B}{t \times K_R} \quad (1)$$

$$C_T = \frac{T_2 - T_1}{t \times K_T} \quad (2)$$

Here T_1 and T_2 are track densities of LR-115 films in radon and thoron chamber, K_R and K_T are respective calibration factors having values of 0.017 tracks/cm^2/d/Bq/m^3 and 0.010 tracks /cm^2 /d/Bq/m^3.

4.2 For measurements of Effective Equivalent Radon/Thoron Concentration

DRPS/DTPS (Deposition Based Radon/Thoron Sensor) was attached with a pin-hole dosimeter to measure EERC/EETC. An absorber of a suitable thickness (50 µm for thoron and 37 µm for radon) was used so that only alpha particles of energy 7.69 MeV emitted by Po-214 for thoron measurement and 8.78 MeV emitted by Po-212 for radon measurement were absorbed by LR-115 films.

For measurement of Equivalent Equilibrium Thoron concentration following equation is used [17]

$$\text{EETC(Bq/m}^3) = \frac{T_T - B}{t \times S_T} \quad (3)$$

Here T_T is the track density of LR-115 attached in DTPS, t is the exposure time, and S_T(0.94 tracks cm^{-2} d^{-1}/(Bq/m^3)is the thoron progeny Sensitivity factor[18]. For measurement of Radon progenies, the tracks of thoron in radon absorbed have to be subtracted, for which we have used the following equation

$$T_{Rn} = T_{DRPS} - \frac{\eta_{RT}}{\eta_{TT}} T_{DTPS} \quad (4)$$

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

Equivalent equilibrium Radon Concentration is calculated using the following equation.

$$\text{EERC (Bq/m}^3) = \frac{T_{Rn} - B}{t \times S_R} \quad (5)$$

Here T_{Rn} is radon track density calculated in equation 4, t is exposure time, and S_R(0.09 tracks cm^{-2} d^{-1}/(Bq/m^3) is the radon progeny sensitivity factor[19]. So, radon/thoron concentration and EERC/EETC were calculated using the above equations.

4.3 For measurement of attached and unattached progenies

Radon and Thoron gases due to their radioactive nature decay into their corresponding progenies by emitting alpha and beta particles. The progenies are generally neutral or positively charged and tend to attach with other air particles, generally known as a coarse fraction.

Table 1 — Indoor radon/thoron and their progeny concentration.

	Radon concentration (Bq/m^3)				Thoron concentration(Bq/m^3)			
	Summer	Rainy	Autumn	Winter	Summer	Rainy	Autumn	Winter
Average	90.42	124.44	106.86	139.49	75.36	88.4	83.62	94.4
Maximum	194.12	333.33	241.83	255.56	267.78	245.56	261.11	193.33
Minimum	32.68	65.36	37.91	73.86	1.11	22.22	11.11	13.33
Std. Dev.	40.34	51.75	38.98	41.89	61.69	45.04	55.75	39.9
Median	85.95	113.73	108.5	134.97	58.89	81.67	80	91.11
Mode	90.85	81.05	129.41	109.15	18.89	88.89	34.44	74.44
Skew	0.77	1.66	0.61	0.55	1.32	1.23	0.73	0.31

The absorbed inhalation doses were also calculated in this report using the following equation.

The neutral progenies that remain unattached are known as unattached progenies or fine fractions. The wire-mesh DRPS/DTPS were used to measure the attached progenies. After calculating the track densities, the attached progenies concentration can be calculated using equations (3), (4) and (5), but for this case, the sensitivity factors are different and given elsewhere[20].

Calculation of unattached progenies can be done by using the following equation.

$$EERC_{Unattached} = EERC - EERC_{Attached} \quad (6)$$

$$EETC_{Unattached} = EETC - EETC_{Attached} \quad (7)$$

Equilibrium factors for radon and thoron gas are calculated using the following equation.

$$F_{Rn} = \frac{EERC}{C_{Rn}} \quad (8)$$

$$F_{Th} = \frac{EETC}{C_{Th}} \quad (9)$$

$$(AED)_{Rn} = [(C_{Rn} \times 0.17) + (EERC \times 9)] \times 8760 \text{ h} \times 0.8 \times 10^{-6} \quad (10)$$

$$(AED)_{Th} = [(C_{Th} \times 0.11) + (EETC \times 40)] \times 8760 \text{ h} \times 0.8 \times 10^{-6} \quad (11)$$

5 Results and Discussion

The indoor radon, thoron and their progenies concentration of 50 dwellings in the Patiala district were studied in this report. A year of investigation is carried out in the study region to see how radon and thoron concentrations change within those homes over time. The pin-hole dosimeters were deployed in dwellings from April 2021 to March 2022, covering the summer season from mid-March to mid-June, rainy from mid-June to mid-September, autumn from mid-September to mid-December and winter from mid-December to mid-March.

