

Measurement of Indoor Radon, Thoron and Their Attached and Unattached Progeny Concentrations in Dwellings of Gurugram, India

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Abstract Estimation of indoor radon levels in the indoor air of a dwelling is an important aspect for the good health of human population spending a substantial portion of their lifetime indoor. Indoor radon combining with thoron and their progenies can accumulate in the houses to a value not suitable for the health of the people living there. The present paper is an attempt in this direction, to find the levels of the above-mentioned radioactive gases with their progenies in the dwellings of the Gurugram district of Haryana. The study was conducted in the summer season in 50 dwellings of the Gurugram district. International Commission on Radiological Protection (ICRP) guidelines were followed to evaluate the results obtained in the study and the district was found to be in the less hazardous zone due to presence of natural radioactive gases in indoor environment of dwellings.

Keywords: PRTM, DTSP/DRPS, indoor radon, thoron, inhalation dose

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1. Introduction

Nuclear radiation is constantly bombarding humans, originating from naturally occurring radioactive elements that are present in varying amounts in our natural environment. Different isotopes of uranium, radium, thorium, and potassium are the most common radioactive elements found in the natural environment (soil, sand, rocks, and water) [1]. Radon, a radioactive gas, a daughter product of radium, has a half-life of 3.8 days, escape from surfaces and travel to locations far from its source [2]. The two most common sources, in a dwelling, of radon gas are the soil beneath buildings & the building construction material [3]. The radon levels in a specific location, on the other hand, are not constant and are affected by a variety of factors [4]. Thoron, a daughter product of radioactive thorium, is also a harmful radioactive inert gas. Both, radon and thoron, are quite harmful gases for human beings, if accumulated more than a certain level in dwellings [5]. However, because of its short half-life of 55.5 sec, thoron is thought to pose a lower health risk than radon [6]. However, some investigations have demonstrated that the dosage element produced by radon and its progeny is comparable to or even lower than that produced by thoron and its progeny. [7-8]. Around the world including India,

a lot of research has been done on the radiation dose from radon, thoron, and their short-lived decay products, such as ²¹⁸Po, ²¹⁴Pb, and ²¹⁴Bi [9-17].

The short-lived decay products ²¹⁸Po, ²¹⁴Pb, and ²¹⁴Bi of radon, as well as ²¹²Pb and ²¹²Bi of thoron, are well-known sources of human radiation dose. The concentrations of decay products are expressed in equilibrium equivalent concentrations (EEC), as defined elsewhere [18] by avoiding the the conventional method due to its uncertainties [19].

The purpose of this study is to look for indoor radon, thoron, and their progeny in homes in the Gurugram district of Haryana, India as not much study has been reported by other researchers, as clear from our group earlier [20]. Pin hole dosimeters are used to estimate indoor radon and thoron levels. The equilibrium equivalent level of indoor radon is calculated using the Direct Radon Progeny Sensor (DRPS), and the equilibrium equivalent level of indoor thoron is calculated using the Direct Thoron Progeny Sensor (DTSP). Wire-mesh capped DRPS/DTSP are also used to measure the attached and unattached fractions of short-lived radon and thoron decay products. The equilibrium factors were calculated as reported elsewhere [18]. Using dose conversion factors, the annual effective dose (AED) for radon, thoron, and their decay products is presented in this paper along with annual effective doses for mouth and nasal breathing.

2. Materials and Methods

2.1. Geology of Study Area

The current work provide insight into the indoor radon, thoron levels of Gurugram district of Haryana, India shown in Figure 1. Haryana is a state in India that is located in the country's northwestern region. On November 1, 1966, it was carved out of the former state of East Punjab on the basis of linguistics. It is the 22nd largest state in terms of land area, accounting for less than 1.4 percent of India's total land area [21].

