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Study on Seasonal Variation of Indoor Radon, Thoron and their Progeny Levels in Belur and Channarayapatna Taluks of Hassan District, Karnataka State, India.

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A B S T R A C T

Seasonal variation of indoor radon, thoron and their progeny concentrations have been measured in different types of buildings at different locations of Belur and Channarayapatna taluks using time integrated passive radon dosimeters containing LR-115 Type II solid state nuclear track detector. The average radon and thoron activity concentrations, their progeny levels, life time fatality risk and annual effective dose due to radon and thoron were estimated in summer, rainy, autumn and winter seasons. A detail analysis of radon and thoron distribution in twenty different houses with seasonal variation is presented in this paper. In general, the levels of radon and thoron concentration were observed to be highest in winter and lowest in summer.

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Introduction:

^{222}Rn (Radon) is a naturally occurring radioactive colorless, odorless, tasteless, imperceptible to senses and chemically inert gas which is the immediate daughter product of ^{226}Ra belong to uranium series of natural radionuclides and ^{220}Ra (Thoron) is the immediate decay product of ^{224}Ra derive from the thorium series. The main natural sources of indoor radon/thoron are soil, building materials (sand, rocks, cement, etc.) and ground water which contain traces of primordial radioactive materials such as ^{226}Ra, ^{232}Th, ^{238}U and their decay products. Both these isotopes decay to isotopes of solid elements. The atoms of these decay products attach themselves to dust particles and condensation nuclei present in air. When we breathe, we also inhale radon and its daughter product along with the normal air. Although most of the radon is exhaled, its daughter products get logged to the inner walls and membranes of our respiratory system and continue causing constant damage due to their alpha activity, which may cause lung cancer [1, 6, 12]. Inhalation of radon and its short-lived decay products, as well as of the thoron series, accounts for about half of the effective dose from natural radiation sources. Worldwide average annual effective dose from the ionizing radiation sources is estimated to be 2.4 mSv of which about 1.275 mSv is due to radon exposure alone [8, 12]. In the past, radon studies were more common than those of thoron, but recent studies in dwellings throughout the world have shown that thoron can be a significant contributor to the radiation exposure [9, 11, 13]. The contributions of radon and thoron and its progeny to radiation exposure are quite different. The decay half life of ^{222}Rn is 3.825 days, which is long enough for its transfer from a source (mainly soil) through cracks and gaps into indoor spaces. Due to its long half life, ^{222}Rn is usually well-mixed in room air. On the other hand, due to the relatively short half life of ^{220}Rn (55.6 s), its presence is highly inhomogeneous in room air and is strongly dependent on distance from the source [2, 14]. Radon and its decay products may pose a significant health hazards, especially when concentrate in some enclosures such as underground mines, caves, cellars or poor ventilated and badly designed houses [10]. On account of this, the dose deriving from the exposure of

^{222}Rn in closed spaces particularly in dwellings has been placed in direct relation to the risk of lung cancer. The concentration of radon in the atmosphere varies, depending on the place, time and the height above the ground, the meteorological condition, the topography, house construction type, soil characteristics, ventilation rate, wind direction, atmospheric pressure and even the life style of people [4]. Most of our time is spent within buildings; therefore, the measurement and limitation of radon concentration of buildings are important. The Environmental Protection Agency (EPA) estimated that 21,000 annual lung cancer deaths in the U.S. are attributable to radon and it is the leading environmental cause of cancer death in North America. Unfortunately, the risks associated with radon exposure have failed to receive widespread attention [5]. According to the US Environmental Protection Agency (EPA) and the World Health Organization (WHO) Handbook on indoor radon is the second leading cause of lung cancer after smoking. The aim of the present study is to estimate the seasonal variation of indoor radon, thoron concentrations and also to estimate annual exposure to occupants, the annual effective dose and the lifetime fatality risk.

The study area:

Hassan district is located on the border of the Western Ghats, in the southern part of Karnataka state. It is located between $12^0 30'$ and $13^0 35'$ North latitude and $75^0 15'$ and $76^0\ 40'$ East longitudes. Hassan town is the district headquarters and the district is divided into eight taluks viz. Alur, Arkalgud, Arsikere, Belur, Chennarayapatna, Hassan, Holenarsipur and Sakleshpur. The soils of the district display a wide diversity and are quite fertile. The main soil types are red, red sandy, black, mixed soil and silty clay soil. The soils in the Belur taluk are derived from granites, laterites and schists. These soils are shallow to medium in depth and the color changes with depth from red at the surface and red and yellow mottles at depth. In the Channarayapatna taluk, the soils are red sandy type, which are derived from granite, gneisses and schists. These are shallow, loamy to sandy loamy in texture and are intermixed with coarse gravel and pebbles and are well drained but poor in moisture retaining capacity.

