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A review on human exposure to indoor radon concentration and measuring techniques in Garhwal Himalaya, Uttarakhand

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Radioactive materials which occur naturally have widely presence in the earth's crust and these materials are the most common sources of ionizing radiation present in an environment. Radon and its decay product contribute significant amount (more than 50%) of ionizing radiation in the atmosphere. This ionizing radiation increases the exposure of radiation to human being in the surroundings. The risk due to radon-222 and its decay products is more in poorly ventilated houses, mines and caves etc. This paper presents a review study on radon-222 and thoron-220 concentration/level done previously in the Garhwal region of Uttarakhand state. In this review paper, the various outcomes of indoor radon-222 and thoron-220 concentration measured in the Garhwal Himalaya region are mainly discussed in details.

Keywords: Radon-222, Thoron-220, Progeny, Dosimeter, LR-115, DTPS/DRPS

Introduction

Radon-222 and its isotopethoron-220 are the only radioactive gases and both the gases emanate from the earth crust depending upon the decay series of uranium and thorium which are abundant everywhere on the earth crust[1]. Radon-222 and thoron-220 are noble gases but they are radioactive in nature so it becomes important to investigate the radiological impact of radon-222 and thoron-220 in the environment. Radon-222 is a decay product of Uranium and thoron-220 belongs to the decay series of Thorium[2] Fig.1. Radon-222 and thoron-220 contribute up to 50% fraction of the total dose that is received by the human being. The natural sources of radiation lead up to 70% of global exposure to radiation. Radon-222 has a Half-Life time that is 3.82 days and hence it sustains for a long period in the environment that of thoron-220[3]. It has been evident that the radon-222 considered the main contributor to dose but we cannot neglect the contribution of thoron-220[4]. The emanation of radon-222 and thoron-220 depends on many factors like porosity of soil, humidity, grain-size and the presence of Uranium content[5,6]. The accumulation of radon-222/thoron-220 in indoors of dwellingis the major cause of human exposure to indoor radiation which causes health problems and increases in enclosed spaces such as indoors of dwelling, caves and mines etc[7]. The indoor concentration/level of radon-222, thoron-220 and their progenies mainly influenced by the factors like type of dwellings, subjacent soil, building material, ores, ventilation conditions and geology of the area[8]. It increases the annual dose of radiation received by the human beings. Humans spent their most of time in the indoor environment so the measurement of the indoor concentration of radon-222 and thoron-220 becomes essential because of the greater chance of human exposure to radiation in the indoor environment. The recommended limit of the radon-222 concentration was referred by World Health Organisation and it was lowered to 100Bq/m^3 from 200 Bq/m^3 and suggested that it is the second most carcinogenic element after smoking[9].Radon-222 enters in indoor environment from soil and building materials through two processes:

Emanation

It is a process in which Radon enters into air-filled pores of soil matrix from the mineral grains.

Exhalation

It is a process in which Radon enters into the upper surface through cracks and joints from air-filled

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pores. The mass/surface exhalation rate of soil samples is the key source of indoor and outdoor radon-222 concentration[10].

Many reliable operating methods for the measurement of indoor exposure of radon-222, thoron-220 and their progeny concentration has been developed and are very important to investigate[11]. These efforts further helpful to calculate the health hazards because of exposure to radon-222. Radon-222 is highly radioactive in nature that emanates from the rocks and soil under earth crust and it continuously tends to concentrate into the indoor environment like dwellings and mines[12]. Building materials and groundwater are also other important sources for the Radon-222 concentration[13]. Due to these sources, the mass population received ionizing radiation doses to a major extent. Radon moves slowly from pores of the soil to the surface by diffusion process or pressure induced during the transport process[14].

Rocks, type of soil, Water, building construction materials (like clay bricks, granite, sandstone and marbles etc), Natural gas etc. are some sources of radon-222 and thoron-220[7]. These sources increase the annual effective dose due to radiation exposure to human beings. Radon-222 in water is also one of the imported sources for the exposure of radon-2229. The average annual dose over the world is about 2.8mSv and the average annual dose received from the decay product of radon-222 is about 1.2mSv[15]. The radon-222 decay products contribute almost 50% to the total dose worldwide[3].