Haryana's climate is classified as subtropical, semi-arid to subhumid, continental, and monsoon. The State's average rainfall is 560 mm. The NCR is divided into three climate zones: hot sub-humid zone, which includes Panipat and Sonipat districts, hot semi-arid zone, which includes Rohtak, Faridabad, and Palwal districts, and hot

arid zone, which includes Rewari, Jhajjar, Gurgaon, and Mewat districts. The agro-ecology and cropping patterns in the region are influenced by these climate types [21]. Gurugram, formerly known as Gurgaon, is a city in Haryana, India. It's about 30 kilometers southwest of New Delhi and 268 kilometers south of Chandigarh, the state capital, near the Delhi-Haryana border. Gurugram, Haryana, India is located at 28.457523 latitude and 77.026344 longitude. Gurugram (Haryana) has four seasons: Winter (January to February), Hot or Summer Monsoon (March to May), South-West Monsoon (June to September), and North-East Monsoon (October to December) (October to December). "The soils of Gurugram are sand to loamy sand in plain areas, sandy loam to clay loam/silty clay loam in alluvial plains, loam sand to loam and calcareous in salt affected plains, silty loam to loam in lowlands and loamy sand to loam and calcareous in hills" [21].

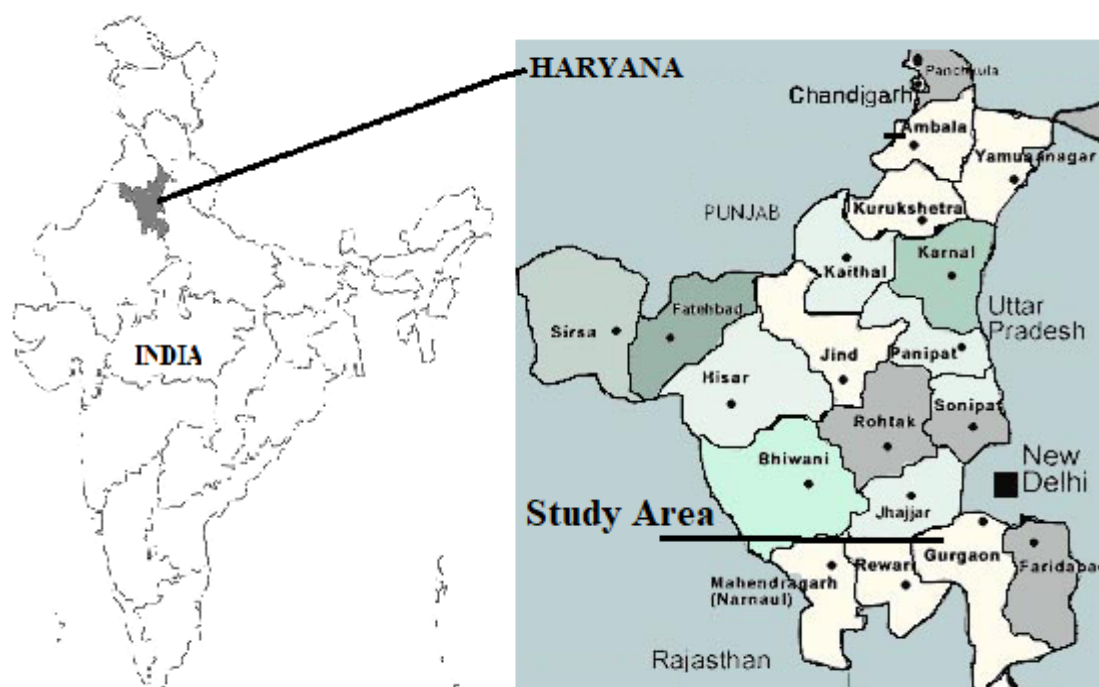


Figure 1. Map of the study area

2.2. Experimental Technique

2.2.1. Pin Hole Based Twin Cup Dosimeter

Indoor radon and thoron gas concentrations were measured using "pin-hole based twin cup dosimeters" (Figure 2) with a single entry for both gases. The dosimeters are made in such a way that tiny pin holes in the central disc between two chambers distinguish between radon and thoron gas. With the help of pin hole dosimeters, the negative value of thoron, which was a problem with twin cup dosimeters, has been solved [22].

