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Study of indoor radon, thoron and their decay products level in residences of Udham Singh Nagar district of Uttarakhand, India

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Abstract

Tendency of radioactive radon gas to accumulate within the indoor environment can cause serious hazard to person. Presented study has been carried in 102 houses of district Udham Singh Nagar of Uttarakhand. Gaseous radon and thoron levels were measured with pinhole twin cup dosimeters, and decay products were measured with progeny sensors (DTPS/DRPS). LR-115 (SSNTD) was used as a detector in both techniques. The average radon and thoron values (in Bq m^{-3}) were found to be 36.7 ± 9.5 and 48.8 ± 21.2, respectively. The radon and thoron progeny were found to be 17.1 ± 4.5 and 1.7 ± 0.5 Bq m^{-3}, respectively. The concentration of radon/thoron and progenies were estimated in different seasons and doses were also calculated by applicable formulae. The total annual effective dose (in mSv $year^{-1}$) due to inhalation of radon, thoron and their progenies concentration was found at 1.64 ± 0.34.

Keywords Radioactive · Hazard · Dosimeters · Progenies · Annual effective dose

Introduction

Because of the carcinogenic effects of radon, thoron and their daughters on humans, it is important to determine their levels [1, 2]. Human always been exposed to the radiation which mainly comes from natural and human sources. Natural radiation significant as it constitute major source of radiation doses to the people. Natural background radiation is generated by cosmic radiation, internal radiation (radionuclide's presents in body), inhalation and external terrestrial radiation [3, 4]. The natural background radiation predominantly depends upon the geological condition, altitude and house type. Radon and its offspring account for more than half of all radiation [5–9]. The alpha decay of ^{226}Ra in uranium decay chain produces radon (^{222}Rn). As radium emits alpha particles, it transforms into radon, a gaseous substance. This gas can break away from the soil grain and move through pore spaces to the surface, where it can be released into the living atmosphere. Thoron (^{220}Rn), another radon radioisotope, is found in the thorium series and contributes significantly to radiation doses. Previously, researchers had completely ignored thoron, and studies had only concentrated on ^{222}Rn and its effects. However, in recent decades, research has focused on the ^{220}Rn as well [10–13]. Due to gaseous nature of radon it can accumulated in the dwellings. The indoor level of radon depends upon the several meteorological parameters like ventilation rate, construction materials, humidity, wind rate, life style of inhibitors etc. [14, 15]. It is important to estimate the ^{220}Rn level as it is found everywhere along with ^{222}Rn and sometimes the quantity is much greater than that of ^{222}Rn, which contributes a significant amount to the total radiation dose [16, 17].

This study was performed in the district Udham Singh Nagar (USN) of Uttarakhand. The USN is third most populated district of Uttarakhand. The location of district Udham Singh Nagar is shown in Fig. 1. The latitude and longitude of Udham Singh Nagar district are 28° N to 58° N, and 78° E to 81° E, respectively. No previous studies for radon & thoron were reported from this district so far. The aim of this research is to determine the levels of ^{222}Rn, ^{220}Rn, and