Among the radon-222 and thoron-220, radon-222 has the higher half-life than the thoron-220. Radon-222 remains up to 3.82 days in the atmosphere. Other elements like Uranium, Thorium, Radium, and Isotope of Potassium are radioactive on the earth. Meanwhile, when they decayed into their daughter nuclei called progenies after emitting corresponding alpha and beta particles (Fig. 1 & 2). These progenies can stick on the surface of respiratory organs and cause lung cancer[16]. According to the different studies that were done in western countries like America and Europe, the World Health Organization (WHO) has a reduced threshold limit of exposure concentration from the value 200 $Bq.m^{-3}$ to 100 $Bq.m^{-3}$[16]. So that radon-222 concentration in the indoor environment becomes important to be measured.

Radon-222 was discovered in 1898 by Fredrich Ernst Dorn. Some of the characteristics of radon-222 as follow (Table 1):

This paper presents review of previous studies of estimation of radon-222 and thoron-220 concentration in Garhwal Himalayan region of Uttarakhand based on the different types of dwellings like cemented house, hybrid houses, mud houses and geology of the area.

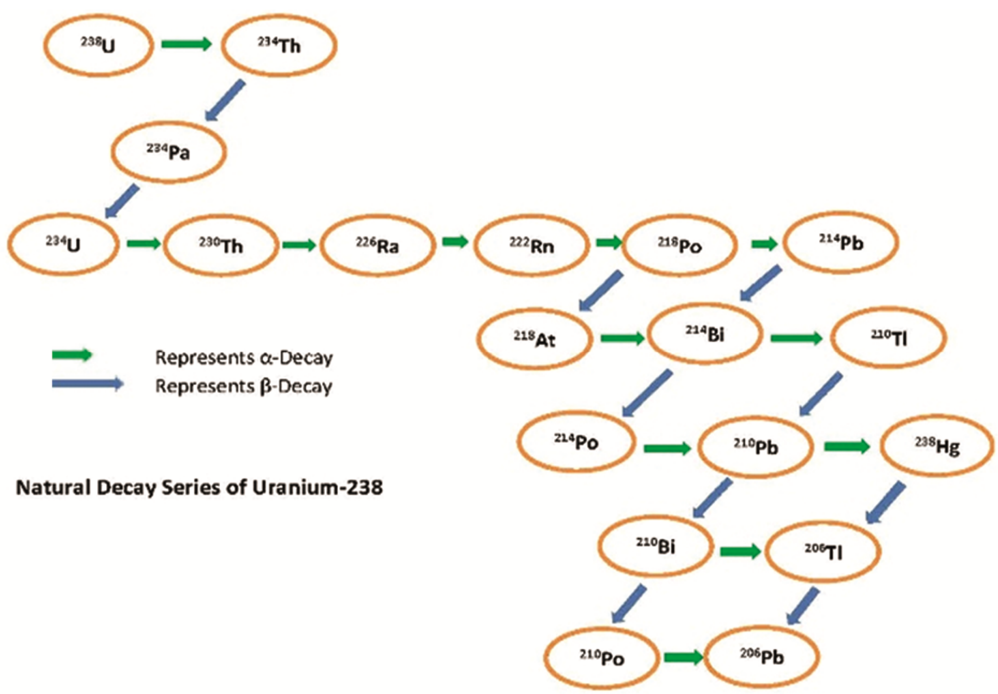

Fig. 1 — Decay series of uranium-238.