PRTM dosimeter has two identical chambers, each measuring 4.1 cm in length and 3.1 cm in radius. The chambers are separated from one another by a central pin hole disc made of high-density polyethylene material [23]. This disc has four pin holes, each with a diameter of 1 mm and a length of 2 mm. These pin holes are ideal for 98 percent thoron cut-off and 97 percent radon transmission

to the second chamber [23]. The Bhabha atomic Research Centre designed (BARC) dosimeters loaded with suitable sized LR-115 type II films were hanged at least 25 cm away from any surface or any disturbance like exhaust fans etc., for summer season, in 50 dwellings of Gurugram district. The dwellings were selected to uniformly cover the whole study area. After completion of the three months of the season, the films were removed, stored, etched dried and counted for tracks using spark counter. The details of the whole process were given elsewhere [14].

2.2.2. DTSP/DRPS

As shown in Figure 3, the DRPS (Direct Radon Progeny Sensor) and DTSP (Direct Thoron Progeny Sensor) measures the concentrations of radon and thoron decay products/progeny (Equilibrium Equivalent Radon/Thoron concentration) in dwellings. The LR-115 detector detects particle that originates from the atom of

deposited products of decay, which is the basis for these progeny sensors. The DRPS element is made up of LR-115 cellulose nitrate, peeled LR-115 cellulose nitrate, and aluminized mylar with a net thickness of 37µm (12µm peeled cellulose nitrate and 25µm mylar). This combination is sensitive to alpha particles of 7.67 MeV produced by ²¹⁴Po and alpha particles of 8.78 MeV produced by ²¹²Po. The DTPS element is made up of LR-115 cellulose nitrate and 50µm aluminized mylar, which is sensitive to 8.78 MeV alpha particles produced by the ²¹²Po. [18]. For measuring the attached and unattached progeny of both radon and thoron the DRPS/DTPS with capping of wire mesh, as shown in Figure 4, are used that actually help to detect attached progenies, the details of which are dealt elsewhere [24]. Two DTPS/DRPS and two DTPS/DRPS with wire mesh were deployed along with one pin hole based dosimeter in the dwelling. The films were removed after the completion of the set period of three months and were processed as discussed above.