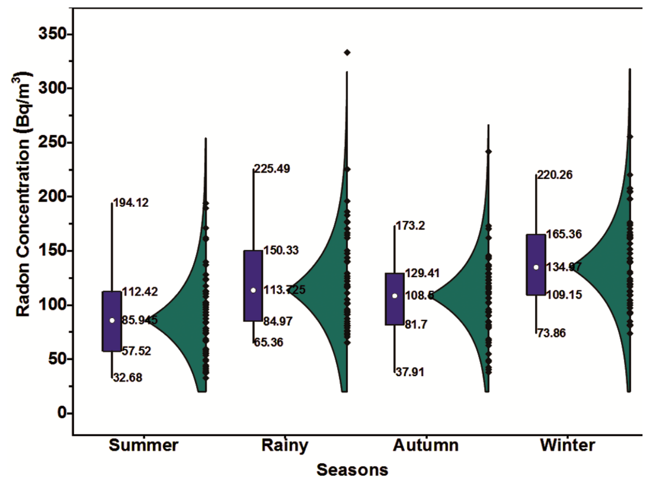

Fig. 2 — Box-whisker plot showing the distribution of radon concentration for different seasons.

The values of radon and thoron concentration for different seasons at various locations are shown in Table 1. The average radon concentration values for summer, rainy, autumn and winter seasons are 90.42 Bq/m^3, 124.44 Bq/m^3, 106.86 Bq/m^3, and 139.49 Bq/m^3. Similarly, the average values of thoron summer, rainy, autumn and winter seasons are 75.36 Bq/m^3, 88.4 Bq/m^3, 83.62 Bq/m^3, and 94.4 Bq/m^3. All these values of radon and thoron concentration for different seasons were found to be under the ICRP action level limit of 200-300 Bq/m^3. The frequency distribution plots (using box whisker plots and distribution plots) of radon and thoron concentration for different seasons were plotted in Fig. 2 and Fig. 3, which suggests a higher concentration of both radon and thoron in the winter followed by rainy, autumn season and minimum in the summer season. The reason for this seasonal variation may be the different ventilation conditions in different seasons, which affect the diffusion of radon to the outdoor environment. Generally, in the winter season, due to cold weather, the door and windows of dwellings are mostly closed so that the diffusion will be less, and much percentage of these gases stays in indoor

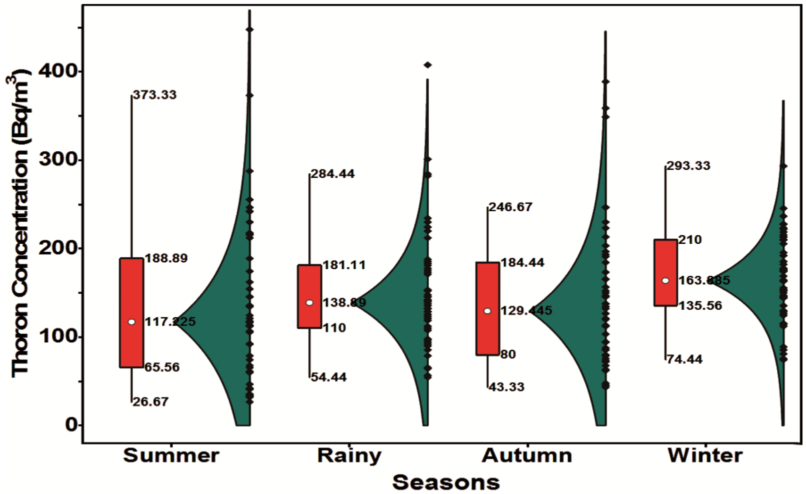

Fig. 3 — Box-whisker plot showing the distribution of thoron concentration for different seasons.