Materials and methods:

The indoor radon, thoron and their progeny concentrations were measured using solid state nuclear track detectors (SSNTDs). The dosimeter used was a cylindrical plastic cup divided into two compartments having a provision for holding the SSNTD films in a specific concentration. The exposure of the detector inside the cup is termed as cup mode and the one exposed open is termed as the bare mode. One of the cups has its entry covered with a Whatman 41 glass fiber filter paper permeates both radon and thoron gases into the cup and is called the filter cup. The other cup covered with a suitable semi permeable membrane like a thin latex rubber sheet sandwiched between two glass fiber filter papers and is called membrane cup that determines ^{222}Rn concentration alone because ^{220}Rn gas is trapped to < 1 %. The bare mode exposure film can be fixed conveniently on the surface of the chamber. The size of the films used in the three different modes of exposure is 2.5 cm×2.5 cm. The dosimeters with the films as described above were exposed for a period of 90 days. At the end of the stipulated period of exposure, the dosimeters are retrieved and etched with 10% NaOH solution at 60^0 C for 90 min. After etching, the films were washed in distilled water properly, and then they were dried up in the laboratory conditions. Then the track density of alphas in the film was determined using a spark counter. The dosimeter cups were designed, fabricated and supplied by Bhabha Atomic Research Center, Mumbai, India.

The radon and thoron concentrations are calculated by using the following relations [12].

$$C_R(Bqm^{-3}) = \frac{T_m}{dS_m} \quad (1)$$

$$C_T(Bqm^{-3}) = \frac{T_f - dC_R S_{rf}}{dS_{tf}} \quad (2)$$

Where T_m is the track density of the film in membrane compartment, d the period of exposure (days), S_m the sensitivity factor of membrane compartment, T_f the track density of the film in filter compartment, S_{rf} the sensitivity of radon in filter compartment, S_{tf} the sensitivity of thoron, in filter compartment, C_R the radon concentration and C_T the thoron concentration.

The inhalation dose due to radon, thoron and their progeny in mSv.y^{-1} can be calculated using the following formula [12].

$$D(mSvy^{-1}) = \{(0.17 + 9F_R)C_R + (0.11 + 40F_T)C_T\} \times 7000 \times 10^{-6} \quad (3)$$

Where F_R and F_T are the equilibrium factors for ^{222}Rn and ^{220}Rn progeny, respectively. The inhalation dose due to radon and thoron was calculated by using conversion coefficient 9 and 40 nSv and equilibrium factor 0.4 and 0.1 for radon and thoron, respectively. The dose coefficient for radon and thoron dissolved in blood are calculated using conversion coefficient 0.17 nSv for radon and 0.11 nSv for thoron.

The progeny working levels or potential alpha energy concentration (PAEC) were evaluated using the following relations [15],

$$R_n(mWL) = \frac{C_R F_R}{3.7} \quad (4)$$

$$R_T(mWL) = \frac{C_T F_T}{0.275} \quad (5)$$

Where R_n the radon progeny concentration, R_T the thoron progeny concentration, F_R and F_T are the equilibrium factors for radon and thoron progeny respectively.

The seasonal variation of daughter concentration of radon and thoron in terms of (PAEC) potential alpha energy concentration (mWL), annual exposure in (WLM), were calculated. The annual exposure have been obtained through radon progeny by using WLM= 36 × P (mWL). Annual exposure due to radon and its progeny have been calculated by using the generic relations given in the report of ICRP [3]. The annual exposure due to radon and thoron, lifetime fatality risks and annual effective dose were calculated. The PAEC was converted into annual effective dose by using dose conversion factors; the radon daughter dose conversion factor for members of the public is 3.88 mSv WLM^{-1} as recommended by ICRP [3], whereas the effective dose equivalent for thoron is 3.4 mSv WLM^{-1} as recommended by UNSCEAR [2]. The lifetime risk associated with indoor radon exposure was calculated by using 1 WLM = 10×10^{-6} cases/year. If the risk persists for 30 years, Life time fatality risk = 3×10^{-4} cases/WLM.

