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Assessment of indoor Radon levels in Residences of Jind District, Haryana using Solid-State Nuclear Track Detectors: Implications for Human Health

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The present study reports the indoor radon levels in the ambience of some residences in Jinddistrict, Haryana. Assessment of absorbed dose due to inhalation of these radioactive gases is critical as a high dose of such gases is hazardous to human health. Pinhole dosimeters with LR-115 solid-state nuclear track detectors were suspended in 50 dwellings for passive measurement of indoor radon and thoron gas. Direct radon/thoron progeny sensors were also attached with dosimeters for equivalent equilibrium radon/thoron concentration measurements. This study calculates the annual absorbed ingestion dose from indoor radon/thoron concentration. From the results, it can be concluded that the absorbed doses are within the permissible limit. The average radon concentration is also below the ICRP recommendations of 200 Bq/m^3- 300 Bq/m^3.

Keywords: Indoor; Radon; Thoron; Progenies; Dosimeters; Dose

1 Introduction

Humans are always imperilled by radiation of many kinds exhibited in our environment. The origin of these radiations may be terrestrial or cosmological[1]. As many radioactive heavy metals are present in the earth's crust, the decay of these radionuclides into their corresponding progenies leads to the emission of many nuclear radiations like alpha particles, beta particles, gamma rays etc. In general, four decay series show how heavy radioactive elements decay to stable nuclei by forming different daughter nuclei with different half-life and decay products. Out of all the daughter nuclei present in these decay series, Radon (Rn^{222}) and Thoron (Rn^{220}) are present in gaseous form. Radon and thoron are radioactive gases and decay into their corresponding progenies (Po^{218} and Po^{216}) by emission of alpha particles of energy 5.59 MeV and 6.40 MeV. The half lime of Rn^{222} is 3.82 days, and Rn^{220} is 55.6 sec[2]. They have the ability to quickly diffuse and spread throughout the air, potentially leading to widespread contamination[3].

Worldwide atmospheric radon concentration has an average value of 40 Bq/m^3 [4]. However, it was reported by many researchers from different parts of the world that the indoor concentration of these radioactive gases is immense as compared with atmospheric concentration. According to a report by UNSCEAR[5], half of the total radiation dose received by humans due to natural radioactivity is due to these radioactive gases[6]. It was reported that we receive an average of 1.3mSv of radiation dose per year due to inhalation and ingestion of these gases. Given that individuals spend a significant amount of time indoors, it is crucial to conduct thorough evaluations of the concentration levels of these gaseous elements within indoor spaces. Inhalation or ingestion of these gases or their progenies present in our surroundings may lead to some probability of accumulating these gases in our lungs[7,8]. If any of the attached heavy metal progeny, especially Po^{214} and Po^{212}, decays in our lungs, then it may lead to some modulation in our body cells and tissue and, in some cases, may lead to cancer[9]. Due to these adverse effects of radionuclides, ICRP declares these gases carcinogenic. It also sets an action level limit of 200-300 Bq/m^3 on the indoor level of this concentration. In this report, measurement of Radon/Thoron concentration is done in 50 dwellings in the Jind district of Haryana, India shown in Fig.1. Indoor radon/thoron concentration depends upon factors like ventilation conditions, building material, soil gas infiltration *etc.*[10,11]. Amongst the various factors that contribute to the variation in indoor radon concentration, the diffusion of radon from the surrounding soil of the dwelling, facilitated by airflow, is the most crucial factor. This diffusion can