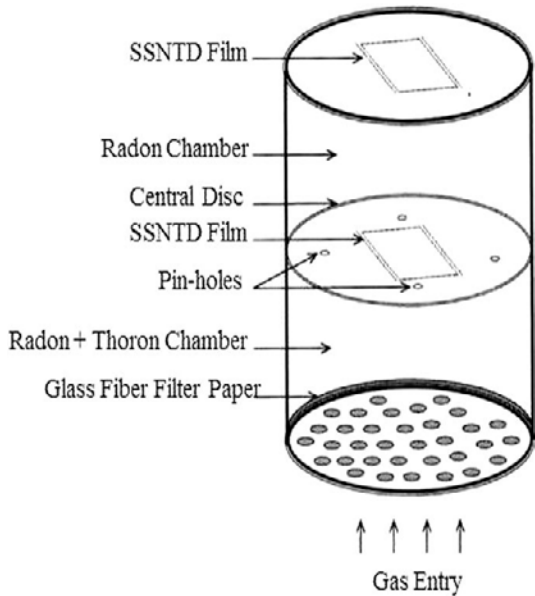


Figure 2. Pin Hole based twin cup dosimeters

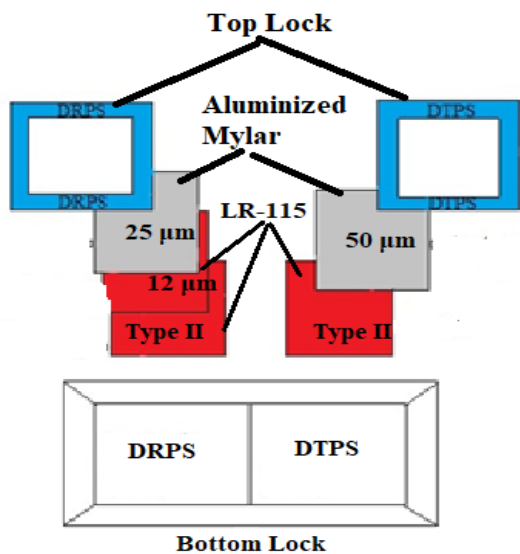


Figure 3. DTPS/DRPS schematic representation

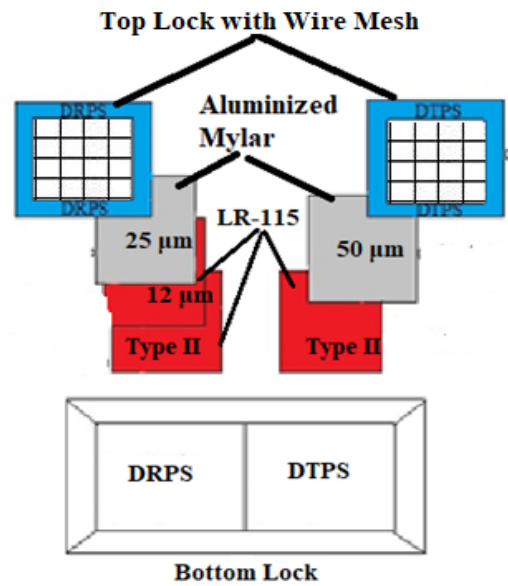


Figure 4. DTPS/DRPS with wire mesh schematic representation

2.2.3. Measurement of Indoor Radon, Thoron Concentration

The track density (tracks/day/cm²) measured by spark counter was converted into radon concentration C_R (Bq/m³) and thoron concentration C_T (Bq/m³) using the following relations [23]

$$C_T = \frac{T_2 - d \cdot C_R \cdot K'_R}{d \cdot K_T} \tag{1}$$

$$C_R = \frac{T_1}{d \cdot K_R} \tag{2}$$

The details of each component of the equations were given elsewhere [23].

2.2.4. Measurement of Equilibrium Equivalent Radon, Thoron Concentrations (EERC/EETC)

The EERC/EETC (attached progeny + unattached progeny) was measured by using the equations 3 and 4.

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

$$EERC(\text{Bq/m}^3) = \frac{T_{Rn}}{t \times S_R} \tag{4}$$

The details of each component of the equations were given elsewhere [25,26].

2.2.5. Measurement of Concentration of Attached and Unattached Progeny of Radon and Thoron

DRPS/DTPS with wire mesh, were used to measure attached progeny concentration. The wire mesh reduces the fine fraction's activity and only detects the coarse fraction's activity concentration. Same equations no. (3) & (4) with different sensitivity factors were used in case of DRPS/DTPS with wire mesh for the calculations of the attached progeny of radon and thoron as explained elsewhere [26]. By subtracting the attached progeny

concentration from total (attached + unattached) progeny concentration, the concentration of unattached progeny of both radon and thoron were calculated.

Fine fractions were calculated using the equations (5) & (6) dealt elsewhere [27]

$$f_{Rn} = \frac{EERC_u}{EERC_{u+a}} \quad (5)$$

$$f_{Tn} = \frac{EETC_u}{EETC_{u+a}} \quad (6)$$

Equilibrium factors for radon and thoron were also calculated using following equations

$$F_{Rn} = \frac{EERC_{u+a}}{C_R} \quad (7)$$

$$F_{Tn} = \frac{EETC_{u+a}}{C_T} \quad (8)$$

2.2.6. Measurement of Dose Conversion Factors (DCF) and Dose

DCF is commonly used to convert concentration into an effective dose received by human through inhalation. The DCFs for mouth and nasal breathing were calculated in mSv WLM⁻¹ using equations (9) and (10) respectively [28]

$$DCF_m = 101 \times f_{Rn} + 6.7 \times (1 - f_{Rn}) \quad (9)$$

$$DCF_n = 23 \times f_{Rn} + 6.2 \times (1 - f_{Rn}) \quad (10)$$

Equation no. (11) was used to calculate the inhalation dose to mouth and nose using above DCFs, the details were given elsewhere [29,30].

$$ID(mSva^{-1}) = C_R \times \frac{F_{Rn}}{3700} \times \frac{7000ha^{-1}}{170} \times DCF \quad (11)$$

The annual inhalation dose from ²²²Rn and ²²⁰Rn i.e AID-R and AID-T is calculated using equations (12) and (13) [31]

$$AID - R (mSva^{-1}) = [(C_R \times 0.17) + (EERC \times 9)] \times 8760h \times 0.8 \times 10^{-6} \quad (12)$$

$$AID - T (mSva^{-1}) = [(C_T \times 0.11) + (EETC \times 40)] \times 8760h \times 0.8 \times 10^{-6} \quad (13)$$