Results and discussion:

The seasonal variation of indoor radon, thoron and their progeny concentrations in different dwellings of the study area as shown in the Fig 1. The calculated annual exposure due to the progenies and the life time cancer risks and annual effective dose due to radon, thoron and their progeny of the study area are summarized in Table 1. The indoor radon and thoron measurements were carried out in the year 2013-14. From the present observation it is found that the values of radon concentration vary from 3.5 to 62.8 $Bq.m^{-3}$ with an average of 18.9 $Bq.m^{-3}$ in summer, 8.4 to 56.5 $Bq.m^{-3}$ with an average of 20.72 $Bq.m^{-3}$ in rainy, 11.3 to 58.1 $Bq.m^{-3}$ with an average of 23.27 $Bq.m^{-3}$ in autumn,14.3 to 67.5 $Bq.m^{-3}$ with an average of 27.75 $Bq.m^{-3}$ in winter, where as values of thoron concentration vary from 1.8 to 29.8 $Bq.m^{-3}$ with an average value of 12.25 $Bq.m^{-3}$ in summer, 4.8 to 27.8 $Bq.m^{-3}$ with an average value of 13.77 $Bq.m^{-3}$ in rainy, 11.3 to 30.2 $Bq.m^{-3}$ with an average value of 16.36 $Bq.m^{-3}$ in autumn, 12.9 to 41.2 $Bq.m^{-3}$ with an average value of 19.81 $Bq.m^{-3}$ in winter respectively. The value of inhalation dose varies from 0.13 to 2.34 $mSv.y^{-1}$ with an average of 0.78 $mSv.y^{-1}$ in summer, 0.33 to 2.13 $mSv.y^{-1}$ with an average of 0.86 $mSv.y^{-1}$ in rainy, 0.56 to 2.23 $mSv.y^{-1}$ with an average of 0.99 $mSv.y^{-1}$ in autumn and 0.67 to 2.73 $mSv.y^{-1}$ with an average of 1.41 $mSv.y^{-1}$ in winter respectively.

Table 2 gives the seasonal variation of the potential alpha energy concentration (PAEC) of radon and thoron daughters in dwellings. The values of radon progeny concentration vary from 0.4 to 6.8 mWL with an average value of 2.0 mWL in summer, 0.9 to 6.1 mWL with an average value of 2.2 mWL in rainy, 1.2 to 6.3 mWL with an average value of 2.5 mWL in autumn, 1.5 to 7.2 mWL with an average value of 2.9 mWL in winter, whereas the values of thoron progeny concentration vary from 0.7 to 11.0 mWL with an average value of 4.5 mWL in summer, 1.7 to 10.0 mWL with an average value of 5.0 mWL in rainy, 4.1 to 11.0 mWL with an average value of 6.0 in autumn, 4.6 to 14.9 mWL with an average of 7.2 mWL in winter respectively. It is observed that there exist radon, thoron gas and progeny concentrations in the dwellings, which vary from house to house and also, vary considerably with the different construction types. The concentration of radon, thoron and their progeny in dwellings depends mainly on the activity of the radium and thorium present in soil, rocks, building materials, and the types of building, methods of construction of buildings and ventilation rate [13]. The results reveal that, quite higher radon and thoron levels were observed in winter season as compared to the other season. This maximum concentration is essentially by the intense temperature inversion, which generally occurs in winter season when the wind velocity is low. The higher radon, thoron and their progeny levels attributed is also due to poor ventilation condition during the winter season.

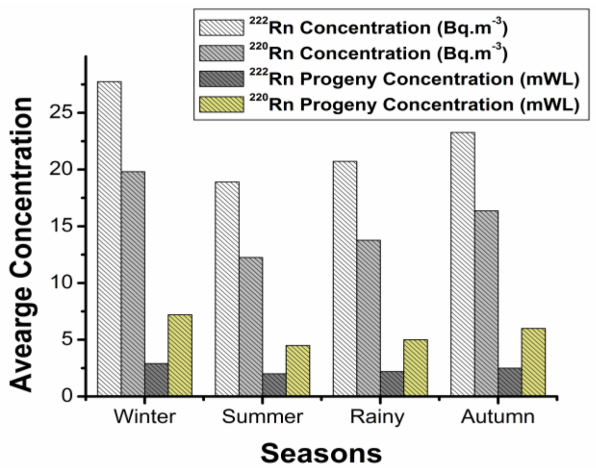

Fig. 1: Seasonal variation of radon, thoron and their progeny concentration in dwellings of the study area.