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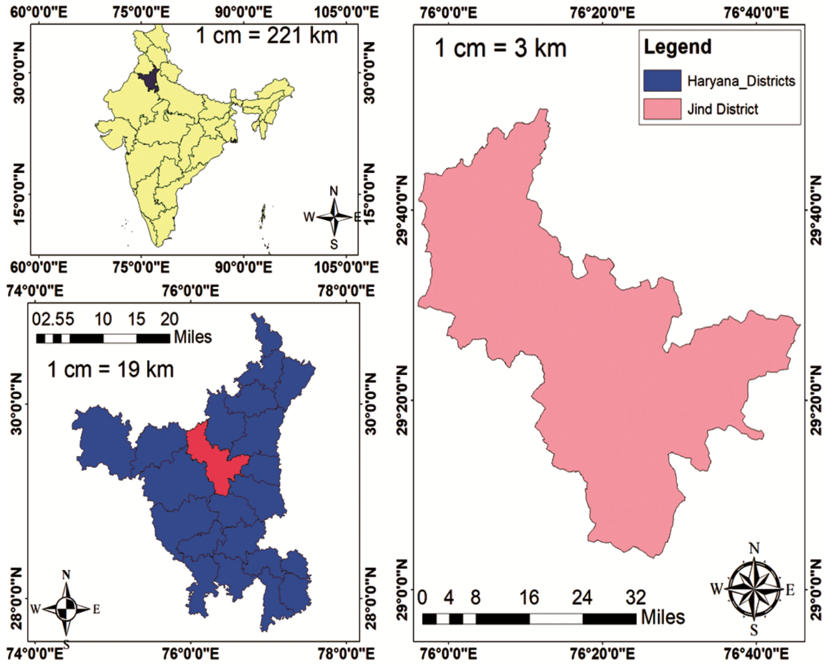

Fig. 1 — Study area map (Jind).

occur either from the ground beneath the dwelling or from the groundwater, making it imperative to monitor indoor radon concentration levels. Very high-energy alpha particles are emitted when these gases decay into their corresponding progenies. Inhalation of these radioactive gases can lead to trapping of their progenies into our lungs, where the emission of alpha particles can further cause damage to cells and tissue[12]. Also, if these gases decay in the indoor atmosphere, then their progenies attach themselves with dust particles, water vapour and many other surfaces. So, inhalation of radon/thoron gas or their progenies for an extended period can have a harmful effect like a change in respiratory function or, in the worst case, can cause lung cancer. Due to the adverse effects of higher concentrations of these gases, research is conducted worldwide, and areas with higher indoor radon concentrations are reported. In one of the reports by ICRP, a limit of 200-300 Bq/m^3 is set as the permissible limit for indoor radon[13]. In the present work, pinhole dosimeters attached with deposition-based radon/thoron sensors (DRPS/DTPS) are deployed in 50 dwellings of the study area. Radon/Thoron concentration, equilibrium equivalent radon/thoron concentration and annual effective dose to the study area residents were accessed in this report.

2 Materials and Methods

For the measurement of indoor radon and thoron concentration in selected dwellings of the Jind district, pin-hole dosimeters were employed for this purpose[14]. These dosimeters are different from twin cup dosimeters (in which there are two side gas entries) as in these dosimeters, gas enters from one side and enters the thoron + radon chamber. Small holes are present in the thoron chamber through which gases diffuse to the radon chamber. As the half-life of thoron gas is small (55.6 sec), only radon gas can diffuse through holes into the radon chamber[15]. These dosimeters were deployed for three months in the respective dwellings and then analysed in the laboratory. The films that were exposed for three months are removed from the dosimeters. Then these films are etched in a 2.5N solution of sodium hydroxide at a constant temperature of 60 °C for 90 minutes to remove some part of the cellulose nitrate films attached over the polyester base. The constant temperature of 60 °C is maintained throughout etching by use of a constant temperature water bath developed by Polltech Pvt. Ltd. Then, the cellulose nitrate part is peeled from the polyester base. The track density was then calculated using Spark Counter. All etching procedures were performed by following the similar procedure.

2.1 Measurement of indoor radon and thoron

Single entry twin cup dosimeters were used to measure indoor radon and thoron concentration. After measurement of the track density of films following equations were used for the measurement[16,17]

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

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

Here T_1 and T_2 are track densities of LR-115 films in radon and thoron chambers, 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.