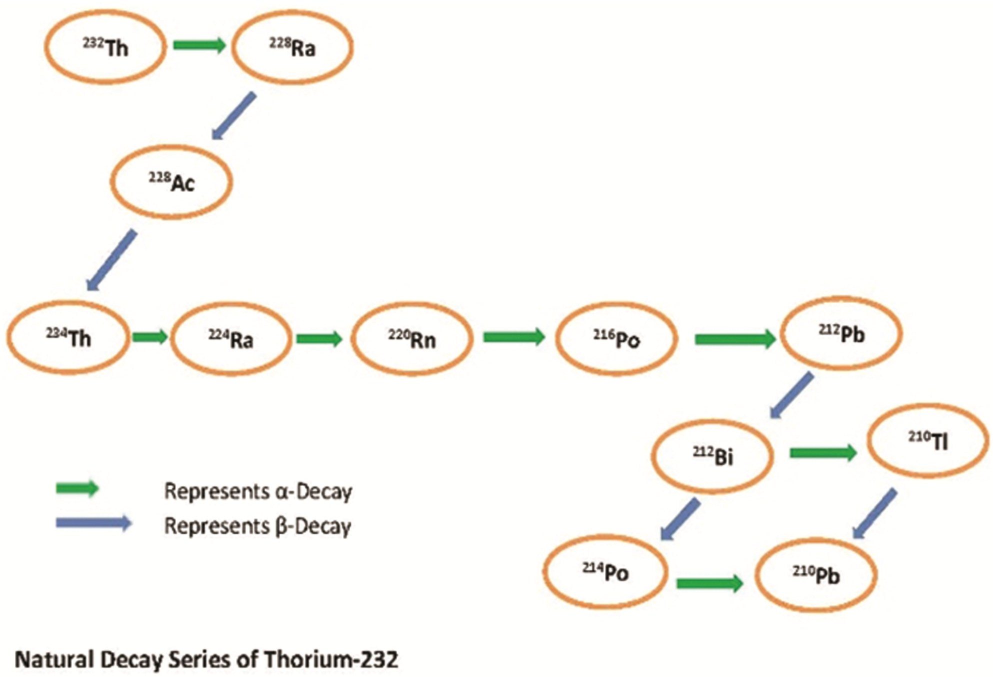

Fig. 2 — Decay series of thorium-232.

Table 1 — Characteristics of Radon.

Density	9.96* 10^{-3} gcm^3 at 20^0C
Melting Point	-71^0C
Boiling Point	-61^0C
Isotopes	35 from Rn(195)- Rn(229)
Density	9.96* 10^{-3} gcm^3 at 20^0C
Electronic Shell	[Xe] $4f^{14}5d^{10}6s^26p^6$
First Ionisation Energy	1037 $kJ.mol^{-1}$
Specific Heat	.094 $J.g^{-1}$ mol^{-1} at 20^0C
Lattice Structure	Face Centered Cubic

Measuring Techniques Indoor Radon-222, Thoron-220 and Their Progeny Level/Concentration

Mostly the techniques include active and passive techniques for the measurement of indoor radon-222 concentration. Active measurement technique is based on online measurement of concentration whereas passive technique is used for long time measurement. In passive method, SSNT (Solid State Nuclear Track) detectors are widely used[17].Studies manifest the seasonal variation of indoor radon-222 and thoron-220 concentration to be higher in winter season and lower in rainy season. This variation is happened due to the ‘offset effect’ that perceive about opening of doors and window of dwellings in winters providing bad ventilation in indoor environment[18].

Active measurement techniques

Active measurement techniques are online monitoring of radon-222 and thoron-220 concentration in real time. Smart Radon Monitor (SRM), Smart Thoron Monitor (STM), Active Progeny Samplers, Rad7 etc. are some active measurement devices. Now days smart RnDuo is used to estimate radon-222 and thoron-220 levels. It is basically a two in one device having both SRM and STM in one shell. The active measurement of radon-222/thoron-220 is done by using this accumulator technique based Smart RnDuo Monitor which is portable and able to monitor radon-222 gas continuously over a particular location (Fig. 3). It works on the principle of scintillation (ZnS:Ag) by which it detects alpha particles decayed by the radioactive materials. Figure 4 shows the growth of Rn-222 activity concentration in the chamber due to the accumulation. The best curve fitting for the growth curve is against the exponential decay equation is given by the following equation[19].

$$Y = Y_0 + Ae^{-x/t1}$$

The detail description of detection, measurements and protocols is given elsewhere[20].

Passive measurement techniques

This technique involves measurement of radon-222, thoron-220 and progeny concentrations for longer time exposure. This measurement is based on SSNT Detector

Fig. 3 — Portable Smart RnDuo.