3. Results and Discussion

3.1. Indoor Radon, Thoron Concentration

Table 1 shows estimated indoor radon & thoron concentrations measured in 50 dwellings of Gurugram district of Haryana using pinhole based twin cup dosimeters for the summer season. Indoor radon concentrations range from 28.10 Bq m⁻³ to 175.82 Bq m⁻³ with an average of 72.48 Bq m⁻³. These values were found to be within the safe limits prescribed by both the ICRP's and the World Health Organization [32,33]. These levels are also lower than the value of 148 Bq m⁻³ as given by the United States Environment Protection Agency [34]. Indoor thoron concentrations range from 10.01 Bq m⁻³ to 217.78 Bq m⁻³ with an average of 57.55 Bq m⁻³. The thoron values in some dwellings of the study area were found to be slightly higher than radon values, possibly due to the higher amount of thorium present in the study area compared to radium. Another explanation could be that fine soil particles have a higher emanation coefficient. Figure 5 shows variation of indoor radon and thoron, in dwellings of Gurugram district during summer season.

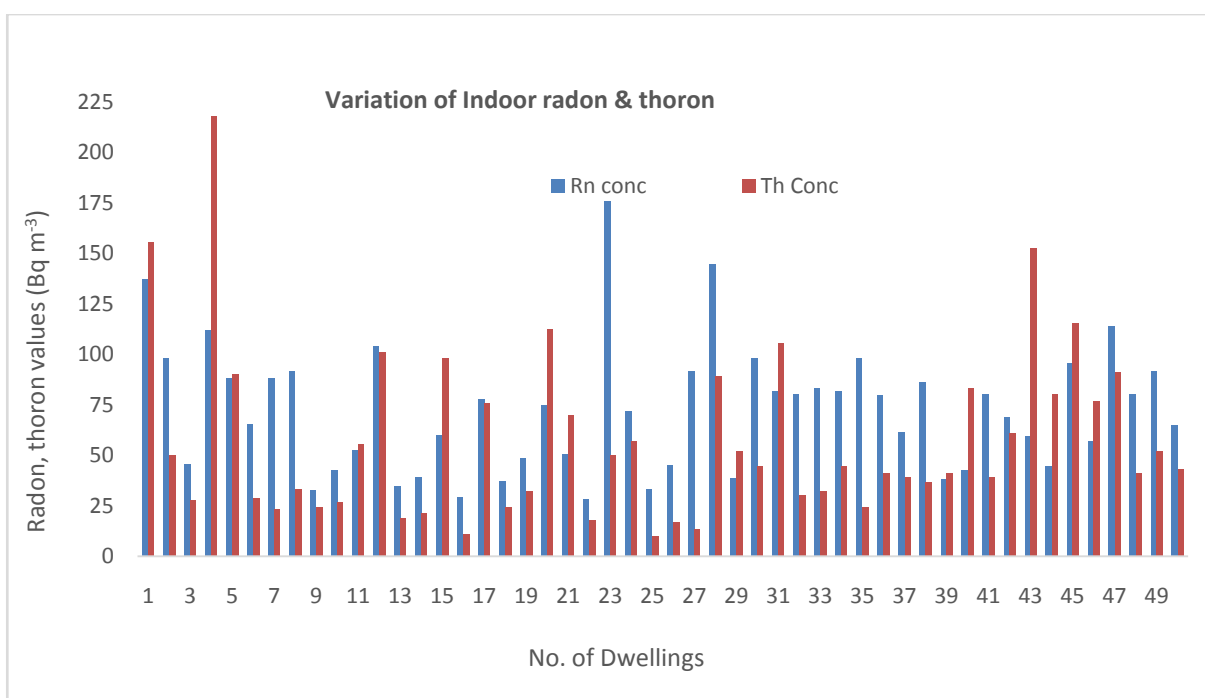


Figure 5.

3.2. Equilibrium Equivalent Radon, Thoron Concentration

Table 1 illustrate the EEC values for radon and thoron found in the study. EERC lies between 7.57 Bq m⁻³ and 47.34 Bq m⁻³ with an average of 14.90 Bq m⁻³.