2.2 Measurement of equilibrium equivalent radon/thoron Concentration

For analysis of EERC/EETC, DRPS/DTPS (Deposition Based Radon/Thoron Sensor) was attached with a pin-hole dosimeter. An absorber of 50 μm for thoron and 37 μm for radon was used to get alpha track only due to alpha particles emitted by Po^{214} and Po^{212}.

For measurement of equilibrium equivalent thoron concentration following equation is used[18,19]

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

Here T_T is the track density of LR-115 attached in DTPS, t is the exposure time, and S_T is the thoron progeny sensitivity factor. For measurement of radon progenies, the tracks of thoron in radon absorbed have to be subtracted, for which we have used the following equation[20]

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

Equivalent equilibrium radon concentration is calculated using the following equation.

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

Here T_{Rn} is radon track density calculated in equation 4, t is exposure time, and S_R is the radon progeny sensitivity factor. So, radon/thoron concentration and EERC/EETC were calculated using the above equations. These values of equivalent equilibrium radon concentration are the total progenies concentration, *i.e.* sum of the attached and unattached progeny concentration. The measurement of attached and unattached progenies is also crucial as the fine, and coarse parts of progenies are used to calculate the total absorbed doses to the body received due to inhalation of these harmful gases.

2.3 Measurement of attached and unattached progenies

To estimate the attached and unattached progeny concentration of indoor radon and thoron gases, a 200-mesh type wire structure is capped over DRPS/DTPS. Out of the fine fraction and coarse fraction, these are sensitive to the later ones and mostly neglect the fine fraction activity progenies. However, the sensitivity factors are different and given elsewhere[21]. By quantifying the track density on a wire-meshed solid state nuclear track detector (SSNTD), the concentration of attached progenies can be determined. The concentration of unattached progenies can then be obtained by subtracting the attached progeny concentration from the total concentration. Equations (3) and (4) were used to calculate attached thoron and radon progenies. The total absorbed effective dose due to ingestion of these radioactive gases was also calculated to check the health risk to the residents of the study area. The following equation is used to calculate the absorbed ingestion dose [22]

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

$$(AED)_{Th} = [(C_{Th} \times 0.11) + (EETC \times 40)] \times 8760 \text{ h} \times 0.8 \times 10^{-6} \quad \ldots(7)$$

3 Results

The indoor radon and thoron concentration was measured in 50 dwellings of Jind city, Haryana using single-entry pin-hole dosimeters. The results of radon and thoron concentration are shown in Table 1. From the results, the radon concentration values range from a minimum value of 35.39Bq/m^3 to 462.7Bq/m^3 with an average value of 152.4Bq/m^3. The thoron concentration in the study area ranged from 2.22 Bq/m^3 to 602.3Bq/m^{3,} with a mean value of 113.1Bq/m^3. Although these values seem to be within the limits set by ICRP, it is crucial to note that WHO[6] has set the permissible limit of indoor radon and thoron concentration to 100 Bq/m^3.

The average value of effective equivalent radon concentration was 28.31Bq/m^3 with a maximum of 93.95Bq/m^3 and a minimum value of 5.35Bq/m^3. The effective equivalent thoron concentration varies from 3.4Bq/m^3 to 12.2Bq/m^3, with an average value of 0.82Bq/m^3. The average inhalation dose to the human body due to the inhalation of these radioactive gases in our environment is also calculated, and the results are shown in Table 1. The maximum value of the inhalation dose was found to have a value of 9.78 and a minimum value of 0.77, with an average value of 2.38.All the data in table 1 is under the permissible and action-level limits of ICRP[13]. Fig 2 shows the single entry pin-hole dosimeter used for measurement

Table 1 — Indoor Radon and Thoron and progeny Concentration.