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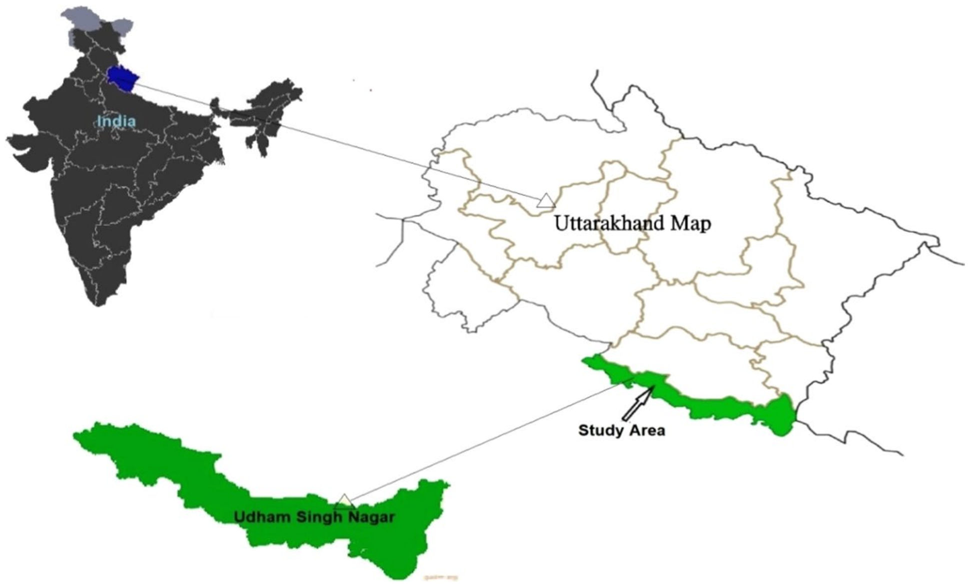


Fig. 1 Map and location of study area

progenies, as well as their seasonal variations, which will be useful in calculating radiation doses and their effects on human health. This data will add to the national database of radon, which can will be useful for the purpose of radiation protection.

Experimental techniques

Exposure of detectors

The passive techniques had been used to evaluate the ^{222}Rn, ^{220}Rn, EERC and EETC values. A total number of 102 houses were covered for this study. For the ^{222}Rn and ^{220}Rn concentration, cylindrical pin-hole-twin-cup dosimeters were used and for progeny concentration direct progeny sensor (DTPS/DRPS) was used. Sahoo et al. (2013) and Mishra et al. (2008) explore the details of these instruments [18–20].

In both pin hole dosimeter (Fig. 2) and DTPS/DRPS (Fig. 3) techniques cellulose nitrate detectors (LR-115) were utilized. These detectors were installed in houses following standard protocol and exposed for the period of 90 days. Dosimeters were retrieved and replaced with new ones after the exposure cycle was completed. The recovered dosimeters were then analysed in lab, where the registered tracks on LR-115 film were etched in a constant temperature bath with sodium hydroxide (2.5 N) to achieve good visibility of the tracks.

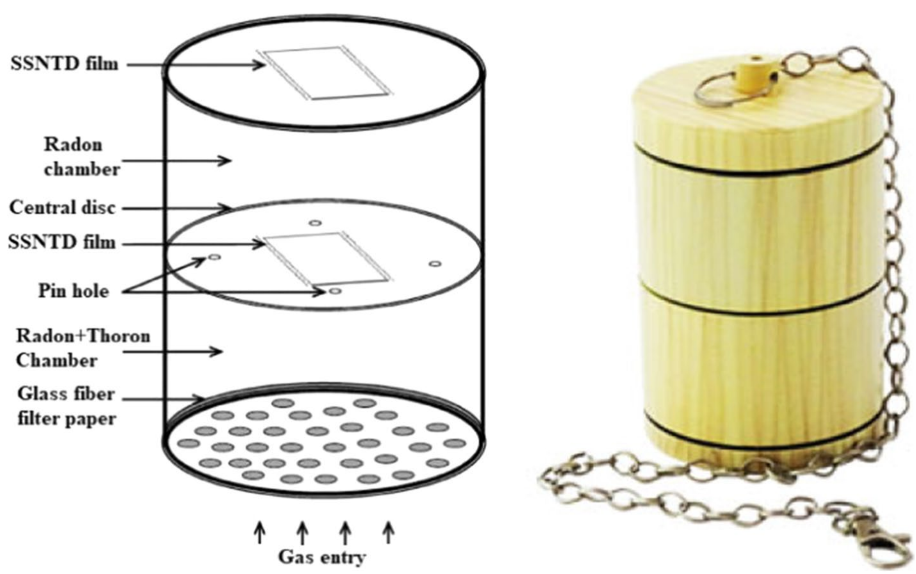


Fig. 2 Pin-hole-twin cup dosimeter

Fig. 3 Direct progeny sensor (DTPS/DRPS)