Similarly EETC lies between 0.84 Bq m⁻³ and 6.50 Bq m⁻³ with an average of 1.80 Bq m⁻³. The measured values of EERC & EETC were found within the range suggested by ICRP i.e. 0.04-2 Bq m⁻³ for EETC and 2–50 Bq m⁻³ for EERC [29]. Table 1 also has the values for attached and unattached progenies of radon and thoron. Again these values are found to be in the safe limits.

Table 1. Observed concentration of indoor radon, thoron, (EERC & EETC), attached & unattached progeny, Equilibrium factors for radon & thoron, Inhalation dose from mouth & nose, Annual Inhalation Dose rates for radon & thoron

S.No	C _R (Bq m ⁻³)	C _T (Bq m ⁻³)	EERC (Bqm ⁻³)	EETC (Bqm ⁻³)	EERC _a (Bqm ⁻³)	EETC _a (Bqm ⁻³)	EERC _u (Bq m ⁻³)	EETC _u (Bq m ⁻³)	F _{Rn}	F _{Th}	ID _m (mSvy ⁻¹)	ID _n (mSvy ⁻¹)	AID-R (mSvy ⁻¹)	AID-T (mSvy ⁻¹)
1	137.25	155.56	18	2.36	14.58	1.52	3.42	0.85	0.13	0.02	4.94	1.88	1.3	0.78
2	98.04	50	16.52	1.77	12.75	1.68	3.78	0.09	0.17	0.04	5.2	1.85	1.16	0.54
3	45.75	27.78	11.54	1.12	10.26	1.01	1.28	0.11	0.25	0.04	2.21	1.04	0.78	0.34
4	111.76	217.78	16.05	1.95	13.53	1.85	2.52	0.1	0.14	0.01	3.85	1.58	1.15	0.71
5	88.24	90	23.56	2.36	15.74	1.92	7.82	0.44	0.27	0.03	9.96	3.09	1.59	0.73
6	65.36	28.89	12.99	1.44	11.29	1.25	1.7	0.2	0.2	0.05	2.75	1.21	0.9	0.43
7	88.24	23.33	13.26	2.01	13.16	1.89	0.1	0.12	0.15	0.09	1.09	0.93	0.94	0.58
8	91.5	33.33	11.56	1.6	10.65	1.52	0.91	0.08	0.13	0.05	1.82	0.97	0.84	0.47
9	32.68	24.44	7.73	1.11	7.61	1.04	0.12	0.07	0.24	0.05	0.71	0.56	0.53	0.33
10	42.48	26.67	9.03	1.06	8.86	0.81	0.16	0.26	0.21	0.04	0.84	0.65	0.62	0.32
11	52.29	55.56	7.77	1.18	6.47	1.17	1.29	0.01	0.15	0.02	1.94	0.78	0.55	0.37
12	103.92	101.11	47.34	6.5	37.45	5.72	9.89	0.78	0.46	0.06	13.9	5.12	3.11	1.9
13	34.64	18.89	9.1	1	8.01	0.98	1.09	0.03	0.26	0.05	1.82	0.83	0.62	0.3
14	39.22	21.11	10.65	1.24	9.05	1.21	1.61	0.03	0.27	0.06	2.48	1.04	0.72	0.36
15	60.13	97.78	12.22	2.54	10.13	2.53	2.09	0.02	0.2	0.03	3.1	1.23	0.84	0.79
16	29.41	11.11	7.57	0.95	7.35	0.71	0.22	0.24	0.26	0.09	0.8	0.56	0.51	0.27
17	77.78	75.56	14.49	1.52	11.71	1.45	2.78	0.08	0.19	0.02	4.0	1.52	1.01	0.49
18	37.25	24.44	10.31	1.03	9.19	0.81	1.12	0.22	0.28	0.04	1.94	0.92	0.69	0.31
19	48.37	32.22	12.01	1.24	10.47	1.11	1.54	0.13	0.25	0.04	2.51	1.12	0.82	0.37
20	74.51	112.22	18.39	1.76	15.73	1.65	2.67	0.11	0.25	0.02	4.17	1.77	1.25	0.58