Location	Radon conc. (Bq/m^3)	Thoron conc. (Bq/m^3)	EERC (Bq/m^3)	EETC (Bq/m^3)	$EERC_{attached}$ (Bq/m^3)	EETC $_{attached}$ (Bq/m^3)	$EERC_{unattached}$ (Bq/m^3)	$EETC_{unattached}$ (Bq/m^3)	$(AED)_{Rn}$ (mSv)	$(AED)_{Th}$ (mSv)	AIDTotal (mSv)
1	62.1	57.8	19.25	2.74	16.60	1.18	02.65	1.56	1.17	0.81	1.99
2	252.2	275.5	79.08	3.85	52.26	2.83	26.82	1.03	4.81	1.29	6.1
3	47.1	38.9	20.78	3.97	09.71	3.16	11.07	0.81	1.24	1.14	2.39
4	298	172.2	45.75	9.13	27.91	7.74	17.84	1.38	2.95	2.69	5.64
5	462.7	603.3	93.95	12.20	83.16	11.6	10.79	0.56	5.89	3.89	9.78
6	116.9	71.1	26.78	3.33	16.20	2.93	10.58	0.4	1.66	0.99	2.65
7	174.5	201.1	13.47	4.00	06.68	3.8	06.79	0.19	0.96	1.27	2.24
8	124.1	85.6	09.78	1.64	06.77	1.48	03.00	0.16	0.7	0.53	1.22
9	166.6	86.7	17.86	11.50	02.68	10.6	15.18	0.95	1.21	3.31	4.51
10	131.3	32.2	05.35	1.04	02.78	0.98	02.57	0.06	0.45	0.32	0.77
11	99.4	163.3	25.44	2.34	14.86	1.55	10.57	0.79	1.57	0.78	2.35
12	124.1	77.8	42.92	3.45	18.20	2.05	24.73	1.4	2.6	1.03	3.63
13	78.4	103.3	29.03	2.23	17.82	1.82	11.21	0.42	1.75	0.71	2.46
14	147.7	82.2	51.59	4.41	41.05	4.04	10.54	0.37	3.12	1.3	4.42
15	156.8	122.2	32.61	6.34	30.33	5.39	02.28	0.95	2.04	1.87	3.91
16	401.3	151.1	81.35	6.75	57.36	5.19	23.99	1.56	5.1	2.01	7.11
17	400.0	375.5	33.76	2.88	25.73	2.32	08.04	0.56	2.37	1.1	3.47
18	110.4	31.1	21.59	2.26	17.45	1.85	04.14	0.41	1.36	0.66	2.02
19	137.2	75.6	21.32	2.77	17.87	2.05	03.45	0.71	1.37	0.83	2.21
20	147.0	188.8	052.7	2.55	39.03	2.12	13.67	0.43	3.18	0.86	4.04
21	81.1	84.4	25.25	2.20	15.14	1.31	10.11	0.89	1.54	0.68	2.22
22	94.8	45.6	16.71	1.82	10.93	1.28	05.78	0.54	1.06	0.55	1.61
23	174.5	96.7	35.11	3.38	25.20	2.49	09.91	0.89	2.2	1.02	3.23
24	103.2	72.2	40.23	2.65	29.16	2.46	11.07	0.19	2.42	0.8	3.22
25	103.2	132.2	43.14	5.24	34.13	3.8	09.00	1.43	2.59	1.57	4.16
26	111.1	138.8	24.94	5.47	18.60	4.51	06.33	0.96	1.55	1.64	3.19
27	167.9	84.4	33.67	3.55	23.05	2.66	10.62	0.89	2.11	1.06	3.17