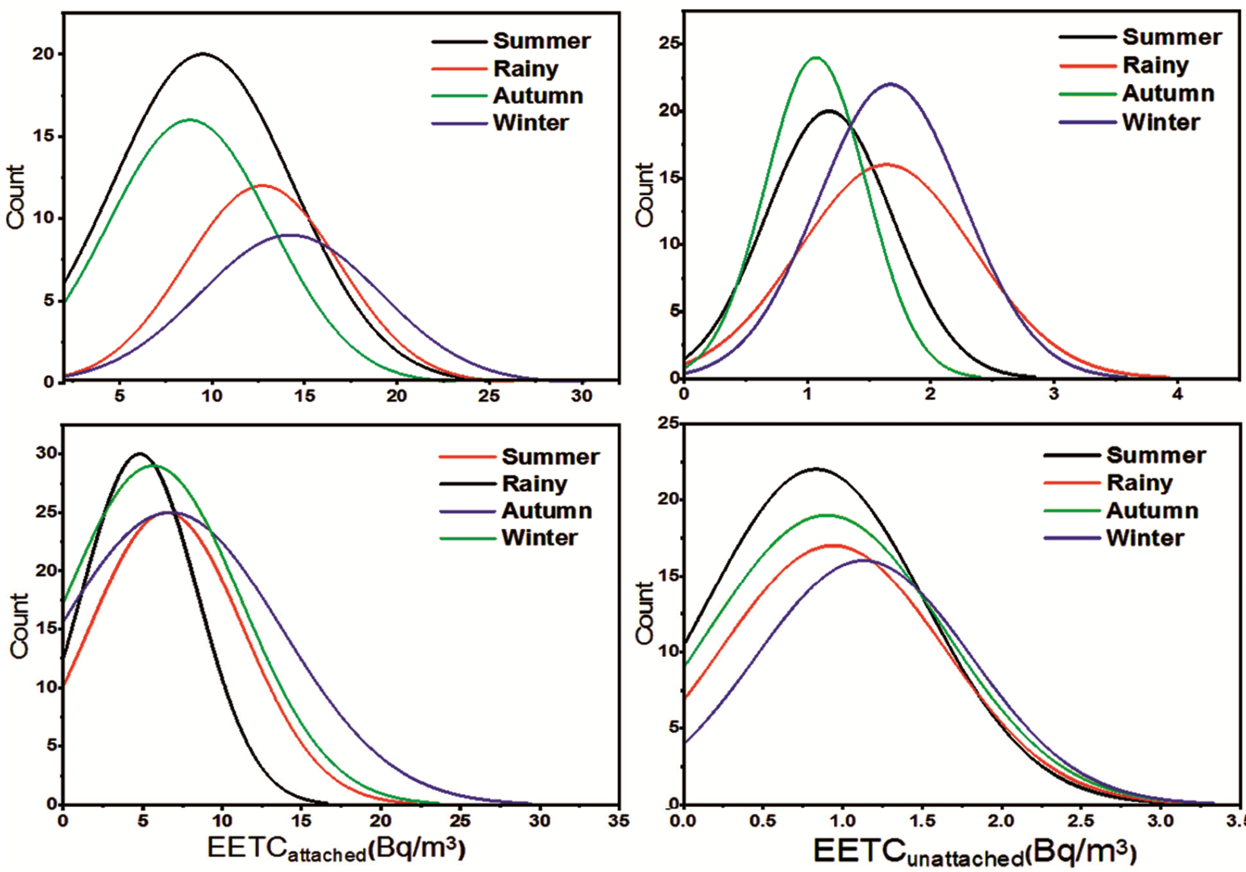

Fig. 4 — Frequency distribution plots of seasonal variation of attached and unattached progenies concentration of radon and thoron gas.

environments during summer, as ventilation conditions are good, the report suggests a lower concentration of radon and thoron in the summer season. The concentration of attached and unattached progenies was also discovered in this study, and it can be concluded from the frequency distribution plots shown in Fig. 4 that the concentration of attached progenies is higher compared with unattached progenies of both radon and thoron. Also, the concentration of these progenies is found to be maximum for winter, followed by rainy and autumn and lowest for the summer season.

The concentration of attached radon progenies was found to be minimum for summer, having a value of 9.51 Bq/m^3 and maximum for winter, with a value of

Table 2 — Equilibrium factors, Fine fractions, Dose Conversion Factors, and Absorbed Effective Dose for different seasons.