Estimation of ^{222}Rn and ^{220}Rn concentrations

After chemical etching of LR-115 films from pinhole dosimeters were counted with a spark counter [21], and the counted tracks were transformed into concentrations using the Eqs. (1) and (2) [18]:

$$C_{\text{Rad}}\left(\text{Bq m}^{-3}\right) = T_{r1}/\left(D_{\text{exp}} * k_{\text{rad}}\right) \quad (1)$$

$$C_{\text{Tho}}\left(\text{Bq m}^{-3}\right) = \left(T_{r2} - T_{r1}\right)/\left(D_{\text{exp}} * k_{\text{tho}}\right) \quad (2)$$

where $C_{\text{Rad,}}$ and C_{Tho} are the ^{222}Rn and ^{220}Rn concentration, T_{r1} and T_{r2} are track density in Radon-chamber and Radon + Thoron-chamber, and D_{exp} is the number of days of exposure. K_{rad} and K_{tho} are the calibration factors for ^{222}Rn (0.172 tr cm^{-2} day^{-1}/(Bq m^{-3})), and ^{220}Rn (0.010 tr cm^{-2} day^{-1}/(Bq m^{-3})) respectively.

Estimation of ^{222}Rn/^{220}Rn progeny concentration

LR-115 from DTPS/ DRPS were etched and counted using spark counting technique [21]. For measuring progeny concentration, Eqs. (3) and (4) has been used to convert tracks into concentration [19, 20]:

$$\text{EETC}\ \left(\text{Bq m}^{-3}\right) = T_{\text{tho}}/\left(d_{\text{exp}} * S_{\text{tho}}\right) \quad (3)$$

$$\text{EERC}\left(\text{Bq m}^{-3}\right) = T_{\text{rad}}/\left(d_{\text{exp}} * S_{\text{rad}}\right) - \text{EETC} \quad (4)$$

Equilibrium factor for ^{222}Rn and ^{220}Rn

Estimation of equilibrium factor between ^{222}Rn, ^{220}Rn and their progenies is always important for assessment of inhalation dose. The Equilibrium factor ('F') is the ratio of total PAEC (potential alpha energy concentration) for the actual progenies to the total PAEC of the progenies which would be equilibrium with the ^{222}Rn and ^{220}Rn [22]. An equilibrium factor 1 defines the equal amount of ^{222}Rn and its progeny.

In past years, equilibrium factor F for indoor radon (0.4) was globally recommended by ICRP and UNSCEAR. With the time, new DTPS/DRPS passive detection techniques were discovered for measuring the short lived daughters of ^{222}Rn and ^{220}Rn [23]. The equilibrium factor for ^{222}Rn (F-$_{\text{Radon}}$) and ^{220}Rn (F-$_{\text{Thoron}}$) was estimated by Eqs. (5) and (6) respectively [24]:

$$\text{F}_{\text{-Radon}} = \text{EETC}\ \left(\text{Bq m}^{-3}\right)/C_{\text{Rad}}\left(\text{Bq m}^{-3}\right) \quad (5)$$

$$\text{F}_{\text{-Thoron}} = \text{EERC}\ \left(\text{Bq m}^{-3}\right)/C_{\text{Tho}}\ \left(\text{Bq m}^{-3}\right) \quad (6)$$

Estimation of annual effective dose (AED) due to inhalation

AED due to inhalation of indoor ^{222}Rn, ^{220}Rn, and their progeny has been calculated using the Eqs. (7) and (8) [25].