28	91.5	55.6	13.28	1.22	04.21	0.88	09.07	0.34	0.86	0.38	1.25
29	217.6	72.2	34.99	3.38	19.37	2.73	15.61	0.65	2.24	1	3.25
30	222.2	91.1	41.82	2.08	33.46	1.85	08.35	0.23	2.64	0.65	3.29
31	107.8	55.6	14.16	1.78	09.22	1.35	04.95	0.44	0.93	0.54	1.47
32	137.2	111.1	27.90	3.62	13.88	1.55	14.02	2.07	1.75	1.1	2.85
33	93.5	22.2	10.71	1.49	05.71	0.71	05.00	0.78	0.72	0.43	1.15
34	111.1	54.4	20.13	1.95	05.59	0.81	14.53	1.14	1.28	0.59	1.86
35	139.8	84.4	17.54	2.43	07.67	1.55	09.87	0.89	1.16	0.75	1.91
36	85.0	100.0	22.90	3.57	04.43	2.09	18.46	1.48	1.41	1.08	2.48
37	35.3	32.2	18.48	4.14	13.44	1.65	05.04	2.49	1.10	1.18	2.28
38	155.5	84.4	41.27	1.54	04.47	1.21	36.80	0.32	2.54	0.5	3.03
39	122.2	118.8	20.95	1.99	06.63	1.04	14.32	0.94	1.33	0.65	1.98
40	156.8	56.7	06.25	0.82	01.65	0.27	04.61	0.55	0.53	0.27	0.8
41	113.7	101.1	19.29	2.32	06.82	1.72	12.47	0.6	1.23	0.73	1.96
42	167.9	28.9	14.75	3.96	07.65	2.69	07.10	1.27	1.03	1.13	2.16
43	110.4	222.2	11.51	1.83	07.06	0.67	04.45	1.16	0.78	0.68	1.47
44	148.3	76.7	13.52	2.29	02.88	0.34	10.65	1.96	0.94	0.7	1.64
45	247.0	2.2	23.16	3.36	09.41	1.18	13.75	2.18	1.6	0.94	2.54
46	165.3	122.2	33.33	2.93	08.35	0.40	24.98	2.53	2.09	0.92	3.01
47	113.7	164.4	18.57	2.60	08.84	1.11	09.73	1.49	1.19	0.86	2.04
48	152.9	108.8	19.50	2.84	12.78	0.81	06.72	2.03	1.28	0.88	2.16
49	139.2	86.7	18.16	1.84	02.88	0.34	15.29	1.51	1.19	0.58	1.78
50	111.1	156.6	09.92	2.12	06.33	0.74	03.59	1.38	0.69	0.71	1.4
Average	152.4	113.1	28.31	3.40	17.27	2.42	11.04	0.98	1.79	1.04	2.38
Max	462.7	603.3	93.95	12.20	83.16	11.6	36.80	2.53	5.89	3.89	9.78
Min	35.3	2.2	05.35	0.82	01.65	0.27	02.28	0.06	0.45	0.27	0.77
Median	134.3	86.1	22.25	2.76	13.11	1.77	10.33	0.89	1.39	0.86	2.37
Sd. Dev.	84.3	96.4	18.36	2.30	15.81	2.29	06.98	0.62	1.12	0.68	1.62
Kurt	4.7	13.2	3.69	6.30	05.38	7.17	02.85	0.02	4.1	7.21	6.25
Skew	4.9	13.3	3.68	6.27	05.37	7.17	03.01	0.14	4.1	7.18	6.26