21	50.33	70	26.27	4.61	25.29	3.54	0.98	1.07	0.52	0.07	2.99	2	1.72	1.35
22	28.1	17.78	8.44	1.13	8.42	0.91	0.02	0.23	0.3	0.06	0.65	0.59	0.57	0.33
23	175.82	50	22.35	2.34	17.88	2.32	4.47	0.02	0.13	0.05	6.36	2.38	1.62	0.69
24	71.9	56.67	15.28	1.88	13.73	1.68	1.55	0.2	0.21	0.03	2.77	1.34	1.05	0.57
25	33.33	10	7.88	0.99	7.36	0.98	0.52	0.02	0.24	0.1	1.13	0.64	0.54	0.29
26	45.1	16.67	8.66	1.06	8.63	1.01	0.03	0.05	0.19	0.06	0.67	0.6	0.6	0.31
27	91.5	13.33	14.31	1.48	12.73	1.41	1.57	0.06	0.16	0.11	2.72	1.28	1.01	0.42
28	144.44	88.89	22.37	2.33	20.37	2.15	2	0.17	0.15	0.03	3.77	1.92	1.58	0.72
29	38.56	52.22	9.66	1.15	8.95	1.01	0.71	0.14	0.25	0.02	1.46	0.8	0.66	0.36
30	98.04	44.44	18.52	1.86	14.5	1.58	4.02	0.27	0.19	0.04	5.6	2.03	1.28	0.55
31	81.7	105.56	21.48	2.54	15.69	1.68	5.79	0.86	0.26	0.02	7.68	2.57	1.45	0.79
32	80.39	30	11.86	1.56	9.65	0.98	2.21	0.58	0.15	0.05	3.2	1.23	0.84	0.46
33	83.01	32.22	10.1	1.58	8.2	1.38	1.9	0.2	0.12	0.05	2.75	1.05	0.74	0.47
34	81.7	44.44	10.18	1.71	8.89	1.35	1.29	0.37	0.12	0.04	2.11	0.94	0.74	0.51
35	98.04	24.44	18.58	2.29	12.86	1.58	5.72	0.71	0.19	0.09	7.39	2.35	1.29	0.66
36	79.74	41.11	15.54	1.48	12.52	1.31	3.02	0.16	0.19	0.04	4.33	1.64	1.08	0.45
37	61.44	38.89	9.43	0.84	8.21	0.81	1.22	0.03	0.15	0.02	1.99	0.88	0.67	0.27
38	86.27	36.67	20.71	1.88	19.12	1.82	1.59	0.06	0.24	0.05	3.21	1.73	1.41	0.56
39	37.91	41.11	9.34	1.21	8.47	1.14	0.87	0.06	0.25	0.03	1.61	0.81	0.63	0.37
40	42.48	83.33	11.79	1.03	10.38	0.91	1.41	0.12	0.28	0.01	2.36	1.08	0.79	0.35
41	80.39	38.89	15.21	2.13	12.82	1.62	2.39	0.51	0.19	0.05	3.64	1.5	1.06	0.63
42	68.63	61.11	17.93	1.05	11.86	1.04	6.07	0.01	0.26	0.02	7.71	2.37	1.21	0.34
43	59.48	152.22	16.68	2.43	16.2	2.09	0.48	0.35	0.28	0.02	1.75	1.24	1.12	0.8
44	44.44	80	17.21	2.01	14.88	1.82	2.34	0.19	0.39	0.03	3.74	1.62	1.14	0.62
45	95.42	115.56	20.22	2.96	19.15	2.36	1.07	0.6	0.21	0.03	2.63	1.59	1.39	0.92
46	56.86	76.67	13.75	1.82	9.8	1.68	3.94	0.14	0.24	0.02	5.17	1.69	0.93	0.57
47	113.73	91.11	23.07	1.18	13.61	0.94	9.47	0.24	0.2	0.01	11.6	3.36	1.59	0.4
48	80.39	41.11	9.22	3.16	7.41	2.9	1.81	0.26	0.11	0.08	2.59	0.97	0.68	0.92
49	91.5	52.22	15.9	1.88	13.28	1.78	2.62	0.09	0.17	0.04	3.93	1.59	1.11	0.57
50	64.71	43.33	13.06	1.58	11.31	1.52	1.75	0.07	0.2	0.04	2.81	1.23	0.9	0.48