During the winter season, the doors, windows and ventilators were kept closed to conserve heat that helped in building up of radon and thoron concentrations and radioactive contents present in household articles, human activities, unscientific construction pattern of the houses, increased exhalations from ground and building materials, porosity and permeability of the underlying soil/rocks, pressure gradient between interface, soil moisture and water saturation grade of the medium, faulted and folded bed rocks [7]. Moreover, during the winter time, the amount of water in air is high. As such as radon and thoron, and their decay products are moderately soluble in water, they remain trapped by water vapor and are more difficult to remove from indoor environ than the free gases. The average indoor radon value in different dwellings of the study area is found to be much lower than the action level of 200–300 $Bq.m^{-3}$ recommended by International Commission on Radiological

Protection[3]. From this study, it is observed that the average radon concentration is lower than the worldwide average value reported for the dwellings of 40 Bq.m^{-3} recommended by UNSCEAR-2000 [12]. The present result reveals that, the average radon concentration is lower than the action level of 100 Bq.m^{-3} recommended by World Health Organization[16]. Present study clears that the values of radon concentration are higher than thoron. It may be due to the difference in half-life of radon and thoron, which affects the exhalation rate from the wall and the concentration distribution inside the dwellings.

Table 1 Seasonal variation of indoor radon, thoron concentration and their annual effective inhalation dose in the dwellings of Belur and Channarayapatha taluks

House No	Winter			Summer			Rainy			Autumn		
	^{222}Rn (Bq.m^{-3})	**^{220}Rn (Bq.m^{-3})**	**Inhal. dose**	**^{222}Rn (Bq.m^{-3})**	**^{220}Rn (Bq.m^{-3})**	**Inhal. dose**	**^{222}Rn (Bq.m^{-3})**	**^{220}Rn (Bq.m^{-3})**	**Inhal. dose**	**^{222}Rn (Bq.m^{-3})**	**^{220}Rn ((Bq.m^{-3})**	**Inhal. dose**
						Belur Taluk						
B_1	23.5	16.2	0.995	10.8	7.2	0.451	12.1	6.9	0.479	16.1	0.74	0.743
B_2	24.9	17.6	1.064	25.3	15.6	1.029	24.6	16.6	1.033	28.2	1.04	1.045
B_3	15.3	12.9	0.702	3.5	1.8	0.134	8.4	4.8	0.332	13.2	0.61	0.610
B_4	27.4	17.1	1.119	27.6	16.7	1.115	30.2	17.3	1.197	22.9	1.06	1.065
B_5	32.1	22	1.356	28.2	22.8	1.272	26.8	20.3	1.177	29.4	1.23	1.23
B_6	32.8	16.3	1.243	17	5.5	0.576	19.2	8.3	0.699	21.8	0.96	0.969
B_7	19.6	19.9	0.978	11.7	7.8	0.489	14.3	12.9	0.676	15.6	0.83	0.838
B_8	24.6	14	0.973	14	6.4	0.517	17.9	9.6	0.694	19	0.79	0.793
B_9	33	27	1.496	24	15.8	0.999	27.9	17.5	1.141	32.2	1.34	1.341
B_{10}	18.3	21.6	0.983	8.2	13.2	0.522	11.6	14.1	0.632	16.9	0.85	0.851
						Channarayapatana Taluk						
C_1	14.3	16.4	0.757	4.7	8.8	0.327	8.6	11.3	0.488	11.3	0.65	0.650
C_2	17.6	24.5	1.032	10.5	7.2	0.443	13.5	8.9	0.562	17.2	0.76	0.762
C_3	30.9	18.2	1.237	17.9	12.1	0.752	23.4	19.4	1.067	27.6	1.09	1.099
C_4	23.2	41.2	1.566	10.9	5.2	0.408	9.4	10.2	0.484	13.6	0.70	0.708
C_5	35.3	13.2	1.237	27	14.8	1.055	30.1	6.2	0.938	26.5	0.96	0.963
C_6	19.4	19.9	0.973	11.1	5.2	0.413	11.7	6.9	0.468	13.8	0.67	0.679
C_7	29	14	1.089	15.8	14.9	0.762	19.9	17.5	0.930	24.7	0.93	0.932
C_8	67.5	34.1	2.571	62.8	29.8	2.347	56.5	27.8	2.135	58.1	2.23	2.233
C_9	42.7	14.5	1.462	34.7	19.4	1.365	34.2	22.6	1.426	37.1	1.34	1.345
C_{10}	23.5	15.7	0.983	12.3	14.8	0.667	14.1	16.4	0.752	20.2	0.99	0.998
Min.	**14.3**	**12.9**	**0.676**	**3.5**	**1.8**	**0.134**	**8.4**	**4.8**	**0.332**	**11.3**	**11.3**	**0.56**
Max.	**67.5**	**41.2**	**2.735**	**62.8**	**29.8**	**2.347**	**56.5**	**27.8**	**2.135**	**58.1**	**30.2**	**2.233**
Avg.	**27.75**	**19.81**	**1.191**	**18.9**	**12.25**	**0.782**	**20.72**	**13.77**	**0.866**	**23.27**	**16.36**	**0.993**