$$\text{AED}_{\text{radon}}\left(\text{mSv y}^{-1}\right) = \left[\left(C_{\text{rad}} \times 0.17\right) + (\text{EERC} \times 9)\right] \times 7000 \times 10^{-6} \quad (7)$$

$$\text{AED}_{\text{thoron}}\left(\text{mSv y}^{-1}\right) = \left[\left(C_{\text{tho}} \times 0.11\right) + (\text{EETC} \times 40)\right] \times 7000 \times 10^{-6} \quad (8)$$

where T_{tho} and T_{rad} are tracks in DTPS and DRPS, S_{tho} and S_{rad} are the sensitivity factor for ^{220}Rn (0.94 ± 0.027 Tr cm^{-2} day^{-1}/EEC (Bq m^{-3}) and ^{222}Rn (0.09 ± 0.0036 Tr cm^{-2} day^{-1}/EEC (Bq m^{-3}) respectively.

Results and discussion

^{222}Rn and ^{220}Rn concentrations, EERC and EETC were measured in the total numbers of 102 houses in Udham Singh Nagar district. This study was carried out in winter,

Table 1 Seasonal variation in ^{222}Rn, ^{220}Rn and progeny concentration

	Winter	Summer	Rainy	Annual mean concentration
^{222}Rn (Bq m^{-3})				
MIN	15.3	7.3	11.6	18.7
MAX	84.1	84.4	81.0	60.5
MEAN	46.3	24.9	38.4	36.7
STDEV	15.7	11.0	12.6	9.5
^{220}Rn (Bq m^{-3})				
MIN	11.7	7.2	11.4	10.1
MAX	149.6	151.5	82.3	100.4
MEAN	61.6	43.8	41.3	48.8
STDEV	32.2	26.7	16.6	21.2
EERC (Bq m^{-3})				
MIN	9.0	2.4	4.2	7.0
MAX	41.3	37.5	56.3	30.5
MEAN	20.8	13.9	17.1	17.1
STDEV	6.7	5.7	8.2	4.5
EETC (Bq m^{-3})				
MIN	0.8	0.4	0.5	0.9
MAX	4.4	3.3	4.8	3.1
MEAN	2.0	1.5	1.7	1.7
STDEV	0.7	0.7	0.7	0.5
F-$_{Radon}$				
MIN	0.17	0.10	0.07	0.17
MAX	1.20	1.48	1.45	1.10
MEAN	0.51	0.60	0.48	0.53
STDEV	0.23	0.28	0.26	0.18
F-$_{Thoron}$				
MIN	0.01	0.01	0.01	0.01
MAX	0.18	0.19	0.18	0.18
MEAN	0.045	0.049	0.049	0.048
STDEV	0.03	0.04	0.03	0.03

MIN = minimum, MAX = maximum, STDEV = standard deviation, F-$_{Radon}$ = Equilibrium factor for ^{222}Rn and its progeny, F-$_{Thoron}$ = Equilibrium factor for ^{220}Rn and its progeny

summer and rainy season. Table 1 illustrates the results of these three seasons.

^{222}Rn in winter season found to be in the range 15.3–84.1 with a mean of 46.3 ± 15.7. In summer, it is found to be in the range 7.3–84.1 with a mean of 24.9 ± 11.0, and the value found to be in the range 11.6–81.0 with a mean of 38.4 ± 12.6 in rainy season. The ^{220}Rn value found to be in the range 11.7–149.6 with a mean of 61.6 ± 32.2, 7.2–151.5 with a mean of 43.8 ± 26.7, and 11.4–82.3 with a mean of 41.3 ± 16.6 within winter, summer and rainy seasons, respectively.