Table 2. Min., Max. Average and Standard Deviation values of indoor radon, thoron, EERC & EETC, attached & unattached progeny, Equilibrium factors for radon & thoron, Inhalation dose from mouth & nose, Annual Inhalation Dose rates for radon & thoron

	C_R (Bq m ⁻³)	C_T (Bq m ⁻³)	EERC (Bqm ⁻³)	EETC (Bqm ⁻³)	EERC _a (Bqm ⁻³)	EETC _a (Bqm ⁻³)	EERC _u (Bq m ⁻³)	EETC _u (Bq m ⁻³)	F_{Rn}	F_{Th}	ID _m (mSvy ⁻¹)	ID _n (mSvy ⁻¹)	AID-R (mSvy ⁻¹)	AID-T (mSvy ⁻¹)
Avg.	72.48	57.55	14.90	1.80	12.52	1.58	2.37	0.23	0.22	0.04	3.60	1.47	1.02	0.55
Max.	175.82	217.78	47.34	6.50	37.45	5.72	9.89	1.07	0.52	0.11	13.91	5.12	3.11	1.9
Min.	28.10	10.01	7.57	0.84	6.47	0.71	0.02	0.01	0.11	0.01	0.65	0.56	0.51	0.27
S.D.	31.46	42.01	6.76	0.97	5.301	0.82	2.25	0.25	0.08	0.02	2.76	0.83	0.44	0.28

3.3. Equilibrium Factor

Table 1 shows the values of equilibrium factor calculated between radon, thoron and their progenies. The F_{Rn} and F_{Th} values varies from 0.11 to 0.52 with an average of 0.22 and from 0.01 to 0.11 with an average value of 0.04 respectively.

3.4. Inhalation Dose

Table 1 show the inhalation dose received by inhabitants by mouth and nose due to radon, thoron and their decay products living in the concerned dwellings of study. The inhalation dose through mouth and nose varies from the 0.65 to 13.91 mSvy⁻¹ with an average of 3.60 mSvy⁻¹ and from 0.56 to 5.12 mSvy⁻¹ with an average of 1.47 mSvy⁻¹ respectively. The average inhalation dose due to mouth breathing was found to be roughly more than twice as high as the inhalation dose due to nasal breathing.

The annual inhalation dose produced from radon fluctuates from 0.51 mSv y⁻¹ to 3.11 mSv y⁻¹ with an average value of 1.02 mSv y⁻¹. Similarly, the indoor thoron annual inhalation dose varies from 0.27 mSv y⁻¹ to 1.90 mSv y⁻¹ with an average value of 0.55 mSv y⁻¹.

The total annual inhalation dose values obtained for the Gurugram district were found to be within the recommended safe range of 0.2-10 mSv y⁻¹ by UNSCERAR [35] and 3 to 10 mSv y⁻¹ by ICRP [32] respectively and also below the recommended reference level of 10 mSv y⁻¹ by WHO [33].

4. Conclusion

- Table 2 represents the minimum, maximum and average values of all the measured quantities viz. indoor radon, thoron concentration, EERC and EETC, attached and unattached progenies of both radon and thoron, equilibrium factors for both radon and thoron, inhalation dose through mouth and nose and annual inhalation dose for both radon and thoron with standard deviation.
- The measured annual average indoor radon, thoron concentrations of 72.48 Bq m⁻³ and 57.55 Bq m⁻³ were found to be less than the values recommended by the ICRP [32].
- The average value of 14.90 Bq m⁻³ and 1.80 Bq m⁻³ for EERC & EETC respectively were found to be in good agreements with the limits suggested by ICRP [29].
- The average values of 1.02 mSv y⁻¹ and 0.55 mSv y⁻¹ of total inhalation dose due to radon and thoron together with their progeny were found to be in safe

limits of 0.2-10 mSv y⁻¹ recommended by UNSCEAR [35].

- The present study suggests a conclusion that the studied area of Gurugram district of Haryana pose no major radiological problems for people living in the dwellings due to indoor radon and thoron concentrations.

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