Quantities	Seasons	Average	Maximum	Minimum	Standard Deviation
F_{Rn}	Autumn	0.15	0.32	0.05	0.06
	Rainy	0.15	0.31	0.05	0.05
	Winter	0.17	0.64	0.05	0.11
	Summer	0.08	2.02	0.05	0.53
F_{Th}	Autumn	0.03	0.1	0.01	0.02
	Rainy	0.04	0.14	0.01	0.03
	Winter	0.07	0.25	0	0.05
	Summer	0.03	0.09	0	0.01
fine fraction$_{Rn}$	Autumn	0.23	0.71	0.17	0.23
	Rainy	0.26	0.55	0.02	0.16
	Winter	0.38	0.83	0.01	0.22
	Summer	0.64	2.52	0.01	0.58
fine fraction$_{Th}$	Autumn	0.37	0.67	0.03	0.16
	Rainy	0.35	0.75	0.04	0.18
	Winter	0.4	0.78	0.01	0.21
	Summer	0.33	0.78	0.01	0.28
DCFm(mSv WLM^{-1})	Autumn	28.2	53.29	9.75	21.72
	Rainy	30.97	58.55	8.69	14.93
	Winter	42.65	84.51	7.25	20.77
	Summer	20.4	84.51	6.3	15.59
DCFn(mSv WLM^{-1})	Autumn	10.03	18.06	3.27	3.87
	Rainy	10.52	15.44	6.55	2.66
	Winter	12.6	20.06	6.3	3.7
	Summer	4.1	20.06	0.88	4.87
AED$_{Rn}$ (mSv/year)	Autumn	0.91	1.23	1.26	1.1
	Rainy	1.01	0.6	1.37	0.55
	Winter	1.18	2.22	0.56	0.41
	Summer	0.82	1.91	0.43	0.47
AED$_{Th}$ (mSv/year)	Autumn	0.39	0.15	0.65	0.47
	Rainy	0.43	0.12	0.67	0.54
	Winter	0.64	1.19	0.31	0.26

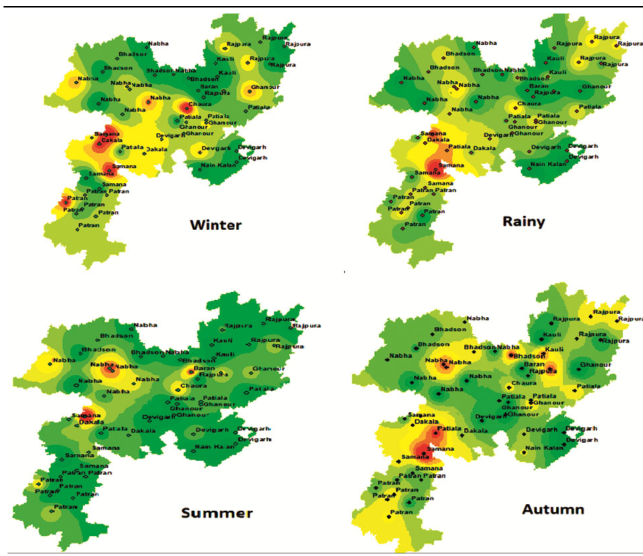

Fig. 5 — Heat map for radon concentration at different locations of Patiala district.

14.23 Bq/m^3. Similar results were discovered for the thoron-attached progeny, with a maximum of 6.48 Bq/m^3 in winter and 4.80 Bq/m^3 in summer. A heat map of different seasons was plotted for radon concentration, showing the areas having lower radon concentration (shown by dark green colour) and areas having higher radon concentration (shown by red colour) and is shown In Fig. 5. The findings indicated that Nabha, Samana, Dakala, and Chaura were the most affected regions. The high concentration of radon gas in these areas may be due to the geology of the surrounding areas or the presence of mineral rocks in these areas.The equilibrium factors, fine fraction, dose conversion factors and inhalation doses to nose and mouth were also calculated from the results and were presented in Table 2.These results also suggest that higher inhalation doses were received for the winter season as compared with rainy, autumn and summer seasons.

6 Conclusions

Following conclusions can be drawn from the results,

1 The radon, thoron and their progeny concentration were highest in winter, followed by rainy, autumn and minimum for the summer.

2 The average radon and thoron concentration for all seasons was under the action level limit of 200-300 Bq/m^3 suggested by ICRP.
3 At some locations, the radon and thoron concentration was found to be above the action level limit, which may be due to poor ventilation, geology or large exhalation from building material.
4 Annual average radon and thoron concentration was calculated by taking the average concentration of all the seasons, and it was discovered that the annual average value comes close to the average concentration of the rainy season.

Acknowledgement

This work is supported under BRNS- DAE research project (Sanction No.:56/14/01/2019-BRNS).

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