The value of EERC found to be 9.0–41.3 and a mean of 20.8 ± 6.7 in winter, 2.4–37.5 with a mean of 13.9 ± 5.7 in

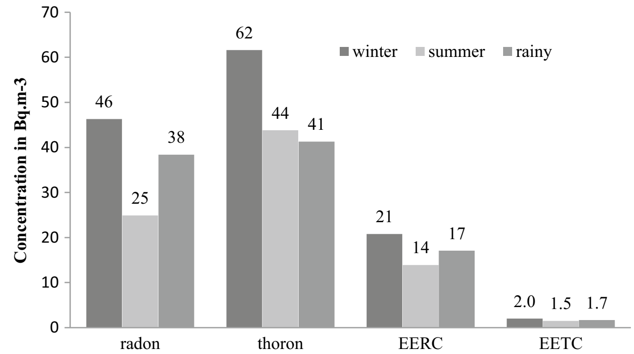


Fig. 4 Seasonal variations in concentration of ^{222}Rn, ^{220}Rn, EERC, and EETC

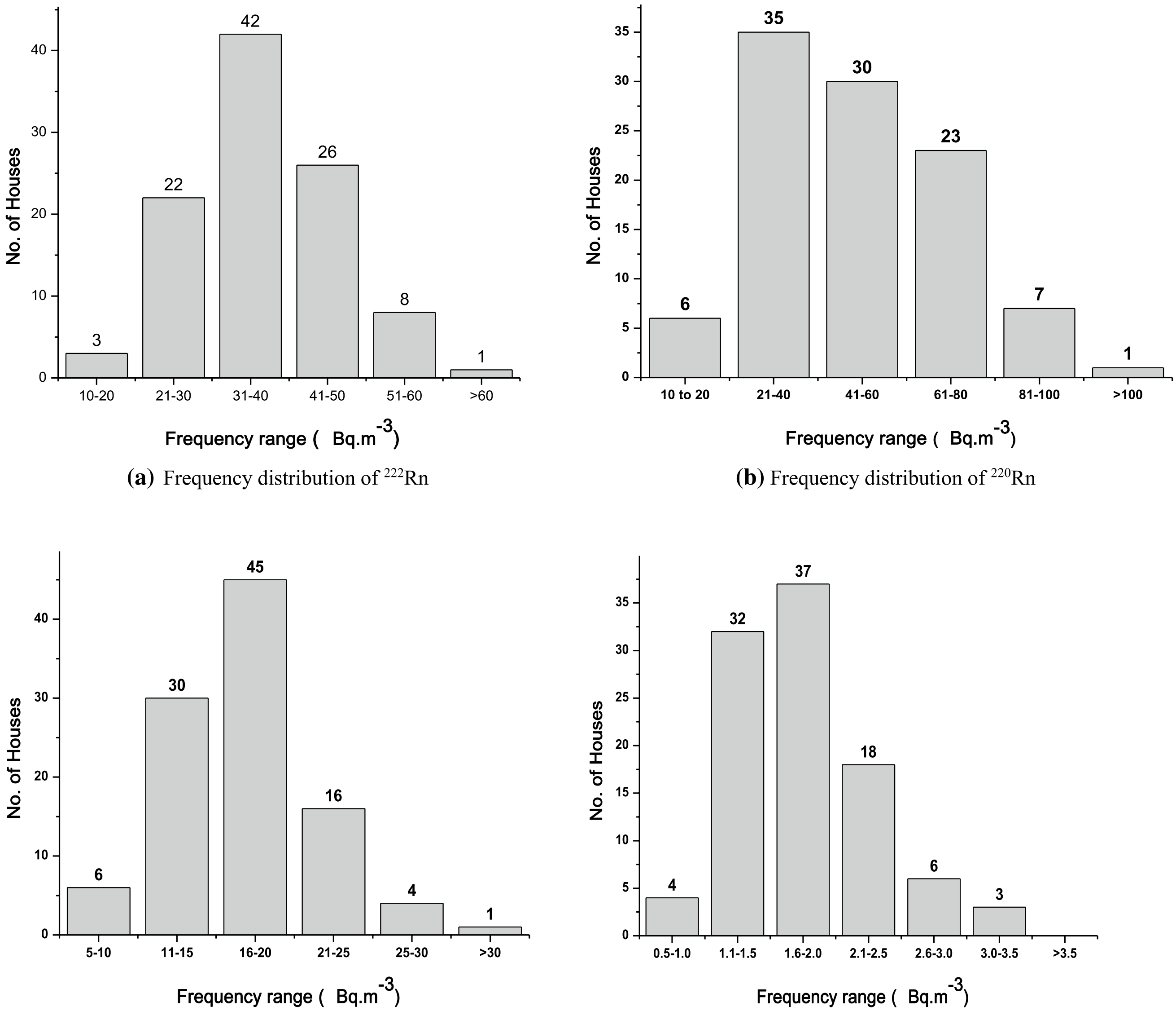
summer, and 4.2–56.3 with a mean of 17.1 ± 8.2 in rainy season. The EETC value in winter found to be 0.8–4.4 through a mean of 2.0 ± 0.7, in summer it is found to be 0.4–3.3 through a mean of 1.5 ± 0.7, and in rainy season it is found to be 0.5–4.8 through a mean of 1.7 ± 0.7.