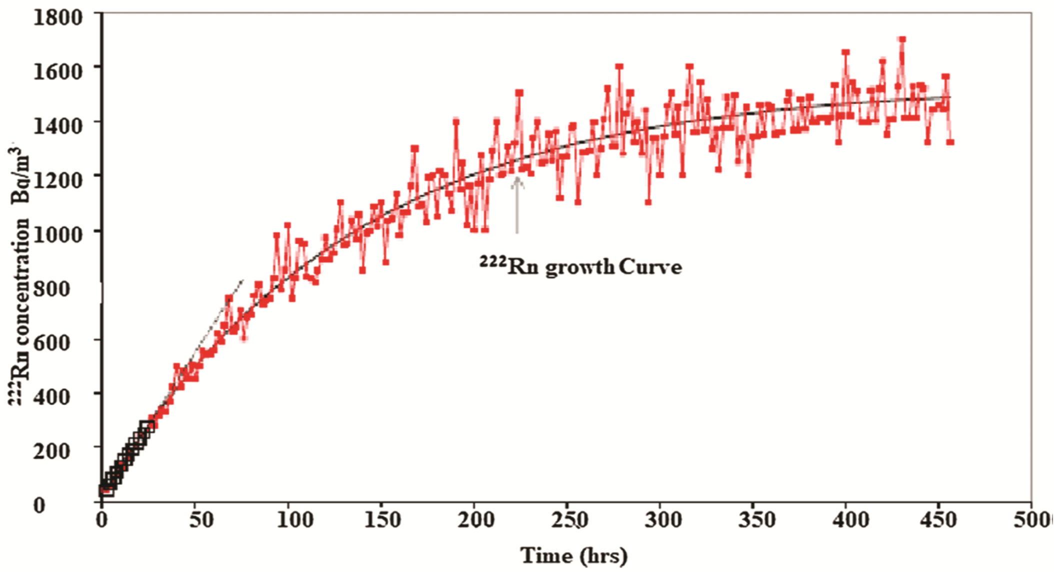

Fig. 4 — Radon-222 Activity concentration Vs Time graph.

technique (like LR-115 film etc.). A specific pinhole dosimeter is used along with progeny sensors in this method[14,21] (Fig. 5). These progeny sensors involve Direct Thoron-220 Progeny Sensor (DTPS), Direct Radon-222 Progeny Sensor (DRPS), Wire Mashed Progeny Sensor WDTPS and WRPS and these sensors are helpful to calculate attached and unattached fractions of solid decay products called progenies (Figs. 6 & 7). These progenies stick on the respiratory organs when inhaled and being radioactive starts damaging tissues of these organs and may cause lung cancer. Time integrated measurement of radon-222, thoron-220 and progenies, these devices deploy in the indoor environment for 3-4 months. Some protocols must be followed during deployment of these devices in the dwellings[8,22]. After retrieval of SSNT detectors, they are being etched by using well calibrated etching bath and the tracks i.e. track density so obtained on the SSNT detectors are counted by using well calibrated spark counter technique (Fig. 8). The radon-222, thoron-220 and progeny concentrations then calculated by track density with the help of following formulations:

Formulations: Radon-222/Thoron-220 Gas Concentration[22]

$$C_R = \frac{t_1}{(d \, . \, k_R)}$$

Fig. 5 — Dosimeter.

Fig. 6 — DPS instrument.

Fig. 7 — WDPS instrument.

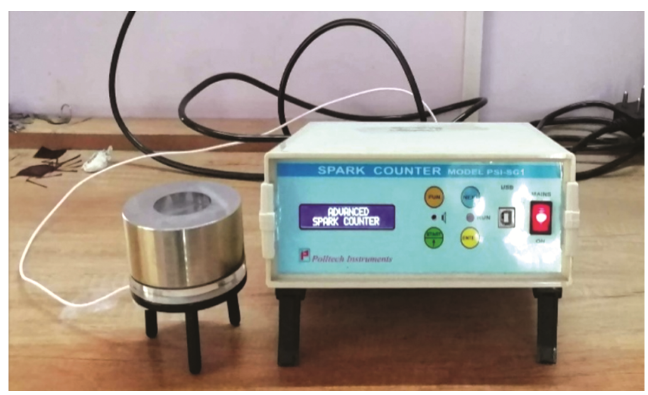

Fig. 8 — Spark Counter.

$$C_T = \frac{t_2 - (d.C_R.k'_R)}{(d.k_R)}$$

Where, t_1 = Track density observed in the 2nd compartment, t_2 = Track density observed in the 1st compartment, k_R = radon-222 Calibration factor in 2nd compartment (0.017 ± 0.02 tracks.cm^{-2} per Bq.m^{-3} .d),