The values of Life time fatality risk and Annual effective dose for the people in dwellings of study area are given in table-3**.** The life time fatality risk value varies from 0.118 $\times10^{-4}$ to 1.922$\times10^{-4}$ with an average of 0.7.20$\times$ 10^{-4} in summer, 0.281 $\times10^{-4}$ to 1.738$\times10^{-4}$ with an average of 0.777$\times10^{-4}$ in rainy, 0.572$\times10^{-4}$ to 1.868$\times10^{-4}$ with an average of 0.918$\times10^{-4}$ in autumn and from 0.658$\times10^{-4}$ to 2.386$\times10^{-4}$ with an average value of 1.091$\times$ 10^{-4} in winter. The annual effective dose due to radon and thoron daughters varies from 0.153 mSv to 2.486 mSv with an average of 0.907 mSv in summer, 0.363 mSv to 2.248 mSv with an average of 1.005 mSv in rainy, 0.741 mSv to 2.416 mSv with an average of 1.187 mSv in autumn and 0.852 mSv to 3.086 mSv with an average of 1.56 mSv in winter. From this study it is evident that, the annual effective dose received by the residents is less than the lower limit of the action level of 3-10 mSv y^{-1} recommended by International Commission on Radiological Protection [3].

Table: 2. Seasonal variation of the potential alpha energy concentration (PAEC) of radon and thoron daughters in dwellings.

House no	Winter		Summer		Rainy		Autumn	
	^{222}Rn (mWL)	^{220}Rn (mWL)	^{222}Rn (mWL)	^{220}Rn (mWL)	^{222}Rn (mWL)	^{220}Rn (mWL)	^{222}Rn (mWL)	^{220}Rn (mWL)
Belur Taluk								
B_1	2.5	5.8	1.2	2.6	1.3	2.5	1.7	5.1
B_2	2.6	6.4	2.7	5.7	2.7	6	3	4.7
B_3	1.6	4.6	0.4	0.7	0.9	1.7	1.4	4.1
B_4	2.9	6.2	3	6.1	3.3	6.3	2.5	7.2
B_5	3.4	8	3	8.3	2.9	7.4	3.2	7.1
B_6	3.5	5.9	1.8	2	2.1	3	2.4	6.2
B_7	2.1	7.2	1.3	2.8	1.5	4.7	1.7	6.7
B_8	2.6	5	1.5	2.3	1.9	3.5	2.1	4.6
B_9	3.5	9.8	2.6	5.7	3	6.4	3.5	7.7
B_{10}	1.9	7.8	0.9	4.8	1.3	5.1	1.8	6.4
Channarayapatana Taluk								
C_1	1.5	5.9	0.5	3.2	0.9	4.1	1.2	5.5
C_2	1.9	8.9	1.1	2.6	1.5	3.2	1.9	4.8
C_3	3.3	6.6	1.9	4.4	2.5	7.1	3	5.8
C_4	2.5	14.9	1.2	1.9	1	3.7	1.5	5.5
C_5	3.8	4.8	2.9	5.4	3.3	2.3	2.9	4.1
C_6	2	7.2	1.2	1.9	1.3	2.5	1.5	4.9
C_7	3.1	5	1.7	5.4	2.2	6.4	2.7	4.4
C_8	7.2	12	6.8	11	6.1	10	6.3	11
C_9	4.6	5.2	3.8	7.1	3.7	8.2	4	5.7
C_{10}	2.5	5.7	1.3	5.4	1.5	6	2.2	7.3
Minimum	**1.5**	**4.6**	**0.4**	**0.7**	**0.9**	**1.7**	**1.2**	**4.1**
Maximum	**7.2**	**14.9**	**6.8**	**11**	**6.1**	**10**	**6.3**	**11**
Average	**2.9**	**7.2**	**2.0**	**4.5**	**2.2**	**5**	**2.5**	**6**