The F-$_{Radon}$ was found to be varying from 0.17 to 1.20 with a mean of 0.51 ± 0.23 in winter, 0.10–1.48 with a mean of 0.60 ± 0.28 in summer and 0.07–1.45 with a mean of 0.48 ± 0.26 in rainy season. The F-$_{Thoron}$ was found to be varying from 0.01 to 0.18 with a mean of 0.045 ± 0.03 in winter, 0.01–0.19 with a mean of 0.049 ± 0.04 in summer and 0.01 to 0.18 with a mean 0.049 ± 0.03 in rainy season.

Figure 4 represents seasonal variation in ^{222}Rn, ^{220}Rn and their progeny concentration. The higher concentration is found in winter season because of the cold climate, people trying to close doors and windows which leads to the poor ventilation condition and more radionuclide's accumulated insight the houses. Due to good ventilation rate, lower value was found in summer season (except ^{220}Rn) which allow the dilution of indoor air by outdoor air.

The annual average concentration for ^{222}Rn, ^{220}Rn, EERC and EETC is found to be 36.7 ± 9.7, 48.8 ± 21.2, 17.1 ± 4.5 and 1.7 ± 0.5 respectively. The annual average ^{222}Rn value (36.7 ± 9.7 Bq m^{-3}) found less than the worldwide standard value (40 Bq m^{-3}) as well as the national standard value (42 Bq m^{-3}). The ^{220}Rn level (48.8 ± 21.2 Bq m^{-3}) found higher when compare with worlds standard value (10 Bq m^{-3}) as well as national average value (12 Bq m^{-3}).

Figure 5a–d represents the frequency distribution of ^{222}Rn, ^{220}Rn, EERC and EETC. Frequency distribution of ^{222}Rn shows that 42 houses fall between 31–40 Bq m^{-3}. And only 9 houses has the value more than 50, but no house has the value equal to or more than 100 Bq m^{-3}. For ^{220}Rn level most of the houses fall between the range 21–40 and 41–60 Bq m^{-3}. Most of the ^{222}Rn progeny and ^{220}Rn progeny fall in range 16–20 and 1.6–2.0 Bq m^{-3} respectively.



(a) Frequency distribution of ^{222}Rn

(b) Frequency distribution of ^{220}Rn

(c) Frequency distribution of EERC

(d) Frequency distribution of EETC

Fig. 5 **a** Frequency distribution of ^{222}Rn. **b** Frequency distribution of ^{220}Rn. **c** Frequency distribution of EERC. **d** Frequency distribution of EETC

Variation with type of houses

Table 2 shows the ^{222}Rn, ^{220}Rn, EERC and EETC in different house type. Of the study area divided into three categories; Pakka House, Kachha house and grass house. The pakka houses were made of cement, bricks etc., and the kachha houses were made of mud, stones etc., and the grass houses were made from grass and bamboos. The results for these three kinds of houses are shown in Table 2. As can be seen, high concentration of ^{222}Rn, ^{220}Rn has been estimated in Kachha houses and the lower value estimated in Grass houses. The Kachha house has mud floor while Pakka houses has cemented/tile/marvel floor, which seal the entry of ^{222}Rn/^{220}Rn gas from underneath soil. The Grass houses generally have lower value as compared to both Pakka as well as Kachha house may be due to the wall and also roof made from bamboos and grasses, which are not a source of radon.