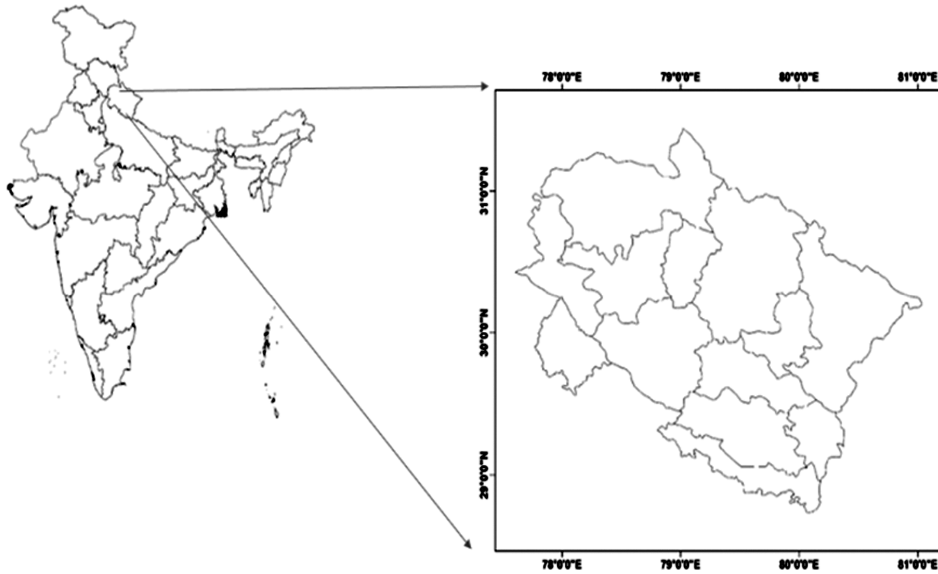

Fig. 9 — Map of Uttarakhand.

k_T = Calibration factor of thoron-220 in 1st compartment (0.010 ± 0.001 tracks.cm^{-2} per Bq.m^{-3}.d), d = Exposure time (in days) and k'_R = Calibration factor of radon-222 in 1st compartment (0.017 ± 0.002 tracks.cm^{-2} per Bq.m^{-3}.d).

Formulations: progeny of Radon-222/Thoron-220 Concentration[8,22]

$$EETC(Bq/m^3) = \frac{Tracks_{DTPS}^{Total}}{k_T * \text{Exposure Period (days)}}$$

$$EERC(Bq/m^3) = \frac{Tracks_{DRPS}^{\text{Only Rn Progeny}}}{k_R * \text{Exposure Period (days)}}$$

Where, k_T and k_R represent the calibration factors (also called sensitivity factors) for DTPS and DRPS, correspondingly. Sensitivity factors for DTPS and DRPS in the natural environment have been estimated by Mishra *et al.,* (2010)[8] which are equals to 0.94 Tracks cm^{-2} d^{-1}/ EETC (Bqm^{-3}) for DTPS and 0.09 Tracks cm^{-2} /EERC (Bqm^{-3}) for DRPS.

Geology of Garhwal Himalaya

The state of Uttarakhand is located within the North- Western Himalayas (Fig.9). It is divided into two subdivisions Garhwal and Kumaun Himalaya. Garhwal Himalayas lies in the West between Tons and Yamuna valley.

Most of the area of Garhwal Himalaya is covered by forest (approximate 60%) (Fig.10). Extreme Northern parts of Himalayas are covered by peaks and

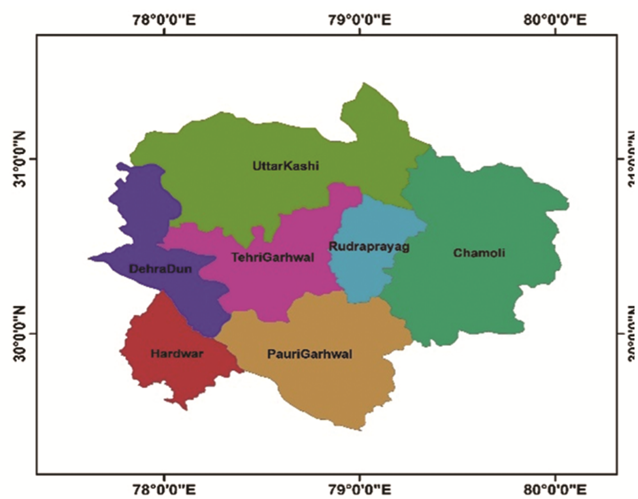

Fig. 10 — Map of Garhwal Himalaya.

glaciers. Longitudinally it can be divided from South to North or lesser Himalayas and central Himalayas. The lesser Himalaya is a complex of thrust and folds. Lesser Himalaya comprises meta sedimentary rocks and remnant crystalline Klippen. It also has sedimentary rocks and low-grade metamorphic rocks.