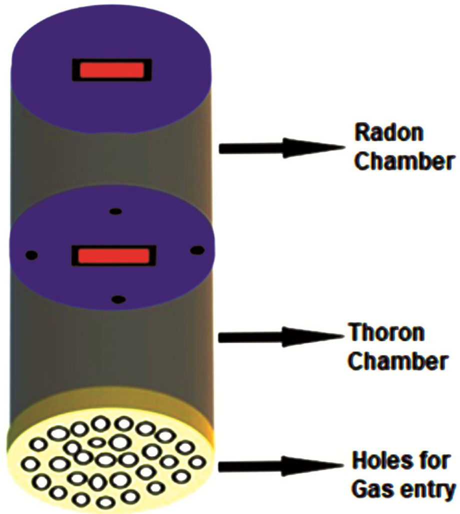

Fig. 2 — Block diagram of pin-hole dosimeter.

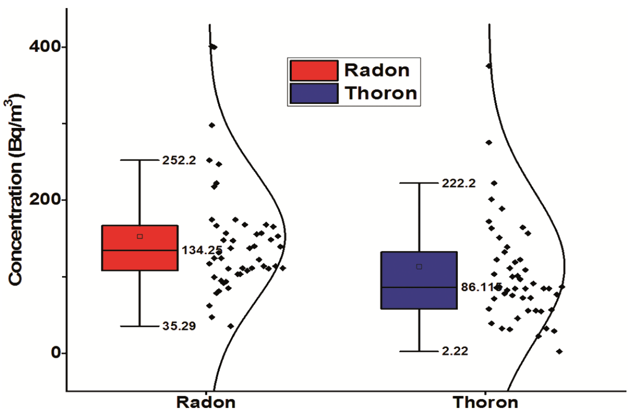

Fig. 3 — Box-whisker plot of radon and thoron concentration.

of radon and thoron Concentration. It can be concluded from the graph that both of these values, though, have a higher value at some locations but have an average value below the permissible limit. Apart from the measurement of radon and thoron concentration, the concentration of attached and unattached progeny concentration was also reported in this paper. The concentration of attached progenies was higher as compared with unattached progeny concentration.

The distribution of indoor radon and thoron concentration in the study area is shown by the box-whisker plot shown in Fig. 3. It can be seen from the plots that average radon concentration values for radon in higher than thoron. The 25% and 75% of the radon and thoron distribution are also given in Fig. 3. Also, 80 % of the dwellings have radon concentration below 200 Bq/m^3, and 90% of the dwellings have thoron concentration below 200Bq/m^3.The box whisker plot showing the distribution of radon and

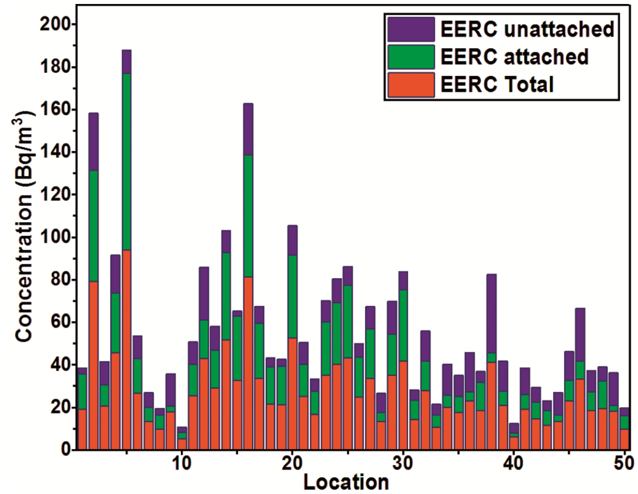

Fig. 4— Bar graph showing the concentration of attached and unattached progenies of indoor radon.

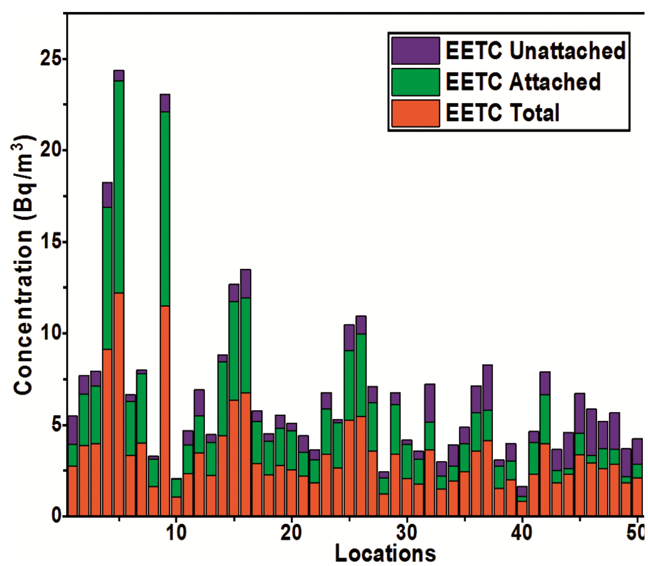

Fig. 5 — Bar graph showing the concentration of attached and unattached progenies of indoor thoron.

thoron concentration is shown in Fig. 3, showing average radon and thoron concentration below the permissible limit of 200-300Bq/m^3.