Table 2 ^{222}Rn, ^{220}Rn, and their progeny level (in Bq m^{-3}) in different house type

	MIN	MAX	MEAN	STDEV
Pakka house				
^{222}Rn	18.7	57.7	36.7	9.2
^{220}Rn	13.1	100.4	49.7	22.5
EERC	7.0	29.4	16.6	4.5
EETC	0.9	2.8	1.6	0.4
Kaccha house				
^{222}Rn	23.2	58.8	40.4	10.4
^{220}Rn	33.9	74.0	57.3	14.2
EERC	13.3	30.5	18.8	5.3
EETC	1.6	3.1	2.3	0.6
Grass house				
^{222}Rn	19.6	65.3	35.0	10.2
^{220}Rn	10.1	60.5	39.0	15.2
EERC	13.9	24.2	19.3	3.4
EETC	1.1	3.0	1.9	0.6

MIN minimum, *MAX* maximum, *STDEV* standard deviation

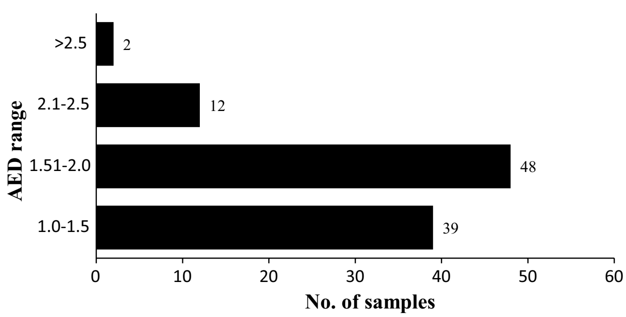


Fig. 6 Frequency distribution of AED due to inhalation

Estimation of radiation doses

The annual radiation doses were calculated to the individuals of the study area by using yearly average concentration of ^{222}Rn, ^{220}Rn and their progenies. Figure 6 represents frequency distribution of dose in studied house. The AED due to inhalation of ^{222}Rn and its progeny was found to be 0.50–1.95 with a mean value of 1.13 ± 0.29 mSv $year^{-1}$. The AED due to ^{220}Rn and its progeny was found to be 0.29–0.93 with an average of 0.53 ± 0.14 mSv $year^{-1}$. It can be seen from the frequency distribution diagram (Fig. 6) that large number of houses found between the ranges 1.51–2.0 mSv $year^{-1}$.

Conclusions

The findings of this study reveals that the annual average ^{222}Rn and ^{220}Rn values did not exceed the WHO recommended safe limits of 100 Bq m^{-3} [26]. The design of house also has an effect on the level of ^{222}Rn, ^{220}Rn and progenies. The concentration of these radio-elements also shows the variation with the season. The F_{Radon} and F_{Thoron} values were 0.53 (greater than the worlds average, 0.4) and 0.048 (lower than the worlds average, 0.10), respectively. The dose (AED) obtained by local residents from indoor ^{222}Rn, ^{220}Rn, and their progenies were found to be less than the UNSCEAR acceptable limits and well below the action limit of ICRP (3–10 mSv $year^{-1}$) [25, 27]. ^{220}Rn and its progeny cannot be disregarded when evaluate the doses, as they contribute significantly (about 1/3rd) to the total radiation doses received by individuals. Although from the data presented in this study may assure that the level of ^{222}Rn and ^{220}Rn is not so high so peoples are safe from the harmful effect of radiation.

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