Radon-222 concentration in Garhwal Himalaya Region, Uttarakhand

The measured values of radon-222 concentration in Garhwal homes is based on various studies that have been performed in the regions of Garhwal Himalaya of Uttarakhand. The of radon-222 concentration that has been seen in the indoor environment as well as in soil and water in Garhwal. Various studies have confirmed the presence of radio nuclides in the soil as well as water in Garhwal Himalaya, Uttarakhand. The measurement of radon-222 concentration is important in Garhwal Himalaya region of Uttarakhand because it has many earthquake-prone areas. So, it becomes essential to monitor radon-222 concentration from time to time in order to correlate radon-222 behaviour with earthquake. In Garhwal Himalaya, the radon-222 level found to vary from 4 to 198Bq.m^{-3}with an average value of 41Bq.m^{-3}and thoron-220 have been found ranging from 1Bq.m^{-3} to 127Bq.m^{-3} having average of 33 Bq.m^{-3}[23].In the region of Tehri Garhwal of Himalaya, the radon-222 and thoron-220 progeny levels have a range from 5.7 to 153.2 Bq.m^{-3} with an average of 37.6 Bq.m^{-3} and 0.3 to 3.2 Bq.m^{-3} with an average value of 1.3 Bq.m^{-3} for summer, respectively. For rainy season, the radon-222 and thoron-220 progeny levels have been estimated in a range from 3.2 to 120 Bq.m^{-3} with an average of 58.2 Bq.m^{-3} and 0.2 to 11.3 Bq.m^{-3} having an average of 3.4 Bq.m^{-3}, respectively. The measured values of radon-222 and thoron-220 progeny have varied from 9.8 to 188.9 Bq.m^{-3} with an average of 70.7 Bq.m^{-3} and 0.1 to 7.5 Bq.m^{-3} with an average of 2.3 Bq.m^{-3}, respectively for the winter season[24].Indoor radon-222level along Main Boundary Thrust (MBT) varies from 35 to 150 Bq.m-3 with an average value of 85 Bq.m-3. The soil gas radon concentration varies from 2 to 12.3 kBq.m-3 andradon-222level in water varies from 1.7 to 57.7 Bq.l^{-1}[25]. The values of radon-222, thoron-220 and their progeny levels measured in the dwellings of Budhakedar region of Garhwal Himalaya, India using prescribed techniques and the radon-222levelis found in the range of 29±6 Bq.m^{-3} to 246±15 Bq.m^{-3}having an average of 92 Bq.m^{-3} and thoron-220level is found in the range 5±2 Bq.m^{-3} to 507±76 Bq.m^{-3} with an average of 39 Bq.m^{-3} [26]. In the dwellings of Rajpur region of Garhwal Himalaya, the average radon-222level varies in a range from 75 to 123 Bq.m^{-3} with an average of 89 Bq.m^{-3} and the average thoron-220level variation found from 29 to Bq.m^{-3} with an average of 38 Bq.m^{-3}[27]. The minimum and maximum value of radon-222 concentration in Pauri Garhwal was reported 30 Bq.m^{-3} to 195.4 Bq.m^{-3} with an average of 84.35 Bq.m^{-3} [6]. In Chamoli region, the measured concentration of radon-222 varies from 3.1 Bq.l^{-1} to 18.4 Bq.l^{-1} in spring water and in the soil gas, it varies from 2.3 kBq.m^{-3} to 12.2 kBq.m^{-3} range[28] .

Conclusions

Radon activity concentration is found in Garhwal region above the safety limit set by WHO, i.e. 100 Bq/m^3. This indicates the presence of source term in the Himalayan region that is transported by several media. Although, Annual Effective dose goes up to 5 mSv/y, yet the average value is not more than the global average. Presence of unattached progenies in atmosphere in aerosols increase the human exposure to radiation as these progenies are short lived and can deposit in human body through inhalation. Further, proper mapping of Radon-222 and thoron-220 in the Himalayan region can provide better picture of active distribution of radio-nuclides.

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