Table 3 The life time fatality risk and annual effective dose for the peoples in the dwellings of the study area.

House Code	Winter		Summer		Rainy		Autumn	
	Life time fatality risk ($\times10^{-4}$)	Annual effective Dose (mSv)	Life time fatality risk ($\times10^{-4}$)	Annual effective Dose (mSv)	Life time fatality risk ($\times10^{-4}$)	Annual effective Dose (mSv)	Life time fatality risk ($\times10^{-4}$)	Annual effective Dose (mSv)
Belur Taluk								
B_1	0.896	1.159	0.410	0.530	0.410	0.530	0.734	0.949
B_2	0.972	1.257	0.907	1.173	0.939	1.215	0.831	1.075
B_3	0.669	0.866	0.118	0.153	0.280	0.363	0.594	0.768
B_4	0.982	1.271	0.982	1.271	1.036	1.340	1.047	1.354
B_5	1.231	1.592	1.220	1.578	1.112	1.438	1.112	1.438
B_6	1.015	1.313	0.410	0.530	0.550	0.712	0.928	1.201
B_7	1.004	1.299	0.442	0.572	0.669	0.866	0.907	1.173
B_8	0.820	1.061	0.410	0.530	0.583	0.754	0.723	0.935
B_9	1.436	1.857	0.896	1.159	1.015	1.313	1.209	1.564
B_{10}	1.047	1.354	0.615	0.796	0.691	0.894	0.885	1.145
Channarayapatana Taluk								
C_1	0.799	1.033	0.399	0.516	0.542	0.698	0.723	0.935
C_2	1.166	1.508	0.399	0.516	0.507	0.656	0.723	0.935
C_3	1.069	1.382	0.680	0.881	1.036	1.340	0.950	1.229
C_4	1.879	2.430	0.334	0.433	0.507	0.656	0.756	0.977
C_5	0.928	1.201	0.896	1.159	0.604	0.782	0.756	0.977
C_6	0.993	1.285	0.334	0.433	0.410	0.530	0.691	0.893
C_7	0.874	1.131	0.766	0.991	0.928	1.201	0.766	0.991
C_8	2.073	2.681	1.922	2.486	1.738	2.248	1.868	2.416
C_9	1.058	1.368	1.177	1.522	1.285	1.662	1.047	1.354
C_{10}	0.885	1.145	0.723	0.935	0.811	1.047	1.026	1.3269
Minimum	**0.658**	**0.852**	**0.118**	**0.153**	**0.280**	**0.363**	**0.572**	**0.740**
Maximum	**2.386**	**3.086**	**1.922**	**2.486**	**1.738**	**2.248**	**1.868**	**2.416**
Average	**1.090**	**1.410**	**0.702**	**0.907**	**0.777**	**1.005**	**0.918**	**1.187**

Conclusions:

The seasonal variations of indoor radon, thoron and their progeny concentration levels, inhalation dose, lifetime fatality risk and annual effective dose were estimated in the dwellings of Belur and Channarayapatna taluks of Hassan district. The indoor radon, thoron and their progeny concentrations are mainly depends on the types of flooring, building materials, ventilation rate and radionuclides present in building materials. The radon concentration level in study area was observed to below the recommended action level (200 $Bq.m^{-3}$) set by ICRP and also this value is lower than the action level of 100 $Bq.m^{-3}$ recommended by World Health Organization. The annual effective dose received by the residents is less than the lower limit of the action level of 3-10 $mSv.y^{-1}$ recommended by International Commission on Radiological Protection. The inhalation dose due to radon, thoron and their progeny in dwellings indicate that the levels were higher in winter than in summer.

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