We can observe in the frequency distribution plot shown in Fig. 4 that most of the dwellings have EERC concentration ranges from 5.35-93.5Bq/m^3 and EETC concentration between 0.82 to 12.2Bq/m^3. Fig. 4 and 5 show the concentration of attached and unattached progenies discovered in dwellings of the study area. The frequency distribution of absorbed dose is also plotted and shown in Fig. 6. A good positive correlation was observed between the attached radon and thoron progenies compared with the total progeny concentration, shown in Fig. 7.

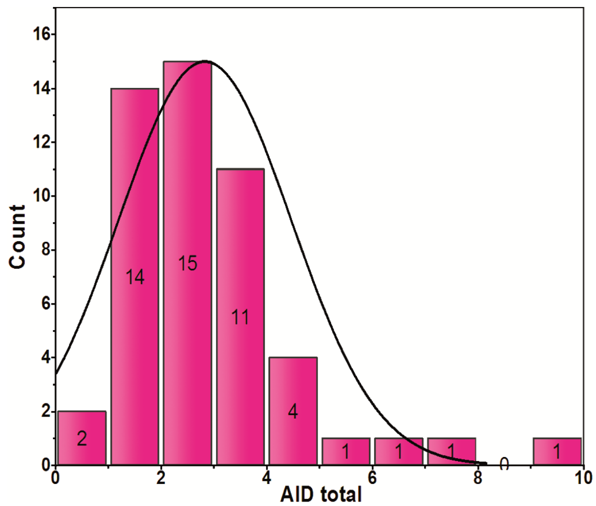

Fig. 6 — Frequency distribution plot for total annual absorbed dose due to inhalation of radon and thoron gas.

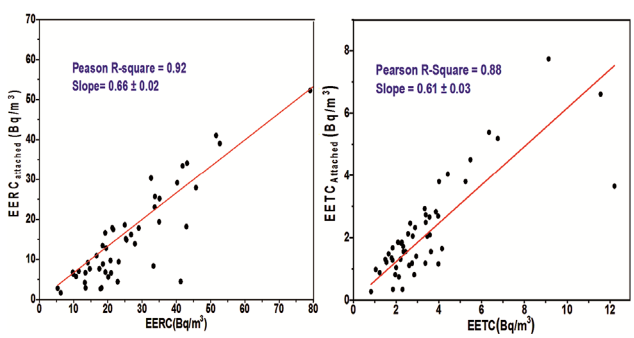

Fig.7 — Correlation plots between total and attached progeny concentrations of radon and thoron gases.

Considering the absorbed ingestion dose, the frequency distribution plot is shown in Fig. 6, and we can see that 70 % of the dwellings have absorbed indoor doses below 2.54 mSv.

4 Conclusions

1. The average indoor and thoron concentration was found to have values of 152.4 and 113.11 Bq/m^3. These values are below the ICRP limit of 200-300Bq/m^3. However, it can be concluded from the results of this study that even though the average values of radon and thoron concentration are below the limits set by ICRP[13] at some locations, these values are still substantial when compared to the limit set by WHO[6].
2. At some locations, higher values of radon and thoron concentration were noted.
3. The absorbed dose to the residents of dwellings of the study was found to have an average value of 2.38 mSv/year.
4. The concentration of attached progenies is found to be higher than unattached progenies. 66% of the radon progenies and 61% of thoron progenies are found to be attached.

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